Chemical Quality of Surface Waters in the Brazos River Basin in Texas

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1779-K

Prepared in cooperation with the Brazos River Authority and the Texas Water Commission

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'URDGE IRELAN *and* H. B. MENDIETA

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[Plates are in pocket]

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GLOSSARY

Quality of water, in its broadest meaning, refers to all properties of water that may affect water's use. Suspended sediment, temperature, kinds and counts of bacteria, and dissolved organic and inorganic compounds are all included in a comprehensive definition of quality of water. In Brazos River basin, high concentrations of dissolved inorganic salts have restricted use of available water. No other factors included in broad definition are known to have resulted in serious basinwide problems. Hence, quality of water in this report refers to dissolved chemical constituents and physical properties, such as conductance and hardness. Problems related to sediment and to organic or bacterial pollution are not considered.

Cubic foot per second (cfs), the rate of discharge of a stream whose channel is 1 square foot in cross-sectional area and whose average velocity is 1 foot per second.

Acre-foot, the quantity of water required to cover an acre of land surface to depth of 1 foot; equivalent to 43,560 cubic feet of water.

Part per million (ppm), a unit weight of constituent per million unit weights of water.

Equivalent per million (epm), a unit of chemical combining weight of constituent per million unit weights of water. Computed by dividing concentration of chemical constituent, in parts per million, by chemical combining weight of constituent.

Percent sodium, computed by dividing equivalents per million of sodium by sum of equivalents per million of cations (calcium, magnesium, sodium, and potassium) and multiplying quotient by 100.

Dissolved solids, approximate quantity of dissolved mineral matter in water. Quantity of dissolved solids usually determined by evaporating a given volume of water, drying residue at 180°C, and weighing dried residue. For some analyses, quantity reported was obtained by a summation of individual constituents shown in analysis, where bicarbonate was included as carbonate.

Salts, general term used in this report to denote any of the numerous chemical compounds dissolved in water; "common salt" means sodium chloride.

Discharge-weighted average, approximate composition of water that would be found on a reservoir containing all water passing a given station during the year after thorough mixing in the reservoir. Discharge-weighted average computed by multiplying discharges for sampling periods by concentrations of individual constituents for corresponding periods and dividing sum of products by sum of discharges.

Water year, term used by U.S. Geological Survey for period from October 1 to September 30 of the succeeding year. Water year 1952, for example, is period from October 1, 1951 to September 30, 1952.

Cumulative-frequency curve, a curve prepared for dissolved-solids concentration by arranging dissolved-solids values of individual samples in order of magnitude and dividing them according to percentages of time during which specific values are equaled or exceeded. This type of curve also referred to as a duration curve.

Specific conductance of water, a measure of water's ability to conduct an electric current. Expressed as micromhos per centimeter at 25°C. Varies with concentration and degree of ionization of different minerals in solution and with temperature of water. Furnishes rough measure of dissolved-solids content of water but does not give any indication of relative quantities of constituents in solution.

Pollution, as used in this report, defines conditions in which dissolved-mineral concentration of water exceeds acceptable limits for a particular use. Artificial pollution refers to conditions which have been manmade; natural pollution refers to conditions that man did not create, such as brine inflow from natural salt deposits.

CHEMICAL QUALITY OF SURFACE WATERS IN THE BRAZOS RIVER BASIN IN TEXAS

By Burdge Irelan and H. B. Mendieta

ABSTRACT

The Brazos River basin, which makes up 15 percent of the land area of Texas, extends from the High Plains, where altitudes reach 4,200 feet and the average precipitation ranges from 15 to 20 inches a year, to the Gulf of Mexico where the annual rainfall is 45–50 inches. Large reservoirs have been built in the Brazos River basin, but the use of the stored water has been limited because the salinity often makes the water undesirable for municipal and industrial use. However, the water is generally satisfactory for irrigation. Records for the Brazos River show that the salinity of the water was a problem even as early as 1906 and that the water more often than not failed to meet today's chemical-quality standards for a municipal supply.

The salt load of the Brazos River comes from the entire basin and is the result of solution, accretion of undetermined amounts of oil-field brine, and accretion of brine from springs and seeps—such as those in Salt Croton Creek—which contribute about 400 tons of chloride a day.

Much of the salinity of the Brazos River is due to inflow of brines above Possum Kingdom Dam. The area above Possum Kingdom Dam is about 52 percent of the total area in the Brazos River basin but contributes only about 17 percent of the total runoff; however, about 50 percent of the annual salt load comes from this part of the basin.

Quality-of-water records show a wide difference in the salinity of the steams in different parts of the basin. Dissolved-solids concentrations ranged from about 100 ppm (parts per million) for flood water to 300,000 ppm for saturated brines from springs.

The quality of the surface water in the Brazos River basin is discussed by areas and by stream reaches. This study indicates that the water of the Salt Fork Brazos River is too saline for most uses. The water of the Double Mountain Fork Brazos River is less saline and might be used for irrigation; however, it probably could not be used as a municipal supply or as a supply for most industries. The water of the Clear Fork Brazos River is generally good but is adversely affected by brine pollution. Chemical-quality records for the Lampasas, Leon, and Navasota Rivers indicate that the water of these streams is of excellent quality; however, more data are needed to determine variations. The quality of the water in other tributaries could only be inferred from the results of miscellaneous sampling and from the probable effect of the underlying rocks. The weighted-average concentration of constituents in the Brazos River at Richmond indicated that inflow below Whitney Reservoir has a dilution effect on the river. For 12 of the 14 years of record, the weighted-average dissolved-solids concentration of the Brazos River at Richmond was less than the 500 ppm maximum limit recommended by the U.S. Public Health Service (1961).

This study indicates that water stored in Possum Kingdom and Whitney Reservoirs tends to become stratified, with the more saline water being at the greater depths. Samples collected in 1956 at Whitney Reservoir showed that the chloride concentration at the bottom was almost twice that at the surface. After a flood in June 1957, the dissolved-solids concentrations of bottom releases at Possum Kingdom were almost double those of surface releases through the spillway even though the flood volume had been more than twice the capacity of the reservoir.

The quality of water in the lower main stem can be improved by control and disposal of brines in the upper basin. Also, the maximum concentrations in the water of the lower main stem can be lowered by dilution with water stored in reservoirs on tributaries that yield water of good quality.

INTRODUCTION

PURPOSE AND SCOPE

Summarized in this report are the findings of a study of the quality-of-water data that have been collected in the Brazos River basin since 1906. Water-quality problems in the Brazos River basin are defined, possible solutions to the problems are outlined, and the areas that need more study are described.

THE PROBLEM

The Brazos River basin makes up about 15 percent of the area of the State and thus has the largest drainage area of any Texas coastal basin. A small part of the Brazos River drainage basin is in the High Plains of New Mexico, where the precipitation is low and the internal drainage is to sinks and wet-weather lakes that rarely overflow into stream channels. Thus, the New Mexico part of the basin contributes only negligible quantities of water and dissolved solids to the Brazos River.

The water of the Brazos River, unlike the water of the Trinity River to the north and the Colorado River to the south, has not been intensively developed for municipal and industrial use because the water is often too saline. Large reservoirs on both the Trinity and the Colorado Rivers store water of good quality. In contrast, those on the upper Brazos River store water that is too saline for municipal use; reservoirs on a number of tributaries in the upper Brazos River basin, however, do provide water for municipal use.

Because of insufficient storage of water in the lower part of the Brazos River basin, the lower basin, despite its heavy rainfall, is largely dependent on the water quality and water discharge of the upper basin. The drainage area above Possum Kingdom Dam, including areas which are usually noncontributing, makes up approximately 52 percent of the basin. Although the area above Possum Kingdom Dam contributes an average of only 17 percent of the runoff from the Brazos River basin, this area is the source of about 50 percent of the dissolved solids carried by the Brazos River at Richmond.

Water-quality management only recently has been considered as a part of many watershed-management programs; this is true of the Brazos River basin. The era of the large reservoir in the Brazos River basin began with the construction of Possum Kingdom Dam. After completion of this dam in 1941, chemical analysis of the stored water first showed that salinity would have to be considered if reservoir projects in the basin were to serve purposes other than those of flood control and power production. The Brazos River Authority became concerned with this problem in the summer of 1941. The rapidly increasing need for potable water in the basin and the concern over the salinity of the available supply have given urgency to the problem of locating both artificial and natural pollution and of finding means of mitigating them.

During discussions with the Brazos River Authority about a proposed comprehensive investigation, that agency noted that much data pertaining to the quality of water in the Brazos River basin had been collected by the U.S. Geological Survey. The Geological Survey proposed that these data be studied and analyzed to determine the saline contributions of the different parts of the Brazos River basin and their effects upon the quality of water below existing reservoirs and at the mouth. Available quality-of-water information was not expected to be sufficient for precise prediction of water quality at all unsampled locations on the Brazos River and its tributaries, though useful generalizations could be made about the probable quality of the water both on the main stem and on the tributaries of the river. In addition, the summary report would serve to indicate where additional quality-of-water records and studies are needed.

PREVIOUS INVESTIGATIONS

Since 1941, the U.S. Geological Survey, in cooperation with the Texas Water Commission (formerly the Board of Water Engineers), the Brazos River Authority, the U.S. Bureau of Reclamation, the U.S. Army Corps of Engineers, and various local groups, has collected information on the chemical quality of surface waters at many points in the Brazos River basin.

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Since 1957, as part of a statewide pollution survey, the Water Pollution Control Division of the Texas State Department of Health has analyzed many samples collected in the Brazos River basin.

Several reports have been written on the hydrology of the Brazos River basin. In a report to the Brazos River Authority, Blank (1955) described the salt flats on creeks tributary to the Salt Fork Brazos River. C. R. Marks, in a series of reports for the Ambursen Engineering Corp. (1956), consultants to the Brazos River Authority, outlined the results of extended studies, and the Brazos River Authority released a combined report of the studies. McMillion (1958) studied the ground-water geology in the vicinity of Salt Croton (Dove) and Croton Creeks. The areas of saline inflow reported by these investigators are discussed in a general way in this report, but no intensive analysis was made. These areas were the object of a more intensive study by R. C. Baker, L. S. Hughes, and I. D. Yost, (written communication, 1962).

To obtain data needed for remedial projects, the U.S. Geological Survey in the fall of 1956 began comprehensive studies of the chemical quality of the water and the quantities of dissolved solids discharged from areas in the upper basin. This program continued in cooperation with the Brazos River Authority and the Texas Water Commission until the spring of 1959 when a comprehensive geologic and hydrologic investigation of the salt-producing areas was started.

CLASSIFICATION OF QUALITY OF WATER

A generalized terminology is used to describe the numerical quantities covering the range of dissolved-solids concentrations in the surface water of the Brazos River basin. Concentrations of dissolved solids in the Brazos River or its principal tributaries range from less than 100 to almost 100,000 ppm (parts per million). Some springs in the upper basin yield water having even higher dissolved-solids concentrations.

The Texas Water Commission (1958) classifies the quality of the surface water as follows: Excellent, good, fair, poor, limited, and unsatisfactory. The U.S. Geological Survey (Winslow and Kister, 1956) classifies water as fresh, slightly saline, moderately saline, very saline, and brines. As indicated in the table that follows, the Texas Water Commission classification is adequate for fresh water or water of low salinity but is inadequate for water of high salinity. The U.S. Geological Survey classification is inadequate for fresh water.

In this report a classification is used which is based on both systems:

Classification	*Dissolved solids (ppm)*
Fresh Water:	
Excellent	<250
Good	250–500
Fair	500–1,000
Saline Water:	
Slightly saline	1,000–3,000
Moderately saline	3,000–10,000
Very saline	10,000–35,000
Brines	>35,000

This classification is helpful in delineating the utility of water. Fresh water in the excellent class is satisfactory for all but the most exacting requirements of industries. Fresh water in the good class meets the dissolved-solids concentration requirements recommended for municipal use (U.S. Public Health Service, 1961). Prior to the writing of this report (1961) the use of water in the fair class was accepted for public supply when better water was not available.

Saline water should not be used for domestic or municipal supply if fresh water is available. Slightly saline water, although not meeting U.S. Public Health Service Standards (1961), is used widely for domestic purposes and even in some municipalities. Slightly saline water is used also in many areas for irrigation. Moderately saline water is used only in areas where the soil is such that the salinity can be tolerated. Livestock may drink moderately saline water but may not thrive if the salinity approaches the upper limits of moderately saline water (California State Water Pollution Control Board, 1952, p. 247). Very saline water is seldom used except as cooling water on a once-through basis. Brines are more concentrated than sea water and probably are not used anywhere in the Brazos River basin except for repressuring oil fields.

Some water supplies are unsuitable for domestic use because of their hardness. Hard water forms insoluble precipitates with soap and is unsuitable for most industrial uses because of its tendency to form scale.

The following classification is used by the U.S. Geological Survey in denoting hardness:

Classification	*Hardness (as ppm* $CaCO_3$*)*
Soft	<60
Moderately hard	61–120
Hard	121–180
Very hard	>180

SOURCES OF INFORMATION

This report is based on chemical analyses obtained from both published and unpublished sources in the files of the U.S. Geological Survey at Austin, Texas. Most of the chemical data were obtained by the Survey during investigations made under cooperative agreements with the Texas Water Commission, the Brazos River Authority, and several local agencies. Other financial assistance was given by the U.S. Bureau of Reclamation of the Department of the Interior and by the U.S. Army Corps of Engineers. In addition, some of the work was supported entirely by Federal funds. Some early unpublished analyses were done for the city of Houston by Pittsburgh Testing Laboratory and Rice Institute, and others were done for the Bureau of Public Roads by the Department of Agriculture. Recent unpublished analyses were obtained from the files of the Bureau of Sanitary Engineers, Texas State Department of Health.

Water analyses made by the U.S. Geological Survey have been published in its annual series of Water-Supply Papers, "Quality of Surface Waters of the United States"; the analyses have also been published by the Texas Water Commission in their annual reports, "Chemical Composition of Texas Surface Waters." Streamflow data have been published by the Geological Survey in an annual series, "Surface Water Supply of the United States," and have been compiled by the Texas Water Commission in Bulletin 5807A, "Compilation of Surface Water Records in Texas through September 1957." A series of previously unpublished analyses of samples collected from the Brazos River near Hempstead, at Orchard Bridge, and at Rosenberg in 1933 and 1934 is listed in table 1. Published analyses generally give concentrations of the individual constituents in parts per million. Where necessary, the analyses from other sources were recomputed to conform to this practice. Therefore, all concentrations are in parts per million. (See glossary for explanation of terms.)

PHYSICAL AND GEOLOGICAL FEATURES OF THE BRAZOS RIVER BASIN

The Brazos River basin heads in northwestern Texas and a small area in eastern New Mexico. The basin trends in a general southeasterly direction across Texas from the New Mexico–Texas border to the Gulf of Mexico (pl. 1).

The straight-line distance from the mouth of the Brazos River to the farthermost point in its basin is about 640 miles, but the river distance between these two points is about 1,210 miles. The drainage area of the basin is about 44,000 square miles. However, the U.S. Geological Survey considers 9,240 square miles of the basin area as normally not contributing to the surface runoff of the river system. The basin's significance to the State of Texas is reflected in the fact that about one-sixth of the inhabitants of the State live in the basin. Cutting across the heartland of Texas, the Brazos River basin encompasses a representative cross section of the agricultural lands of the State.

The altitude of the basin ranges from about 4,200 feet in the High Plains to sea level at the mouth. Average annual precipatation ranges from 15 inches in the headwater reaches to about 45 inches in the lower reaches of the basin. In the High Plains, the average runoff approaches zero but increases steadily eastward until it exceeds 6 inches in most of the Coastal Plain. Net evaporation rates average about 10 inches on the coast and as much as 70 inches in the west.

Rainfall in semiarid areas is characteristically erratic in both intensity and amounts. "Only rarely does the annual rainfall happen to coincide with the average, and more rarely does it happen that the same rainfall is observed in two consecutive years" (Lowry, 1959). Rainfall ranging from 2 to 6 inches in a single storm is not unusual, and occasionally 10 or more inches may fall in a 24-hour period.

The large drainage area of the Brazos River basin is the predominant factor that gives some degree of uniformity to the flow of the lower Brazos during much of the year. The riverbed in the lower basin is never dry, even in years of drought. Nevertheless, erratic rainfall throughout the basin is reflected by erratic runoff from season to season and year to year. During the 39-year period of record through 1959, average annual discharge at the Richmond station was 5,280,000 acre-feet; for this period, the minimum discharge was 1,027,000 acre-feet (in 1951), and the maximum discharge was 16,120,000 acre-feet (in 1941).

The Brazos River basin is within four sections of three major physiographic provinces (Fenneman, 1931). It rises in the Llano Estacado or High Plains section of the Great Plains Province and in the Osage Plains section of the Central Lowland Province crosses the central Texas section of the Great Plains Province and ends in the West Gulf section of the Coastal Plain Province (pl. 1).

The Ogallala Formation of Pliocene age crops out over most of the High Plains (pl. 2). The Ogallala is moderately permeable and consists largely of sand, gravel, silt, clay, and some caliche. Surface drainage in the High Plains is poor, and most of the scant precipitation is held by wet-weather lakes or playas, from which the water evaporates or seeps into the ground. The High Plains is bounded on the east by a prominent east-facing escarpment that is several hundred feet high and is known as the Caprock Escarpment or "break of the plains."

In the Osage Plains part of the Brazos River basin, the surface rocks are mostly of Triassic, Permian, and Pennsylvanian age. The Triassic rocks that crop out at and near the edge of the Caprock Escarpment consist principally of red shale and clay containing some beds of sandstone and conglomerate. The beds of sandstone in the Triassic generally are fine grained and cemented. Percolation rates in these beds are low but are sufficient to yield the first perennial flow in the upper basin of the Brazos River.

The Permian rocks in the Brazos River basin consist of shale, fine-grained sandstone, gypsum, and dolomite. Beds of salt are present in the subsurface. Ground water percolating through the salt and gypsum and surface water flowing over the beds of gypsum dissolve large quantities of these soluble minerals and contribute a large part of the dissolved-solids content of the Brazos River.

The rocks of Pennsylvanian age in the Brazos basin consist largely of beds of limestone, shale, and some sandstone. A number of small reservoirs have their entire drainage area underlain by Pennsylvanian age rocks. All of these reservoirs store water of good or excellent quality.

A belt of Cretaceous rocks crops out in the central part of the Brazos River basin. North of the river the belt is in the West Gulf section of the Coastal Plain Province. South of the river the Cretaceous rocks form a minor physiographic division known as the Comanche Plateau, which is not included in the Osage Plains or in the Coastal Plain. The Cretaceous rocks consist largely of sand, clay, and limestone. Rocks that underlie the area contain a good-quality calcium bicarbonate water.

The lower part of the Brazos River basin is in the West Gulf section of the Coastal Plain Province. The rocks cropping out in this area consist largely of unconsolidated sand and clay of Tertiary and Quaternary age. The abundant rainfall of this area has leached most of the more soluble minerals from these rocks; the surface-water contribution to this reach is of fair to good quality.

FACTORS AFFECTING QUALITY OF SURFACE WATER

The chemical quality of surface water is controlled by many factors, the most significant of which is geologic. The type and arrangement of the rocks, their structural features and mineralogical composition, and the nature of the soils formed from them determine what kind and how much material the water dissolves.

Climatic factors, including rainfall intensity and frequency, temperature variations, and evaporation rates also affect water quality.

Geographic factors, including differences in the topography and in the number and arrangement of tributaries, are significant because of their effects on the pattern in which flow occurs and on the order in which blending of the basin waters takes place.

Man's cultural activities also have major effects on water quality. Reservoirs promote uniformity in water quality through impounding and mixing of flows of different salinity. Diversions that remove water of preferred quality may lead to quality deterioration downstream. Seasonal irrigation requirements not only change the total load but also introduce changes in the ratios of constituents when the irrigation-return flows get back to the stream. Canalization of rivers may lead to salt water encroachment from the sea. Industrial wastes or domestic sewage may change the quality of stream water locally. Brines produced along with oil amd wasted into streams may alter the quality of the water in entire downstream reaches of the streams and in the contiguous ground-water aquifers.

All these factors influence the quality of the water in the Brazos River basin. Some have a greater effect on water quality than others.

SOLUBILITY OF ROCK MINERALS

The earth's land surface is composed of aggregates of minerals that are called rocks and soils. The rocks are continually going through a slow process of chemical and physical decomposition termed "weathering." All minerals in rocks or produced by weathering are soluble in water to some extent. Soils are products of rock decomposition. Because the water solubility of different rocks and soils varies, the dissolved-solids content of runoff water also varies.

Of the three major classes of rocks—igneous, metamorphic, and sedimentary—only sedimentary rocks crop out in the Brazos River basin. Sedimentary rocks are formed by the accumulation of material transported by water or by air. Most of the minerals that compose sedimentary rocks are only slightly soluble and contain few soluble inclusions. Clay minerals and shale, for example, are only slightly soluble. However, some clays or shales may consist in part of, or may contain, soluble salts and hence are sources of slightly to highly saline water.

Limestone (principally calcium carbonate) and dolomite (calcium magnesium carbonate) are only slightly soluble in pure water, but the solubility of these minerals is increased if the water contains dissolved carbon dioxide. The principal constituents of water in contact with calcareous or dolomitic rocks are calcium, magnesium, and bicarbonate (the carbonate is hydrolyzed to bicarbonate when dissolved in water). Much of the runoff from the middle Brazos River basin is from limestone terranes; thus, the dissolved solids of this water consist principally of calcium, magnesium, and bicarbonate.

Sandstone consists of sand-sized particles of minerals, predominantly quartz (silica), which are cemented together. The cementing mineral generally is calcite (calcium carbonate), quartz (silica), or some iron mineral. Although the quartz grains in sandstone are nearly insoluble, the cementing material generally is soluble. Sandstones, like shales, may also contain salts trapped at the time of rock formation. Hence, water from regions underlain by sandstone may be of many types of chemical composition, including a chemical composition similar to that of water from limestone terranes.

Gypsum (calcium sulfate) occurs in extensive areas of the upper Brazos River basin both as massive beds and disseminated in other rocks. Water that has been in contact with gypsum contains large amounts of calcium and sulfate. Gypsum deposits generally contain some sodium chloride (table salt). Hence, runoff from an area underlain by gypsiferous rocks is generally too saline for many uses.

Halite (sodium chloride) is one of the most soluble rock minerals. Because of its high solubility, it cannot persist at the earth's surface in humid climates. However, ground water may move over buried salt deposits, become very saline, and emerge at the surface as salt springs or seeps. A few salt springs and seep areas are found in the upper Brazos River basin.

Rocks containing soluble salts in or near the land surface are more prevalent in the upper Brazos River basin than in other parts of the basin. As a result, quantities of dissolved minerals in equal volumes of runoff from equal-sized areas vary. Some rocks that crop out in the upper Brazos River basin contain beds of sandstone, shale, and gypsum; also, beds of halite are near the land surface. These rocks contribute large quantities of soluble salts to both surface runoff and ground-water seepage. Hence, the quality of the water in the upper Brazos River basin depends on the source areas of the water. In contrast, little soluble material is in the rocks and the soils at the surface in the lower Brazos River basin, and water in many of the tributaries of the Brazos River in the lower part of the basin is nearly always low in dissolved solids.

DILUTION BY STORM RUNOFF

Rainwater, which is formed by a natural distillation process, is nearly free of dissolved minerals. As soon as the rain reaches the earth and begins to flow across the land surface or to percolate through the soil and the openings in the rocks, the water attacks both rocks and soils. It dissolves the mineral consituents in proportion to their solubility and relative abundance.

Where precipitation is heavy, rocks and soils are quickly leached of their soluble minerals. Therefore, in areas of heavy precipitation the dissolved-solids content of surface water is usually low. In areas where precipitation is slight, soluble minerals produced by weathering of rock tend to accumulate on rock and soil surfaces until they are flushed by heavy rains. Thus, runoff from areas of low precipitation commonly contains higher concentrations of dissolved solids than does runoff from areas of high precipitation.

As the annual precipitation in the lower Brazos River basin is more than 30 inches, the rocks and soils in the lower basin are generally more completely leached than those of the upper basin.

Water flowing in a stream is a constantly changing mixture of overland runoff and ground-water discharge. Most of the flood flow is from overland runoff, whereas all the low flow may be from springs or seeps. The overland runoff is usually low in dissolved-mineral content because the surface flow has contacted only small amounts of soluble materials and usually for too short a time for much solution to have taken place. In contrast, ground water moves slowly through rocks and soils so that there is longer contact with the minerals and more of the available salts are dissolved. Consequently, the dissolved-solids concentration of surface water in areas of high precipitation is nearly always greater during low flow than during floods.

In areas of low precipitation the streams may flow only intermittently in some reaches. Surface runoff carries dissolved salts into the stream channels where part or all of this runoff evaporates and leaves soluble salts deposited in the sands and gravels of the channel. Other salts may be deposited by the evaporation of ground water that seeps into the channel.

When rains produce runoff in a channel that has been dry, the first flow of water rapidly dissolves the saline residues in the sand and gravel and a surge of salty water moves down the stream. After this surge, the stream water usually contains much less dissolved material. If the stream has several tributaries, variations in the intensity of the rain and in the movement of the storm pat-

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tern will cause the water from different tributaries to reach the main stem at different times; thus, a series of individual slugs of salty water may move down the channel. After the flushouts, the stream water may be low in dissolved solids as long as the overland flow persists. However, the dissolved-solids content usually increases with time and with a decrease in streamflow, as a greater part of the flow is lost through evaporation and as the proportion contributed by ground water becomes larger.

INFLOW OF OIL-FIELD BRINES

Oil-field brines are the source of a part, and often a large part, of the dissolved solids in the surface water of the Brazos River basin. Oil fields are widely distributed in the basin. Some brine is produced in nearly all oil fields, and the amount of brine produced in proportion to the oil produced generally increases as the fields become older. Some of the salt water reaches the streams by direct discharge into the channels, some reaches the streams when disposal pits overflow, and some reaches the streams as ground-water seepage from improperly sealed wells and surface pits. In most of the newer fields and in some of the older fields, subsurface injection of the salt water is reducing or eliminating brine inflow into streams.

Oil-field brines vary in chemical composition, but generally the ratios of constituents in these brines differ from the ratios of constituents in surface water. A high ratio of calcium to sodium is one of the most frequently noted characteristics of oil-field brines and is often used to identify pollution by oil-field brines. The concentration in oil-field brines varies, but all are too saline to be desirable increments of surface flow.

Some streams that flow through the oil fields of the Brazos River basin are naturally saline; hence, the saline water of many streams contains salts from natural sources as well as from oil-field brines. Although elimination of pollution by brines would not make all the surface water in the Brazos River basin usable, the quality of water available at many locations would be substantially improved.

INFLOW OF IRRIGATION WASTE WATER

Irrigation not only involves the application of water to the soil but also the application of the dissolved solids in the water. Dissolved solids in irrigation water may be precipitated on the soil particles, exchanged for other salts by the ion-exchange process, and concentrated in the soil by evaporation and transpiration. The quality of the water in the soil may be improved by precipitation of salts, but the exchange of constituents through ion exchange may be either beneficial or harmful, depending on the exchange properties of the soil. High concentration of dissolved solids in the soil solution is detrimental to plant growth. Calcium carbonate, magnesium carbonate, and calcium sulfate precipitate at low to moderate concentrations. Sodium carbonate, sodium and magnesuim sulfates, and practically all chloride salts are very soluble, and concentrations of these salts can be increased in the soil solution to levels that severely depress or even prevent plant growth.

To prevent accumulations of soluble salts in the soil and soil solution, it is usually necessary to provide deep drainage for irrigated land and to apply more water than is required for plant growth. Because the extra water percolates through the soil and leaches out accumulated soluble salts, the drain water is more saline than the water applied to the soil. The drain water ultimately returns to the stream system, and the effect of diversion of water from a stream for irrigation is that immediately downstream from the point receiving the return flows the stream water has a higher average salinity than it would have if there had been no irrigation diversions. However, where calcium and sulfate are the dominant constituents, as in the so-called "gyp" waters, the increase may be small because part of the sulfate may be retained in the soil as precipitated calcium sulfate.

During the past 20 years, irrigation has expanded rapidly in the Brazos River basin. Much of the expansion has been in the High Plains and in the coastal rice belt. In addition, irrigation has been started at scattered places along the length of the Brazos River and some of its tributaries. Water pumped from the Ogallala Formation in the High Plains contains low concentrations of dissolved salts—usually less than 500 ppm—so soil salinity has not become a problem. In rice irrigation, alternate flooding and draining of land prevents salt accumulation. Whether saline irrigation water has damaged crops or croplands between the High Plains and the coastal rice belt is not known.

If irrigation is expanded in the upper Brazos River basin, where the water is more saline, the chloride concentration of the river water below Whitney reservoir may increase. However, this increase might be partly offset by a decrease in average sulfate concentration.

INFLOW OF MUNICIPAL AND INDUSTRIAL WASTES

Ordinarily, 60–70 percent of the water pumped for municipal use is returned to streams as sewage (Fair and Geyer, 1954). Although the chief effect of sewage disposal in streams may be due to the biological factors, the changes in chemical characteristics also may be significant. Effluents from municipal sewage treatment plants generally contain higher chloride and sulfate concentrations than do source waters. Nitrate is one of the decomposition products of organic nitrogen compounds and is always more abundant in sewage effluents than in normal stream water. Some industrial wastes contain large amounts of chloride, sulfate, and nitrate compounds. Inflow of municipal and industrial wastes usually increases the dissolved-solids concentration of the stream and always increases the dissolved-solids load.

Municipal and industrial wastes discharged to the streams in the Brazos River basin have not been large in comparison to the discharge of the Brazos River. Hence, the salt loads from effluent sewage have been minor. If the growth of basin cities such as Lubbock, Abilene, and Waco within the basin continues, sewage effluent may cause significant changes in water quality.

QUALITY-OF-WATER RECORDS

STREAM RECORDS

In the Brazos River basin the U.S. Geological Survey has collected continuous daily records of water quality for periods of a year or more at 21 stations. The location of sampling sites where continuous records are available and the periods of operation of all daily sampling stations are shown on plate 3. Table 2, which is a summary of the chemical-quality records, lists the maximum, minimum, and discharge-weighted-average concentration of major constituents and the corresponding water discharges for each year of record at each daily sampling station.

The longest record of chemical analyses on the Brazos River is for the station below Possum Kingdom Dam. This station has been in operation since January 1942. Samples have been collected continuously at Richmond since 1941, but comprehensive analyses of these samples have been made only since October 1945. Samples have been collected near Whitney since September 1947, and the record spans a period that includes the construction of Whitney Dam and the filling of Lake Whitney. Other continuous but shorter water-quality records are given in table 2.

Except for boron, the summaries include the concentrations of the principal constituents and the properties that govern the suitability of surface water for municipal, industrial, and irrigation uses. Determinations for boron have been made only for samples collected at the Richmond station. However, analyses of samples collected at many points in and near the Brazos River basin indicate that concentrations of boron are less than the level considered harmful to the agricultural utility of surface water in the basin.

The summaries show the concentrations of the reported constituents at the sampling points during each year. Where the maximums are low, water of good quality is available 100 percent of the time; similar water probably is available in adjacent unsampled areas of similar geologic characteristics. Where the minimums are consistently high, saline inflows can be inferred; and the water from the stream and from adjacent areas may have limited usefulness.

LAKE RECORDS

Most of the daily-sampling records in the Brazos River basin are for sites on the main stem or on tributaries on which the construction of reservoirs has been proposed and on which quality-of-water problems existed or were expected. Many tributaries draining small areas, as well as some of the larger tributaries, have not been continuously sampled. Where daily-sampling records are not available, analyses of samples collected from lakes and reservoirs have been helpful in making quality-of-water appraisals. The records of quality of lake water are not as definitive as daily records of stream water because many of the smaller reservoirs were specifically located in areas where quality-of-water problems were minimized. Only a few samples have been collected from the smaller reservoirs in the basin. The analyses of one or two samples from a reservoir are not likely to be as representative of average water quality as would be shown by a continuous sampling schedule. However, where more detailed information is not available, the occasional analyses of lake and reservoir water serve as an index to water quality in larger areas, and the analyses are major aids in the areal discussion in this report. Table 3 lists representative analyses of samples from lakes and reservoirs in the Brazos basin, and plate 3 shows the location of these lakes. Samples from Possum Kingdom and Whitney reservoirs are not included in the table because the quality of the water in those reservoirs is better covered by the daily record summaries.

MISCELLANEOUS RECORDS

In addition to the daily sampling-station records, the chemical analyses of lake water and analyses of hundreds of miscellaneous samples, collected by the U.S. Geological Survey and others, have been used in this study. These analyses are valuable background information about surface-water quality at locations scattered over most of the Brazos River basin. Many of the miscellaneous analyses are fragmentary and include only chloride concentrations and determinations of one or two other constituents or characteristics. Other analyses are more complete and include information about most of the constituents in the sampled water. Information about the source of samples is sometimes incomplete. Many times, only approximate locations were identifiable; and only approximate stream discharges were known. For many locations, the miscellaneous analyses and streamflow data are insufficient for the computation of quantitative estimates of the average water quality or of the stream loads but are very useful in determining general patterns of water quality.

Many of the miscellaneous analyses show that streams with high sulfate concentrations flow from or through areas in which gypsum is at or near the land surface. Miscellaneous analyses of water from limestone areas show a characteristic predominance of calcium and bicarbonate. Some areas of oil-field pollution are characterized by higher chloride concentrations in the water and a higher ratio of calcium to sodium than is usually found in unpolluted water.

Miscellaneous analyses have not been listed in this report, however, many of the conclusions are based on a study of the miscellaneous analyses.

QUALITY OF WATER IN BASIN SUBDIVISIONS OR STREAM REACHES

Because of the wide range of geologic, climatic, and cultural factors in the Brazos River basin, the basin was divided into areas or stream reaches and the water quality variations in each division are described. In the upper basin, where geologic or climatic conditions are the controlling factors, the divisions are areal. Where sustained flow is characteristic of the main stem and principal tributaries, quality-of-water variations are described by stream reaches or by individual tributary basins. Also, the quality of the water available in different parts of the Brazos River basin is discussed in the following sections by areas or by stream reaches.

THE HIGH PLAINS

About 9,240 square miles of the High Plains of New Mexico and Texas is in the Brazos River basin. This area, which is above the Caprock Escarpment, is underlain by a productive aquifer in the Ogallala Formation and has a poorly defined stream pattern. Much of the area drains into shallow circular depressions commonly called wet-weather lakes.

The U.S. Geological Survey maintained stream-gaging stations on the White River at Plainview and on the Double Mountain Fork at Lubbock during the period 1939–49. The records indicate that the High Plains supplies virtually no runoff to the Brazos River except in years of exceptionally heavy rainfall.

No quality-of-water records were obtained at the two stations, but many analyses of water samples from wells in the Ogallala Formation have been made in connection with the studies of ground water by the U.S. Geological Survey. The quality of the ground water from the Ogallala Formation is remarkably uniform over wide areas. The water is low in dissolved solids (250–500 ppm) but is very hard. Analyses of a few samples collected from the wet-weather lakes show that the lake water has lower dissolved-solids concentrations and less hardness than the water from nearby wells. (See table 3.) Analyses of samples collected intermittently from the White River east of Crosbyton during a period of 10 years have shown that the base flow, which is mostly derived from seeps and springs in the Ogallala, contains about 500 ppm of dissolved solids. Thus, although runoff records of the High Plains part of the Brazos basin are meager, they show that little if any saline water originates there.

AREA UNDERLAIN BY TRIASSIC ROCKS

Immediately downstream from the Caprock Escarpment in Dickens, Crosby, and Garza Counties, rocks of the Dockum Group of late Triassic age are at the land surface. Many vaguely defined channels are shown on the geologic map of Texas (Darton and others, 1937) as originating on or crossing the Triassic rocks. Small reservoirs probably can be built in this area, and the quality of the water probably would be good.

Lake J. B. Thomas, in the Colorado River basin immediately to the south, drains an area underlain by similar rocks of Triassic age. Records of chemical analyses of water stored in Lake J. B. Thomas show that the dissolved-solids concentration has not exceeded 400 ppm during the period of record and that the hardness of the water has ranged from 55 to 114 ppm. Water from Lake J. B. Thomas is used as a public supply and for oil-field flooding. A few samples collected in or near the eastern edge of the Triassic outcrop in the Brazos River basin indicate seepage of some moderately saline water. The quality of water in these areas should be determined before any development of water resources is planned. A careful study might show that the saline water comes from Permian rocks instead of Triassic rocks.

AREA UNDERLAIN BY PERMIAN ROCKS

Rocks of Permian age crop out in a large area west of the former gaging stations on the Double Mountain Fork near Rotan and on the Salt Fork near Peacock. No streamflow records are available for this area. Numerous chemical analyses of water from pools and low flows of streams in the area show that the water is slightly to moderately saline. Some of the surface water is gypsiferous—high in calcium and sulfate and low in sodium and chloride. The water in other streams is very saline, containing high concentrations of chloride in relation to sulfate.

DOUBLE MOUNTAIN FORK BRAZOS RIVER

The chemical-quality records for the Double Mountain Fork Brazos River near Rotan show that the low flow is not very saline and that during floods the water is of fair quality. The weighted average dissolved-solids concentrations for the station were 812 ppm for the 1950 water year and 1,300 ppm for the 1951 water year (table 2).

Though the maximum concentration of dissolved solids in the Double Mountain Fork Brazos River at the Aspermont station was not as high as the concentration at Rotan during the same period, the minimum and weighted averages at Aspermont were somewhat higher, indicating that water of higher salinity must come in between the two stations. The weighted averages for several years of record at the Aspermont station indicate that if a reservoir were constructed on the Double Mountain Fork near this station, the impounded water would be slightly saline and undesirable for municipal use. The water in the reservoir, however, would have concentrations of sulfate substantially greater than the concentrations of chloride, and the percent sodium would range from 30 to 40. The water would, hence, be satisfactory for the irrigation of many kinds of crops.

SALT FORK BRAZOS RIVER

Quality-of-water records for the Salt Fork Brazos River near Peacock and near Aspermont show that the Salt Fork is much more saline than the Double Mountain Fork. Although the two rivers drain areas underlain by rocks of Permian age, local differences in the type of rocks are abundant enough to result in completely different patterns of water quality in the two streams.

The maximum dissolved-solids concentration measured in the Salt Fork near Peacock was about 10,000 ppm, which is much less than the maximum concentration observed at the Aspermont station where the concentration exceeds 10,000 ppm for months at a time and occasionally exceeds 70,000 ppm. The increase in the dissolved-solids concentration between the two stations indicates inflows of very highly mineralized water. Salt springs rise in barren flats in the basins of Croton and Salt Croton Creeks, and these creeks enter the Salt Fork between the two stations. A study of the chemical quality of the water from these creeks has shown that they contribute a large amount of dissolved solids to the Salt Fork.

The chloride content of the Salt Fork near Aspermont is nearly always higher than the sulfate content, and the ratio between the two ions increases as the dissolved-solids concentration increases. The percent sodium ranged from 60 to more than 90, limiting the use of the water of the Salt Fork for irrigation.

BRAZOS RIVER ABOVE THE CLEAR FORK

The Brazos River main stem is formed by the confluence of the Salt and Double Mountain Forks in Stonewall County. Below the confluence the dissolved solids in the water are largely a mixture of the mineral constituents in the water of the two forks. Saline tributary inflow between the confluence of the two forks and the Seymour gaging station has been indicated by analyses of spot samples. Whether the saline water flowing into the Brazos River in this reach is from salt springs or from other sources is not known. A more detailed study is needed to pinpoint the source or sources of the pollution. A daily quality-of-water station was established on the Brazos River at Seymour on August 4, 1959. The record covers too short a period to be very meaningful. The maximum dissolved-solids concentration is much less than the maximum for the Salt Fork at Aspermont and a little more than the maximum for the Double Mountain Fork at Aspermont. Apparently, the quality of water stored in a proposed reservoir on the Brazos River near Seymour would vary from year to year. The water would be slightly or moderately saline depending on whether most of the inflow comes from the Salt or Double Mountain Fork and depending on the proportion of storm runoff to the total flow.

Downstream from Seymour and above the mouth of the Clear Fork, several tributaries, each with drainage areas of a hundred square miles or more, flow into the Brazos River. Several samples collected from Millers Creek indicate that this intermediate area contributes water of good quality to the river. Throckmorton City Lake on Elm Creek in this area contains water of good quality (table 3).

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CLEAR FORK BRAZOS RIVER

Continuous quality-of-water records were collected from the Clear Fork Brazos River at Nugent during the water years 1949–53 and at Fort Griffin during the water years 1950–51.

Concentrations of dissolved solids in the water of the Clear Fork are much lower than in the water of the Double Mountain and Salt Forks. For four of the five years the yearly maximum dissolved-solids concentrations at the Nugent station ranged from 3,250 to 3,910 ppm; in the other year the maximum was only about 1,300 ppm. The amounts of sulfate exceeded those of the chloride. The minimum concentration each year was about 250 ppm. The weighted-average dissolved-solids concentrations ranged from 260 to 569 ppm (table 2).

Although the water at Nugent would be satisfactory for municipal use if impounded, the present system of selective pumping from the Clear Fork into Fort Phantom Hill reservoir results in stored water of better quality than would be available in an on-channel reservoir near the Nugent station.

The quality of the water at the Fort Griffin gaging station was consistently better than it was at Nugent. The yearly maximum dissolved-solids concentration, however, exceeded 1,000 ppm, and the excessive chloride content indicated oil-field contamination. The yearly minimum concentrations at Fort Griffin were 160 ppm in 1950 and 183 ppm in 1951. The weighted averages for the same water years were 333 and 393 ppm. The water was hard; the weighted-average hardness for the 2 water years was 118 and 94 ppm. Water impounded by a reservoir near the Fort Griffin station would be satisfactory for municipal use provided the reservoir did not receive significant amounts of oil-field drainage.

Field reconnaissance indicates that oil-field brine has caused rather serious contamination of the Clear Fork near its mouth; however, the quantity of chlorides entering the river has not been determined.

Daily samples were collected on Paint Creek below California Creek near Haskell during extended periods in 1950 and 1951. The records were not continuous enough during either year to compute yearly weighted averages. The water having the highest dissolved-solids concentration was slightly saline and would be poor for municipal use. As indicated by the chloride content, the water apparently contains some oil-field wastes. The water having the lowest dissolved-solids concentration was of excellent quality, was moderately hard, and was low in both chlorides and sulfates. After these records were collected, a reservoir, Lake Stamford, was constructed on Paint Creek above California Creek. The water impounded in the lake is of excellent quality (table 3).

Since 1956, continuous sampling of Hubbard Creek at the gaging station near Breckenridge has shown that the stream is a potential source of water of suitable quality for municipal use. The water having the highest dissolved-solids concentrations is high in chlorides, which indicates an oil-field pollution problem. The minimum and weighted-average concentrations indicate that water impounded in a reservoir that is under construction would be similar to that in the Stamford reservoir, provided the oil-field pollution does not increase.

Analyses of samples from numerous reservoirs in the Clear Fork drainage basin show that most of the tributary basins yield water of good quality. However, in the extreme western part of the basin, water in the Roby City Lake is moderately saline (table 3).

BRAZOS RIVER AT SOUTH BEND

Daily sampling on the Brazos River at South Bend was begun in 1942. The Clear Fork flows into the Brazos River 1.6 miles upstream from the sampling site, and the samples of water collected at South Bend did not always represent a uniform mixture of the flows of the Brazos and the Clear Fork. Samples were collected at several points in the river during high flows, but it was not always possible to determine the average quality at the station accurately. The station was discontinued in March 1948.

Although the chemical-quality record for the Brazos River at South Bend was not completely representative, the record is the only means of evaluating the day-to-day quality of inflow into Possum Kingdom Reservoir. During most years, the maximum concentrations were in the moderately saline range although very saline water flowed past the station at times. Much of the salinity can be attributed to the contributions of the Salt Fork, but some of it may be due to oil-field brine flowing in near the mouth of the Clear Fork.

SALT CREEK

Salt Creek, a minor tributary to the Brazos River, flows into the river near the city of Graham and close to the upper end of Possum Kingdom Reservoir. Oil fields are scattered throughout the Salt Creek drainage basin and have almost continuously polluted the stream. After the construction of a new municipal reservoir, Lake Graham, on Salt Creek, the U.S. Geological Survey in 1958 began a detailed study of the quality of the inflow and of the water stored in the new lake. The study revealed that very saline seeps and pools were common in and near Salt Creek. At the gaging station at Olney near the upper end of the basin, the water was very saline during the low flows of 1958. A campaign to reduce pollution and to encourage subsurface injection of salt water resulted in an almost immediate improvement so that in 1959 the water of Salt Creek at Olney was moderately saline during low flow. During the 1958 and 1959 water years the high flows had dissolved-solids concentrations of less than 250 ppm and weighted averages of less than 500 ppm.

At the Newcastle gage, just above Lake Graham, flows of maximum concentration were moderately saline in 1958 but only slightly saline in 1959. The minimum dissolved-solids concentrations were 142 ppm in 1958 and 51 ppm in 1959. The weighted average just exceeded the excellent classification limits in 1958 and was well within that class limit in 1959.

Water in Lake Graham has been sampled at the dam at monthly intervals during the period 1958–60 (table 3). The impounded water has been of good quality, though hard, and has improved as the quantity of stored water increased. Salt Creek records indicate that if efforts to control pollution are continued, water in the reservoir will continue to be of good quality and will probably improve in quality as accumulated salts are washed out of the contaminated areas.

BRAZOS RIVER AT POSSUM KINGDOM DAM

Quality-of-water records of the outflow from Possum Kingdom Reservoir have been collected since January 1942.

The salinity of the outflow of Possum Kingdom Reservoir has been less than that in the Salt and Double Mountain Forks because of the mixing of saline water with fresh water, but only during years of high runoff has the water in the reservoir been as dilute as that in the Clear Fork.

The quality of the water released from the reservoir varied widely during and after the floods of 1941 and 1957. Intermittent sampling in the summer of 1941, at the time the reservoir first filled, showed that water of good quality was being spilled. By February 1942 the concentration of the dissolved solids in releases through the turbines had increased to 2,130 ppm. Water of good quality was not released again until the flood of May and June 1957, when a very large volume of water passed over the dam. During the 1957 water year, the dissolved-solids concentrations ranged from 311 to 2,130 ppm.

The reservoir spilled briefly in September and October 1955, and a minimum of 806 ppm of dissolved solids was recorded during early October. Three months later, in January, the dissolved solids in the releases had increased to a maximum of 2,640 ppm. Then, without further significant inflow to the reservoir, the dissolved-solids concentration of the water gradually decreased to 1,600 ppm by May 1. Apparently the decrease in salinity was caused by the slow mixing of flood water with the more saline water already in storage.

The quality-of-water record indicates that mixing in Possum Kingdom Reservoir is slow. Water of good quality flowing into the reservoir during flood periods moves, with only partial mixing, over the more dense impounded water. During other periods when the inflow is saline, the water moves in a density current along the reservoir bottom. Saline water is thus trapped in the bottom part of the reservoir and remains here mostly unmixed. As a result, bottom releases from the reservoir are too saline for muncipal use even after floods of volumes sufficient to fill the reservoir three or four times.

BRAZOS RIVER AT WHITNEY DAM

Since 1948, daily samples have been collected from the Brazos River near Whitney, Tex. The records of water quality thus antedate the beginning of storage in Whitney Reservoir in December 1951 and cover a period of changing river conditions. Before construction of the dam, the quality of the water below Whitney Reservoir was for long periods virtually the same as the quality of water below Possum Kingdom Reservoir. Since the completion of Whitney Dam, runoff from the intervening area between the two dams has helped to dilute some of the releases from Possum Kingdom Reservoir. Although no daily quality-of-water stations have been operated on streams in the intermediate reach, several lakes on tributary streams have been developed for municipal use and contain water of excellent quality. The records for the Brazos River below Possum Kingdom and Whitney Reservoirs, as well as the type of rocks that underlie the intermediate drainage area, also indicate that the intermediate tributary runoff is, on the average, low in dissolved solids, chloride, and sulfate. Hence, the larger the proportion of tributary water in Whitney Reservoir, the better will be the quality of the water released. Before the floods of May 1957, the water released from Whitney Reservoir usually was near the lower limit of the slightly saline class, although after some storm inflow the releases occasionally would meet the fair class limits. Since the large floods of May 1957, quality of water released from Whitney Reservoir has been in the good or fair class limits. Thus, one of the benefits of storage in the Whitney Reservoir that was not evaluated economically when the reservoir was planned has been an improvement of the day-today quality of the water downstream.

BOSQUE RIVER

No daily records of water quality have been collected from the Bosque River. Lake Waco, which is currently being enlarged, has been used by the city of Waco for municipal supply for many years. Analyses of two samples collected from the lake in 1943 and 1952 showed dissolved-solids concentrations of 225 and 335 ppm. The 1952 analysis is given in table 3. As the two samples probably represent an average of inflowing water, the water to be stored in the enlarged reservoir probably will be of good or excellent quality. If the flood flows are stored for release when needed, the released water will dilute the more mineralized water released from Whitney Reservoir and this dilution will provide water of better day-to-day quality in the Brazos River downstream from the Bosque River.

BRAZOS RIVER AT WACO

During the period December 1906–November 1907 the U.S. Geological Survey obtained a daily record of the quality of water of the Brazos River at Waco. Information now available does not indicate where the samples were collected, but they were probably collected below the mouth of the Bosque River. The 1906–07 samples were composited in groups of 10 or 11 in equal amounts regardless of flow. Hence, the early data are not as representative as more recent records would be. However, the record does show that the Brazos River water contained high concentrations of both chloride and sulfate before any significant developments were made in the basin.

LITTLE RIVER

The Little River, formed by the junction of the Lampasas and Leon Rivers, has by far the largest drainage area of any tributary of the Brazos River. A daily chemical-quality sampling station was established on the Little River at Cameron in October 1959. The records indicate that normal flows of the Little River contain less than 500 ppm of dissolved solids and the flood flows contain less than 250 ppm. Both chloride and sulfate concentrations usually are less than 50 ppm. As the average flow of the Little River at Cameron is nearly equal to the flow of the Brazos at Whitney, controlled releases of water from reservoirs built or planned on the Little River tributaries could be used to dilute the releases from Whitney Reservoir. Such an arrangement should at all times provide water of good quality to users downstream from the mouth of the Little River.

Brine from oil-field operations has contaminated some streams in the upper part of the Leon River drainage basin. A daily sampling station was operated on the Leon River near Eastland in 1951–53.

Although the water at this station was at all times in the excellent-to-good range, high concentrations of chlorides were noted. Small reservoirs in the area generally contain water of good quality. Some pollution of surface water has been caused by surface storage of oil-field brines. Colony Creek, which flows into the Leon River below the sampling site, was rather badly polluted during the water years 1951–53. Leon Reservoir, constructed in 1954 just above the Eastland station, has contained water of excellent quality when sampled (table 3).

General samples have been collected from the Leon River and its tributaries above Lake Belton. Analyses of these samples indicate that, in general, the quality of the surface water above the lake is excellent to good but that some of the streams in the upper end of the basin, where oil-field wastes enter the streams, are saline. The water in Belton Reservoir is low in dissolved solids but is hard (table 3). Analyses of miscellaneous samples from the Lampasas River indicate that the quality of the water that would be stored in the proposed reservoir on the Lampasas River would be similar to that in Lake Belton. A few municipal reservoirs are in the lower Little River drainage basin, and the available chemical-quality information indicates that all of these reservoirs contain water that is entirely satisfactory for municipal use.

NAVASOTA RIVER

Records of water quality are available for two stations on the Navasota River. The Navasota River was sampled daily near Easterly during 1941–42, but only specific conductance and chloride content were determined on most of the samples. These records indicate that at that time, chloride pollution existed in the Navasota River basin above Easterly.

A daily sampling station was established on the Navasota River near Bryan in October 1958. The brine pollution indicated by the previous sampling upstream near Easterly was not as apparent at the new sampling station near Bryan. The record near Bryan indicated that the Navasota River is a potential source of water of suitable quality for domestic use and that water impounded in a reservoir on the Navasota River would probably be soft or moderately hard. Hence, it would be suitable for municipal and many industrial uses with minimum treatment. However, because of the early record of a persistent chloride-pollution problem in the upper reaches of the stream, a longer period of record at the Bryan station is desirable to determine whether the upstream pollution still exists and to determine whether the dilution effect of water from the intervening area will continue to be large enough to give water of good quality.

YEGUA CREEK

Yegua Creek is a Brazos River tributary having a drainage area of about 1,000 square miles but an average water discharge greater than that of either the Salt Fork or the Double Mountain Fork, whose drainage areas are much larger. The quality-of-water record for this stream consists of the analysis of only two samples—one in 1942 and another in 1959. Both of these samples were taken at low flow, and the water was of only fair quality. Much better water could be expected during high flows, and water stored in a reservoir on Yegua Creek probably would contain less than 500 ppm of dissolved solids. Water in Yegua Creek should be similar to that of the Navasota River, whose drainage area is directly across the Brazos and is underlain by similar rocks. Available chemical-quality data indicate that all streams draining the belt of Tertiary rocks, which extends along the Texas gulf coast, have produced water of good quality.

BRAZOS RIVER AT RICHMOND

Quality-of-water records of the Brazos River at Richmond date from October 1941. From 1941 to 1945, only specific conductance was determined on many of the samples. Since October 1945 a quality-of-water record of comprehensive analyses has been maintained and weighted-average concentrations have been computed annually. The quality-of-water record at Richmond is long enough to indicate the effects of the Whitney and Belton Reservoirs on water quality in the lower Brazos River.

Before 1952 the water at Richmond contained less than 500 ppm of dissolved solids during periods of high flow and as much as 1,400 ppm during periods of low flow. The quality at low flows was similar to that in Possum Kingdom Reservoir. After storage in Whitney Reservoir began in 1951, the maximum dissolved-solids concentrations at Richmond decreased in most years. However, during the extremely dry 1956 water year, the maximum concentration was again high, and the weighted-average concentration exceeded that of all other years of record. In 1956 a large part of the flow of the Brazos River at Richmond was saline water released from Whitney Reservoir.

Since the 1957 flood the maximum dissolved-solids concentrations observed at Richmond have been substantially lower than in previous years, whereas the weighted averages have been almost the same from year to year.

Storage in Whitney Reservoir has stabilized water quality and has lowered the maximum salinity in the lower reaches of the river. Belton Reservoir was not designed to regulate the water quality in the lower Brazos River, but it could be operated to provide appreciable quality regulation.

BRAZOS RIVER BELOW RICHMOND

Quality-of-water data for the Brazos River below Richmond has been collected since September 1957 by the Texas State Department of Health under its statewide sampling program. Sampling stations are on State Highway 36 at Velasco, on State Highway 35 at East Columbia, and on the county road ending at the Brazos River east of South Thompson. Conductivity measurements indicate that saline water is in almost all the samples from the Velasco station, is rarely in samples from the East Columbia station, and is in none of those collected near South Thompson. How far the sea water moves upstream from the gulf under various stream-flow and tidal conditions is not known. Samples taken at different depths might show the saline water to move along the bottom for many miles upstream. Increased industrial development may require delineation of the river-seawater interface.

SALT LOADS

The Brazos River and its tributaries transport water from areas where it falls as precipitation to the Gulf of Mexico. The river network also transports immense quantities of minerals dissolved in the water. From chemical analyses and water discharge records, computations can be made of the amount of dissolved solids that has moved past a sampling point during any interval of time. The amount of dissolved solids is the salt load of the river at the sampling point. Loads of individual constituents may also be computed.

Salt loads are additive—that is, the sum of the salt load of a river upstream from a tributary and the load of the tributary is equal to the load carried by the river below the mouth of the tributary. Hence, the computations of the salt loads at sampling points serve to identify the tributaries or stream reaches which are major contributors to the salt load carried by the river.

Natural processes limit the dissolved load carried by a river to a few major constituents, and many other constituents occur in only trace or minor amounts. Chloride and sulfate are the constituents most likely to restrict the use of the water for domestic and industrial use. Neither chloride nor sulfate is removed from stream water to any significant extent by natural processes, so that in any period of

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time the total quantities of chloride and sulfate moving in a river continually increases downstream except where water is diverted or where movement of the water is delayed by reservoir storage.

Table 4 lists yearly discharges, weighted-average concentrations, and mean loads of chlorides, sulfates, and dissolved solids for periods of record at selected points in the Brazos basin.

Relations between yearly discharges, weighted-average concentrations, and salt loads in the Brazos River basin vary not only from station to station but from year to year at the same station. Nevertheless, definite conclusions about sources of salinity in the Brazos River basin can be made from table 4.

The long quality-of-water record at the outflow of Possum Kingdom Reservoir is a convenient base for evaluating the effect of different sources of saline water. The water discharge at the station below Possum Kingdom Reservoir is water released from the reservoir or spilled during floods. The annual average daily load of chloride at the station has always exceeded the sulfate load, and the sum of the chloride and sulfate loads has always been more than half the dissolved-solids load. These relations are not the same for many of the tributaries, particularly in the lower basin.

The perennial flows of the Double Mountain Fork Brazos River and the Salt Fork Brazos River originate below the Caprock Escarpment. The two streams cross rocks of the same age in the same rainfall belt. Their average water discharges are about the same. Hence, they might be expected to contribute similar quantities of salts to the Brazos River. The chemical-quality data, however, show that a much smaller part of the salt load passing Possum Kingdom Dam originates in the Double Mountain Fork basin than originates in the Salt Fork basin. These data also show that the sulfate load of the Double Mountain Fork is greater than its chloride load, whereas the chloride load of the Salt Fork always exceeds the sulfate load. The data for the 1950 and 1951 water years for the Double Mountain Fork do not indicate much increase in salt load between the Rotan and Aspermont stations. In contrast, both the chloride and the sulfate loads of the Salt Fork between the Peacock and Aspermont stations increased substantially in the 1950 and 1951 water years. Salt-spring inflow from the Croton Creek and Salt Croton (Dove) Creek salt flats in the Salt Fork drainage basin account for a large part of this increase. (See p. K30.) The chemical-quality records suggest that additional unlocated saline springs above the Peacock station on the Salt Fork may contribute part of the salt load.

The chemical-quality data for the Clear Fork Brazos River and its tributaries show that the Clear Fork basin is the source of much less saline water than is either the Salt Fork or Double Mountain Fork basins. Some variation in the quality of water occurs in different parts of the Clear Fork drainage basin. The ratio of chloride to sulfate is higher in the Hubbard Creek drainage basin than in the Clear Fork basin above Fort Griffin and is probably due to contamination by oil-field brine. The data indicate that if more reservoirs are constructed amd more water is used in the Clear Fork drainage basin, the average concentration of dissolved solids in the water released from Possum Kingdom Dam will increase. At least one-third of the water stored in Possum Kingdom Reservoir comes from the Clear Fork drainage basin, whereas only about one-tenth of the salt load comes from that basin.

Salt loads of the Brazos River at the Possum Kingdom and Whitney stations cannot be compared directly on an annual basis because of storage in Whitney Reservoir. However, when the water stored in Whitney Reservoir is considered, the salt loads at the two stations can be compared. Computations for the period 1949–59 indicate that water entering the Brazos River between Possum Kingdom and Whitney Reservoirs had average concentrations of about 160 ppm of dissolved solids, 25 ppm of chloride, and 13 ppm of sulfate.

In the lower basin, the Navasota River is the only tributary of the Brazos River for which load data can be calculated. Comparisons of loads carried by the Brazos River at Whitney and by the Navasota River at Bryan indicate the potential value of storage reservoirs on the lower tributaries that can be used to regulate the quality of the Brazos River. Though about three-fourths as much water flowed past the station on the Navasota River near Bryan in the 1959 water year as was released from Whitney Reservoir, the load of dissolved salts of the Navasota River was only about one-fifth as great as that of the Brazos River at the Whitney station. Also, the water of the Navasota River has a lower proportion of both chloride and sulfate salt.

Water passing the Richmond station is a mixture of flows from the entire basin. In some years a large part of the flow at Richmond originates in the Brazos River basin above the Whitney Reservoir. In other years much more than half the flow enters the river downstream from Whitney Reservoir. The different sources of flow result in a marked variability of both weighted-average concentrations and mean daily loads. Thus, the mean daily loads usually are greater in high-flow years than in low-flow years.

For the 11 water years 1949–59, computations indicate that the weighted-average dissolved-solids concentration of the inflow into the Brazos River between Whitney Reservoir and Richmond was about 215 ppm; the average chloride content was 22 ppm, and the average sulfate content was 25 ppm. In the 1959 water year, the weighted-average concentration of dissolved solids for the inflow was about 220 ppm, the chloride content was 32 ppm, and the sulfate content was 30 ppm.

Water from the Brazos River is used industrially at Freeport and Texas City, and proposals have been made to divert water to the Houston area. The approximate weighted-average concentrations computed from the load data show that it would be possible to maintain at low levels the concentrations of dissolved salts in the Brazos River water from Richmond downstream provided substantial storage becomes available on the lower tributaries of the river.

The largest contribution to the salt load of the basin is furnished by the Salt Fork Brazos River. Saline springs and seeps of Salt Croton Creek and its tributaries, Dove and Haystack Creeks, are a major source of salt inflows to the Salt Fork Brazos River. Water-discharge measurements have been made at several sites in the Salt Croton Creek basin, and water samples have been collected for chemical analysis. From the analyses and discharge measurements, chloride and sulfate loads at the time of sampling have been computed. Many samples contain as much as 145,000 ppm of chloride, a concentration close to the saturation point. Evaporation causes precipitation of salts along the stream channels, and flushouts of the precipitated salts by storm flows occur from time to time. Hence, a close estimate of the annual quantities of chlorides and other measured constituents contributed by Salt Croton Creek is difficult to obtain. However, based on winter measurements when evaporation is at a minimum, the average daily load of chloride that originates in the area of the salt flats is about 400 tons. Recent calculations based on a 4-year period show a total of 485 tons per day of chloride for both base and flood flow (Baker, Hughes, and Yost, 1962, written communication). These calculations compare with a longtime average daily chloride load at the Possum Kingdom station on the Brazos River of about 1,000 tons. Obviously, one way of substantially improving the quality of the water in the lower Brazos River would be to prevent the flow of Salt Croton Creek from reaching the Salt Fork Brazos River.

RESERVOIR STRATIFICATION

Because of stratification, the quality of water stored in reservoirs in the Brazos River basin is sometimes different in different parts of the reservoirs. The density of water flowing into a reservoir may be different from that of the stored water because of differences in temperature and suspended-sediment or dissolved-solids concentrations. Dense water flowing into a reservoir tends to slide under the less dense water, and the water thus becomes stratified. Stratification of the stored water has been observed in other reservoirs, such as Lake Mead (U.S. Bureau of Reclamation, 1941, 1948).

Many factors affect stratification. Sediment tends to settle to the bottom and to reduce or increase density differences, although fine sediments may settle very slowly. Saline layers may not remain stratified indefinitely, as they tend to be mixed by movement of the water as a result of wave action, temperature differences, or surface disturbances such as those caused by power boats. Thus, in time, there is a natural blending of the water in a reservoir, so that near uniformity in water quality may be approached.

Inflow into Possum Kingdom Reservoir and, to a lesser extent, into Whitney Reservoir is high in dissolved solids for long periods, particularly during the winter when the temperatures are low. The first inflows immediately following a rainstorm are generally higher in dissolved solids and contain more sediment than the later flood flows. Both conditions result in stratification of the water in Possum Kingdom and Whitney Reservoirs. The deeper part of the reservoirs is more saline than the layers near the surface. Stratification in Possum Kingdom Reservoir has been noted by W. W. Hastings (1942, written communication) and by others (Ambursen Engineering Corp., 1956).

In 1956 the U.S. Army Corps of Engineers investigated the variation of the chemical quality of water with depth in Whitney Reservoir. At monthly intervals a series of samples were collected at each of four stations along the length of the reservoir. The results of chloride determinations for the samples collected on May 15 and June 11 are plotted in figure 1, which diagrammatically pictures lake stratification for two sets of conditions.

The flood of 1957 greatly affected the stratification in Possum Kingdom Reservoir. For many months before this flood, the dissolved-solids concentration of water released from Possum Kingdom ranged from 1,600 to 1,800 ppm, and specific conductance ranged from 2,600 to 2,800 micromhos. Chloride concentration generally was about 600 ppm, and sulfate concentration was somewhat more than 500 ppm. This water was drawn from the lower levels through the power plant. During most of May and the early part of June, water was released through the spillway. The dissolved-solids concentration of spilled water ranged from 300 to 500 ppm; both chloride and sulfate concentrations remained near 100 ppm. The spillway gates were closed on June 9, and release was continued through the

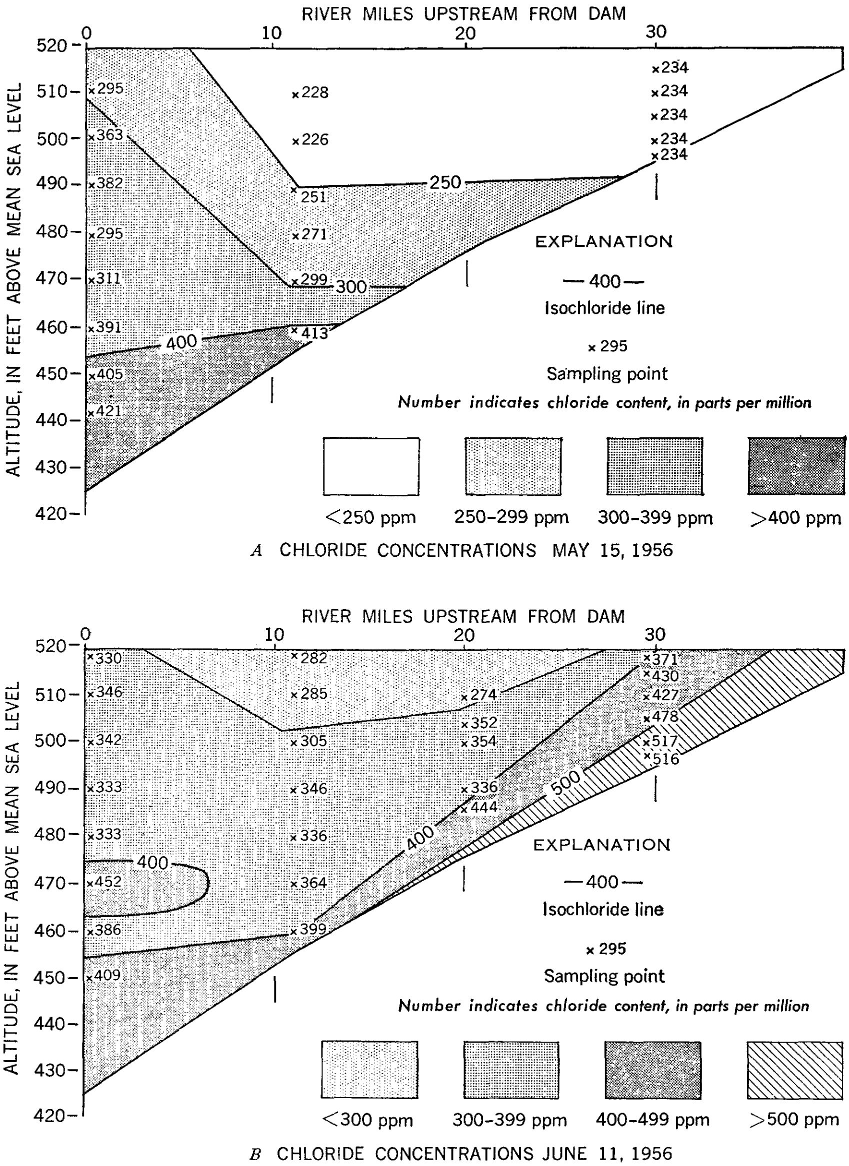

FIGURE 1.—Schematic diagrams showing chloride concentration in Lake Whitney. *A*, May 15, 1956; *B*, June 11, 1956.

turbines from the low levels of the lake. The dissolved-solids concentration of this water was about 800 ppm, or about double the concentration observed in the flood flows, and specific conductance ranged from 1,200 to 1,300 micromhos. Although during May the volume of water passing through the reservoir exceeded twice the capacity of the reservoir, inflow water of good quality tended to remain near the surface and to mix only slightly with the water of poor quality at the lower levels. Plate 4 shows the relation of specific conductance to reservoir contents and discharge at Possum Kingdom Dam for the period April 1–July 31, 1957.

Until May 15, inflow to the reservoir had been low in chloride as the result of a flood of Palo Pinto Creek and reduced releases from Possum Kingdom Reservoir. The upper diagram of figure 1 shows that the water of lower concentration was on top of the denser and more concentrated water already in storage. When the June 11 samples were collected, the inflow from tributaries below Possum Kingdom Reservoir since May 15 had been small, and most of the recent inflow into Whitney Reservoir had come from releases from Possum Kingdom Reservoir. This inflow, with its higher dissolved-solids concentration, had followed the bottom of the reservoir (lower diagram of fig. 1).

Although information is not available to describe the patterns of reservoir stratification in detail, sufficient information is available to show that mixing of water in Possum Kingdom and Whitney Reservoirs is slow and that stratification continues for long periods. If the pattern of stratification in the two reservoirs were known or could be predicted, methods of managing releases to induce better mixing and to improve the quality of stored water might be possible.

CUMULATIVE-FREQUENCY ANALYSIS

The preceding discussions of water-quality relationships in the Brazos River basin have been based on the study of weighted averages, analyses of samples collected from reservoirs, miscellaneous analyses, and salt-load computations. These discussions have pointed out that any river system has a day-to-day variation in water quality—it has periods of low concentration, periods of intermediate concentration, and still other periods of high concentration of dissolved constituents. The frequency with which particular concentrations of dissolved solids occur can be shown by cumulative dissolved-solids frequency curves that are similar to flow-duration curves (Searcy, 1959). Thus, a visual appraisal of water-quality variations at different sampling points can be obtained by comparing cumulative-frequency curves.

Cumulative-frequency curves of dissolved-solids concentrations have been prepared for selected stations in the Brazos River basin. Figure 2 is a typical curve. Many of the stations were operated for short periods, and these periods often included days of no flow. Several daily samples were included in a single composite. Because of these limitations, the extremes of some curves were not well defined. The cumulative-frequency data for 15 stations are given in table 5. The percentage of days of flow when disslved-solids concentrations exceeded 500 and 1,000 ppm was also determined for these stations and for other stations with a more limited record. The river-basin map, plate 3, shows the location of the stations and the percentage of days of flow when the dissolved-solids concentrations exceeded 500 and 1,000 ppm.

GENERAL PRINCIPLES

The cumulative-frequency curve (fig. 2) shows the percentage of days of flow in which specified concentrations of dissolved solids were equaled or exceeded during a given period. It combines in one curve the changing values of mineral content, which are characteristic of a sampling station throughout the range of concentration, without regard to sequence of occurrences. If the period on which the curve is based represents the long-term variations at the sampling point, the curve may be used to estimate the probable percentage of days of flow that a specified dissolved-solids concentration will be equaled or exceeded in the future.

In this study, daily samples were used if available. If no daily samples were available, the dissolved solids for a composited sample was used for each day in the composite period. The use of a single dissolved-solids value for a composite period results in some inaccuracies, but as the length of the record increases, the inaccuracies are decreased.

For stations where dissolved solids had been determined for only part of the sampling period and the rest of the record consisted of specific conductance data or chloride content data, the relation of these data to the dissolved-solids concentration was used to estimate the dissolved solids for the missing period of record. The lower left part of a curve denotes the periods of high flow following rain storms, times when the dissolved-solids concentration of the water is lowest. The percentage of time that high flow occurs usually is small, yet the volume of the flow makes up the greater part of the annual discharge. Thus, the yearly weighted averages of the dissolved-solids concentration usually is exceeded 60–80 percent of the time by the daily dissolved-solids concentration.

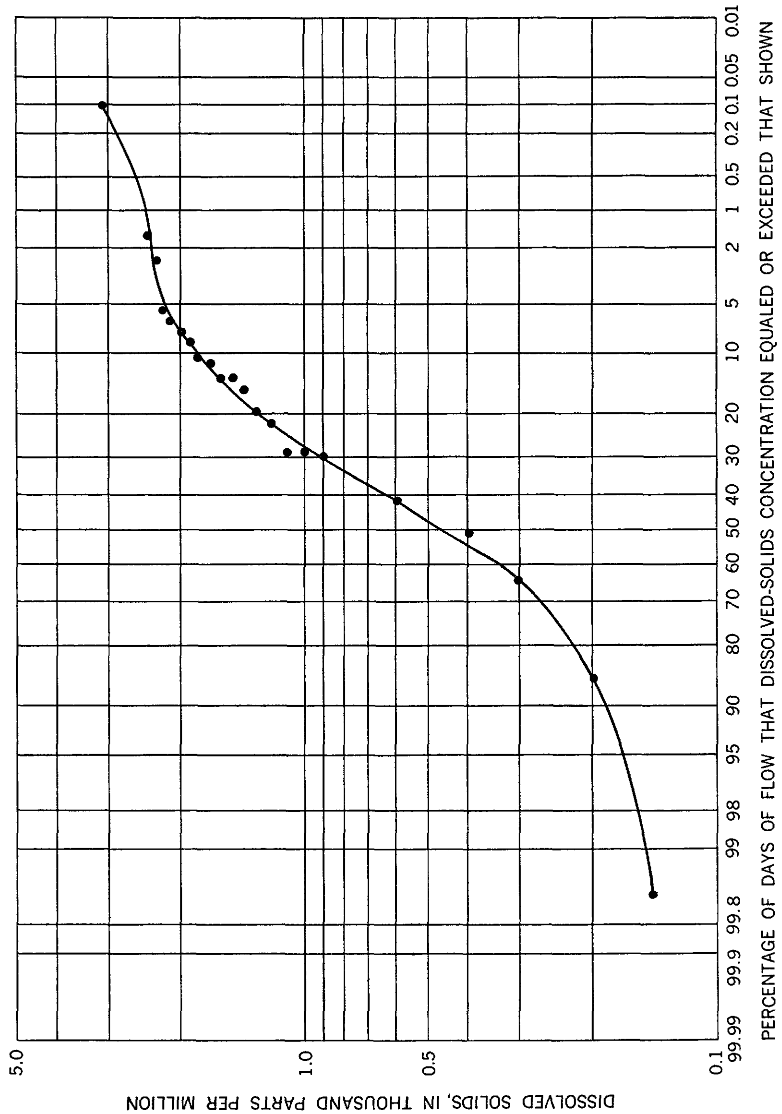

Figure 2.—Cumulative frequency curve for dissolved-solids concentrations, Hubbard Creek near Breckenridge, Oct. 1, 1955–Sept. 30, 1959.

For this study, only the records of complete water years were used to compute the frequency data.

STATION ANALYSIS

The following discussion of the cumulative-frequency analysis of dissolved-solids concentration for individual stations supplements the subbasin and stream-reach study based on maximum, minimum, and weighted-average dissolved-solids concentration.

The data for the 2-year record for the Double Mountain Fork Brazos River near Rotan shows a great variation in water quality. This variation is a common feature of an ephemeral saline stream. For the higher concentration of dissolved solids in low flows, the variation is not as great as for higher flows. This indicates that the quality of ground-water inflow is more uniform than the quality of surface flow. The cumulative-frequency data also shows that the water at this station was saline about three-fourths of the time and very saline about 15 percent of the time.

The 6-year record for the Double Mountain Fork Brazos River near Aspermont shows that the quality fluctuates greatly about one-third of the time. Most of the fluctuations occur during flood periods, at which times the quality of the surface runoff ranges from fair to slightly saline. A relative uniformity of the quality for more than half the time is indicated when the dissolved-solids concentration is between 3,000 and 5,000 ppm. The effect of evaporation on the extremely low flow is indicated by a further increase in concentration for about 2 percent of the time. Nevertheless, the salinity at this station never approaches the high salinity at the Rotan station.

The 2-year record for the Salt Fork Brazos River near Peacock shows that saline water flowed past this point more than 98 percent of the time. Extended periods of low flow occurred at the Peacock station, and during these periods the dissolved-solids concentration ranged from 16,000 to 24,000 ppm. Variations in concentration at this station were overshadowed by the persistently high concentrations.

The data from the 6-year record for the Salt Fork near Aspermont indicate even greater and more persistent salinity there than at the Peacock station. At the Aspermont station the water would be classified as a brine about half of the time when the concentration exceeded 35,000 ppm of dissolved solids. At this station even the variable part of the record, that tempered by surface runoff, shows saline water that would be unfit for nearly any use.

The cumulative-frequency data for the 5-year record for the Clear Fork Brazos River at Nugent are very different from the data of stations discussed previously. Half of the time the water at this station contained less than 1,000 ppm of dissolved solids. The flow for the rest of the period was only moderately saline. Though the flow at the Nugent station has been perennial, the low flow has never been very saline.

The cumulative-frequency data for the 2-year record of Paint Creek near Haskell indicate water that was generally of good quality (more than 80 percent of the time) and was slightly saline only about 10 percent of the time.

The cumulative-frequency data for the 2-year record of the Clear Fork Brazos River at Fort Griffin indicate that the flow was slightly saline only 2 percent of the time. The water was of good quality about 90 percent of the time.

Variability in water quality is the most noticeable feature of the cumulative-frequency data for Hubbard Creek near Breckenridge. The flood flows were of excellent quality, and the annual weighted-average dissolved-solids concentrations were in the good-quality class, yet the 4-year record shows a flow of saline water 26 percent of the time. The saline water probably was the result of pollution by oil-field brines. The natural base flows, as well as flood flows, probably were of excellent quality, and the weighted averages for the years of record indicate that the water to be stored in a reservoir on Hubbard Creek will be of suitable quality for domestic use.

The cumulative-frequency data for the full year of record (water year 1959) for Salt Creek at Olney (table 5) indicate the variability in water-quality characteristics of a small watershed that has been polluted with oil-field brines. The 1-year record was compiled after a watershed cleanup program had been in effect for 6 months. Even greater variability was evident during the cleanup period. Within a few hours on August 20, 1958, dissolved-solids concentrations at the station ranged from 200 to more than 19,000 ppm. During the 1959 water year the water was saline about 45 percent of the time; but, despite the serious pollution, the water was of good quality during periods of high flow.

The 1-year record for Salt Creek near Newcastle showed variations in quality similar to those at the Olney station, but the range in concentration of dissolved solids was lower near Newcastle. The water of Salt Creek near Newcastle was saline only about 20 percent of the time, and during flood flows the dissolved-solids concentrations were among the lowest recorded at any station in the Brazos River basin.

The cumulative-frequency data for the 17-year record (1942–59) of the Brazos River at Possum Kingdom Dam indicate the results for a stream whose water of highly variable quality has been mixed in a reservoir. There was little variation in water quality except for the discharge of water with low dissolved-solids content during the 1957 flood. This flood release passed over the spillway without mixing with the more saline water already stored. Except for the 1957 water year, the dissolved-solids concentrations have ranged from 700 to 2,600 ppm and have exceeded 1,000 ppm about 92 percent of the time.

The record for the Brazos River near Whitney station began before the construction of Whitney Dam. Cumulative-frequency data were prepared for the period before and after the construction of the dam. The year in which impoundage began is not included in this study because the impoundage began in the middle of a water year and only complete water years were considered in the frequency analysis. The salinity of the Brazos River near Whitney was much lower than at Possum Kingdom Dam both before and after construction of Whitney Dam.

The cumulative-frequency study from October 1, 1947, to September 30, 1951, indicates two separate types of variation in quality. When the water was saline there was little change in dissolved-solids concentration. This condition occurred about 68 percent of the time and represented the saline releases from Possum Kingdom Dam. The other phase showed more diverse qualities of water, ranging from excellent to saline, which reflected the mixing of an excellent quality of water from the drainage area below Possum Kingdom with the releases from the upstream reservoir.

The cumulative-frequency study for the period during which flow was controlled by Whitney Dam showed more uniformity in the dissolved-solids concentration than had been experienced during the uncontrolled period. The quality of the water ranged from fair to moderately saline except for flood spillage, which was of excellent quality.

The cumulative-frequency study of the Leon River near Eastland for the water years 1950–53 indicates that the water was of better quality than at any other station in the Brazos River basin for which a comprehensive record is available. The dissolved-solids concentration did not exceed 320 ppm, and much of the time (64 percent) the concentration was not less than 250 ppm. The sampling site was above Colony Creek, which is polluted by oil-field brine. A dam was constructed in 1954 just below the sampling point. The water stored in the new lake, Leon Reservoir, has been of excellent quality.

The 1-year record (water year 1959) for the Navasota River near Bryan indicates that the dissolved-solids concentration was less than the slightly saline level (1,000 ppm) for the full year. Because of the inflow of brine from oil fields upstream, this is remarkable. The dissolved-solids concentration exceeded 500 ppm only 17 percent of the time. If efforts to keep oil-field pollution in check in the upper part of the basin, were continued, the water of the Navasota could meet the most exacting demands of municipal and industrial supply.

The 17-year quality-of-water record of the Brazos River at Richmond has been divided into three periods—the years between the construction of Possum Kingdom and Whitney Dams, the years between the construction of Whitney and Belton Dams, and the years subsequent to the operation of the three major reservoirs in the Brazos River basin. Water at this station does not have the wide range and variability in quality generally found in water at most of the upstream stations.

The greatest variation in water quality was during the first period, when Possum Kingdom Reservoir was the only sizeable control on the flow of the river. Both the maximum and the minimum dissolved-solids concentrations for this station were recorded during this first part of the record. This period included 5 years of above-average flow and 5 years of below-average flow.

During the 3-year period following the completion of Whitney Reservoir, the discharge of the Brazos was only 40 percent of the long-term average. Nevertheless, the range of dissolved-solids concentrations was not as great as in the first period of study. The flow was just barely saline during 10 percent of the time. A study of the record at Richmond shows that the quality was best when most of the water came from the drainage area below Whitney Reservoir and became poorer when releases from Whitney Reservoir were a large part of the flow.

The last cumulative-frequency analysis is for the period during the operation of Possum Kingdom, Whitney, and Belton Reservoirs. This period (1954–59 water years) spans 2½ years of extreme drought which floods ended in 1957; 1 year of above-normal runoff in 1958; and 1 year of below-normal runoff in 1959.

A detailed study of the records indicates that the Belton Reservoir has not had an appreciable effect on water quality at Richmond because no significant releases, which would have diluted the more concentrated water from the upper basin, were made during low-flow periods. Water of good quality was released from Belton Reservoir in the droughty year of 1956, when the reservoir was lowered to conservation capacity within a few days. If the water had been held in storage and released gradually for mixing with water from Whitney Reservoir, the quality of the water available in the lower Brazos during the low-flow period would have been much improved. During this extremely dry summer, the lower Brazos received most of the saline releases from Whitney. These high concentrations coupled with the low concentrations during and after the large floods of 1957 gave this period of study almost as wide a range in concentrations as that in the period of unregulated flow.

CONCLUSIONS

The conclusions of this study are:

1. Before construction of Possum Kingdom Dam, the Brazos River contained saline water from the confluence of the Salt and Double Mountain Forks to the mouth for extended periods each year.

2. Possum Kingdom and Whitney Reservoirs have reduced variations in water quality of the Brazos River by decreasing the maximum and increasing the minimum concentrations downstream, except during extended droughts.

3. Natural sources that contribute large quantities of highly saline water to the Brazos River and its tributaries are restricted to the upper part of the basin where rocks of Permian age are at or near the land suface.

4. Both quality-of-water and streamflow records are insufficient to determine whether a substantial quantity of water of usable quality could be impounded on the Salt and Double Mountain Forks Brazos River above known areas of saline inflows.

5. The Salt Fork Brazos River contributes more dissolved solids to the Brazos River than any other tributary. Water stored in a reservoir on the Salt Fork near Aspermont would be too saline for most uses.

6. Double Mountain Fork Brazos River is the source of saline water that has sulfate as the dominant constituent. Water from a reservoir on the Double Mountain Fork near Aspermont could be used for irrigation but would be too saline for municipal and most industrial uses.

7. Water of good quality could be impounded in reservoirs constructed on the Clear Fork Brazos River and its tributaries above Fort Griffin.

8. Saline inflows from oil-field wastes degrade water quality in the lower reaches of the Clear Fork above the South Bend gaging station.

9. Increased use of water stored in reservoirs on tributaries of the Brazos River upstream from Possum Kingdom Reservoir will result in an increase of salinity of the water stored in Possum Kingdom and Whitney Reservoirs.

10. Constructing the proposed reservoir on the Brazos River near South Bend or increasing the storage capacity of Possum Kingdom Reservoir might result in better mixing of the stored water and a more uniform water quality downstream from Possum Kingdom Dam.

11. During periods of low flow the inflow to Possum Kingdom and Whitney Reservoirs is saline and, being denser than the water near the surface of the reservoirs, moves to the bottom of the reservoirs. During floods the inflowing water is better in quality and less dense than the water in the reservoir and moves over the impounded water with only partial mixing. The reservoir waters become stratified, and the reservoirs are only partly effective in stabilizing and improving quality downstream.

12. Release of saline water from the lower levels of Possum Kingdom and Whitney Reservoirs during floods would have little effect on quality of the flood flows, and the quality of the water stored for subsequent release during low-flow periods would be improved.

13. Almost all the saline inflow to tributaries in the Brazos River below Possum Kingdom Dam comes from oil-field brines.

14. All reservoirs planned or under construction on the lower tributaries of the Brazos River will impound water of good quality.

15. The suitability of the water in the lower Brazos River basin for municipal and most industrial uses can be assured by mixing different amounts of water from existing and proposed reservoirs.

16. Encroachment of saline water from the Gulf of Mexico into the lower Brazos River occurs during periods of low discharge.

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BASIC DATA

Quality-of-water records for the Brazos River basin are published in the following U.S. Geological Survey Water-Supply Papers and Texas Board of Water Engineers Bulletins:

Water year	*Water-supply paper*	*Texas Board of Water Engineers Bulletin*
1942	950	[1] 1938–45
1943	970	[1] 1938–45
1944	1,022	[1] 1938–45
1945	1,030	[1] 1938–45
1946	1,050	[1] 1946
1947	1,102	[1] 1947
1948	1,133	[1] 1948
1949	1,163	[1] 1949
1950	1,188	[1] 1950
1951	1,199	[1] 1951
1952	1,252	[1] 1952
1953	1,292	[1] 1953
1954	1,352	[1] 1954
1955	1,402	[1] 1955
1956	1,452	5905
1957	1,522	5915
1958	-----	6104
1959	-----	6205

[1] "Chemical Composition of Texas Surface Waters" was designated only by water year from 1938 through 1955.

TABLE 1.—*Miscellaneous chemical analyses of water of lower Brazos River, October 1933–November 1934*

[Results in parts per million. Analyses by Rice Institute except as indicated]

Date of collection	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids (calculated)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate
Brazos River at Hempstead-Bellville Road Bridge											
Oct. 26, 1933 [1]	13	147	8.4		272	226	270	388	1,210	402	216
Brazos River at Orchard Bridge											
Oct. 26, 1933 [1]	11	139	8.2		271	216	256	420	1,210	380	204
Nov. 8 [1]	11	185	28		444	164	437	673	1,860	576	442
Nov. 14 [1]	16	89	15		139	191	158	176	687	284	127
Brazos River at Rosenberg Bridge											
Oct. 26, 1933 [1]	14	147	9.5		294	211	282	424	1,270	406	233
Nov. 8 [1]	13	154	25		369	168	379	542	1,560	487	350
Nov. 14 [1]	18	80	14		125	190	133	155	618	257	102
Nov. 17	19	104	24		106	225	163	167	694	358	174
Nov. 20	38	107	21		105	221	155	170	705	354	172
Nov. 24	21	79	16		55	262	56	78	434	263	48
Nov. 27	8.0	97	20		41	268	73	85	456	324	104
Dec. 4	22	86	14		92	256	104	110	554	272	62
Jan. 10, 1934		63	8.0		7.6	141	26	46		190	74
Feb. 15		39	9.0		12	98	33	32		134	54
Mar 12	9.0	38	5.0		42	91	55	53	247	116	41
Mar. 21	12	56	8.0		62	134	42	110	356	172	62
Apr. 4		36	5.0		36	128	28	39		110	6
Apr. 18		40	6.0		25	110	39	35		124	34
May 2		74	11		70	192	67	110		230	72
May 16	22	114	19		106	195	167	184	708	362	202
June 6	30	60	9.0		90	196	71	106	462	186	26
June 20	26	74	10		88	220	76	113	495	226	45
July 2	23	86	12		96	218	97	138	559	264	86
July 18	25	76	10		118	232	80	52	475	230	40
Aug. 1	27	78	11		124	244	97	149	606	240	40
Aug. 15	13	72	10		110	242	78	128	530	220	22
Sept. 5	10	70	10		92	238	68	106	473	216	20
Sept. 20	18	54	8.0		104	226	62	106	463	168	0
Oct. 4	36	36	5.0		35	143	19	35	236	110	0
Oct. 18	7.0	66	16		106	219	94	131	528	230	51
Nov. 1	15	78	20		96	244	92	135	556	276	76
Nov. 15	12	86	15		141	250	112	185	674	276	71

[1] Analyses by Pittsburgh Testing Laboratory.

TABLE 2.—*Summary of chemical analyses of streams in the Brazos River Basin, 1906–7, 1941–59*

[Results in parts per million except as indicated. Analyses by U.S. Geological Survey]

Date of collection	Mean discharge (cfs)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (calculated)			Hardness as $CaCO_3$		Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH
													Parts per million	Tons per acre-foot	Tons per day	Calcium, magnesium	Noncarbonate				
Double Mountain Fork Brazos River near Rotan																					
Water year 1950																					
Maximum, Jan. 21–31, 1950	[1] 0	14	800	156	6,170		126	2,190	9,700	------	------	------	19,100	26.0	0.0	2,640	2,530	84	52	28,900	7.6
Minimum, Sept. 5–9	1,542	13	49	8.3	118		120	177	91	------	1.2	------	[2] 531	.72	2,210	156	58	62	4.1	871	8.1
Weighted average	146	15	97	16	152		126	294	160	------	1.4	------	812	1.10	320	308	205	52	3.8	1,270	----
Water year 1951																					
Maximum, Oct. 22–24, 1950	[1] 0	18	559	110	3,070		117	1,590	4,800	------	------	------	10,200	13.9	.0	1,850	1,750	78	31	15,800	7.7
Minimum, Aug. 21–25, 1951	910	18	98	16	115		127	300	101	------	1.2	------	[2] 731	.99	1,800	310	206	45	2.8	1,100	7.8
Weighted average	32.6	19	176	28	218		121	525	270	------	------	------	1,300	1.77	114	554	455	46	4.0	1,940	----
Double Mountain Fork Brazos River near Aspermont																					
Water year 1949																					
Maximum, Mar. 1–10, 1949	0.77	13	636	92	779		116	1,770	1,220	------	1.5	------	4,570	6.22	9.5	1,970	1,870	46	7.6	6,340	----
Minimum, Sept. 11–20	1,168	14	81	13	110		115	254	95	------	2.2	------	[2] 664	.90	2,090	256	162	48	3.0	1,020	7.7
Weighted average	139	14	138	20	130		120	380	150	------	2.6	------	916	1.25	344	426	328	40	2.7	1,410	----
Water year 1950																					
Maximum, Feb. 1–13, 19–28, 1950	1.62	13	614	82	595		116	1,700	920	------	1.2	------	3,980	5.41	17	1,870	1,770	42	6.0	5,350	7.8
Minimum, May 11–13	2,275	16	74	9.6	132		120	240	114	------	1.0	------	646	.88	3,970	224	126	56	3.8	1,030	7.6
Weighted average	171	15	162	18	138		109	460	148	------	2.3	------	1,010	1.37	466	478	388	39	2.7	1,470	----

Water year 1951																				
Maximum, Aug. 5, 8, 1951	[1] 0	23	816	115	553	76	2,340	860	----	.0	----	4,740	6.45	.0	2,510	2,450	32	4.8	5,920	7.8
Minimum, Aug. 23–29	743	18	105	17	142	133	330	132	----	3.5	----	[2] 842	1.15	1,690	332	223	48	3.4	1,280	7.9
Weighted average	63	18	249	29	167	106	700	203	----	2.4	----	1,430	1.94	243	740	654	33	2.7	1,980	----
Water year 1957																				
Maximum, July 9–16, 1957	4.62	26	588	83	787	59	1,720	1,190	----	1.6	----	4,420	6.01	55.1	1,810	1,760	49	8.0	6,020	7.5
Minimum, June 1–7, 13–14, 19–20	2,849	16	104	14	89	122	273	87	----	4.2	----	[2] 689	.94	5,300	317	217	38	2.2	1,020	7.8
Weighted average	352	14	152	16	110	110	400	123	----	3.0	----	910	1.24	865	445	355	35	2.3	1,300	----
Water year 1958																				
Maximum, Feb. 23–28, 1958	9.02	10	640	102	1,470	130	1,660	2,400	----	----	----	6,350	8.64	155	2,020	1,910	61	14	9,430	8.0
Minimum, Oct. 22–28, 1957	492	11	61	10	138	137	208	115	----	2.5	----	[2] 636	.86	845	193	80	61	4.3	989	8.0
Weighted average	130	14	217	22	207	110	592	265	----	2.5	----	1,390	1.89	488	632	542	42	3.6	1,970	----
Water year 1959																				
Maximum, Aug. 1–7, 1959	4.96	18	590	80	969	103	1,600	1,530	----	1.0	----	4,840	6.58	64.8	1,800	1,720	54	9.9	6,690	7.2
Minimum, July 1–6	4,604	15	110	14	99	110	318	88	----	3.0	----	[2] 715	.97	8,890	332	242	39	2.4	1,060	7.4
Weighted average	219	15	153	18	149	113	429	168	----	2.6	----	999	1.36	591	456	363	42	3.0	1,460	----

Salt Fork Brazos River near Peacock

Water year 1950																				
Maximum, Apr. 14–15, 1950	0.19	13	1,050	375	11,200	123	3,250	17,800	----	----	----	33,700	45.8	17	4,160	4,060	85	75	45,100	7.3
Minimum, Sept. 26–28	720	12	56	18	241	121	141	345	----	4.8	----	[2] 934	1.27	1,820	214	114	71	7.2	1,560	7.7
Weighted average	134	16	158	46	731	137	412	1,160	----	4.3	----	2,610	3.55	944	583	470	73	13	4,380	----
Water year 1951																				
Maximum, Apr. 20–24, 30, 1951	.75	24	796	303	8,280	145	2,410	13,200	----	----	----	25,100	34.1	51	3,230	3,110	85	63	35,900	7.7
Minimum, May 19–27	313	22	64	17	163	133	159	218	----	2.5	----	[2] 728	.99	615	230	120	61	4.7	1,280	7.8
Weighted average	31.2	24	195	54	1,150	139	550	1,790	----	----	----	3,840	5.22	323	708	594	78	19	6,280	----

See footnotes at end of table.

TABLE 2.—*Summary of chemical analyses of streams in the Brazos River Basin, 1906–7, 1941–59*—Continued

[Results in parts per million except as indicated. Analyses by U.S. Geological Survey]

Date of collection	Mean discharge (cfs)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (calculated): Parts per million	Dissolved solids (calculated): Tons per acre-foot	Dissolved solids (calculated): Tons per day	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH
Salt Croton Creek near Aspermont																					
Water year 1957																					
Maximum, Oct. 9, 1956	----	----	----	----	89,700	----	----	3,370	146,000	----	----	----	----	----	----	9,860	----	95	393	----	----
Minimum, May 31, 1957	760	----	----	----	517	12	167	1,450	800	----	----	----	----	----	----	1,580	1,440	41	5.6	4,810	6.9
Water year 1958																					
Maximum, Sept. 3, 1958	.43	----	----	----	101,000	----	----	2,590	159,000	----	----	----	----	----	----	10,400	----	95	431	----	----
Minimum, Nov. 5, 1957	360	----	----	----	778	----	140	1,060	1,130	----	----	----	----	----	----	1,110	----	60	10	5,010	7.6
Water year 1959																					
Maximum, Aug. 5, 1959	.6	----	----	----	98,800	----	----	2,710	155,000	----	----	----	----	----	----	9,830	----	96	433	----	----
Minimum, July 17	280	----	----	----	1,790	----	----	640	2,800	----	----	----	----	----	----	----	----	----	----	9,240	----
Salt Fork Brazos River near Aspermont																					
Water year 1949																					
Maximum, Mar. 21, 24–28, 1949	8.50	14	1,330	490	28,400		105	2,850	45,400	----	----	----	78,500	107	1,800	5,330	5,250	92	169	90,000	7.6
Minimum, July 16, 31, Aug. 1	109	17	128	34	433		138	336	662	----	5.0	----	1,680	2.28	494	460	346	67	8.8	2,790	----
Weighted average	157	15	274	46	1,160		112	709	1,820	----	----	----	4,080	5.55	1,730	873	781	74	17	6,380	----
Water year 1950																					
Maximum, Apr. 1–15, 30, 1950	1.41	11	1,440	274	16,900		159	3,440	26,880	----	----	----	48,900	66.5	54	4,720	4,590	89	107	60,900	7.7
Minimum, Sept. 6–10, 27–29	1,004	15	166	26	448		116	435	670	----	4.0	----	1,820	2.48	4,930	521	426	65	8.5	3,060	7.8
Weighted average	166	16	320	52	1,400		117		2,230	----	----	----	4,870	6.62	2,180	1,010	916	75	19	7,640	----

Water year 1951																		
Maximum, Mar. 11–13, 27, 1951	9.60	17	1,220	445	27,500	114	2,760	43,800	------	------	------	75,800	103	1,960	4,870	4,780	92	171	95,500	7.3
Minimum, May 19–24	713	26	118	19	423	153	320	588	------	6.3	------	1,580	2.15	3,040	372	247	71	9.5	2,760	7.9
Weighted average	64.5	24	384	79	2,250	118	1,020	3,560	------	------	------	7,380	10.0	1,290	1,280	1,190	79	27	11,000	----
Water year 1957																		
Maximum, Feb. 1–6, 1957	.68	12	1,490	455	27,600	149	3,190	44,100	------	------	------	76,900	110	149	5,590	5,470	91	160	86,600	7.9
Minimum, June 2–4	4,590	15	126	19	300	127	319	428	------	6.1	------	1,280	1.74	15,860	392	288	62	6.6	2,080	7.8
Weighted average	299	17	247	33	882	117	625	1,360	------	------	------	3,220	4.38	2,600	752	656	72	14	5,080	----
Water year 1958																		
Maximum, Sept. 1–14, 1958	.72	13	1,540	348	20,700	135	3,630	32,900	------	------	------	59,200	83.7	115	5,270	5,160	90	124	74,100	7.5
Minimum, Oct. 14–19, 23–26, 1957	399	14	119	27	848	129	311	1,290	------	2.9	------	2,670	3.63	2,880	408	302	82	18	4,650	7.9
Weighted average	71.4	13	330	68	2,800	124	826	4,410	------	------	------	8,500	11.6	1,640	1,100	1,000	85	37	12,700	----
Water year 1959																		
Maximum, Mar. 30–31, 1959	.60	24	1,570	556	36,100	90	3,510	57,400	------	------	------	99,200	145	161	6,200	6,130	93	199	101,000	7.3
Minimum, Aug. 8–12	648	23	140	22	609	123	362	910	------	3.5	------	2,130	2.90	3,730	440	339	75	13	3,530	8.2
Weighted average	126	17	263	47	1,540	121	666	2,420	------	------	------	5,020	6.83	1,710	850	750	80	23	7,700	----

Clear Fork Brazos River at Nugent

Water year 1949																		
Maximum, Mar. 21–31, 1949	4.15	4.1	370	138	774	140	1,460	1,090	------	2.5	------	3,910	5.32	44	1,490	1,380	53	8.7	5,650	7.8
Minimum, Sept. 15–16	860	8.8	34	1.1	20	104	32	8.0	------	2.5	------	158	.21	367	89	4	32	.9	264	7.4
Weighted average	58.1	10	65	15	54	120	145	63	------	2.3	------	425	.58	67	224	125	34	1.6	659	----
Water year 1950																		
Maximum, Mar. 11–20, 1950	1.42	6.0	314	149	573	106	1,300	852	------	1.0	------	3,250	4.42	12	1,400	1,310	47	6.6	4,760	7.7
Minimum, Oct. 22, 24, 26–28, 1949	234	9.0	33	8.2	13	106	36	13	------	1.8	------	[2] 181	.25	114	116	29	19	.5	294	7.3
Weighted average	64.6	14	59	17	47	119	131	59	------	3.2	------	410	.56	72	217	120	32	1.4	624	----
Water year 1951																		
Maximum, Feb. 11–19, 1951	3.94	6.8	352	157	619	194	1,470	835	------	4.2	------	3,540	4.81	38	1,520	1,360	47	6.9	5,060	7.9
Minimum, July 2–4, 27–31	140	16	36	11	25	117	47	29	------	4.0	------	[2] 234	.32	88	135	39	29	.9	390	7.9
Weighted average	43.8	17	77	24	76	136	197	96	------	4.4	------	569	.77	67	290	179	36	1.9	871	----

See footnotes at end of table.

TABLE 2.—*Summary of chemical analyses of streams in the Brazos River Basin, 1906–7, 1941–59*—Continued

[Results in parts per million except as indicated. Analyses by U.S. Geological Survey]

Date of collection	Mean discharge (cfs)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (calculated): Parts per million	Dissolved solids (calculated): Tons per acre-foot	Dissolved solids (calculated): Tons per day	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH
Clear Fork Brazos River at Nugent—Continued																					
Water year 1952																					
Maximum, May 28–29, 1952	5.35	17	325	97	772		132	1,310	1,000	------	7.3	------	3,590	4.88	52	1,210	1,100	58	9.6	5,070	7.9
Minimum, Sept. 22, 24–25	102	8.8	37	7.3	14		104	44	12	------	5.2	------	[2] 201	.27	55	122	37	20	.6	318	7.7
Weighted average	10.8	12	65	28	81		165	165	106	------	2.8	------	558	.76	16.3	277	142	39	2.1	895	----
Water year 1953																					
Maximum, Feb. 11–28, 1953	.22	12	82	86	262		131	383	438	------	4.0	------	1,330	1.81	.79	558	450	50	4.8	2,250	8.2
Minimum, July 15–22	203	14	32	7.3	15		111	22	17	------	4.7	------	[2] 179	.24	98.1	110	19	22	.6	301	8.1
Weighted average	12.4	15	40	10	29		124	48	37	------	3.4	------	260	.35	8.7	141	40	31	1.1	419	----
Paint Creek near Haskell																					
Water year 1950																					
Maximum, July 25–26, 28, 1950	67.5	14	98	40	294		93	100	615	------	1.8	------	1,210	1.65	221	409	333	61	6.3	2,260	8.0
Minimum, Aug. 17	27.0	12	18	4.4	12		86	9	4.2	------	3.0	------	[2] 108	.15	7.9	63	0	28	.7	173	8.0
Water year 1951																					
Maximum, May 21–22, 24, 26, 1951	118	20	94	42	209	-----	114	168	410	------	1.5	------	1,000	1.36	319	407	314	53	4.5	1,790	6.9
Minimum, May 18–19	911	17	26	7.9	12		116	12	8.0	------	5.0	------	[2] 157	.21	386	97	2	21	.5	249	8.1

Clear Fork Brazos River at Fort Griffin

Water year 1950																				
Maximum, Apr. 17, 1950	2,064	8.4	123	44	445	84	112	898	------	4.2	-----	1,680	2.38	9,360	488	419	66	8.8	3,120	7.2
Minimum, Nov. 9-21, 1949	.92	14	32	8.4	12	126	17	14	------	.8	-----	160	.22	.4	114	11	19	.5	267	7.0
Weighted average	131	12	47	12	45	117	68	67	------	2.9	-----	333	.45	118	167	71	37	1.5	544	----
Water year 1951																				
Maximum, May 20-21, 1951	1,533	7.4	132	51	192	101	492	255	------	2.5	-----	1,180	1.60	4,880	539	456	44	3.6	1,900	7.7
Minimum, May 19-20	1,119	8.8	31	7.8	21	121	28	18	------	3.0	-----	[2] 183	.25	553	109	10	30	.9	314	7.6
Weighted average	88.7	16	58	15	44	119	101	67	------	3.5	-----	393	.53	94	206	108	32	1.3	630	----

Hubbard Creek near Breckenridge

Water year 1956																				
Maximum, Apr. 17-28, 1956	1.28	5.6	268	48	498	132	32	1,280	0.2	1.2	-----	2,200	2.99	7.60	866	758	56	7.4	4,120	7.9
Minimum, Oct. 3-10, 1955	88.7	10	32	3.6	13	101	8.7	20	.5	3.5	-----	[2] 152	.21	36.4	95	12	23	.6	256	7.9
Weighted average	22.7	11	38	4.4	32	106	11	58	.4	2.7	-----	212	.29	13.0	113	26	38	1.3	386	----
Water year 1957																				
Maximum, Aug. 8-31, 1957	.50	14	204	51	384	149	259	820	.4	5.9	-----	1,810	2.46	2.44	718	596	54	6.2	3,160	7.8
Minimum, Feb. 6-8	7,473	6.2	25	2.3	15	79	7.0	21	.2	2.0	-----	118	.16	2,380	72	7	31	.7	213	7.8
Weighted average	633	8.4	36	4.1	24	98	10	46	.5	2.9	-----	180	.25	308	107	26	33	1.0	331	----
Water year 1958																				
Maximum, June 13, 1958	20.0	6.7	325	76	741	132	81	1,800	.4	3.0	-----	3,100	4.22	167	1,120	1,020	59	9.6	5,600	7.7
Minimum, Oct. 14-15, 1957	10,020	6.4	29	3.2	19	87	10	31	.5	1.0	-----	143	.19	3,870	86	14	33	.9	258	7.6
Weighted average	204	7.6	50	8.6	61	103	23	129	.5	1.8	-----	332	.45	183	160	76	45	2.1	622	----
Water year 1959																				
Maximum, Apr. 16-30, 1959	a0	5.8	325	81	389	144	702	840	.4	6.8	-----	2,420	3.29	0	1,140	1,030	41	5.0	3,780	7.9
Minimum, July 16	251	6.8	28	2.5	20	79	12	31	.1	3.5	-----	143	.19	96.9	80	15	35	1.0	254	7.6
Weighted average	47.9	9.4	51	8.4	56	104	24	121	.2	3.6	-----	325	.44	42.0	162	76	43	1.9	628	----

See footnotes at end of table.

TABLE 2.—*Summary of chemical analyses of streams in the Brazos River Basin, 1906–7, 1941–59*—Continued

[Results in parts per million except as indicated. Analyses by U.S. Geological Survey]

Date of collection	Mean discharge (cfs)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (calculated): Parts per million	Dissolved solids (calculated): Tons per acre-foot	Dissolved solids (calculated): Tons per day	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH
Brazos Rivre near South Bend																					
Water year 1942																					
Maximum, Aug. 21–23, 1942	364	------	496	80	1,310		109	1,240	2,140	------	4.5	-----	5,320	7.24	5,230	1,570	1,480	64	14	8,250	----
Minimum, Sept. 7–9	9,335	------	40	7.3	60		91	53	92	------	1.8	-----	299	.41	8,910	130	56	50	2.3	580	----
Weighted average	1,309	------	110	24	251		125	226	411	------	2.2	-----	1,080	1.48	4,070	373	270	59	5.6	1,840	----
Water year 1943																					
Maximum, May 20, 1943	310	------	410	107	2,630		142	949	4,310	------	.5	-----	8,480	11.5	7,100	1,460	1,350	80	30	13,800	----
Minimum, Oct. 17–20, 1942	24,920	------	64	9.7	85		89	111	138	------	1.0	-----	453	.62	30,500	200	126	48	2.6	901	----
Weighted average	678	------	136	27	340		118	305	549	------	2.2	-----	1,420	1.93	2,600	450	354	62	7.0	2,440	----
Water year 1944																					
Maximum, Dec. 11–20, 1943	3.35	------	538	148	1,650		167	390	3,540	------	2.5	-----	6,350	8.64	57	1,950	1,810	65	16	10,800	----
Minimum, Sept. 1–3, 6, 1944	568	------	55	11	90		95	50	174	------	4.3	-----	431	.59	661	182	104	52	2.9	821	----
Weighted average	236	------	139	27	318		113	284	539	------	4.9	-----	1,370	1.86	873	458	366	60	6.5	2,320	----
Water year 1945																					
Maximum, Dec. 11, 1944	350	------	535	113	4,550		111	1,130	7,380	------	9.7	-----	13,800	18.8	13,000	1,800	1,710	85	46	22,700	----
Minimum, July 8, 1945	959	------	42	9.2	39		96	48	69	------	2.5	-----	257	.35	665	143	64	37	1.4	453	----
Weighted average	545	------	146	24	358		113	294	598	------	3.3	-----	1,480	2.01	2,170	463	370	63	7.2	2,470	----
Water year 1946																					
Maximum, Aug. 11–20, 1946	0	------	428	113	1,540		93	413	3,100	------	2.5	-----	5,640	7.67	0	1,530	1,460	69	17	10,100	7.3
Minimum, Aug. 23, 29–30	3,461	------	42	6.3	64		103	30	108	------	2.5	-----	[2] 332	.45	3,100	131	46	51	2.4	557	----
Weighted average	503	------	173	25	379		108	394	610	------	2.1	-----	1,660	2.26	2,250	534	446	61	7.1	2,670	----

a er year 1947																				
Maximum, Apr. 11-16, 1947	62.3	------	530	127	2,290	110	1,240	3,860	------	------	-----	8,100	11.0	1,360	1,840	1,750	73	23	12,800	----
Minimum, Nov. 5-6, 1946	1,710	------	44	9.0	66	107	33	118	------	2.0	-----	[2] 361	.49	1,670	147	60	49	2.4	625	----
Weighted average	1,032	------	165	26	308	106	358	514	------	3.0	-----	1,450	1.97	4,040	519	432	56	5.9	2,310	----
Water year 1948																				
Maximum, Feb. 21-26, 29, 1948	420	------	364	84	1,380	131	932	2,250	------	------	-----	5,070	6.90	5,750	1,250	1,150	70	17	8,190	----
Minimum, Nov. 21-23, 1947	471	------	117	21	236	102	275	370	------	.0	-----	1,070	1.46	1,360	378	295	58	5.3	1,810	----
Salt Creek at Olney																				
Water year 1958																				
Maximum, July 4-5, 1958	0	4.8	1,190	260	5,910	59	52	11,900	0.0	------	-----	19,300	26.5	0	4,040	3,990	76	40	29,800	6.7
Minimum, Sept. 26	1.2	------	------	-----	------	90	------	15	------	------	-----	120	------	------	78	4	------	------	214	8.1
Weighted average	2.74	14	41	9.0	118	88	6.6	222	.4	------	-----	458	.62	3.39	140	68	65	4.3	853	----
Water year 1959																				
Maximum, Apr. 23-26, 1959	0	3.9	194	56	1,140	55	61	2,190	.6	------	-----	3,670	4.99	0	714	670	78	19	6,670	7.0
Minimum, Sept. 3	20.0	6.0	25	1.7	9.8	84	2.6	12	.1	2.5	-----	101	.14	5.45	69	1	23	.5	182	7.7
Weighted average	.36	6.0	41	7.7	125	94	9.8	225	.3	1.7	-----	463	.63	.45	134	57	67	4.7	890	----
Salt Creek near Newcastle																				
Water year 1958																				
Maximum, June 21-30, July 1-5, 1958	[1] 0.15	4.2	350	87	1,190	86	59	2,620	0.2	------	-----	4,350	5.92	1.76	1,230	1,160	68	15	7,870	7.2
Minimum, May 1-4	289	9.9	21	2.8	26	65	7.2	40	.2	3.0	-----	142	.19	111	64	11	47	1.4	265	7.3
Weighted average	14.7	11	32	5.4	55	81	9.9	99	.4	3.0	-----	255	.35	10.1	102	36	54	2.4	477	----
Water year 1959																				
Maximum, Apr. 14-16, 1959	[1] 0	4.1	194	43	568	56	95	1,240	.5	------	-----	2,170	2.95	0	661	615	65	9.6	3,940	7.5
Minimum, July 18-19	170	13	5.4	2.1	5.8	26	3.6	5.0	------	3.2	-----	51	.07	23.4	22	1	37	.5	72	7.0
Weighted average	3.12	12	22	4.5	45	58	8.3	81	.3	3.2	-----	205	.28	1.73	73	26	57	2.3	382	----

See footnotes at end of table.

TABLE 2.—*Summary of chemical analyses of streams in the Brazos River Basin, 1906–7, 1941–59*—Continued

[Results in parts per million except as indicated. Analyses by U.S. Geological Survey]

Date of collection	Mean discharge (cfs)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (calculated): Parts per million	Dissolved solids (calculated): Tons per acre-foot	Dissolved solids (calculated): Tons per day	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH
Brazos River at Possum Kingdom Dam near Graford																					
Water year 1942																					
Maximum, Feb. 2–9, 1942	189	----	194	43	523		192	424	850	----	2.0	----	2,130	2.90	1,090	661	504	63	8.8	3,670	----
Minimum, Sept. 1–10	4,225	----	94	18	182		136	176	290	----	1.5	----	829	1.13	9,460	308	197	56	4.5	1.450	----
Weighted average	1,750	----	119	23	220		144	242	352	----	1.6	----	1,030	1.40	5,030	392	274	55	4.8	1,770	----
Water year 1943																					
Maximum, Jan. 11–20, 1943	536	----	132	27	302		140	242	516	----	3.0	----	1,290	1.76	1,870	440	326	60	6.3	2.330	----
Minimum, Dec. 21–31, 1942	350	----	98	18	183		123	187	298	----	1.8	----	846	1.15	799	318	218	56	4.5	1.570	----
Weighted average	1,161	----	109	21	223		138	201	370	----	1.6	----	994	1.35	3,110	358	246	57	5.1	1,760	----
Water year 1944																					
Maximum, Feb. 11–20, 1944	73.3	----	138	23	336		148	279	535	----	2.5	----	1,390	1.89	275	439	318	62	7.0	2,350	----
Minimum, Dec. 21–31, 1943	40.0	----	131	27	275		136	276	450	----	3.2	----	1,230	1.67	133	438	326	58	5.7	2,200	----
Weighted average	164	----	137	28	301		152	274	498	----	2.5	----	1,310	1.78	580	457	332	59	6.1	2,270	----
Water year 1945																					
Maximum, Mar. 21–31, 1945	883	----	150	32	381		137	279	658	----	3.2	----	1,570	2.14	3,740	506	394	62	7.4	2,740	----
Minimum, Sept. 21–30	320	----	118	26	296		140	204	508	----	1.8	----	1,220	1.66	1,050	402	287	62	6.4	2,130	----
Weighted average	528	----	135	27	335		140	256	561	----	2.5	----	1,390	1.89	1,980	448	334	62	6.9	2,410	----
Water year 1946																					
Maximim, Nov. 21–30, 1945	173	----	148	26	375		132	280	630	----	3.5	----	1,530	2.08	715	476	382	63	7.5	2,660	----
Minimum, July 21–31, 1946	617	----	132	23	285		142	255	468	----	1.0	----	1,230	1.67	2,050	424	308	59	6.0	2,180	----
Weighted average	502	----	137	24	310		135	262	519	----	1.3	----	1,320	1.80	1,790	440	330	61	6.4	2,300	----

Water year 1947																					
Maximum, Oct. 1-10, 1946	2,123	----	164	31	359		126	325	620	----	1.0	----	1,560	2.12	8,940	537	434	59	6.7	2,670	----
Minimum, Sept. 1-30, 1947	620	----	149	23	264		116	338	420	----	2.0	----	1,250	1.70	2,090	466	372	55	5.3	2,080	----
Weighted average	1,343	----	145	24	321		113	303	530	----	1.7	----	1,380	1.88	5,000	460	368	60	6.5	2,360	----
Water year 1948																					
Maximum, Aug. 1-31, 1948	926	12	166	28	330	12	131	379	538	----	.5	----	1,530	2.08	3,830	530	422	57	6.2	2,550	7.6
Minimun, Oct. 1-31, 1947	304	----	150	22	281		120	344	438	----	2.0	----	1,300	1.77	1,070	465	366	57	5.7	2,160	----
Weighted average	470	----	162	26	321		118	374	510	----	1.5	----	1,460	1.99	1,850	512	415	58	6.2	2,450	----
Water year 1949																					
Maximum, Apr. 1-30, 1949	125	8.6	184	29	377		119	417	612	----	2.8	----	1,690	2.30	570	578	480	59	6.8	2,860	7.8
Minimum, Sept. 1-30	1,130	9.0	133	20	295		108	298	465	----	1.2	----	1,270	1.73	3,870	414	326	61	6.3	2,220	7.4
Weighted average	769	9.9	161	26	333		115	375	531	----	1.2	----	1,500	2.04	3,110	509	415	59	6.4	2,540	----
Water year 1950																					
Maximum, July 1-31, 1950	2,255	12	135	22	287		108	286	472	----	.8	----	1,270	1.73	7.730	428	339	59	6.0	2,200	7.6
Minimum. Jan. 1-31	140	7.5	122	22	248		108	265	404	----	.8	----	1,120	1.52	423	395	306	58	5.4	1,940	7.4
Weighted average	898	10	128	21	281		109	280	451	----	1.3	----	1,230	1.67	2,980	406	316	60	6.1	2,130	----
Water year 1951																					
Maximum, Aug. 1-10, 1951	1,281	11	139	27	361		126	309	580	----	.8	----	1,490	2.03	5,150	458	355	63	7.3	2,620	7.5
Minimum, Dec. 1-31, 1950	386	9.4	123	24	254		110	267	418	----	1.0	----	1,150	1.56	1,200	406	316	58	5.5	1,990	7.2
Weighted average	603	12	131	24	308		120	291	490	----	1.7	----	1,320	1.80	2,150	426	327	61	6.5	2,280	----
Water year 1952																					
Maximum, Sept. 1-30, 1952	48.5	12	152	27	352	----	136	307	578	----	1.5	----	1,500	2.04	196	490	378	61	6.9	2,510	7.5
Minimum, Feb. 1-29	84.9	11	130	24	308		119	288	492	----	1.8	----	1,310	1.78	300	423	326	61	6.5	2,240	7.6
Weighted average	294	13	135	23	331		124	295	527	----	1.5	----	1,390	1.89	1,100	432	330	63	6.9	2,410	----
Water year 1953																					
Maximum, June 1-30, 1953	334	14	158	31	417		137	344	678	0.3	1.0	----	1,710	2.33	1,540	522	409	63	7.9	2,940	7.6
Minimum, Sept. 1-30	748	13	139	29	356		127	295	588	----	.8	----	1,480	2.01	2,990	466	362	62	7.2	2,570	7.4
Weighted average	220	13	152	29	388		130	322	636	----	1.0	----	1,610	2.19	956	498	392	63	7.6	2,770	----
Water year 1954																					
Maximum, Feb. 6-19, 1954	39.6	12	148	30	463		124	324	750	----	4.0	----	1,790	2.43	191	493	392	67	9.1	3,170	7.9
Minimum, July 1-31	985	16	114	20	259		111	250	410	----	1.0	----	1,120	1.52	2,980	366	276	61	5.9	1,960	7.6
Weighted average	1,052	14	118	18	289		113	245	460	----	1.3	----	1,200	1.63	3,410	368	276	63	6.6	2,100	----

See footnotes at end of table.

TABLE 2.—*Summary of chemical analyses of streams in the Brazos River Basin, 1906–7, 1941–59*—Continued

[Results in parts per million except as indicated. Analyses by U.S. Geological Survey]

Date of collection	Mean discharge (cfs)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (calculated)			Hardness as $CaCO_3$		Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH
													Parts per million	Tons per acre-foot	Tons per day	Calcium, magnesium	Noncarbonate				
Brazos River at Possum Kingdom Dam near Graford—Continued																					
Water year 1955																					
Maximum, May 1–31, 1955	699	14	148	22	379		118	333	595	------	1.0	-----	1,550	2.11	2,930	460	364	64	7.7	2,620	7.6
Minimum, Sept. 26–30	41,280	15	124	16	253		115	286	378	------	1.0	-----	1,130	1.54	125,900	376	282	59	5.7	1,850	7.5
Weighted average	1,120	13	133	18	291		114	301	448	------	1.0	-----	1,260	1.71	3,810	406	312	61	6.3	2,120	----
Water year 1956																					
Maximum, Jan. 1–31, 1956	584	13	266	40	620		128	660	980	------	1.3	-----	2,640	3.59	4,160	828	723	62	9.4	4,230	7.8
Minimum, Oct. 1–16, 1955	10,920	11	102	12	152		97	235	220	------	1.1	-----	[2] 806	1.10	23,760	304	224	52	3.8	1,310	7.3
Weighted average	983	11	156	21	292		107	379	445	------	1.2	-----	1,370	1.86	3,640	476	388	57	5.8	2,220	----
Water year 1957																					
Maximum, Oct. 1–31, 1956	67.3	12	219	30	501		128	518	790	------	.8	-----	2,130	2.90	387	670	565	62	8.4	3,430	7.6
Minimum, Apr. 26–30, May 1–10, 1957	38,920	7.4	45	5.4	60		74	73	91	------	1.8	-----	[2] 331	.45	34,780	135	74	49	2.3	573	7.1
Weighted average	4,145	8.0	61	7.2	79		85	108	119	------	1.8	-----	443	.60	4,960	182	112	49	2.6	743	----
Water year 1958																					
Maximum, Apr. 1–30, 1958	459	8.0	126	18	389		125	253	615	------	1.5	-----	1,470	2.00	1,820	388	286	69	8.6	2,570	7.4
Minimum, Dec. 1–31, 1957	845	7.6	109	17	208		117	216	335	------	.5	-----	951	1.29	2,170	342	246	57	4.9	1,640	7.6
Weighted average	1,226	9.6	120	20	276		121	248	443	------	1.1	-----	1,180	1.60	3,910	382	282	61	6.2	2,010	----
Water year 1959																					
Maximum, Sept. 1–30, 1959	208	12	134	22	327		125	294	515	------	1.8	-----	1,370	1.86	769	425	322	63	6.9	2,310	7.4
Minimum, Mar. 1–31	68.1	10	104	19	229		114	195	382	------	1.0	-----	996	1.35	183	338	244	60	5.4	1,780	7.7
Weighted average	458	9.2	115	21	264		123	235	425	------	.9	-----	1,130	1.54	1,400	374	272	61	5.9	1,950	----

Brazos River near Whitney

Water year 1948																			
Maximum, May 1-10, 1948	816	9.0	152	24	312	130	341	492	------	0.8	-----	1,390	1.89	3,060	478	372	59	6.2	2,400	----
Minimum, Dec. 8, 12-18, 1947	1,748	------	40	5.9	36	103	44	50	------	1.2	-----	[2] 256	.35	1,210	124	40	38	1.4	420	----
Water year 1949																			
Maximum, Oct. 1-10, 1948	249	13	161	34	345	114	391	562	------	.0	-----	1,560	2.12	1,050	542	448	58	6.5	2,650	----
Minimum, May 17-22, 1949	24,760	10	43	5.7	21	134	22	30	------	2.2	-----	[2] 216	.29	14,400	131	21	26	.8	360	8.0
Weighted average	1,566	10	89	16	155	129	172	242	------	1.7	-----	765	1.04	3,230	288	182	54	4.0	1,300	----
Water year 1950																			
Maximum, Oct. 11-24, 1949	1,121	9.5	126	22	282	112	282	448	------	.8	-----	1,230	1.67	3,720	405	313	60	6.1	2,090	8.0
Minimum, May 9, 16-21, 1950	1,517	11	38	6.7	39	125	45	39	------	2.5	-----	[2] 242	.33	991	122	20	41	1.5	390	7.9
Weighted average	1,520	9.2	84	15	159	127	157	244	------	2.4	-----	748	1.02	3,070	271	167	56	4.2	1,290	----
Water year 1951																			
Maximum, Sept. 21-30, 1951	299	7.8	133	29	344	121	288	565	------	3.0	-----	1,430	1.94	1,150	451	352	62	7.0	2,500	7.4
Minimum, May 17-21, 25-31	748	9.4	44	8.1	62	102	59	94	------	1.5	-----	[2] 341	.46	689	144	60	48	2.3	616	7.7
Weighted average	840	8.2	119	23	276	127	260	437	------	2.6	-----	1,190	1.62	2,700	392	288	61	6.1	2,060	---
Water year 1952																			
Maximum, Oct. 1-10, 1951	514	9.0	131	28	317	144	278	512	------	2.0	-----	1,350	1.84	1,870	442	324	61	6.6	2,350	7.7
Minimum, June 11-20, 1952	94.1	9.0	30	5.2	27	100	22	35	------	2.2	-----	[2] 183	.25	46.5	96	14	38	1.2	328	7.8
Weighted average	348	8.3	92	18	211	146	167	332	------	2.1	-----	912	1.24	857	304	184	60	5.2	1,590	----
Water year 1953																			
Maximum, Nov. 1-10, 1952	42.9	8.8	120	22	269	151	233	430	------	2.5	-----	1,160	1.58	134	390	266	60	5.9	2,020	7.9
Minimum, June 21-30, 1953	808	8.8	71	11	112	143	93	178	------	1.2	-----	[2] 547	.74	1,190	222	105	52	3.3	985	8.0
Weighted average	141	9.2	76	12	137	154	112	209	------	1.8	-----	651	.89	248	239	113	55	3.8	1,140	----
Water year 1954																			
Maximum, Nov. 19-20, 22-23, 1953	76.8	13	124	17	291	119	235	475	------	1.5	-----	1,220	1.66	253	380	282	63	6.5	2,140	8.0
Minimum, Oct. 1-13	56.2	14	91	16	185	150	144	298	------	2.0	-----	824	1.12	125	293	170	58	4.7	1,440	7.8
Weighted average	912	9.6	107	18	242	131	198	392	------	1.8	-----	1,040	1.41	2,560	341	234	61	5.7	1,850	----
Water year 1955																			
Maximum, Apr. 1-30, 1955	78.3	8.0	120	18	289	130	248	450	------	2.8	-----	1,200	1.63	254	374	267	63	6.5	2,080	7.7
Minimum, June 17-30	4,408	9.0	88	14	190	115	168	298	------	2.0	-----	[2] 850	1.16	10,120	277	183	60	5.0	1,470	7.8
Weighted average	997	10	104	16	238	124	205	374	------	1.8	-----	1,030	1.40	2,770	326	224	61	5.7	1,760	----

See footnotes at end of table.

TABLE 2.—*Summary of chemical analyses of streams in the Brazos River Basin, 1906–7, 1941–59*—Continued

[Results in parts per million except as indicated. Analyses by U.S. Geological Survey]

Date of collection	Mean discharge (cfs)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (calculated)			Hardness as $CaCO_3$		Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH
													Parts per million	Tons per acre-foot	Tons per day	Calcium, magnesium	Noncarbonate				
Brazos River near Whitney—Continued																					
Water year 1956																					
Maximum, Sept. 1–30, 1956	609	10	137	22	289		115	345	430	------	1.2	-----	1,290	1.75	2,120	432	338	59	6.1	2,160	7.8
Minimum, Nov. 1–30, 1955	411	8.8	92	14	159		107	196	242	------	1.0	-----	766	1.04	850	287	200	55	4.1	1,340	7.4
Weighted average	1,571	10	116	16	220		116	255	333	------	1.4	-----	1,010	1.37	4,280	356	260	57	5.1	1,710	----
Water year 1957																					
Maximum, Oct. 1–31, 1956	639	13	147	26	303		115	361	470	------	1.0	-----	1,380	1.88	2,380	474	380	58	6.1	2,230	7.9
Minimum, June 11–20, 1957	34,260	12	51	5.6	53		104	67	78	------	1.5	-----	[2] 337	.46	31,170	150	65	44	1.9	548	7.7
Weighted average	6,213	11	62	7.9	82		106	96	126	------	1.5	-----	459	.62	7,700	187	100	49	2.6	766	----
Water year 1958																					
Maximum, Sept. 1–30, 1958	564	11	88	14	181		136	147	288	------	1.5	-----	876	1.19	1,330	277	166	59	4.8	1,390	8.2
Minimum, May 12–31	4,512	13	58	7.4	61		141	61	89	------	3.2	-----	362	.49	4,410	175	60	43	2.0	621	8.0
Weighted average	2,322	11	80	12	110		146	122	170	------	1.9	-----	604	.82	3,790	249	130	49	3.0	997	----
Water year 1959																					
Maximum, Feb. 1–28, 1959	596	11	93	18	196		114	176	322	------	.5	-----	[2] 947	1.29	1,520	306	212	58	4.9	1,560	7.6
Minimum, Aug. 1–31	711	11	87	16	177		137	138	290	------	2.2	-----	[2] 845	1.15	1,620	283	170	58	4.6	1,400	7.6
Weighted average	681	10	93	17	191		134	165	309	------	1.0	-----	893	1.21	1,640	302	192	58	4.8	1,500	----

Brazos River near Waco																					
1906–07 Period																					
Maximum, June 22–July 1, 1907	----------	31	218	26	346		119	555	533	------	1.5	-----	[2] 1,850	2.52	----------	651	554	54	5.9	------	----
Minimum, May 23–June 1	----------	11	60	6.3	69		118	84	119	------	5.6	-----	[2] 420	.57	----------	176	79	51	2.3	------	----
Mean	----------	22	121	19	234		158	279	338	------	2.2	-----	1,140	1.55	----------	380	250	58	5.2	------	----
Leon River near Eastland																					
Water year 1951																					
Maximum, Feb. 1–10, 1951	----------	4.1	64	10	37		206	39	50	------	0.0	-----	[2] 316	0.43	----------	200	32	28	1.1	555	7.9
Minimum, July 24–26	----------	9.2	29	4.7	12		99	9.8	18	------	1.8	-----	[2] 152	.21	----------	92	11	22	.5	244	7.2
Water year 1952																					
Maximum, May 17–20, 1952	----------	8.8	52	6.6	30		124	21	70	------	1.3	-----	[2] 291	.40	----------	157	55	30	1.0	466	7.4
Minimum, Sept. 18–19, 22–24	----------	9.0	26	3.6	11		81	8.6	18	------	3.0	-----	119	.16	----------	80	13	23	.5	211	7.5
Water year 1953																					
Maximum, Apr. 6, 8–9, 1953	----------	6.6	51	6.1	29		164	13	47	------	1.0	-----	[2] 259	.35	----------	152	18	29	1.0	437	7.5
Minimum, Nov. 24–26, 28–29, 1952	----------	5.1	21	3.6	2.7	-----	69	4.4	4.8	------	2.8	-----	77	.10	----------	67	11	8	.1	139	7.3
Navasota River near Bryan																					
Water year 1959																					
Maximum, Sept. 20–25, 1959	17.8	13	66	15	263		87	44	480	------	3.8	-----	928	1.26	44.6	226	154	72	7.6	1,760	7.3
Minimum, Feb. 15	3,400	8.2	8.4	1.5	13		25	14	14	------	1.2	-----	72	.10	661	27	6	52	1.1	114	7.5
Weighted average	529	12	21	4.9	52		55	25	80	------	1.1	-----	226	.31	323	73	28	61	2.6	414	----
Brazos River at Richmond																					
Water year 1946																					
Maximum, Dec. 3–4, 1945	6,610	------	63	12	294		172	46	465	------	1.5	-----	966	1.31	17,200	206	66	76	8.9	1,840	----
Minimum, May 21–31, 1946	32,590	------	39	5.3	15		124	19	21	------	1.8	-----	[2] 195	.27	17,200	119	18	22	.6	304	8.3
Weighted average	10,220	------	51	8.6	37		155	39	53	------	1.8	-----	299	.41	8,250	163	36	33	1.3	487	----

See footnotes at end of table.

TABLE 2.—*Summary of chemical analyses of streams in the Brazos River Basin, 1906–7, 1941–59*—Continued

[Results in parts per million except as indicated. Analyses by U.S. Geological Survey]

Date of collection	Mean discharge (cfs)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (calculated): Parts per million	Dissolved solids (calculated): Tons per acre-foot	Dissolved solids (calculated): Tons per day	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH
Brazos River at Richmond—Continued																					
Water year 1947																					
Maximum, Nov. 1–4, 1946	4,128	------	114	20	246		155	211	392	------	1.0	-----	1,060	1.44	11,800	366	240	59	5.6	1,870	----
Minimum, Aug. 27–31, 1947	31,140	------	29	5.9	10		92	16	18	------	1.0	-----	[2] 133	.18	11,200	97	21	18	.4	228	----
Weighted average	8,765	------	63	11	63		152	70	100	------	1.9	-----	425	.58	10,100	202	78	40	1.9	691	----
Water year 1948																					
Maximum, Sept. 1–10, 1948	1,334	11	134	27	271		147	294	432	------	.2	-----	1,240	1.69	4,470	446	325	57	5.6	2,120	----
Minimum, Nov. 21–26, 1947	2,538	------	37	7.1	38		130	31	45	------	1.2	-----	[2] 245	.33	1,680	122	15	40	1.5	400	----
Weighted average	2,687	------	65	11	82		162	84	118	------	1.7	-----	479	.65	3,480	207	74	46	2.5	791	----
Water year 1949																					
Maximum, Oct. 11–20, 1948	621	14	126	29	220		220	235	345	------	.8	-----	1,080	1.47	1,810	434	253	52	4.6	1,860	----
Minimum, Apr. 23, 25–27, 29–30, 1949	33,050	11	34	5.8	21		120	24	20	------	2.8	-----	[2] 184	.25	16,400	109	10	29	.9	289	----
Weighted average	4,645	12	59	10	70		141	76	103	------	2.1	-----	423	.57	5,310	188	72	45	2.2	703	----
Water year 1950																					
Maximum, Aug. 21–31, 1950	2,033	13	124	21	260		144	254	408	0.4	3.5	-----	1,150	1.56	6,310	396	278	59	5.7	2,010	7.4
Minimum, Feb. 20–28	13,710	12	37	4.4	28		112	21	40	.3	.8	-----	[2] 213	.29	7,880	110	19	36	1.2	357	7.4
Weighted average	5,783	13	53	8.1	60		136	58	87	.3	1.3	-----	368	.50	5,750	166	54	44	2.0	613	----
Water year 1951																					
Maximum, Sept. 1–10, 1951	564	11	122	29	341	1.6	120	291	538	.3	2.0	0.16	1,400	1.90	2,130	424	325	64	7.2	2,440	7.5
Minimum, June 21–25	5,692	17	40	7.0	25	-----	120	34	36	.3	3.5	-----	[2] 222	.30	3,410	129	30	30	1.0	386	8.0
Weighted average	1,418	13	80	16	139	2.4	160	134	214	.3	2.2	.21	696	.95	2,660	266	134	53	3.7	1,180	----

Water year 1952																					
Maximum, Oct. 21–31, 1951	606	15	108	23	233	.8	196	191	369	.3	1.5	.39	1,040	1.41	1,700	364	204	58	5.3	1,790	7.5
Minimum, June 1–10, 1952	7,734	21	37	4.5	13	1.6	123	16	16	.2	4.0	.19	[2] 187	.25	3,900	111	10	20	.6	290	8.0
Weighted average	1,820	18	51	8.8	60	2.8	143	54	85	.3	3.5	.19	370	.50	1,820	163	46	44	2.0	608	----
Water year 1953																					
Maximum, Oct. 1–10, 1952	142	17	83	19	138	5.2	216	113	214	.2	1.5	.13	[2] 739	1.01	283	285	108	51	3.6	1,210	8.2
Minimum, Jan. 1–10, 1953	9,914	11	31	3.7	17	3.2	99	21	20	.5	3.2	.25	160	.22	4,280	93	11	28	.8	276	7.6
Weighted average	4,105	13	36	5.7	23	3.8	115	25	31	.3	3.6	.14	215	.29	2,380	114	20	30	.9	342	----
Water year 1954																					
Maximum, Aug. 21–31, 1954	800	13	100	19	240	6.7	143	194	372	.2	1.8	.11	1,020	1.39	2,200	328	210	61	5.7	1,810	7.8
Minimum, Oct. 29–31, 1953	23,870	14	32	3.7	14	3.3	111	18	13	.4	4.8	-----	[2] 168	.23	10,830	95	4	24	.6	244	8.0
Weighted average	2,727	17	55	9.1	83	4.1	124	72	127	.5	2.5	.14	453	.62	3,340	174	73	50	2.7	754	----
Water year 1955																					
Maximum, May 29–31, June 1, 9–11, 1955	9,837	12	105	15	225	6.9	124	200	370	.4	2.2	.16	1,050	1.43	27,890	324	222	60	5.4	1,740	7.9
Minimum, Apr. 14–21	9,624	12	31	4.5	16	4.2	105	18	18	.6	2.5	.12	[2] 161	.22	4,180	95	9	26	.7	267	7.6
Weighted average	2,168	13	60	8.9	95	4.9	132	83	145	.4	2.6	.14	498	.68	2,920	186	78	52	3.0	842	----
Water year 1956																					
Maximum, Sept. 21–30, 1956	741	12	127	21	254	7.0	127	300	400	.4	1.5	.23	1,190	1.62	2,380	404	300	57	5.5	1,960	7.6
Minimum, Feb. 14–19	3,212	9.6	41	4.8	53	4.3	104	45	77	.5	2.2	.14	[2] 318	.43	2,760	122	37	48	2.1	519	7.6
Weighted average	2,158	12	95	14	166	5.8	136	185	260	.5	1.5	.18	834	1.13	4,860	294	183	54	4.2	1,380	----
Water year 1957																					
Maximum, Oct. 1–10, 1956	593	12	130	22	275		136	307	412	------	1.0	-----	1,230	1.67	1,970	415	304	59	5.9	2,020	7.9
Minimum, Apr. 24–30, 1957	61,290	8.2	35	4.1	14	3.2	110	23	16	.5	3.0	-----	161	.22	26,640	104	14	22	.6	280	7.9
Weighted average	15,290	13	50	6.9	46		124	54	65	------	2.5	-----	317	.43	13,090	154	52	39	1.6	519	----
Water year 1958																					
Maximum, Aug. 21–31, 1958	2,930	13	76	17	122	4.6	183	113	183	------	.5	-----	[2] 645	.88	5,100	260	110	50	3.3	1,070	7.8
Minimum, Oct. 16–22, 1957	74,000	7.8	31	4.0	11	3.2	99	21	13	------	2.0	-----	142	.19	28,370	94	13	20	.5	246	8.0
Weighted average	11,870	11	54	7.7	37	3.8	142	50	57	------	4.2	-----	303	.41	9,710	166	50	32	1.2	508	----
Water year 1959																					
Maximum, Apr. 1–7, 1959	1,320	9.2	84	19	124	5.1	188	125	198	.3	.5	-----	[2] 718	.98	2,560	288	134	48	3.2	1,160	8.1
Minimum, Apr. 11–22	26,950	11	35	4.6	16	4.0	108	23	22	------	2.0	-----	171	.23	12,440	106	18	24	.7	298	7.6
Weighted average	4,450	12	49	8.0	49	4.5	130	51	74	------	1.9	-----	323	.44	3,880	156	49	40	1.7	553	----

[1] Includes days of less than 0.05 cubic foot per second discharge.
[2] Residue at 180 °C.

TABLE 3.—*Miscellaneous chemical analyses of lakes in the Brazos River basin*

[Results in parts per million except as indicated. Analyses by U.S. Geological Survey]

No.	Lake	Date of collection	Capacity (ac-ft)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)		Hardness as $CaCO_3$		Percent sodium	Sodium adsorption ratio	Specific conductance (micro-mhos at 25°C)	pH
															Parts per million	Tons per acre-foot	Calcium, magnesium	Noncarbonate				
	High Plains																					
1	Wet-weather lake near Halfway.	June 25–27, 1959.	-------	28	-----	12	3.0	4.8	7.9	59	5.4	2.5	0.5	4.2	[1] 98	0.13	42	0	17	0.3	132	7.0
	Double Mountain Fork Brazos River basin																					
2	Lake Sellers near Aspermont.	Aug. 3, 1950	500	1.4	-----	140	16	29		121	327	27	0.4	1.0	630	0.86	416	316	13	0.6	885	7.2
	Clear Fork Brazos River basin																					
3	City Lake near Roby.	Sept. 15, 1947	-------	16	0.08	628	180	389	13	304	2,170	456	0.8	20	[1] 4,020	5.47	2,310	2,060	27	3.5	4,730	7.8
4	City Lake near Hamlin.	Sept. 20, 1946	1,900	9.0	.00	27	7.1	9.8	5.6	118	8.1	13	.0	2.0	158	.21	97	0	17	.4	249	6.8
5	North City Lake near Anson.	Sept. 20, 1946	2,500	8.0	.05	99	24	24	7.2	172	203	38	.0	.0	500	.68	346	204	13	.6	751	7.3
6	South City Lake near Anson.	July 30, 1953	-------	6.3	.00	63	15	35	9.6	52	174	61	.3	2.0	429	.58	218	176	25	1.0	659	7.5
7	Lake Trammel near Sweetwater.	July 2, 1946	3,183	7.6	.00	52	6.8	7.7		164	16	16	.0	1.0	193	.26	158	23	10	.3	338	8.4
8	Lake Sweetwater near Sweetwater.	Jan. 18, 1952	3,183	3.0	.05	59	13	13	3.6	197	41	20	.0	.0	270	.37	201	39	12	.4	453	7.7
9	Lake Abilene near Abilene.	Apr. 18, 1946	9,786	9.6	.25	51	15	9.3	5.1	210	21	15	.2	.0	234	.32	189	17	9	.3	407	7.6
10	Lake Kirby near Abilene.	Apr. 18, 1946	7,600	5.5	.70	44	12	13	4.9	202	11	9.0	1.0	.5	209	.28	159	0	14	.4	390	8.0

11	Fort Phantom Hill Reservoir near Nugent.	Jan. 18, 1952	74,310	1.2	.05	40	23	57	8.0	236	40	65	.3	.2	362	.49	194	1	38	1.8	642	7.8
12	Lake Penick near Stamford.	Sept. 19, 1946	2,295	3.6	.00	76	20	63	6.6	152	161	88	.4	.4	508	.69	272	147	33	1.7	836	7.3
13	Lake Stamford near Stamford.	Oct. 2, 1953	60,000	9.4	.17	33	9.5	10	5.2	157	9.4	7.2	.4	1.5	178	.24	121	0	15	.4	297	7.9
14	City Lake near Putnam.	Nov. 1945	-------	7.6	.12	30	10	37	4.4	150	51	18	.0	.0	242	.12	116	0	40	1.5	398	7.4
15	Lake McCarty near Albany.	July 1944	4,000	21	.04	57	17	79	11	160	26	170	.2	.5	1 461	.63	212	82	43	2.4	893	7.7
16	Lake Cisco near Cisco.	Mar. 12, 1959	49,100	2.2	-----	38	3.6	4.5	4.5	128	12	6.0	.2	.2	141	.19	110	5	8	.2	249	8.0
17	Lake Daniels near Breckenridge.	Mar. 12, 1959	10,000	1.3	-----	36	4.1	14		123	9.6	18	.2	.0	150	.20	107	6	22	.6	274	7.7
	Small Tributary Drainage to Brazos River above Possum Kingdom Dam																					
18	City Lake near Throckmorton.	Sept. 19, 1946	1,675	10	0.11	30	4.8	31	3.5	126	26	25	0.2	0.8	197	0.27	95	0	41	1.4	317	7.4
19	Lake Graham near Graham.	Feb. 10, 1960	39,000	3.2	-----	38	8.4	56		101	8.0	112	.2	.8	303	.41	130	46	48	2.1	549	7.7
20	Lake Eddleman near Graham.	Mar. 22, 1960	5,917	6.4	.16	38	3.9	17	5.3	113	9.2	38	.3	.2	1 175	.24	111	18	24	.7	318	7.4
	Small Tributary Drainage to Brazos River—Possum Kingdom Dam to Whitney																					
21	Lake Mineral Wells near Mineral Wells.	Nov. 1945	9,030	9.8	0.04	38	10	14	5.2	137	33	19	0.2	0.0	221	0.30	136	24	18	0.5	348	7.4
22	Lake Hagaman near Ranger.	Nov. 1945	1,250	5.0	.04	39	6.2	38		102	18	73	.2	.0	248	.34	123	39	40	1.5	438	7.2
23	City Lake near Strawn.	Nov. 1945	1,200	9.9	.12	41	5.6	7.0	4.4	132	13	17	.2	.0	175	.24	125	17	10	.3	288	7.4
24	City Lake near Gordon	Nov. 1945	-------	8.6	.30	28	6.6	5.2		101	13	8.0	.2	.2	128	.17	97	14	10	.2	211	7.2
	Bosque River basin																					
25	Lake Waco near Waco.	Feb. 29, 1952	22,000	6.2	0.01	50	6.6	15	0.0	164	30	14	0.3	0.5	225	0.31	152	18	18	0.5	367	7.6

See footnote at end of table.

TABLE 3.—*Miscellaneous chemical analyses of lakes in the Brazos River basin*—Continued

[Results in parts per million except as indicated. Analyses by U.S. Geological Survey]

No.	Lake	Date of collection	Capacity (ac-ft)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)		Hardness as $CaCO_3$		Percent sodium	Sodium adsorption ratio	Specific conductance (micro-mhos at 25°C)	pH
															Parts per million	Tons per acre-foot	Calcium, magnesium	Noncarbonate				
											Leon River basin											
26	Lake Brelsford near Eastland.	Nov. 1945	1,900	7.3	0.67	27	3.1	11		88	10	15	0.4	0.2	[1] 118	0.16	80	12	24	0.5	213	7.1
27	Olden Lake near Eastland.	June 8, 1950	1,275	15	.48	43	8.7	22		106	37	44	.4	2.2	249	.34	144	50	25	.8	402	7.2
28	Leon Reservoir near Ranger.	Mar. 12, 1959	27,290	3.0	-----	48	6.6	26		137	24	46	.2	.1	236	.32	147	35	28	.9	415	8.1
29	Lake Eanes near Comanche.	Mar. 20, 1946	1,221	6.4	.08	54	13	32	5.2	200	47	36	.2	.0	[1] 292	.40	188	24	26	1.0	505	7.4
30	City Lake near Hamilton.	Mar. 19, 1946	614	7.8	.22	59	5.2	9.4	4.8	183	25	13	.2	.5	226	.31	169	19	10	.3	375	8.0
31	Belton Reservoir near Belton.	Mar. 24, 1958	-------	9.0	.00	67	9.1	22		201	30	35	.2	7.7	300	.41	204	40	19	.7	484	8.1
											City lakes in lower Brazos River basin											
32	Old City Lake near Marlin.	June 13, 1944	-------	14	0.10	41	2.7	5.4	3.4	125	13	5.0	2.0	1.5	160	0.22	114	11	9	0.2	243	7.6
33	City Lake near Rosebud.	June 13, 1944	-------	2.6	.05	80	7.1	15	4.7	105	166	4.0	.8	.2	336	.46	228	142	12	.4	534	7.7
34	City Lake near Teague.	Apr. 1943	860	1.3	.04	12	4.0	26	6.4	68	19	24	.2	.5	129	.18	46	0	51	1.7	------	7.8
35	City Lake near Thorndale.	Feb. 1943	-------	3.2	.05	56	8.1	15	8.4	210	24	12	.4	.5	[1] 231	.31	174	1	15	.5	------	8.0

[1] Calculated.

TABLE 4.—*Yearly discharges and weighted average concentrations and mean daily loads of chlorides, sulfates, and dissolved solids for periods of record at selected points in the Brazos River basin*

Water year	Yearly discharge (cfs)	Weighted average concentrations (ppm)			Loads (tons per day)		
		Sulfate	Chloride	Dissolved solids	Sulfate	Chloride	Dissolved solids
Double Mountain Fork Brazos River near Rotan							
1950	146	294	160	812	116	65.4	320
1951	32.6	525	270	1,300	46.2	23.8	114
Double Mountain Fork Brazos River near Aspermont							
1949	139	380	150	916	143	56.3	344
1950	171	460	148	1,010	212	68.3	466
1951	63.0	700	203	1,430	119	34.5	243
1957	352	400	123	910	380	112	865
1958	130	592	265	1,390	208	93.0	488
1959	219	429	168	999	254	99.3	591
Salt Fork Brazos River near Peacock							
1950	134	412	1,160	2,610	149	420	944
1951	31.2	550	1,790	3,840	46.3	151	323
Salt Fork Brazos River near Aspermont							
1949	157	709	1,820	4,080	301	771	1,730
1950	166	786	2,230	4,870	352	999	2,180
1951	64.5	1,020	3,560	7,380	178	620	1,290
1957	299	625	1,360	3,220	505	1,050	2,600
1958	71.4	826	4,410	8,500	159	850	1,640
1959	126	666	2,420	5,020	227	823	1,710
Clear Fork Brazos River at Nugent							
1949	58.1	145	63	425	22.7	9.88	66.7
1950	64.6	131	59	410	22.8	10.3	71.5
1951	43.8	197	96	569	23.3	11.4	67.3
1952	10.8	165	106	558	4.81	3.09	16.3
1953	12.4	48	37	260	1.61	1.24	8.70
Clear Fork Brazos River at Fort Griffin							
1950	131	68	67	333	24.1	23.7	118
1951	88.7	101	67	393	24.2	16.0	94.1
Hubbard Creek near Breckenridge							
1956	22.7	11	58	212	0.67	3.55	13.0
1957	633	10	46	180	17.1	78.6	308
1958	204	23	129	332	12.7	71.1	183
1959	47.9	24	121	325	3.10	15.6	42.0
Brazos River near South Bend							
1942	1,309	226	411	1,080	799	1,450	4,070
1943	678	305	549	1,420	558	1,000	2,600
1944	236	284	539	1,370	181	343	873
1945	545	294	598	1,480	433	880	2,170
1946	503	394	610	1,660	535	828	2,250
1947	1,032	358	514	1,450	998	1,430	4,040

TABLE 4.—*Yearly discharges and weighted average concentrations and mean daily loads of chlorides, sulfates, and dissolved solids for periods of record at selected points in the Brazos River basin*—Continued

Water year	Yearly discharge (cfs)	Weighted average concentrations (ppm)			Loads (tons per day)		
		Sulfate	Chloride	Dissolved solids	Sulfate	Chloride	Dissolved solids
Salt Creek at Olney							
1958	2.74	6.6	222	458	0.05	1.64	3.39
1959	.36	9.8	225	463	.01	.22	.45
Salt Creek at Newcastle							
1958	14.7	9.9	99	255	0.39	3.93	10.1
1959	3.12	8.3	81	205	.07	.68	1.73
Brazos River at Possum Kingdom Dam Near Graford							
1942	1,715	242	352	1,030	1,120	1,630	5,030
1943	1,161	201	370	994	630	1,160	3,110
1944	164	274	498	1,310	121	221	580
1945	528	256	561	1,390	365	800	1,980
1946	502	262	519	1,320	355	703	1,790
1947	1,343	303	530	1,380	1,100	1,920	5,000
1948	470	374	510	1,460	475	647	1,850
1949	769	375	531	1,500	779	1,100	3,110
1950	898	280	451	1,230	679	1,090	2,980
1951	603	291	490	1,320	474	798	2,150
1952	294	295	527	1,390	234	418	1,100
1953	220	322	636	1,610	191	378	956
1954	1,052	245	460	1,200	696	1,310	3,410
1955	1,120	301	448	1,260	910	1,350	3,810
1956	983	379	445	1,370	1,010	1,180	3,640
1957	4,145	108	119	443	1,210	1,330	4,960
1958	1,226	248	443	1,180	821	1,470	3,910
1959	458	235	425	1,130	291	526	1,400
Brazos River near Whitney							
1949	1,566	172	242	765	727	1,020	3,230
1950	1,520	157	244	748	644	1,000	3,070
1951	840	260	437	1,190	590	991	2,700
1952	348	167	332	912	157	312	857
1953	141	112	209	651	42.6	79.6	248
1954	912	198	392	1,040	488	965	2,560
1955	997	205	374	1,030	552	1,010	2,770
1956	1,571	255	333	1,010	1,080	1,410	4,280
1957	6,213	96	126	459	1,610	2,110	7,700
1958	2,322	122	170	604	765	1,070	3,790
1959	681	165	309	893	303	568	1,640
Brazos River near Waco							
1907 [1]	1,678	281	294	1,060	1,270	1,330	4,800
Navasota River near Bryan							
1959	529	25	80	226	35.7	114	323

[1] Period from Dec. 14, 1906, to Nov. 19, 1907.

TABLE 4.—*Yearly discharges and weighted average concentrations and mean daily loads of chlorides, sulfates, and dissolved solids for periods of record at selected points in the Brazos River basin*—Continued

Water year	Yearly discharge (cfs)	Weighted average concentrations (ppm)			Loads (tons per day)		
		Sulfate	Chloride	Dissolved solids	Sulfate	Chloride	Dissolved solids
Brazos River at Richmond							
1946	10,220	39	53	299	1,080	1,460	8,250
1947	8,765	70	100	425	1,660	2,370	10,100
1948	2,687	84	118	479	609	856	3,480
1949	4,645	76	103	423	953	1,290	5,310
1950	5,783	58	87	368	906	1,360	5,750
1951	1,418	134	214	696	513	819	2,660
1952	1,820	54	85	370	265	418	1,820
1953	4,105	25	31	215	277	344	2,380
1954	2,727	72	127	453	530	935	3,340
1955	2,168	83	145	498	486	849	2,920
1956	2,158	185	260	834	1,080	1,510	4,860
1957	15,290	54	65	317	2,230	2,680	13,090
1958	11,870	50	57	303	1,600	1,830	9,710
1959	4,450	51	74	323	613	889	3,880

TABLE 5.—*Duration table of dissolved-solids concentration for 15 stations in the Brazos River basin*

Chemical-quality stations	Number of years	Dissolved-solids concentration, in parts per million, that was equaled or exceeded for indicated percentage of days of flow																
		99.5	99	98	95	90	80	70	60	50	40	30	20	10	5	2	1	0.5
Double Mountain Fork Brazos River near Rotan	2	-------	-------	540	610	718	940	1,200	1,590	2,310	3,420	5,150	7,950	12,400	14,800	17,000	-------	-------
Double Mountain Fork Brazos River near Aspermont	6	-------	658	700	810	960	1,270	1,780	3,020	3,420	3,680	3,900	4,100	4,420	4,550	4,900	5,350	5,850
Salt Fork Brazos River near Peacock	1	910	990	1,130	1,580	2,480	5,900	12,300	16,300	17,300	18,000	18,600	19,300	20,000	20,900	22,300	24,500	28,000
Salt Fork Brazos River near Aspermont	6	1,910	2,180	2,400	2,800	3,800	8,100	15,100	26,000	35,200	39,300	42,500	45,200	49,000	55,000	63,500	71,000	81,000
Clear Fork Brazos River at Nugent	5	210	216	222	243	295	405	540	705	940	1,220	1,600	2,160	2,650	3,280	3,620	3,810	-------
Paint Creek near Haskell	2	-------	-------	-------	153	168	192	219	246	278	317	370	468	980	1,090	-------	-------	-------
Clear Fork Brazos River at Fort Griffin	2	-------	-------	-------	162	182	240	280	310	332	354	379	411	494	838	-------	-------	-------
Hubbard Creek near Breckenridge	4	145	150	156	170	186	225	268	335	455	620	920	1,280	1,800	2,190	2,350	2,430	2,580
Salt Creek at Olney	1	-------	-------	194	245	303	412	513	613	805	1,270	1,900	2,400	3,100	3,410	3,590	-------	-------
Salt Creek near Newcastle	1	-------	78	123	154	183	247	405	605	750	823	900	990	1,160	1,310	1,500	-------	-------
Brazos River at Possum Kingdom Dam	17	400	760	830	940	1,040	1,170	1,230	1,280	1,320	1,350	1,420	1,520	1,660	1,760	2,120	2,220	2,430
Brazos River at Whitney Dam	4	-------	-------	260	308	405	670	930	1,080	1,130	1,180	1,240	1,320	1,400	1,480	1,500	-------	-------
Do	8	-------	-------	400	490	595	705	805	885	950	1,010	1,080	1,170	1,230	1,260	-------	-------	-------
Leon River near Eastland	3	-------	-------	-------	124	142	171	190	203	216	234	282	308	310	316	-------	-------	-------
Navasota River near Bryan	1	-------	-------	123	138	161	219	260	292	332	365	415	495	630	760	880	-------	-------
Brazos River at Richmond	10	176	190	201	220	247	298	350	408	470	545	660	810	950	1,050	1,160	1,290	1,380
Do	3	-------	161	165	178	207	252	297	350	417	515	703	860	999	1,020	1,030	1,030	-------
Do	5	-------	-------	178	208	263	330	368	428	505	580	690	828	990	1,090	-------	-------	-------

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