Reconnaissance of the Chemical Quality of Surface Waters of the Neches River Basin, Texas

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1839-A

Prepared in cooperation with the Texas Water Development Board

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By LEON S. HUGHES *and* DONALD K. LEIFESTE

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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RECONNAISSANCE OF THE CHEMICAL QUALITY OF SURFACE WATERS OF THE NECHES RIVER BASIN, TEXAS

By LEON S. HUGHES and DONALD K. LEIFESTE

ABSTRACT

The kinds and quantities of minerals dissolved in the surface water of the Neches River basin result from such environmental factors as geology, streamflow patterns and characteristics, and industrial influences. As a result of high rainfall in the basin, much of the readily soluble material has been leached from the surface rocks and soils. Consequently, the water in the streams is usually low in concentrations of dissolved minerals and meets the U.S. Public Health Service drinking-water standards. In most streams the concentration of dissolved solids is less than 250 ppm (parts per million).

The Neches River drains an area of about 10,000 square miles in eastern Texas. From its source in southeast Van Zandt County the river flows in a general southeasterly direction and empties into Sabine Lake, an arm of the Gulf of Mexico.

In the basin the climate ranges from moist subhumid to humid, and the average annual rainfall ranges from 46 inches in the northwest to more than 52 inches in the southeast. Annual runoff from the basin has averaged 11 inches; however, runoff rates vary widely from year to year. The yearly mean discharge of the Neches River at Evadale has ranged from 994 to 12,720 cubic feet per second.

The rocks exposed in the Neches River basin are of the Quaternary and Tertiary Systems and range in age from Eocene to Recent. Throughout most of the basin the geologic formations dip generally south and southeast toward the gulf coast. The rate of dip is greater than that of the land surface; and as a result, the older formations crop out to the north of the younger formations. Water from the outcrop areas of the Wilcox Group and from the older formations of the Claiborne Group generally has dissolved-solids concentrations ranging from 100 to 250 ppm; water from the younger formations has concentrations less than 100 ppm.

The northern half of the basin has soft water, with less than 60 ppm hardness. The southern half of the basin has very soft water, usually with less than 30 ppm hardness.

The chloride concentrations are less than 20 ppm in surface water in the southern half of the basin and usually range from 20 to 100 ppm in the northern half of the basin. Concentrations greater than 100 ppm are found only where pollution is occurring.

The Neches River basin has an abundance of surface water, but uneven distribution of runoff makes storage projects necessary to provide dependable water supplies. The principal existing reservoirs, with the exception of Striker Creek Reservoir, contain water of excellent quality. Chemical-quality data for the Striker Creek drainage area indicate that its streams are affected by the disposal of brines associated with oil production. Sam Rayburn Reservoir began impounding water in 1965. The water impounded should prove of acceptable quality for most uses, but municipal and industrial wastes released into the Angelina River near Lufkin may have a degrading effect on the quality of the water, especially during extended periods of low flows. Water available for storage at the many potential reservoir sites will be of good quality; but, if the proposed salt-water barrier is to impound acceptable water, the disposal of oil-field brine into Pine Island Bayou should be discontinued.

INTRODUCTION

The investigation of the chemical quality of the surface water of the Neches River basin, Texas, is part of a statewide reconnaissance study. This report is the second in a series presenting the results of the study, as well as summaries of available chemical-quality data. The first report, on the Sabine River basin, Texas and Louisiana, has been published (Hughes and Leifeste, 1965). A report on the San Jacinto River basin is in preparation, and a report is planned for each major river basin in Texas.

Knowledge of the quality of water that will be available is essential in planning any water-use project, because the chemical character of the water determines its suitability for domestic, irrigation, or industrial purposes. For public supply, of course, water must serve all three of these purposes. If raw water is not satisfactory for a specific use, then chemical analyses are necessary to determine the type or extent of treatment needed.

In addition to determining the suitability of water for specific uses, chemical-quality data are needed for the (1) inventory of water resources, (2) detection and control of pollution of water supplies, (3) study of techniques for preventing salt-water encroachment into coastal streams and aquifers, (4) planning for reuse of water, and (5) demineralization of water.

A network of daily chemical-quality stations on principal streams in Texas is operated by the U.S. Geological Survey in cooperation with the Texas Water Development Board (formerly Texas Board of Water Engineers and Texas Water Commission) and with Federal and local agencies. However, this network has not been adequate to inventory completely the chemical quality of the surface water of the entire State. To supplement the information being obtained by the network, a cooperative statewide reconnaissance study by the U.S. Geological Survey and the Texas Water Development Board was begun in September 1961. In this study, samples for chemical analyses have been collected periodically at numerous sites throughout the State so that quality-of-water information would be available for locations where water-development projects are likely to be built. These data aid in the delineation of water-quality problem areas and in the identification of probable sources of pollution; thus they indicate areas in which more detailed investigations are needed.

During the period September 1961 to June 1964, water-quality data were collected for the principal streams, the major reservoirs, a number of potential reservoir sites, and many tributaries in the Neches River basin.

Agencies that have cooperated in the collection of chemical-quality and streamflow data include the U.S. Army Corps of Engineers, Lower Neches Valley Authority, Upper Neches River Municipal Water Authority, the City of Tyler, and the Texas State Department of Health.

NECHES RIVER DRAINAGE BASIN

GENERAL DESCRIPTION

The Neches River drains an area of about 10,000 square miles in eastern Texas (fig. 1). The basin is about 200 miles long, averages about 50 miles wide, and includes all or part of 21 counties. From its source in southeast Van Zandt County (fig. 2), the Neches River flows generally southeastward and empties into Sabine Lake, an arm of the Gulf of Mexico.

Low divides separate the Neches River basin from the Sabine River drainage basin on the north and east and from the Trinity River drainage basin on the west and southwest.

The basin slopes from an altitude of about 600 feet to sea level. The northwestern third of the basin has rolling hills and grassy plains. The area from central Cherokee County southward to southern Hardin County consists of heavily forested low hills and wide flat flood plains along the Neches River and its major tributaries. Southern Hardin County and Jefferson County have prairies and poorly drained flatlands.

The Neches River basin is drained by two major streams and many tributaries. The Angelina River heads in southwest Rusk County and, at Dam B Reservoir, joins the Neches River. Upstream from their confluence, the Neches River drains 3,808 square miles and the Angelina River drains 3,556 square miles. Village Creek and Attoyac and Pine Island Bayous, with drainage areas of 1,113, 670, and 657 square miles respectively, are the only other tributaries that drain more than 500 square miles.

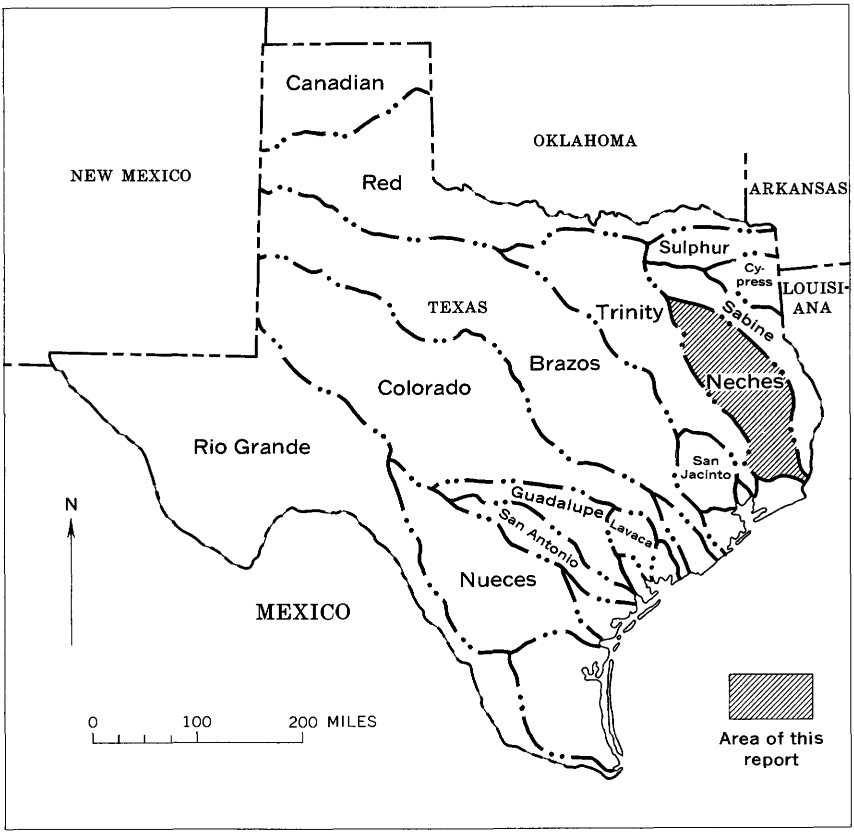


FIGURE 1.—Map of Texas showing major river basins.

The climate in the Neches River basin ranges from moist subhumid to humid. The average annual precipitation, about 49 inches, exceeds the average for the State of Texas by 60 percent. Within the basin, the average annual precipitation ranges from about 46 inches in the northwest to more than 54 inches in the southeast. At Rockland, in Tyler County, annual rainfall for the period 1931–60 averaged 49.85 inches. Mean annual precipitation, average (normal) monthly precipitation of four Weather Bureau stations, and annual precipitation for 1910–63 at one station are shown on figure 2.

Runoff is defined as that part of the precipitation appearing in surface streams, and is the same as streamflow unaffected by artificial storage or diversion (Langbein and Iseri, 1960, p. 17). Streamflow in the Neches River basin has been affected only slightly by diversions or storage. Temperature, seasonal distribution of rainfall, storm intensity, infiltration rates, and types and density of vegetation also affect the amount of runoff from a drainage basin.

Runoff data plotted on figure 2 show that average runoff from subbasins during the period 1940–63 has ranged from 8.9 to 13.1 inches annually. Runoff from the entire basin measured at the lowermost gaging station, Neches River at Evadale, averaged 11.0 inches annually for the period 1921–63. Annual runoff, expressed as mean discharge in cubic feet per second and inches per year, in shown for the Evadale station on figure 2.

Precipitation and runoff in the Neches River basin are subject to much greater variations than indicated by the annual and monthly averages. The yearly mean discharge of the Neches River at Evadale has ranged from 994 to 12,700 cfs (cubic feet per second), as shown in figure 2, but instantaneous flows have varied much more widely. Normal monthly rainfall at Rockland ranges from 2.88 inches for August to 5.39 inches for January (fig. 2), but in 1963 the monthly rainfall ranged from 0.00 inches in October to 8.10 inches in September. Thus, in spite of relatively high averages, precipitation so unevenly distributed in time does not sustain streamflow, and flood runoff must therefore be stored to make surface water continuously available in dependable quantities.

POPULATION AND MUNICIPALITIES

The population of the Neches River basin in 1960 was 568,000, which was about 6 percent of the total population of the State. About half the people in the basin live on farms. No large cities are entirely within the basin, Lufkin being the only city with a population of more than 15,000 in 1960. Although the towns have grown, the population of most of the counties has decreased since 1940; the counties with the larger towns, however, have had an increase in population.

The principal cities of the Neches River basin and their populations are given below.

City	Population	City	Population
Lufkin	19,000	Silsbee	6,277
Nacogdoches	12,750	Rusk	4,900
Jacksonville	9,750	Jasper	4,889

The principal cities and their populations that are on stream divides and only partly in the basin are given below.

City	Population
Beaumont	119,175
Tyler	51,230
Henderson	9,750

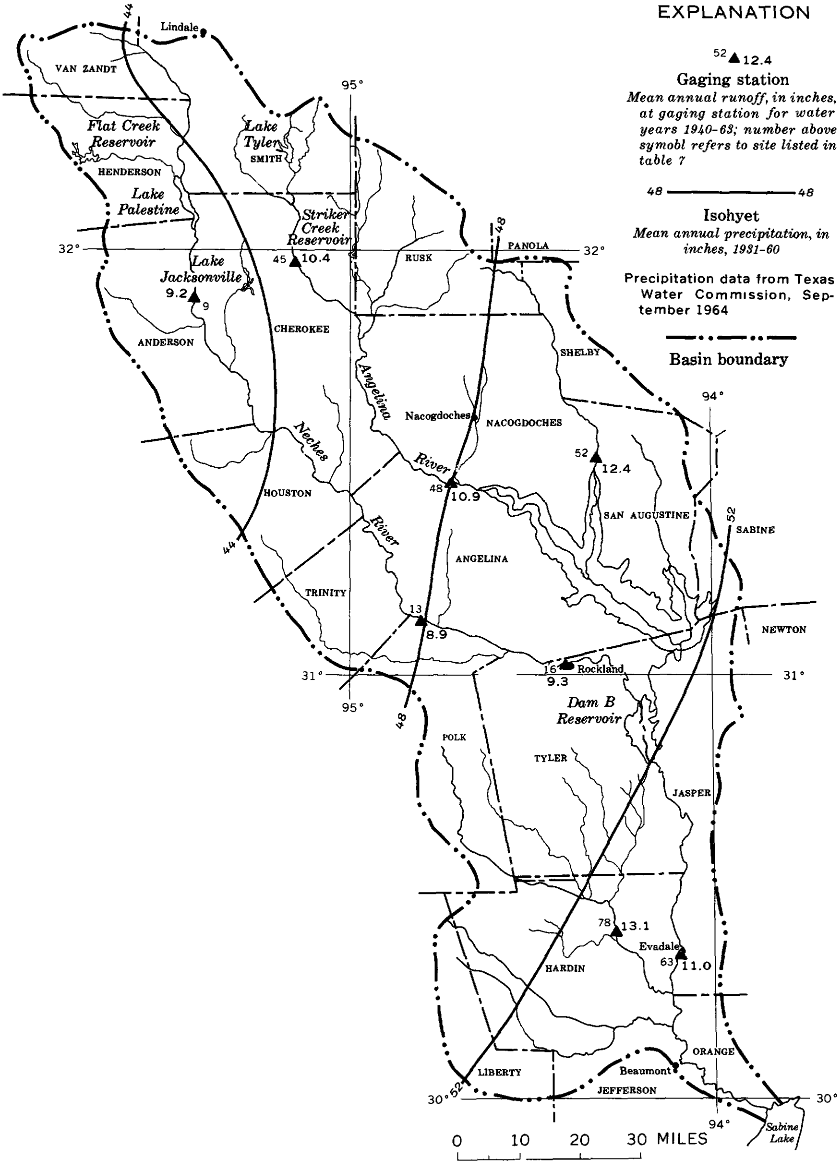
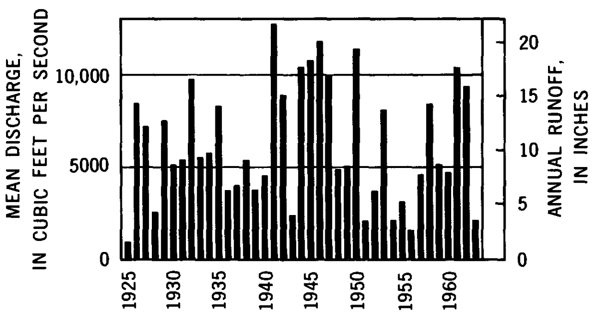
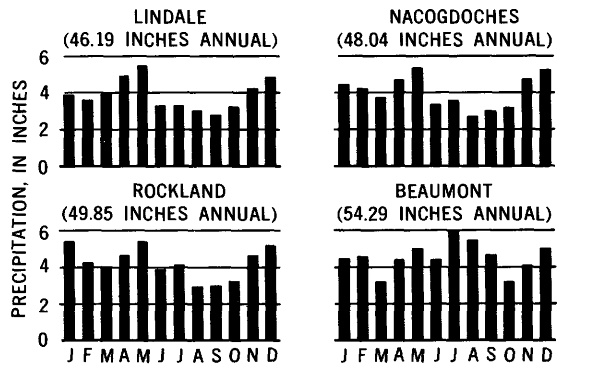


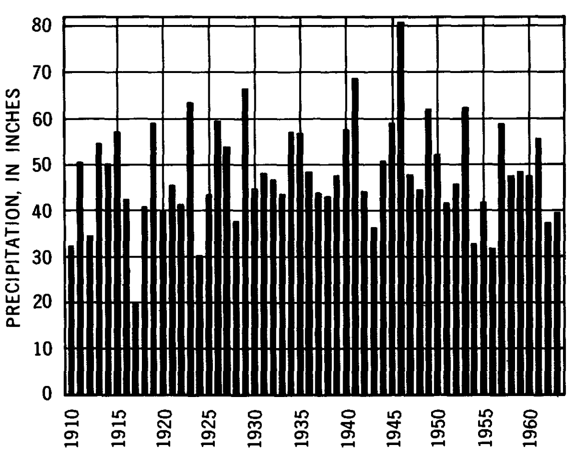
FIGURE 2.—Precipitation (this page) and runoff (facing page).



ANNUAL RUNOFF, NECHES RIVER AT EVADALE, 1925-63



NORMAL PRECIPITATION (AVERAGE 1931-60 CALENDAR YEARS)



ANNUAL PRECIPITATION AT ROCKLAND 1910-63

FIGURE 2.—Continued

AGRICULTURAL AND INDUSTRIAL DEVELOPMENT

Although the number of farms has decreased since 1940, agriculture is still of great importance to the economy of the Neches River basin.

Corn, cotton, sorghums, rice, fruit and truck-farm products are the principal crops. Corn, cotton, and sorghums are grown chiefly in the northern part of the basin and rice is grown only in the southern part. Fruit and truck-farm products are grown over the entire basin. In the central part of the basin, beef cattle, poultry, dairy farming and truck-farm products have replaced field crops as the major source of farm income.

The lumber industry is another important segment of the economy. The central and southern parts of the basin are in the great treegrowing region of Texas. Many large and small sawmills process southern yellow pine and hardwood trees in large quantities. Pulpwood and powerline poles are other forest products. Many small farms have been allowed to grow over or have been planted with trees.

The production of oil and gas has been of great importance in the economic development of the Neches River basin since the development of the East Texas oil field began in 1930 with the discovery of oil west of Henderson. Many other oil and gas fields are in the basin (fig. 3), the most intensive concentration of oil production being in the southern part.

The Beaumont metropolitan area near the mouth of the Neches River contains a variety of both light and heavy industries. Some of the more important industries include petroleum refining, the manufacturing of oil-field equipment, petrochemicals, synthetic rubber, iron, and steel.

DEVELOPMENT OF SURFACE-WATER RESOURCES

With an average runoff of 11 inches per year, the Neches River basin contributes about 17 percent of the total runoff for the State (fig. 4). As the basin has only about 4 percent of the State's total area and about 6 percent of the popuation, the quantity of surface water available for development is considerably more than the average for the State.

The Texas Board of Water Engineers (1961, p. 64) reported that 170,410 acre-feet of water was used in the Neches River basin in 1959. Of this amount, 96,630 acre-feet was from surface-water sources. Surface water supplements ground-water supplies for some cities and provides the total supply for others. Cities using surface water impounded in the Neches River basin include: Athens (in the Trinity River basin), from Flat Creek Reservoir; Tyler, from Lake Tyler; Rusk, from Lake Palestine; and Jacksonville, from Lake Jacksonville.

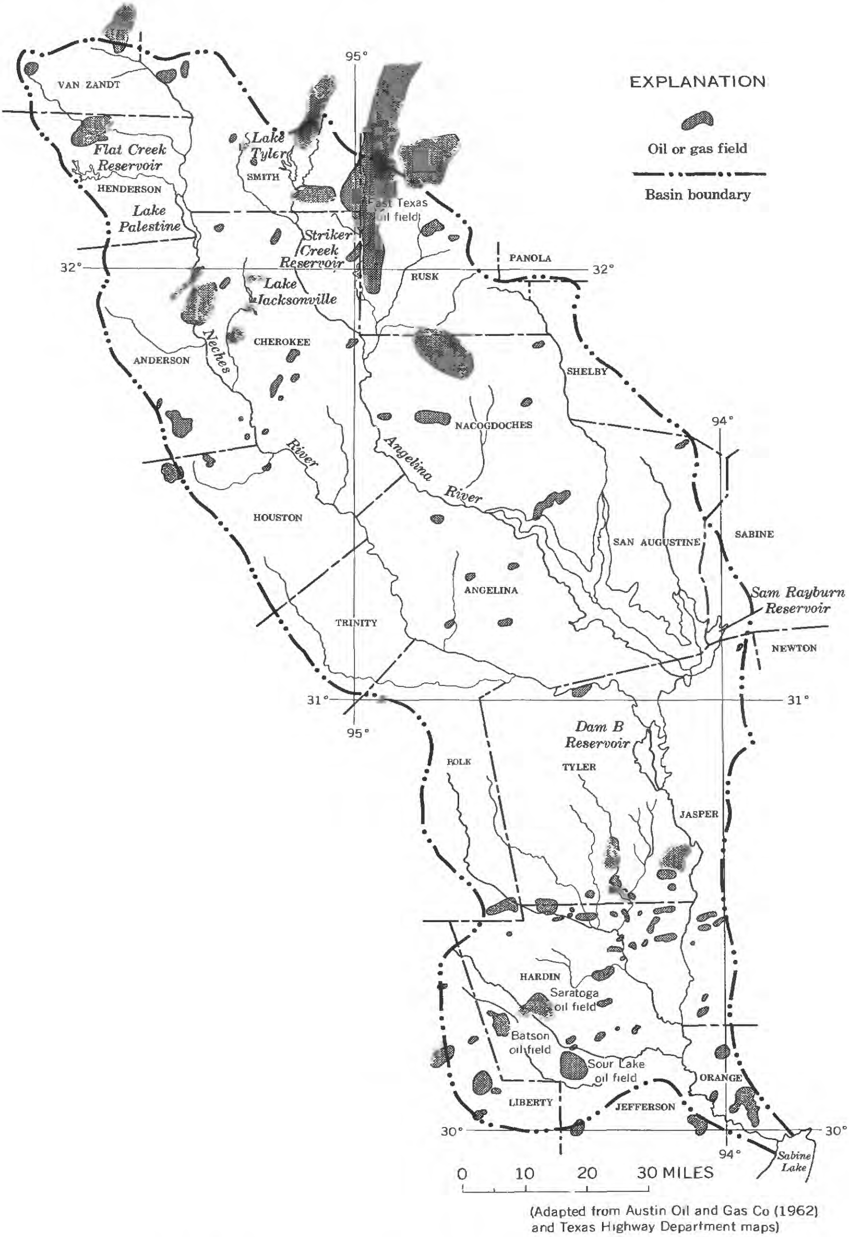


FIGURE 3.—Generalized map of the oil and gas fields.

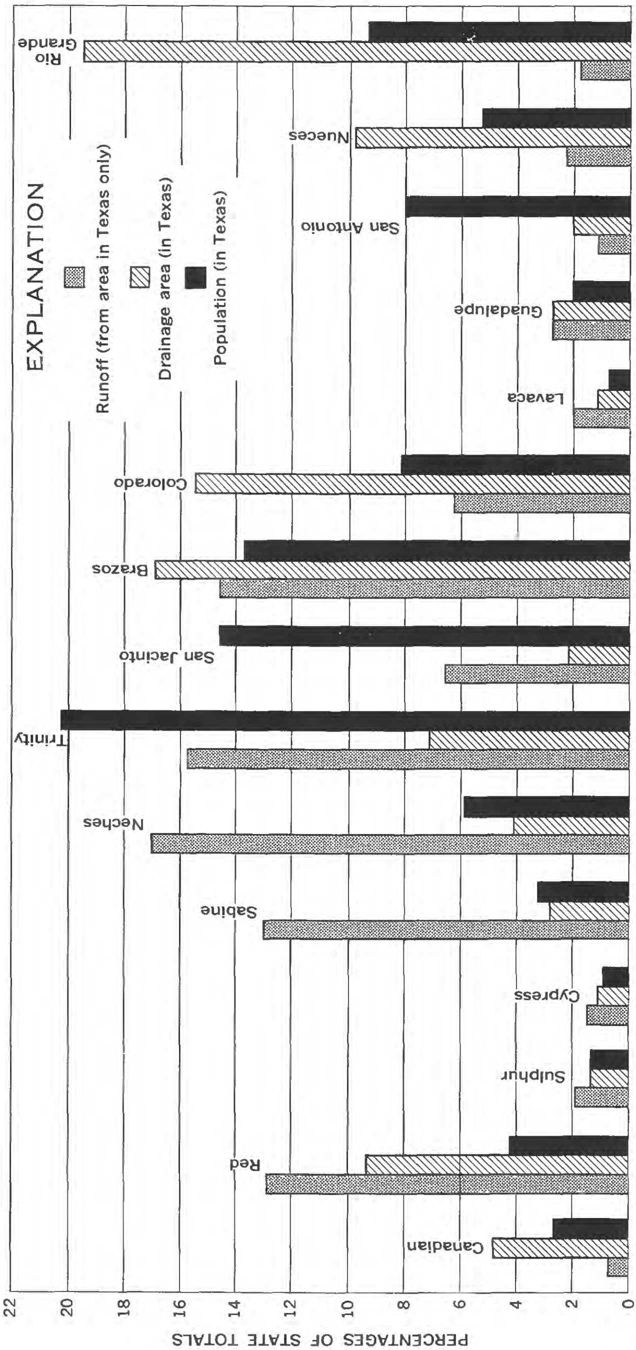


FIGURE 4.—Average annual runoff, drainage area, and 1960 population of major river basins in Texas, as percentages of State totals.

Large quantities of surface water are used in the lower part of the basin for municipal, industrial, and irrigation purposes. The city of Beaumont uses surface water for its municipal supply, and the Lower Neches Valley Authority supplies surface water to the Beaumont–Port Arthur industrial area and to rice farms west and southwest of Beaumont (fig. 5). Sea water intrudes up the river, and the riverflow required to keep the salt water away from the intakes of the Lower Neches Valley Authority's pumping plant at Voth is about twice the average rate of use for the Beaumont–Port Arthur area. The construction of a salt-water barrier on the Neches River near Beaumont is considered by the Texas Water Development Board to be one of the most important requirements in the development of the water resources of the Neches River basin (Texas Board of Water Engineers, 1961, p. 64).

FIGURE 5.—Lower Neches Valley Authority pumping plant at Voth.

Before 1950, Lake Tyler was the only reservoir with a capacity of of 5,000 acre-feet or more in the Nehces River basin. In January 1965, eight major reservoirs were in existence or under construction. Table 1 lists these reservoirs and gives their capacities and uses; locations are shown on figure 6. Most of the reservoirs in the basin were built by cities or by water districts to supply water for local municipal and industrial use, but Dam B Reservoir and Sam Rayburn Reservoir are joint projects of the U.S Army Corps of Engineers and the Lower

Neches Valley Authority to provide flood control and water for municipal, industrial, and irrigation use in the coastal area. Sam Rayburn Reservoir is the largest reservoir in the basin, with a capacity of 4,478,800 acre-feet, of which 2,891,900 acre-feet is conservation storage.

Figure 6 also shows the location of two additional reservoir projects for which permits have been issued and a number of locations which have been considered by various agencies as potential dam sites.

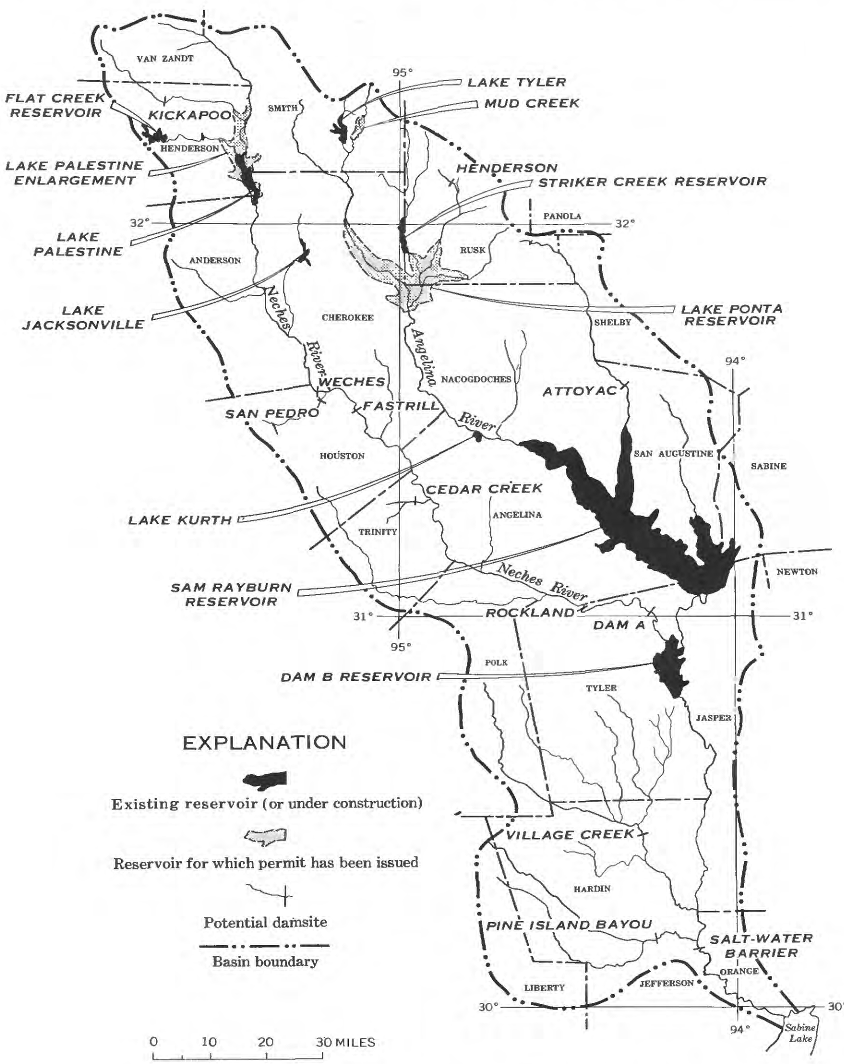


FIGURE 6.—Major reservoirs and potential damsites.

TABLE 1.—*Reservoirs with capacities of 5,000 acre-feet or more in the Neches River basin*

[The purpose for which the impounded waters are used is indicated by the following symbols: M, municipal; I, industrial; D, domestic; Ir, irrigation; R, recreation; P, hydroelectric power; FC, flood control]

Name of reservoir	Year operation began	Stream	Total storage capacity (acre-feet)	Owner	County	Use
Flat Creek Reservoir.	1962	Flat Creek	32,840	Athens Municipal Water Authority.	Henderson	M.
Lake Palestine	1962	Neches River	57,550	Upper Neches River Municipal Water Authority.	Anderson, Henderson, Smith, Cherokee.	M, I.
Lake Jacksonville	1957	Gum Creek	30,500	City of Jacksonville.	Cherokee	M, R.
Striker Creek Reservoir.	1957	Striker Creek	26,700	Angelina-Nacogdoches Counties WCID No. 1.	Cherokee, Rusk	M, I.
Lake Tyler	1949	Prairie Creek	43,400	City of Tyler	Smith	M, I, D.
Lake Kurth	1961	Angelina River off-channel.	16,200	Southland Paper Mills, Inc.	Angelina	I.
Sam Rayburn Reservoir.	1965	Angelina River	4,478,800	U.S. Army Corps of Engineers, Lower Neches Valley Authority.	Jasper, Sabine, San Augustine, Angelina, Nacogdoches.	M, I, Ir, P, FC.
Dam B Reservoir	1951	Neches River	124,700	do	Tyler, Jasper	M, I, Ir.

CHEMICAL-QUALITY RECORDS

The U.S. Geological Survey began the collection of chemical-quality data on surface waters of the Neches River in 1939. Samples for chemical analysis were collected intermittently for 3 years from the Neches River at Rockland, from Village Creek at Fletcher, and from Pine Island Bayou at Voth. Daily sampling stations were established at Evadale in 1947, near Alto in 1960, and on the Angelina River near Lufkin in 1954. In addition, numerous miscellaneous samples have been collected by the Geological Survey since 1953.

Quality-of-water records for the Neches River basin are published in the following U.S. Geological Survey water-supply papers and the TWC (Texas Water Commission) bulletins. Prior to January 1962, the TWC was known as the Texas Board of Water Engineers.

Water Year	*Water-Supply Paper*	*TWC Bull.*	*Water Year*	*Water-Supply Paper*	*TWC Bull.*
1940–45	----	[1] 1938–45	1954	1352	[1] 1954
1946	050	[1] 1946	1955	1402	[1] 1955
1947	1102	[1] 1947	1956	1452	5905
1948	1133	[1] 1948	1957	1522	5915
1949	1163	[1] 1949	1958	1573	6104
1950	1188	[1] 1950	1959	1644	6205
1951	1199	[1] 1951	1960	----	6215
1952	1252	[1] 1952	1961	----	6304
1953	1292	[1] 1953	1962	1944	6501

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

Collection of chemical-quality data for this reconnaissance began in 1961 and continued through June 1964. Samples were collected periodically from the principal tributary streams and from four reservoirs. Single samples were collected at many additional sites.

Data were collected over a wide range of water-discharge rates. At low flows, concentrations of dissolved minerals are likely to be highest; and the data commonly indicate where pollution and salinity problems exist. Data collected during medium and high flows indicate the probable quality of the water that would be stored in reservoirs. Stream-gaging stations were selected as sampling sites wherever possible in order that chemical analyses could be considered in relation to water discharge. At sites other than stream-gaging stations, water discharge was usually measured when the samples were collected.

The periods of record of all data-collection sites are given on plate 1 and the locations are shown on plates 2 or 3. The chemical-quality data for the daily stations are summarized in table 7 (p. 52), and the complete records are published in an annual series of U.S. Geological Survey water-supply papers and in bulletins of the Texas Water Commission. (See list of references.) Results of all the periodic and miscellaneous analyses are given in table 3 (p. 22).

The Texas State Health Department makes available to the U.S. Geological Survey the data collected in its statewide stream-sampling program, which includes the periodic determination of pH, biochemical oxygen demand, total solids, dissolved oxygen, chloride, chlorine demand, and sulfate at 19 locations in the Neches River basin. The data-collection sites of the State Department of Health are listed in the following table. Some of them are at Geological Survey stream-gaging stations. The numbers refer to sites shown on plates 2 or 3.

Reference No.	*Data-collection site*
1	Neches River near Chandler.
9	Neches River near Neches.
11	Neches River near Alto.
13	Neches River near Diboll.
16	Neches River near Rockland.
23	Bowles Creek near Turnertown.
39	Striker Creek near Summerfield.
47	Angelina River near Alto.
48	Angelina River near Lufkin.
50	Angelina River near Etoile.
52	Attoyac Bayou near Chireno.
53	Angelina River near Zavalla.
	Angelina River near Jasper.
62	Neches River at Town Bluff.
63	Neches River at Evadale.
	Village Creek near Silsbee.
88	Pine Island Bayou at Voth.
	Neches River at Beaumont.
	Neches River near Groves.

STREAMFLOW RECORDS

Streamflow records in the Neches River basin date from 1903 when the U.S. Weather Bureau installed a staff gage on the Neches River at Rockland. A gaging station was established at Evadale in 1904, discontinued in 1906, and reestablished in 1921. More than 20 years of discharge records are available for several stations on the Neches and Angelina Rivers, and records for more than 10 years are available for several of the smaller streams in the basin.

In 1964 the U.S. Geological Survey operated 6 stream-gaging stations on the Neches River and 11 stations on tributaries, 3 reservoir-content stations, and 1 low-flow partial-record station. In addition, discharge measurements were made at other sites where samples were collected for chemical analysis.

The periods of record for all the stream-gaging stations are given on plate 1, and the locations are shown on plate 2. Records of discharge and stage of streams, and contents and stage of lakes or reservoirs from 1903 to 1907 and from 1924 to 1960, have been published in an annual series of U.S. Geological Survey water-supply papers as follows:

Year	*Water-Supply Paper*	*Year*	*Water-Supply Paper*	*Year*	*Water-Supply Paper*
1903	99	1934	763	1948	1118
1904	132	1935	788	1949	1148
1905	174	1936	808	1950	1178
1906	210	1937	828	1951	1212
1924	588	1938	858	1952	1242
1925	608	1939	878	1953	1282
1926	628	1940	898	1954	1342
1927	648	1941	928	1955	1392
1928	668	1942	958	1956	1442
1929	688	1943	978	1957	1512
1930	703	1944	1008	1958	1562
1931	718	1945	1038	1959	1632
1932	733	1946	1058	1960	1712
1933	748	1947	1088		

Beginning with the 1961 water year, streamflow records have been released by the U.S. Geological Survey in annual reports on the State-boundary basis (U.S. Geological Survey, 1961, 1962, 1963). Summaries of discharge records giving monthly and annual totals have been published (U.S. Geological Survey, 1939, 1960, 1964; Texas Board of Water Engineers, 1958).

FACTORS AFFECTING CHEMICAL QUALITY OF WATER IN THE NECHES RIVER BASIN

As soon as water from rain or melting snow comes in contact with the earth's crust, it begins to dissolve materials. The kinds and quantities of materials dissolved are the result of many environmental factors, including geology, precipitation, streamflow, and the activities of man.

GEOLOGY

The minerals in the rocks and their susceptibility to weathering and solvent action have a direct bearing on the chemical quality of the water of the area. Where industrial influences are small, the chemical character of surface water is dependent primarily on the chemical and physical properties of the rocks and soils in the drainage basin. In areas of high rainfall, as in the Neches River basin, circulating water has so leached the mantle rock and residual soil that only relatively small amonuts of readily soluble minerals remain.

The rocks exposed in the Neches River basin are of the Tertiary and Quaternary Systems and range in age from Eocene to Recent. Plate 2 is a generalized map of the geology of the basin. The rocks were deposited during repeated marine transgressions and regressions, and form an alternating sequence of marine and continental sediments which are characterized by clay, shale, marl and minor amounts of sand.

Throughout most of the basin the geologic formations dip generally south and southeast toward the gulf coast. The rate of dip is greater than that of the land surface; and as a result, the older formations crop out to the north of the younger formations. In the northern part of the basin, the general slope of the formations is controlled by two major structural features. The formations dip eastward and westward toward the axis of a structural trough known as the East Texas syncline. The axis of this trough strikes generally northward across the Neches River in eastern Anderson and western Smith Counties. On the eastern flank of the trough, the formations dip westward and southwestward from the Sabine uplift, a dome-shaped structual high centered in Panola County. Because of subsequent erosion on the uplift, the oldest rocks crop out along the northeast boundary of the basin. The stratigraphic succession of formations with brief description of the rock units are given in table 2.

Water from the outcrop area of the Claiborne Group, in the northern part of the Neches River basin (pl. 2), generally has dissolved-solids concentrations ranging from 100 to 250 ppm (parts per million), as shown in figure 9. Water from the outcrop areas of the younger formations has concentrations less than 100 ppm. The shales and clays which predominate in some formations of the Claiborne Group (table 2) apparently have been less completely leached of readily soluble material than have the more sandy formations in the southern half of the basin.

STREAMFLOW

Runoff and streamflow usually have a definite influence on the chemical characteristics of water in a drainage basin. Water discharge of any stream not regulated by upstream reservoirs usually varies from day to day and even from hour to hour. As a general rule, the low flow of a stream is sustained by ground-water inflow that contains minerals dissolved from the rocks and soil particles. At high flows and during floods the dissolved-mineral concentration of the stream is diluted by the surface runoff. The effect of rates of streamflow on the dissolved-solids concentration of streams generally is greater in streams whose low-flow waters have high concentrations of dissolved minerals. In the Neches River basin only a few streams that are locally polluted by oil-field wastes have, even at low flow, high concentrations of dissolved minerals.

TABLE 2.—*Stratigraphic units in the Neches River basin*

System	Series	Group	Stratigraphic unit	Description
Quaternary	Recent		Alluivum, beach sand, and terrace deposits	Unconsolidated gravel, sand, silt, and clay.
	Pleistocene		Beaumont Clay	Calcareous clay, silt, sand, and gravel.
			Lissie Formation	Beds of sand, gravel, silt, and clay.
Tertiary(?)	Pliocene(?)		Willis Sand	Gravel, calcareous sand, silt, and clay.
Tertiary	Miocene(?)		Lagarto Clay	
	Miocene		Oakville Sandstone	
	Miocene(?)		Catahoula Sandstone	Sand and clay; some volcanic ash and fuller's earth.
	Eocene	Jackson	Sedimentary and volcanic rocks	Sand, sandy clay, clay, and volcanic ash.
		Claiborne	Yegua Formation	Sand, sandy shale, clay, and lignite.
			Cook Mountain Formation	Predominantly shale with some sand.
			Sparta Sand	Sand, interbedded with clay and shale.
			Weches Greensand	Glauconitic sandstone and shale.
			Queen City Sand	Medium to fine sand, silt, and clay.
			Reklaw Formation	Shale with thin sand layers.
			Carrizo Sand	Fine to medium sand with thin interbedded shale.
		Wilcox	Sedimentary rocks	Interbedded sand, sandy shale, shale, clay, and thin beds of lignite.

Because of the topography, the rate of runoff in the Neches River basin is much slower than in most of the other river basins in Texas. The streambed gradient of the Neches River is, for much of its length, about 1.0 foot per mile; and the river meanders through its flood plain with many sloughs, overflow channels, and marshes. For long periods after heavy rains large areas are inundated, not only because the heavy forest cover and dense underbrush prevent rapid runoff into streams but also because the clay subsoils inhibit rapid downward movement of water. Thus the flow in the major streams is sustained for long periods by surface runoff, and changes in chemical quality occur gradually.

Streamflow records show that between periods of surface runoff the base flow of many streams in the Neches River basin is maintained by ground-water inflow. Most of this ground-water inflow is low in dissolved material, and the dissolved-solids concentration of the streamflow varies only slightly with changes in water discharge.

The relation of the annual weighted-average concentration of dissolved solids to the annual mean discharge of the Angelina River near Lufkin and the Neches River at Evadale is shown on figure 7.

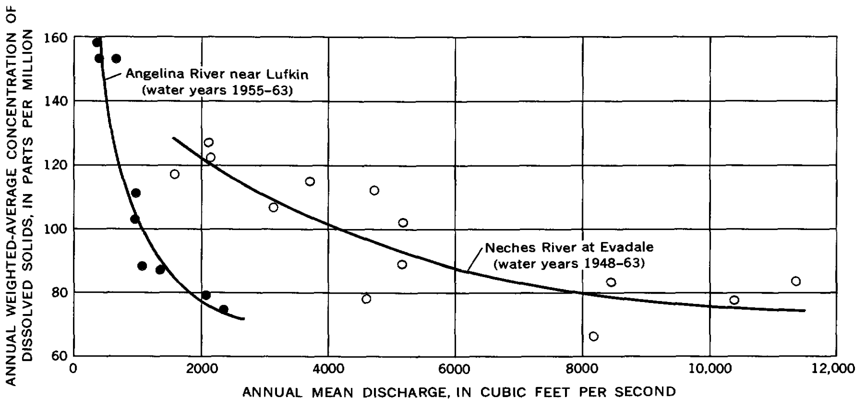


FIGURE 7.—Relation of annual weighted-average concentration of dissolved solids to annual mean discharge, Angelina River near Lufkin and Neches River at Evadale.

The plots for both stations show decreases in dissolved solids with increases in discharge. That part of the basin which is above Lufkin has the lowest rainfall, and the dissolved-solids concentration of the Angelina River near Lufkin varies over a wide range. The water quality of the Neches River at Evadale shows the effect of inflow from the high rainfall area where the dissolved solids are always low and subject to only slight variations. Also, streamflow at Evadale is partly regulated by Dam B, 59 miles upstream. Duration curves for the Lufkin and Evadale stations (fig. 8) show the relation of dissolved-solids concentrations to water discharge at the two stations. The curves also show the inverse relationship of rates of water discharge to the concentration of dissolved solids in the streams during water years 1955–63.

ACTIVITIES OF MAN

The activities of man often have a significant effect on the chemical quality of surface water. Changes in water quality are produced by depleting streamflow by diversion for municipal and industrial uses, disposing of oil-field brines and of municipal and industrial wastes, and altering streamflow by storing water.

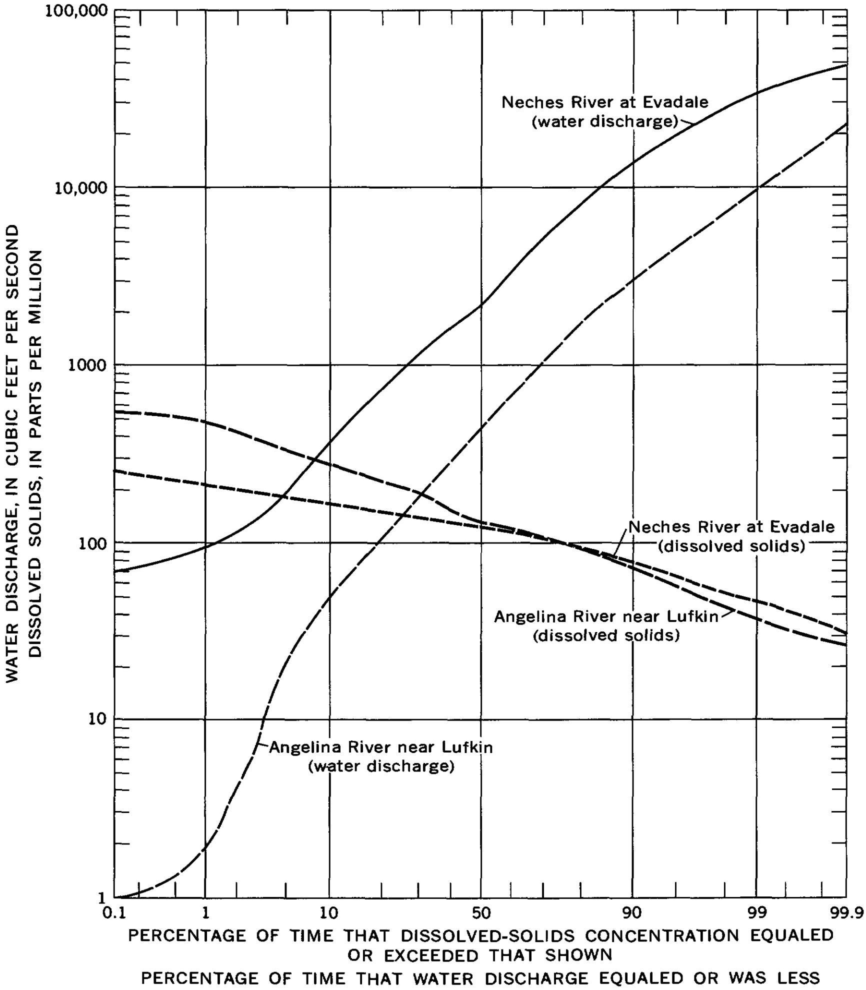


FIGURE 8.—Duration curves for dissolved solids and water discharge for Angelina River near Lufkin and Neches River at Evadale, water years 1955–63.

Municipal use of water tends to increase the concentration of dissolved solids in a stream system. The depletion of flow by diversion and consumptive use, the loss of water because of increased evaporation, and the disposal of municipal wastes into a stream result in higher average concentrations of dissolved solids in the remaining water. On the other hand, storage of dilute floodwater in reservoirs and subsequent controlled release of the stored water serves to improve water quality in streams below reservoirs. Floodwater released from Dam

B helps to improve the average quality of water in the Neches River at Evadale and at diversion points near Beaumont.

The quality of water from the Neches and Angelina Rivers has been changed only slightly by municipal use, and the flow throughout the reaches of both rivers has been adequate to dilute the municipal wastes introduced. Nevertheless, industrial and municipal wastes released into the Angelina River in the vicinity of Lufkin are causing some local deterioration in water quality, particularly the depletion of dissolved oxygen. These wastes may have a degrading effect on the quality of water stored in Sam Rayburn Reservoir, especially during extended periods of low flows.

Brine is produced with oil in nearly all oil fields and, if improperly handled, eventually reaches the streams. Pollution of streams by oil-field brine can be a major problem in areas where oil production is extensive. The composition of brines varies, but the principal constituents, in the order of the magnitude of their concentration (in ppm), are generally chloride, sodium, calcium, and sulfate. The presence of brine in surface water is therefore usually indicated by an abnormally high chloride concentration.

Oil is produced in many areas in the Neches River basin (fig. 3), but most of the brine is reinjected into wells and the effect on the main stem of the Neches River has been minor. However, the disposal of oil-field brine is significantly affecting water quality in two areas of the basin. The Striker Creek watershed and Striker Creek Reservoir are polluted with brine from the East Texas oil field, and Pine Island Bayou receives brine from three oilfields in Hardin County. Water-quality surveys of these two areas were made during the period of this study.

STRIKER CREEK AND THE EAST TEXAS OIL FIELD

Striker Creek, formed by the confluence of its principal tributaries, Bowles and Johnson Creeks, drains the part of the East Texas oil field that lies in the Neches River basin (pl. 3). Striker Creek Reservoir is a 26,700-acre-foot impoundment completed in 1957. Water is used by a paper company and for condenser cooling by a stream-electric generating plant.

The East Texas oil field was discovered in September 1930 with the completion of a well in northern Rusk County. Production was soon extended into Gregg, Upshur, and Smith Counties, and the field became the most productive in the Nation (fig. 3).

Soon after oil production started, wells along the western edge of the field began to yield salt water with the oil, and the handling and disposal of the water became a serious problem (Plummer, 1945). At first, all the brine was stored in earthen tanks and then drained into streams at times of rains. Fish kills in the streams, pollution of surface waters being used for public water supply, and the actual or potential pollution of shallow fresh ground water made imperative the need for another method of salt-water disposal. In 1936 a group of oil companies developed a method for returning the brine to the deep subsurface, in or below the oil-producing formation. In 1942 a salt-water disposal company was organized to collect, treat, and dispose of the salt water as a service to oil producers, and by 1947 more than 90 percent of the brine produced in the East Texas field was being reinjected (East Texas Salt Water Disposal Co., 1958, p. 17). An inventory by the Texas Railroad Commission showed that 99 percent of the salt water produced in the East Texas field in 1961 was injected underground (Texas Water Commission and Texas Water Pollution Control Board, 1963). However, some unlined earthen surface pits are still in use, and oil wastes along the banks of water courses indicate that spills of brine still occur from these. In addition to deliberate dumpage, brine also reaches streams as a result of leaks in the collection systems, breaks in pipelines, overflow of storage tanks, and other accidents incidental to the handling of large volumes of waste water.

Reports of salinity problems in the reservoir drainage area prompted water-quality surveys of Striker Creek and its tributaries in March and June 1964. Both surveys were made during base-flow conditions, but streamflow rates were much lower in June than in March. Comparison of chemical analyses for Striker Creek Reservoir (site 40, table 3) shows that from October 1962 to March 1964 the dissolved-solids concentration increased from 342 to 525 ppm, and the chloride concentration increased from 171 to 272 ppm. This increase in salinity occurred during a period of low surface runoff, when the saline base flows in streams were seldom diluted by floodflows.

During the water-quality surveys chemical-quality data were collected at 24 sites in the Striker Creek watershed. The data are included in table 3 (sites 17–38, 40, 41), and the pH and chloride and sulfate concentrations are given on the map (pl. 3). These data show that:

1. Bowles Creek and its tributaries are the source of most of the salinity in Striker Creek Reservoir.
2. Many streams carry acid water, with the pH as low as 3.2.
3. Sodium and chloride are the principal dissolved constituents; sulfate concentrations are generally low throughout the watershed.
4. Where acid water occurs outside the oil-field area, sulfate is the principal anion.
5. High-chloride water was not found outside the oil field area.
6. Johnson Creek and its tributaries are relatively unpolluted, and pH's are not less than 6.0.

TABLE 3.—*Chemical analyses of streams and reservoirs in the Neches River basin for locations other than daily stations*

[Station numbers are located on pls. 2, 3. Results in parts per million except as indicated. Asterisks indicate analysis by Texas State Department of Health]

Date of collection	Discharge (cfs)	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 (calculated)		Hardness as $CaCO_3$		Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25° C)	pH
													Parts per million	Tons per acre-foot	Calcium, magnesium	Noncarbonate				
1. Neches River near Chandler																				
Feb. 27, 1952	------	12	------	8.6	4.8	25		22	33	29	------	1.8	[1]130	0.18	41	23	57	1.7	207	6.8
3. Flat Creek at FM Road 607 near Athens																				
Nov. 14, 1961	11.2	23	------	3.5	2.7	16		15	12	20	0.2	0.5	85	0.12	20	8	63	1.6	117	5.8
May 2, 1962	27.6	17	------	6.0	3.1	12		19	12	17	.2	1.2	78	.11	28	12	48	1.0	125	6.5
June 5	8.88	21	------	6.0	2.5	11		19	13	14	.1	1.0	78	.11	25	10	49	1.0	109	6.8
July 11	1.66	21	------	6.0	2.7	12		28	8.0	14	.1	.5	78	.11	26	3	50	1.0	109	6.9
Oct. 24	4.31	24	------	6.2	2.5	13		26	7.8	17	.2	.2	84	.11	26	4	52	1.1	119	5.9
Nov. 28	53.6	20	------	6.2	3.2	19		8	25	26	.2	.2	104	.14	29	22	59	1.5	158	5.4
Mar. 13, 1963	11.9	15	------	9.5	5.2	26		20	27	39	.2	.8	[1]146	.20	45	29	55	1.7	221	6.1
Apr. 18	4.12	21	------	8.5	4.3	21		29	17	30	.2	.2	116	.16	39	15	54	1.5	176	6.0
May 21	2.57	23	------	9.5	4.4	27		36	16	23	.2	.5	112	.15	42	12	47	1.1	168	5.8
July 30	.11	23	------	2.5	.9	7.0	1.7	15	4.0	7.2	.3	.0	54	.07	10	0	56	1.0	63	6.0
Oct. 8	.26	23	------	3.0	1.1	7.4	2.2	17	4.4	8.8	.1	.2	58	.08	12	0	52	.9	70	6.5
4. Saline Creek at County Road 7 miles northwest of Bullard																				
Mar. 25, 1964	[2]4	28	------	34	15	35		17	136	48	0.1	0.0	304	0.41	146	133	34	1.3	479	6.6
June 8	[2].2	26	------	49	13	31		30	154	41	.2	.2	329	.45	176	152	28	1.0	510	6.3

5. Frick Run 7 miles northwest of Bullard																				
Mar. 25, 1964	[2]0.3	------	------	------	------	------		13	------	35	------	------	------	------	59	48	------	------	246	7.3
6. Saline Creek at FM Road 344 near Bullard																				
Mar. 25, 1964	[2]5	------	------	------	------	------		15	------	78	------	------	------	------	146	134	------	------	565	7.5
7. Lake *Palestine* near Frankston																				
Jan. 23, 1962*	------	------	------	9	4	15		12	32	24	0.2	0.4	111	------	40	------	------	------	185	6.2
May 17*	------	------	------	12	5	19		26	23	29	.2	.4	135	------	50	------	------	------	225	6.5
Sept. 8*	------	------	------	13	5	17		54	14	21	.1	.4	124	------	52	------	------	------	193	7.0
Oct. 24	------	10	------	13	4.7	19		53	14	24	.2	.5	111	0.15	52	8	41	1.1	196	6.2
Jan. 8, 1963*	------	------	------	10	4	10		28	24	30	.1	.4	128	------	41	------	------	------	213	6.8
Feb. 7	------	14	------	12	4.7	26		18	32	41	.2	.0	139	.19	49	35	54	1.6	239	5.6
May 15*	------	------	------	9	3	16		21	20	23	.3	.4	94	------	36	------	------	------	171	6.5
May 22	------	4.6	------	9.5	3.5	18		23	21	26	.2	.5	94	.13	38	19	51	1.3	169	5.8
July 2	------	9.4	------	13	4.8	22		48	15	32	.2	.5	121	.16	52	13	48	1.3	232	6.4
Sept. 5	------	14	------	15	5.5	26		68	11	34	.2	.2	139	.19	60	4	48	1.5	246	6.5
Sept. 9*	------	------	------	------	------	24		68	9	34	.3	.4	151	------	59	------	------	------	255	7.2
Jan. 9, 1964*	------	------	------	14	5	31	5	59	17	46	.3	.4	178	------	57	------	------	------	308	7.8
May 13*	------	------	------	14	6	32		29	37	48	.2	.4	166	------	59	------	------	------	316	7.3
10. Lake Jacksonville near Jacksonville																				
Oct. 25, 1962	------	11	------	6.0	2.6	7.3	1.9	34	5.2	7.8	0.1	0.0	59	0.08	26	0	36	0.3	92	6.2
Mar. 26, 1964	------	6.5	------	7.2	2.9	11		44	6.6	7.2	.1	.8	64	.09	30	0	45	.9	112	7.1
12. Neches River near Pollok																				
Dec. 18, 1953	------	20	------	7.7	4.6	23		27	21	31	------	1.0	[1]146	0.20	38	16	57	0.8	184	6.9

See footnotes at end of table.

TABLE 3.—*Chemical analyses of streams and reservoirs in the Neches River basin for locations other than daily stations*—Continued

[Station numbers are located on pls. 2, 3. Results in parts per million except as indicated. Asterisks indicate analysis by Texas State Department of Health]

Date of collection	Discharge (cfs)	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 (calculated)		Hardness as $CaCO_3$		Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25° C)	pH
													Parts per million	Tons per acre-foot	Calcium, magnesium	Noncarbonate				
14. Piney Creek near Groveton																				
Dec. 3, 1962	0.56	4.9	------	5.2	1.6	7.1	3.8	13	16	8.2	0.3	0.2	53	0.07	20	9	39	0.7	90	5.7
Jan. 7, 1963	34.4	5.7	------	4.0	1.8	5.7	3.4	13	10	7.8	.2	.0	45	.06	17	7	36	.6	73	5.6
Feb. 11	.51	15	------	22	7.5	46		23	81	58	.1	.5	[1] 251	.34	86	67	54	2.2	400	6.1
Feb. 20	308	3.5	------	4.0	1.1	3.9	2.9	9	6.0	5.0	.2	.5	31	.04	14	7	32	.5	54	5.4
Mar. 18	2.16	16	------	21	6.9	43		30	68	55	.2	.5	[1] 247	.34	81	56	54	2.1	370	6.1
Mar. 3, 1964	118	4.8	------	4.2	1.1	6.2	3.0	12	7.6	9.1	.3	.5	43	.06	15	5	42	.7	71	6.3
Mar. 9	1.87	6.8	------	7.0	2.1	6.1	3.6	20	9.6	9.1	.3	.0	55	.07	26	10	30	.5	92	6.1
15. Caney Creek at State Highway 94 near Groveton																				
Nov. 21, 1961	[2] 0.1	16	------	68	19	184		40	308	208	0.2	1.2	[1] 856	1.16	248	214	62	5.1	1,350	6.3
17. Bowles Creek at Overton																				
June 9, 1964	[2] 0.001	44	------	130	67	2,180		0	34	3,990	------	------	6,450	8.79	600	600	84	------	11,300	[3] 3.2
18. Right Fork Bowles Creek near Old London																				
June 9, 1964	[2] 0.3	32	------	26	11	278		0	9.6	520	0.3	0.0	878	1.19	110	110	81	12	1,770	[4] 3.5

19. Unnamed tributary to Left Fork Bowles Creek at State Highway 323 near Old London																				
June 9, 1964	[2] 0.05	27	----	21	10	188		0	1.6	362	0.3	0.2	610	0.83	94	94	80	8.4	1,230	[5] 3.7
20. Left Fork Bowles Creek at FM road 838 near Old London																				
Mar 25, 1964	[2] 3	----	0.09	----	----	----		0	----	620	----	----	----	----	126	126	----	----	2,090	[4] 3.6
June 9	[2] .4	31	----	36	13	394		0	13	720	0.3	0.0	1,210	1.65	144	144	83	14	2,420	[4] 3.9
21. Unnamed creek at FM Road 838 at Old London																				
June 9, 1964	[2] 0.01	58	----	3.8	1.6	29		7	15	40	0.2	0.5	151	0.21	16	10	80	3.2	198	5.4
22. Unnamed tributary to Bowles Creek at county road 2 miles Northwest of Turnertown																				
Mar. 25, 1964	[2] 0.1	41	9.9	55	16	483		0	38	940	----	1.5	1,590	2.16	203	203	77	15	3,230	[6] 3.2
June 9	[2] .05	38	----	128	54	2,000		0	33	3,480	----	----	5,730	7.79	542	542	88	37	10,100	[7] 3.6
23. Bowles Creek near Turnertown																				
Sept. 15, 1960*	----	----	----	----	----	----	----	----	215	960	----	----	1,980	----	----	----	----	----	----	5.5
Oct. 18*	----	----	----	----	----	----	----	----	175	3,600	----	----	7,050	----	----	----	----	----	----	5.6
Dec. 6*	----	----	----	----	----	----	----	----	11	150	----	----	330	----	----	----	----	----	----	5.8
Jan. 28, 1961*	----	----	----	----	----	----	----	----	27	620	----	----	1,320	----	----	----	----	----	----	3.9
Apr. 9*	----	----	----	----	----	----	----	----	25	300	----	----	670	----	----	----	----	----	----	4.4
June 18*	----	----	----	----	----	----	----	----	9	730	----	----	1,560	----	----	----	----	----	----	4.0
Aug. 13*	----	----	----	----	----	----	----	----	8	1,060	----	----	2,190	----	----	----	----	----	----	5.7
Oct. 30*	----	----	----	----	----	----	----	----	20	880	----	----	1,830	----	----	----	----	----	----	5.3
Jan. 25, 1962*	----	----	----	----	----	----	----	----	24	490	----	----	990	----	----	----	----	----	----	4.0
Mar. 28*	----	----	----	----	----	----	----	----	23	1,900	----	----	3,900	----	----	----	----	----	----	3.8
June 25*	----	----	----	----	----	----	----	----	19	2,050	----	----	4,380	----	----	----	----	----	----	4.6
Aug. 28*	----	----	----	----	----	----	----	----	14	1,500	----	----	3,450	----	----	----	----	----	----	4.3
Nov. 28*	----	----	----	----	----	----	----	----	15	565	----	----	1,190	----	----	----	----	----	----	4.6
May 30, 1963*	----	----	----	----	----	----	----	----	21	780	----	----	1,820	----	----	----	----	----	----	4.1
Sept. 28*	----	----	----	----	----	----	----	----	21	66	----	----	207	----	----	----	----	----	----	6.7
Mar. 25, 1964	[2] 8	----	0.11	----	----	----	----	0	----	580	----	----	----	----	98	98	----	----	1,990	[8] 3.5

See footnotes at end of table.

TABLE 3.—*Chemical analyses of streams and reservoirs in the Neches River basin for locations other than daily stations*—Continued

[Station numbers are located on pls. 2, 3. Results in parts per million except as indicated. Asterisks indicate analysis by Texas State Department of Health]

Date of collection	Discharge (cfs)	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 (calculated): Parts per million	Dissolved solids (calculated): Tons per acre-foot	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25° C)	pH
24. Wright Branch near Wright City																				
June 9, 1964	[2] 0.2	32	------	20	9.0	252		0	21	465	0.3	0.2	800	1.09	87	87	81	12	1,650	[9] 3.5
25. Henson Creek near Wright City																				
June 9, 1964	[2] 0.1	34	------	12	5.8	78		0	11	157	0.3	0.1	298	0.41	54	54	73	4.6	594	[5] 3.8
26. Denton Creek at FM Road 15 near Wright City																				
June 9, 1964	[2] 0.02	41	------	32	14	173		0	72	332	0.3	0.2	665	0.90	138	138	69	6.4	1,320	[4] 3.5
27. Denton Creek at county road 5 miles south of Wright City																				
Mar. 25, 1964	[2] 0.15	------	0.12	------	------	------	------	0	------	352	------	------	------	------	122	122	------	------	1,360	[8] 3.5
28. Bowles Creek at county road 7 miles south of Wright City																				
Mar. 25, 1964	[2] 12	29	0.09	36	9.2	323		0	42	580	0.3	0.2	1,020	1.39	130	130	81	12	2,040	[4] 3.7

29. Horsepen Branch at FM Road 15 near Troup																			
June 9, 1964	[2] 0.001	21	------	33	17	25	2	168	21	0.3	0.0	286	0.39	152	151	26	0.9	455	5.5
30. McNeil Creek Near Price																			
Mar. 25, 1964	[2] 0.4	------	------	------	------	------	156	------	190	------	------	------	------	93	0	------	------	994	7.2
June 9	[2] .5	28	------	7.2	5.3	144	234	45	79	0.6	0.2	424	0.58	40	0	89	9.9	702	7.1
31. Bowles Creek at F M Road 13 near Price																			
Mar. 25, 1964	[2] 20	------	0.03	------	------	------	0	------	528	------	------	------	------	114	114	------	------	1,810	[10] 4.3
June 9	[2] 1.5	18	------	29	13	294	22	24	512	0.3	0.0	901	1.23	126	108	84	11	1,740	6.4
32. Hampton Creek near Henry Chapel																			
June 9, 1964	[2] 0.01	20	------	16	7.8	35	0	109	32	0.1	0.0	220	0.30	72	72	48	1.8	382	[5] 4.1
33. Bowles Creek at county road 6 miles southeast of Price																			
Mar. 25, 1964	[2] 40	15	0.00	24	8.8	215	1	40	368	0.2	0.5	672	0.91	96	95	83	9.5	1,300	4.8
34. Johnson Creek near Old London																			
June 9, 1964	[2] 0.1	30	------	8.0	3.2	15	20	14	24	0.2	0.0	104	0.14	33	17	49	1.1	169	6.0
35. Johnson Creek near Price																			
Mar. 25, 1964	[2] 6	------	------	------	------	------	8	------	142	------	------	------	------	73	66	------	------	588	6.2
36. Johnson Creek at county road 6 miles south of Price																			
Mar. 24, 1964	[2] 20	19	0.02	14	6.1	97	8	24	169	0.2	0.0	333	0.45	60	54	78	5.4	631	6.4

See footnotes at end of table.

TABLE 3.—*Chemical analyses of streams and reservoirs in the Neches River basin for locations other than daily stations*—Continued

[Station numbers are located on pls. 2, 3. Results in parts per million except as indicated. Asterisks indicate analysis by Texas State Department of Health]

Date of collection	Discharge (cfs)	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 (calculated): Parts per million	Dissolved solids (calculated): Tons per acre-foot	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25° C)	pH
37. Unnamed tributary to Johnson Creek at county road 6 miles south of Price																				
Mar. 25, 1964	[2]0.01	8.2	0.19	891	284	11,800	33	114	153	20,400	------	------	33,600	46.7	3,390	3,300	88	------	46,400	6.7
38. Willis Ditch at county road 6 miles northeast of New Summerfield																				
Mar. 25, 1964	[2]5	--------	------	--------	------	--------	------	11	------	13	------	------	--------	------	22	13	------	------	116	6.4
39. Striker Creek at U.S. Highway 79 near New Summerfield																				
Apr. 13, 1949	390	12	0.5	20	10	170		4	49	315	------	0.2	[1]640	0.87	91	88	74	7.8	1,140	5.6
40. Striker Creek Reservoir																				
Oct. 25, 1962	----------	8.6	------	14	7.1	100		28	15	171	0.3	0.0	342	0.47	64	41	77	5.4	644	6.3
Mar. 25, 1964	----------	12	0.00	22	9.5	158		4	48	272	.2	1.0	525	.71	94	90	79	7.1	1,010	6.3
41. Buford Branch near New Salem																				
Mar. 25, 1964	[2]0.8	--------	------	--------	------	--------	------	23	------	7.4	------	------	--------	------	20	1	------	------	71	7.0

42. Angelina River near Sacul																				
Mar. 25, 1964	[2] 200	13	------	10	6.8	20		17	43	26	0.0	0.2	127	0.17	53	39	45	1.2	224	6.3
43. Lake Tyler near Whitehouse																				
Oct. 25, 1962	----------	9.9	------	6.2	3.9	6.9	2.6	28	8.2	12	0.3	0.2	64	0.09	32	9	30	0.5	102	6.1
Sept. 5, 1963	----------	.3	------	7.0	3.1	7.4	2.7	28	10	11	.2	.2	56	.08	30	7	32	.6	110	6.4
44. Kickapoo Creek near Arp																				
June 9, 1964	[2] 0.05	28	------	2.0	0.2	4.2	1.2	9	2.4	4.3	0.1	0.2	47	0.06	6	0	55	0.7	41	5.7
45. Mud Creek near Jacksonville																				
Nov. 14, 1961	64.8	21	------	4.5	3.9	24		22	14	32	0.2	0.2	111	0.15	27	9	65	2.0	172	6.0
Dec. 14	638	15	------	7.2	4.0	15		9	30	20	.2	.0	95	.13	34	27	49	1.1	155	6.3
Aprl 3, 1962	182	19	------	11	6.9	19		17	45	25	.2	.8	[1] 144	.20	56	42	43	1.1	218	6.1
May 3	1,660	9.3	------	6.5	3.3	7.9	2.6	16	18	12	.2	.5	68	.09	30	17	34	.6	110	6.3
July 11	31.8	26	------	12	6.6	23		26	49	25	.2	.0	[1] 165	.22	57	36	47	1.3	232	6.7
Sept. 18	27.3	23	------	14	4.3	19		38	23	27	.1	.8	130	.18	53	22	44	1.1	201	6.6
Oct. 25	36.2	24	------	8.5	4.1	34		26	22	47	.2	.0	[1] 156	.21	38	17	66	2.4	243	6.1
Nov. 29	215	22	------	9.5	5.3	25		11	43	33	.2	.0	143	.19	46	36	55	1.6	226	5.5
Jan. 4, 1963	128	25	------	12	7.0	28		13	53	38	.1	.2	169	.23	59	48	51	1.6	266	5.7
Feb. 7	108	19	------	13	6.8	30		14	52	42	.2	.0	[1] 180	.24	60	49	52	1.7	282	5.7
Mar. 14	207	18	------	12	6.7	24		14	48	34	.2	.0	[1] 155	.21	58	46	48	1.4	244	5.5
Apr. 19	49.8	21	------	12	6.9	35		24	44	49	.2	.5	[1] 184	.25	58	39	57	2.0	285	5.9
May 22	33.9	21	------	10	4.9	34		18	33	49	.2	.8	162	.22	45	30	62	2.2	264	5.7
July 30	25.2	16	------	7.0	2.8	21		14	28	23	.2	.0	105	.14	29	18	61	1.7	176	5.8

See footnotes at end of table.

TABLE 3.—*Chemical analyses of streams and reservoirs in the Neches River basin for locations other than daily stations*—Continued

[Station numbers are located on pls. 2, 3. Results in parts per million except as indicated. Asterisks indicate analysis by Texas State Department of Health]

Date of collection	Discharge (cfs)	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 (calculated)		Hardness as $CaCO_3$		Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25° C)	pH
													Parts per million	Tons per acre-foot	Calcium, magnesium	Noncarbonate				
47. Angelina River near Alto																				
Nov. 15, 1961	519	12	------	4.5	3.6	19		14	20	24	0.2	0.2	90	0.12	26	15	61	1.6	149	5.7
Jan. 25, 1962	1,640	11	------	10	5.5	30		10	41	44	.2	.0	147	.20	48	39	58	1.9	264	6.0
Feb. 16	895	11	------	8.2	5.1	23		17	31	31	.2	.2	[1] 120	.16	41	28	54	1.6	203	6.1
Apr. 5	745	11	------	10	6.3	32		20	34	48	.2	.2	[1] 162	.22	51	34	58	1.9	276	6.2
May 10	2,280	12	------	8.5	4.6	19		24	20	29	.2	.0	105	.14	40	20	51	1.3	190	5.9
June 12	487	16	------	8.8	4.5	37		26	21	55	.1	.0	[1] 166	.23	40	19	67	2.5	268	6.6
July 17	106	16	------	9.2	5.2	32		34	20	46	.2	.5	146	.20	44	16	61	2.1	255	6.5
Aug. 21	92.3	14	------	11	5.5	55		33	16	89	.2	.0	207	.28	50	23	71	3.4	391	6.4
Sept. 25	79.6	18	------	8.2	4.4	33		28	17	49	.2	.5	144	.20	39	16	65	2.3	251	6.4
Oct. 30	136	16	------	8.5	5.1	46		26	18	72	.2	.2	179	.25	42	21	70	3.1	325	6.2
Dec. 4	585	16	------	9.5	5.2	50		14	30	79	.2	.0	[1] 211	.29	45	34	71	3.2	351	5.7
Jan. 8, 1963	714	14	------	9.5	6.0	41		13	36	63	.1	.0	[1] 186	.25	48	38	65	2.6	311	5.9
Feb. 12	331	7.3	------	9.0	5.5	27		18	36	36	.1	.0	130	.18	45	30	56	1.7	231	6.2
Mar. 19	580	10	------	10	5.9	34		22	36	48	.2	.2	[1] 160	.22	49	31	60	2.1	266	7.6
Apr. 22	183	18	------	9.5	5.7	26		34	25	35	.3	.5	[1] 146	.20	47	19	55	1.6	216	6.1
May 27	194	13	------	20	4.2	70		30	31	114	.2	.2	268	.36	67	43	69	3.7	504	7.2
July 2	61.2	16	------	6.0	2.7	19		26	18	19	.2	.0	94	.13	26	5	61	1.6	155	7.6
Sept. 16	23.4	12	------	16	7.8	103		28	24	175	.2	.2	352	.48	72	49	76	5.3	692	6.1
Mar. 10, 1964	448	16	------	10	4.9	28		11	48	32	.2	.8	145	.20	45	36	57	1.8	245	6.0
49. Paper Mill Creek near Herty																				
July 28, 1964	[2] 20	13	0.58	44	4.9	241	4.8	204	89	272	1.4	0.5	772	1.05	130	0	79	9.2	1,340	6.7

50. Angelina River near Etoile

June 9, 1964	------	------	------	------	------	------	------	25	------	34	------	------	------	------	33	12	------	------	242	6.3
July 28	------	16	1.2	30	5.1	213	4.4	205	75	216	1.2	4.8	669	0.91	96	0	82	9.5	1,170	6.9

52. Attoyac Bayou near Chireno

Oct. 15, 1962	45.5	17	------	4.0	2.4	7.4	1.7	24	6.0	7.5	0.2	0.0	57	0.08	20	2	42	0.6	75	5.9
Nov. 19	80.0	16	------	3.5	2.4	6.0	1.9	19	7.6	7.0	.1	.0	54	.07	19	3	38	.6	72	6.3
Dec. 17	77.4	16	------	4.0	2.8	6.6	1.2	18	9.0	9.0	.1	.0	58	.08	22	7	38	.6	79	5.8
Jan. 28, 1963	13.4	14	------	6.0	4.3	10		20	21	12	.1	.0	77	.10	33	16	41	.8	121	6.3
Mar. 4	369	14	------	9.0	6.1	14		18	38	16	.1	.2	106	.14	48	33	38	.9	176	5.6
Apr. 9	1,070	7.7	------	5.0	3.5	7.7	3.1	10	22	10	.2	2.2	66	.09	27	19	35	.6	101	5.6
Mar. 4, 1964	850	10	------	6.0	3.2	8.2	2.8	12	26	8.3	.2	.0	71	.10	28	18	36	.7	116	6.2

53. Angelina River near Zavalla

June 9, 1964	------	16	------	9.0	3.8	35		31	29	41	0.3	0.2	149	0.20	38	13	67	2.5	267	6.5
July 28	------	15	0.98	20	5.8	157	3.8	161	70	145	.7	1.5	500	.68	74	0	81	7.9	857	7.0

56. Angelina River below Sam Rayburn Dam

Oct. 1, 1963	[11] 80	12	0.24	11	3.5	67	3.5	52	24	87	0.2	1.2	236	0.32	42	0	76	4.5	433	6.4
Apr. 21, 1964	2,620	13	.42	9.2	3.9	19	2.7	28	25	24	.2	1.5	113	.15	39	16	49	1.3	181	6.9
June 9	[11] 830	14	------	8.5	3.6	23	2.8	29	27	25	.2	.5	119	.16	36	12	56	1.7	204	6.5
July 28	[11] 78	16	.29	12	4.6	58	3.3	72	25	64	.2	.8	220	.30	49	0	70	3.6	393	6.8

57. Angelina River near Horger

Aug. 24, 1945	------	------	------	10	4.1	48		51	30	52	------	0.2	[1] 194	0.26	42	0	71	3.2	263	------
Dec. 6, 1962	562	15	------	7.0	3.6	34		19	26	45	0.3	.0	140	.19	32	17	70	2.6	234	5.9
Jan. 10, 1963	2,110	15	------	8.0	4.5	28		13	35	36	.1	.2	133	.18	38	28	61	2.0	215	5.8
Feb. 14	1,150	11	------	9.0	4.2	26		24	34	29	.2	.8	126	.17	40	20	59	1.8	209	6.2
Mar. 20	1,320	11	------	12	6.3	39		31	40	52	.2	.2	176	.24	56	30	60	2.3	305	6.5
Apr. 24	634	14	------	12	6.4	39		35	33	54	.3	.5	[1] 184	.25	56	28	60	2.3	297	6.1

See footnotes at end of table.

TABLE 3.—*Chemical analyses of streams and reservoirs in the Neches River basin for locations other than daily stations*—Continued

[Station numbers are located on pls. 2, 3. Results in parts per million except as indicated. Asterisks indicate analysis by Texas State Department of Health]

Date of collection	Discharge (cfs)	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 (calculated): Parts per million	Dissolved solids (calculated): Tons per acre-foot	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25° C)	pH
58. Wolf Creek near Town Bluff																				
Sept. 13, 1954	19.7	19	------	4.1	0.9	5.9		20	1.2	6.2	------	0.5	[1] 53	0.07	14	0	48	0.7	56	6.7
59. Rush Creek near Town Bluff																				
Sept. 3, 1954	1.24	32	------	--------	------	95		225	2.9	103	------	0.8	[1] 397	0.54	126	0	62	3.7	675	7.7
60. Sandy Creek near Jasper																				
Sept. 13, 1954	20.4	20	------	2.2	0.6	5.0		10	2.0	5.0	------	1.8	[1] 46	0.06	8	0	57	0.8	67	6.4
64. Village Creek at U.S. Highway 69 near Kountze																				
Oct. 15, 1953	18.8	--------	------	--------	------	--------	------	19	------	8.0	------	------	--------	------	7	0	------	------	58	6.9
Sept. 2, 1954	15.1	11	------	--------	------	--------	------	18	------	7.5	------	0.2	--------	------	15	3	------	------	64	6.6
Oct. 17, 1962	48.4	9.6	------	3.5	0.6	5.3	1.6	12	1.8	8.5	0.2	.2	37	0.05	11	1	47	0.7	48	5.9
Dec. 20	50.2	15	------	4.0	1.4	5.0	.8	12	2.8	10	.1	.2	45	.06	16	6	39	.5	60	5.7
Mar. 7, 1963	165	12	------	5.5	1.4	6.3	.7	14	4.4	12	.1	.8	50	.07	19	8	40	.6	74	5.9
June 19	13.9	12	------	8.0	.7	5.4	1.2	26	.2	10	.1	.2	51	.07	23	2	33	.5	75	6.4
Sept. 20	300	9.5	------	3.2	1.0	4.5	1.2	5	1.0	8.0	.2	.2	31	.04	12	8	42	.6	54	5.1
Mar. 3, 1964	997	5.4	------	2.8	.7	3.6	.8	6	.4	5.5	.1	.0	22	.03	10	5	42	.5	41	6.1

65. Hickory Creek 3.5 miles west of Warren																				
Sept. 1, 1954	5.71	11	------	--------	------	4.8		16	1.2	7.0	------	0.2	49	0.07	14	1	43	0.6	53	6.6
66. Hickory Creek at U.S. Highway 69 near Warren																				
Sept. 2, 1954	12.7	12	------	--------	------	5.0		14	1.3	6.8	------	0.5	47	0.06	12	1	47	0.6	50	6.6
Oct. 17, 1962	46.6	11	------	2.5	1.1	4.1	1.0	10	.4	8.2	0.1	.2	34	.05	11	3	42	.5	45	5.7
Dec. 19	30.1	14	------	2.5	1.3	4.3	.7	9	1.6	9.0	.1	.0	38	.05	12	4	43	.5	50	5.9
Mar. 7, 1963	81.6	12	------	--------	------	5.3	.8	12	3.2	10	.1	.5	--------	------	15	5	42	.6	62	6.0
June 19	13.6	12	------	4.5	.4	4.0	1.1	14	.0	8.0	.1	.2	37	.05	13	1	38	.5	52	5.9
Sept. 19	329	8.1	------	2.8	.2	2.8	.3	4	.4	5.5	.1	.2	22	.03	8	4	43	.4	39	5.4
Mar. 2, 1964	304	8.0	------	3.0	.9	4.4	1.1	7	.8	7.1	.1	.0	28	.04	11	5	43	.6	51	5.7
67. Big Turkey Creek at Woodville																				
Sept. 15, 1961	----------	13	------	5.2	1.0	5.2	1.8	15	5.4	9.0	0.1	0.0	48	0.07	17	5	37	0.5	66	5.9
68. Big Cypress Creek at U.S. Highway 190 near Woodville																				
Mar. 19, 1959	[2] 15	13	------	9.2	1.5	5.3	0.6	29	3.0	9.5	0.0	0.0	56	0.08	29	5	28	0.4	88	6.8
69. Horsepen Creek 9.5 miles west of Woodville																				
Oct. 15, 1953	1.64	--------	------	--------	------	--------	------	18	------	8.5	------	------	--------	------	9	0	------	------	56	7.4
Sept. 1, 1954	1.27	14	------	--------	------	--------	------	15	------	8.2	------	0.2	--------	------	13	1	------	------	54	6.5
70. Horsepen Creek 9 miles suothwest of Woodville																				
Oct. 15, 1953	7.57	--------	------	--------	------	--------	------	12	------	7.5	------	------	--------	------	5	0	------	------	45	7.3
Sept. 1, 1954	6.30	12	------	--------	------	--------	------	12	------	7.0	------	0.2	--------	------	10	0	------	------	45	6.6

See footnotes at end of table.

TABLE 3.—*Chemical analyses of streams and reservoirs in the Neches River basin for locations other than daily stations*—Continued

[Station numbers are located on pls. 2, 3. Results in parts per million except as indicated. Asterisks indicate analysis by Texas State Department of Health]

Date of collection	Discharge (cfs)	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 (calculated): Parts per million	Dissolved solids (calculated): Tons per acre-foot	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25° C)	pH
71. Little Cypress Creek near Woodville																				
Sept. 15, 1961	----------	11	------	5.1	1.3	4.5	1.7	16	4.4	8.2	0.1	0.0	44	0.06	18	5	33	0.5	65	5.9
72. Big Cypress Creek near Hillister																				
Oct. 17, 1962	67.5	8.7	------	5.8	1.4	4.0	1.2	15	4.4	8.8	0.2	0.5	42	0.06	20	8	29	0.4	61	6.2
Dec. 20	28.0	14	------	2.5	1.3	4.3	1.0	10	1.2	9.0	.1	.2	39	.05	12	3	42	.5	52	5.6
Mar. 7, 1963	60.1	13	------	5.0	1.7	5.4	1.1	16	3.2	11	.1	.5	49	.07	20	6	36	.5	68	6.0
June 19	14.1	13	------	4.2	.6	3.9	1.2	14	.2	7.5	.4	.2	38	.05	13	2	37	.5	49	6.0
Sept. 20	73.0	10	------	3.8	.6	3.8	1.5	8	4.0	7.2	.1	.2	35	.05	12	5	37	.5	53	5.3
Mar. 2, 1964	270	7.5	------	3.5	.5	3.7	1.2	9	3.6	5.6	.1	.0	30	.04	11	3	39	.5	46	5.8
73. Big Turkey Creek 6 miles southeast of Warren																				
Oct. 14, 1953	25.7	--------	------	--------	------	--------	------	16	------	7.5	------	------	--------	------	8	0	------	------	55	7.4
Sept. 2, 1954	17.9	14	------	--------	------	--------	------	18	------	7.8	------	0.2	--------	------	14	0	------	------	58	6.7
74. Beech Creek at FM Road 1013 near Spurger																				
Oct. 14, 1953	0.89	--------	------	--------	------	--------	------	11	------	6.2	------	------	--------	------	4	0	------	------	43	7.2
Sept. 3, 1954	.06	9.6	------	--------	------	--------	------	11	------	6.0	------	0.5	--------	------	10	1	------	------	41	6.3

75. Beech Creek 2.5 miles northwest of Fred																				
Oct. 14, 1953	0.37	--	--	--	--	--	--	9	--	7.2	--	--	--	--	2	.0	--	--	40	7.0
Sept. 3, 1954	.23	9.8	--	--	--	--	--	8	--	7.5	--	0.5	--	--	7	0	--	--	38	6.7
76. Theuvenins Creek 7 miles southeast of Warren																				
Oct. 14, 1953	5.94	19	--	16	6.1	313		9	1.2	522	--	1.5	[1] 939	1.28	65	58	91	17	1,700	6.6
Sept. 3, 1954	1.41	13	--	--	--	55		8	1.6	100	--	.5	[1] 204	.25	29	22	81	4.5	353	6.4
77. Beech Creek near Village Mills																				
Oct. 17, 1962	10.1	14	--	6.5	2.4	84		5	2.8	142	0.2	0.2	[1] 278	0.38	26	22	87	7.2	496	5.4
Dec. 19	25.2	17	--	6.2	3.4	73		1	3.0	130	.1	.0	[1] 253	.34	29	29	84	5.9	437	5.1
Mar. 7, 1963	97.0	12	--	5.0	2.6	43		4	3.4	78	.1	.8	147	.20	23	20	80	3.9	275	5.4
June 19	1.93	11	--	9.0	3.5	81		7	.0	147	.1	.2	255	.35	37	31	83	5.8	497	6.1
Sept. 20	574	5.5	--	4.2	1.6	20		0	1.0	42	.2	.2	75	.10	17	17	72	2.1	171	4.3
Mar. 3, 1964	1,170	4.4	--	2.5	.7	11	0.9	2	.4	20	.1	.0	41	.06	9	8	70	1.6	89	5.0
Mar. 24	[2] 175	11	--	3.2	1.9	24		4	.2	45	.1	.8	88	.12	16	12	77	2.6	177	5.4
78. Village Creek near Kountze																				
Mar. 19, 1959	277	15	--	6.2	2.1	31		14	2.8	54	0.1	0.0	118	0.16	24	13	73	2.7	214	6.5
Apr. 17	1,890	9.0	--	3.2	1.7	8.7	1.2	10	3.6	16	.1	.5	49	.07	15	7	53	1.0	83	5.9
Sept. 14, 1961	2,920	6.2	--	2.8	1.0	9.4	1.0	3	2.8	19	.1	.0	43	.06	11	9	62	1.2	81	5.2
Oct. 17, 1962	75.8	13	--	4.5	1.4	20		14	2.4	32	.2	.2	81	.11	17	6	72	2.1	127	5.7
Nov. 19	91.0	13	--	4.0	1.6	17		10	.4	31	.1	.0	72	.10	17	8	68	1.8	127	5.8
Dec. 20	160	15	--	4.5	1.9	19		11	2.6	34	.1	.0	82	.11	19	10	68	1.9	136	5.7
Jan. 29, 1963	387	15	--	5.0	1.7	19		8	5.0	34	.1	.2	84	.11	20	13	68	1.8	148	5.7
Mar. 7	585	12	--	6.0	2.1	22		7	4.0	43	.1	.5	93	.13	24	18	67	2.0	168	5.4
June 17	52.8	12	--	5.5	1.3	10		18	.6	18	.1	.2	57	.08	19	4	54	1.0	99	6.0
Sept. 18	3,960	1.5	--	2.0	.2	4.8	.9	4	2.0	8.0	.1	.2	22	.03	6	2	60	.9	44	5.5
Mar. 3, 1964	3,460	1.0	--	1.5	.3	6.2	.9	2	.0	10	.1	.0	21	.03	5	3	69	1.2	51	5.4

See footnotes at end of table.

TABLE 3.—*Chemical analyses of streams and reservoirs in the Neches River basin for locations other than daily stations*—Continued

[Station numbers are located on pls. 2, 3. Results in parts per million except as indicated. Asterisks indicate analysis by Texas State Department of Health]

Date of collection	Discharge (cfs)	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 (calculated): Parts per million	Dissolved solids (calculated): Tons per acre-foot	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25° C)	pH
79. Cypress Creek near Kountze																				
Sept. 2, 1954	0.2	1.9				65		82	3.2	62		0.5	[1] 203	0.28	18	0	89	6.6	339	7.1
Mar. 18, 1959		7.8		16	4.4	106		14	.0	196	0.2	1.0	338	.46	58	46	80	6.1	680	6.2
80. Jackson Creek 2.5 miles northwest of Sour Lake																				
Apr. 22, 1964	[2] 0.5	1.6		16	2.9	38		94	0.4	39	0.3	0.8	145	0.20	52	0	61	2.3	297	6.7
81. Jackson Creek at State Highway 105 near Sour Lake																				
Mar. 23, 1964	[2] 50	4.5		8.5	2.1	10		38	0.0	14	0.2	1.0	59	0.08	30	0	43	0.8	117	6.6
Apr. 22	[2] .5	1.2				38		85	.4	59	.3	.8			73	3	53	1.9	353	6.7
82. Ditch below State Highway 105, 0.5 mile west of Sour Lake																				
Apr. 22, 1964	[2] 0.3	23		1,700	413	22,100		248	188	38,000			62,500	88.7	5,940	5,740	89		75,600	6.7
83. Lake, 1 mile southwest of Sour Lake																				
Apr. 22, 1964		3.0		600	154	9,290		116	87	15,700			25,900	35.8	2,130	2,040	90		37,100	6.3

84. Pine Island Bayou at State Highway 326 near Sour Lake

Mar. 24, 1964	------	4.2	------	10	2.7	39		27	0.6	68	0.3	1.2	139	0.19	36	14	70	2.8	290	6.5
Apr. 22	------	2.0	------	21	4.3	44		52	5.6	82	.2	.5	186	.25	70	28	58	2.3	380	6.4

85. Pine Island Bayou at State Highway 105 near Sour Lake

Mar. 23, 1964	[2] 500	3.9	------	9.2	1.7	28		23	0.6	49	0.2	1.5	105	0.14	30	11	67	2.2	223	7.0
Apr. 22	[2] 200	7.8	------	16	2.9	37		38	14	61	.2	1.0	159	.22	52	21	61	2.2	298	6.3

86. Little Pine Island Bayou at State Highway 326 near Sour Lake

Mar. 23, 1964	[2] 50	3.7	------	5.2	1.5	17		18	0.2	28	0.2	1.2	66	0.09	19	4	66	1.7	137	6.1
Apr. 22	[2] 5	9.5	------	12	3.4	60		20	.4	111	.2	1.5	208	.28	44	28	75	3.9	426	6.0

87. Little Pine Island Bayou 1.5 miles from mouth

Feb. 24, 1964	------	6.8	0.16	17	3.3	96	1.3	27	5.6	165	0.5	1.5	310	0.42	56	34	78	5.6	602	6.8

88. Pine Island Bayou at Voth

Feb. 20, 1964	------	6.0	------	15	3.1	64	2.5	32	5.6	114	0.3	0.0	227	0.31	50	24	72	3.9	445	6.9
Mar. 3	------	2.9	------	7.5	1.8	53	1.7	10	.2	97	.1	.2	169	.23	26	18	80	4.5	360	5.9
Mar. 24	------	3.7	------	7.2	1.5	21		22	.4	35	.3	1.5	82	.11	24	6	65	1.9	166	6.3

[1] Residue at 180° C.
[2] Field estimate.
[3] Contains 6.5 ppm total acidity as H^{+1}.
[4] Contains 0.6 ppm total acidity as H^{+1}.
[5] Contains 0.2 ppm total acidity as H^{+1}.
[6] Contains 2.3 ppm total acidity as H^{+1}.
[7] Contains 1.3 ppm total acidity as H^{+1}.
[8] Contains 0.7 ppm total acidity as H^{+1}.
[9] Contains 0.9 ppm total acidity as H^{+1}.
[10] Contains 0.3 ppm total acidity as H^{+1}.
[11] Estimated records at Angelina River near Zavalla and Ayish Bayou near San Augustine.

The absence of significant pollution in Johnson Creek is explained by the history of the occurrence and disposal of salt water. Wells on the extreme western side of the East Texas field were the first to produce salt water, and the area affected gradually increased toward the east. In 1958, wells in only the western two-thirds of the field in the Striker Creek watershed were producing water with the oil (East Texas Salt Water Disposal Co., 1958, p. 5). Thus, salt water has been produced in only a small part of the Johnson Creek drainage area, and production began after reinjection of the water was the established procedure. The pollution of the watershed by surface disposal of brine has therefore not been extensive.

A check of other sources of chemical-quality data showed that the Texas State Department of Health had investigated the Striker Creek area in August 1960, following a fish kill in Bowles Creek. Investigators found that a discharge of acid iron-bearing wastes had apparently been responsible for the fish kill and decided that this waste material probably reached the stream as a result of well-acidizing operations at the head of Bowles Creek (N. E. Davis, oral commun., 1964). They also found acid water, with a pH as low as 4.0, in a number of small streams in the upper part of the Bowles Creek drainage area.

As a result of the fish-kill incident, the Texas State Department of Health began periodic sampling of Bowles Creek at State Highway 64 near Turnertown (site 23, pl. 3) and of Striker Creek at U.S. Highway 79 (site 39, actually in the headwaters of Striker Creek Reservoir). Typical analyses for Bowles Creek, included in table 3, show that the pH usually has been less than 5.0 and frequently has been less than 4.0, while the chlorides and dissolved-solids concentrations indicate that almost continuous pollution exists.

The 1964 analyses by the Geological Survey showed that the occurrence of acid water in streams of the Bowles Creek drainage area was much more widespread than the earlier investigation by the Texas State Department of Health had indicated and that further study was warranted. Because oil-field brines in the East Texas field are not acid (pl. 1, and Plummer, 1945, p. 10–12), other factors are required to explain the acidity of the streams.

Acid ground water generally associated with lignitic and iron-bearing formations, is known to occur in wide areas of east Texas (Broom and others, 1965). Dillard (1963) reports analyses for several wells outside the oil-field area in Smith County which yield acid water from the Queen City and Sparta Sands. Sulfate is the principal anion in this acid ground water, whereas in the Bowles Creek area sulfate concentrations are low in both the oil-field brine and the stream waters, with the exception of two tributaries, outside the oil-field area (sites

29 and 32), where acid water was found to contain more sulfate than chloride. Thus, the acid water in streams of the oil-field area of Bowles Creek is different in chemical type from any other east Texas acid water known to be of natural occurrence.

The authors received the suggestion (John D. Hem, oral commun., 1964) that the source of the acidity might by hydrogen ions absorbed on clay minerals in the soils or subsurface formations and transferred to the oil-field brine by base exchange. Clay minerals are characterized by their property of absorbing cations which may then be exchanged for other cations in aqueous solutions coming into contact with the clay material. Hydrogen ions are commonly adsorbed by clay minerals near the land surface in humid regions and can be displaced from the clay when the clay is wetted by a solution containing a preponderance of sodium ions. As a consequence, neutral salt solutions are made acidic by contact with certain soils (Kelley, 1948, p. 9). Thus, the oil-field brine, if passed through clays on which hydrogen ions were adsorbed, could become acid as the result of acquiring hydrogen ions in place of some of the sodium ions.

To test the application of the base-exchange theory to conditions in the Bowles Creek area, samples of clay for leaching tests were collected at the three sites shown as A, B, and C on plate 3. The sample from site A is sandy clay, samples from B and C are silty clay, and all are from the central part of the Claiborne Group of Eocene age. A quantity of untreated oil-field brine was obtained from the brine-collection system of the East Texas Salt Water Disposal Co. at its Shaw-Moyar injection well near Overton. The clay samples were broken into granular particles, and 800-gram portions were poured loosely into columns 3 inches in diameter. Brine was then passed through the clays and 250-milliliter samples of the effluent were obtained. Similar clay samples were also leached with distilled water. Results of analysis of the raw brine and of the brine and distilled water effluents are given in table 4.

TABLE 4.—*Results of leaching tests of clays collected in the Striker Creek watershed*

[Analyses in parts per million except as indicated]

Constituent or property	Untreated brine	Effluent from leaching clays, with brine, from site—			Effluent from leaching clays, with distilled water, from site—		
		A	B	C	A	B	C
Sodium (Na)	21,700	17,900	17,600	26,700	13	200	8,010
Potassium (K)	85	92	119	62	2.7	19	19
Bicarbonate (HCO_3)	421	0	0	0	6	8	4
Carbonate (CO_3)	0	0	0	0	0	0	0
Sulfate (SO_4)	246	124	191	1,590	.4	18	1,740
Chloride (Cl)	37,800	33,800	36,900	48,200	32	1,160	13,600
Hardness as $CaCO_3$	4,180	7,520	13,000	8,700	20	1,120	3,150
Specific conductance (micromhos at 25°C)	77,300	68,800	73,100	91,300	126	3,590	34,700
pH	7.0	3.2	4.3	4.0	6.6	5.6	4.9

Acid solutions were obtained from all three clay samples when they were leached with the brine; but when the samples were leached with distilled water, the effluents were much less acid. Data from the leaching of the sample from site A provide a plausible explanation for the occurrence of the acid water in Bowles Creek. The analyses show that in passing through the clay the brine became acidic (picked up hydrogen ions); decreased in sodium, sulfate, and chloride concentration; and increased in hardness. The acid effluent from the sample of site A, when diluted to varying degrees, will yield solutions very similar in composition to the acid surface waters of the Bowles Creek watershed. In the field, such dilutions would occur naturally as the brine became mixed with uncontaminated ground water derived from percipitation.

The reasons for the results obtained by the leaching of clay samples from sites B and C are not entirely clear. Clay from site C contained large quantities of soluble material, as shown by the results of leaching with distilled water and brine; and both liquids dissolved considerable sodium, sulfate, and chloride, and increased in hardness. The sulfate content, much greater than in the oil-field brine, suggests that at least part of the soluble material was derived from a different source, perhaps having been present when the clays were originally laid down. Clay from site C was almost impermeable; and by the time the 250-ml samples had been collected, the columns of clay were so thoroughly sealed that no additional liquid could be passed through. The impermeability of clay from site C suggests that soluble salts, whether or not derived from oil-field brines, could be leached out only with great difficulty and that this clay layer may have little effect on the quality of water in the streams. The clay sample from site B was more permeable than the sample from C and contained much less of the soluble material. From both clays, however, sufficient hydrogen ions were displaced by the brine to yield an acid effluent.

Other locations have been found in Texas where oil-field brines apparently have become acid while passing through the subsurface. Burnitt (1962, p. 11), in his report of an investigation of ground-water pollution in the Henderson oil field (about 10 miles east of the Bowles Creek area), gives analyses of three high-chloride stream samples having pH's less than 4.0. Near Quitman, in Wood County, Hughes and Leifeste, (1965, p. 33) found an acid stream in which oil-field pollution appeared to be the source of the high chloride content. The acidity in these streams is also probably due to base exchange between clay minerals and the oil-field brine.

The scope of this investigation did not permit additional research into the occurrence and cause of acid saline waters; but the results obtained emphasize the need for research of considerable magnitude, having as its purpose the study of the geochemistry of oil-field brines. In the East Texas oil-field area such research should include the determination of base-exchange capacity of the various clays, the study of shallow ground water, an inventory of past and present brine production and disposal, and detailed mapping of the geology of the study area.

The presence of oil-field brine pollution in the Bowles Creek drainage area several years after the elimination of most of the original sources points up one of the great hazards of improper disposal of oil-field brine. Brine that is added to the ground may not affect the quality of the water in wells or streams for many years, but once water quality is degraded the damage cannot be immediately corrected by stopping pollution at its source. Ground water moves so slowly that purification by leaching and dilution requires more time than did the original pollution. Residual salt left in the soils and ground water of the Bowles Creek area by earlier brine-disposal practices probably is the principal source of pollution in surface streams at present, and will cause poor water quality for many years to come.

PINE ISLAND BAYOU AND THE HARDIN COUNTY OIL FIELDS

Disposal of brine produced with oil in the Sour Lake, Saratoga, and Batson oil fields in Hardin County (fig. 3) periodically affects the quality of water in Pine Island Bayou, a major tributary entering the Neches River a few miles north of Beaumont.

Large volumes of water are pumped from Pine Island Bayou by the Lower Neches Valley Authority at its Voth pumping plant (fig. 5; and site 88, pl. 2) and distributed by canal to irrigators, industrial users, and municipalities in the Beaumont-Port Arthur area. During periods of low flow in Pine Island Bayou, water from the Neches River flows upstream in Pine Island Bayou to the pumping plant and constitutes a large part of the water being pumped.

Most of the salt water produced with oil in the Sour Lake, Saratoga, and Batson fields eventually reaches the surface streams. Although one or two producers in the Sour Lake field reinject the brine underground, others store the brine temporarily in unlined pits and release it to the surface streams during flood-runoff periods. During periods following rains, Pine Island Bayou at the pumping plant frequently contains chloride in concentrations higher than desirable for some industrial uses (Lower Neches Valley Authority, oral commun., 1964).

Analyses for nine locations are given in table 3 for the Pine Island Bayou drainage area (sites 80–88). Although these analyses indicate a maximum of 114 ppm chloride in Pine Island Bayou at the Voth pumping plant, records of the Lower Neches Valley Authority (written commun., 1963) show that much higher concentrations occasionally occur. Table 3 gives analyses of oil-field brine (site 82) and water from a brine-storage lake (site 83). The March 23, 1964, analysis for Jackson Creek (site 81) indicates that natural runoff in the area is very low in all dissolved constituents.

In a report on ground water in Hardin County, Baker (1964, p. 78) discusses the disposal of oil-field brines as a possible source of pollution of ground water. Although present damage to ground-water supplies appears to be minor, Baker stresses the long-term effects of such pollution.

RELATION OF QUALITY OF WATER TO USE

Quality-of-water studies usually are concerned with determining the suitability of water—judged by the chemical, physical, and sanitary characteristics—for its proposed use. In the Neches River basin, surface water is used primarily for municipal and industrial supplies and for irrigation. This report considers only the chemical character of the water and its relations to the principal uses.

Most mineral matter dissolved in water is in the form of ions. An ion is an atom or group of atoms having an electrical charge. The principal cations (positive charge) found in natural waters are calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), and iron (Fe). The principal anions (negative charge) are carbonate (CO_3), bicarbonate (HCO_3), sulfate (SO_4), chloride (Cl), fluoride (F), and nitrate (NO_3). Other constituents and properties are often determined to aid in the definition of the chemical and physical quality of water. Table 5 lists the constituents and properties commonly determined by the U.S. Geological Survey, and includes a résumé of their sources and significance.

Surface water of the Neches River basin is generally of excellent chemical quality. With a minimum of treatment, it is suitable for domestic, industrial, and irrigation use.

DOMESTIC PURPOSES

The safe limits for the mineral constituents found in water are usually based on the U.S. Public Health Service drinking-water standards. These standards were established first in 1914 to control the quality of water used for drinking and culinary purposes on interstate carriers. These standards have been revised several times, the latest revision having been in 1962 (U.S. Public Health Service, 1962), and adopted by the American Water Works Association as minimum standards for all public water supplies.

TABLE 5.—*Source and significance of dissolved mineral constituents and properties of water*

Constituent or property	Source or cause	Significance
Silica (SiO_2)	Dissolved from practically all rocks and soils, commonly less than 30 ppm. High concentrations, as much as 100 ppm, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment. More than 1 or 2 ppm of iron in surface waters generally indicates acid wastes from mine drainage or other sources.	On exposure to air, iron in ground water oxidizes to reddish-brown precipitate. More than about 0.3 ppm stain laundry and utensils reddish-brown. Objectionable for food processing, textile processing, beverages, ice manufacture, brewing, and other processes. U.S. Public Health Service (1962) drinking-water standards state that iron should not exceed 0.3 ppm. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Calcium (Ca) and magnesium (Mg).	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see hardness). Waters low in calcium and magnesium desired in electroplating, tanning, dyeing and in textile manufacturing.
Sodium (Na) and potassium (K).	Dissolved from practically all rocks and soils. Found also in ancient brines, sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers and a high content may limit the use of water for irrigation.
Bicarbonate (HCO_3) and carbonate (CO_3).	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium, cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in mine waters and in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process. U.S. Public Health Service (1962) drinking-water standards recommend that the sulfate content should not exceed 250 ppm.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial brines.	In large amounts in combination with sodium, gives salty taste to drinking water. In large quantities, increases the corrosiveness of water. U.S. Public Health Service (1962) drinking-water standards recommend that the chloride content should not exceed 250 ppm.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Added to many waters by fluoridation of municipal supplies.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth, depending on the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptibility of the individual. (Maier, 1950).
Nitrate (NO_3)	Decaying organic matter, sewage, fertilizers, and nitrates in soil.	Concentration much greater than the local average may suggest pollution. U.S. Public Health Service (1962) drinking-water standards suggest a limit of 45 ppm. Waters of high nitrate content have been reported to be the cause of methemoglobinemia (an often fatal disease in infants) and therefore should not be used in infant feeding. Nitrate has been shown to be helpful in reducing inter-crystalline cracking of boiler steel. It encourages growth of algae and other organisms which produce undesirable tastes and odors.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Includes some water of crystallization.	U.S. Public Health Service (1962) drinking-water standards recommend that waters containing more than 500 ppm dissolved solids not be used if other less mineralized supplies are available. Waters containing more than 1,000 ppm dissolved solids are unsuitable for many purposes.

TABLE 5.—*Source and significance of dissolved mineral constituents and properties of water*—Continued

Constituent or property	Source or cause	Significance
Hardness as $CaCO_3$.	In most waters nearly all the hardness is due to calcium and magnesium. All the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called noncarbonate hardness. Waters of hardness as much as 60 ppm are considered soft; 61–120 ppm, moderately hard; 121–180 ppm, hard; more than 180 ppm, very hard.
Specific conductance (micromhos at 25°C).	Mineral content of the water..	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents.
Hydrogen ion concentration (pH).	Acids, acid-generating, salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, and phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals.

According to the drinking-water standards, the limits in the following table should not be exceeded:

Constituent	*Maximum concentration (ppm)*
Sulfate	250
Chloride	250
Nitrate	45
Fluoride	[1] 1.0
Dissolved solids	500

[1] Based on annual average of maximum daily air temperatures at Beaumont.

In the Neches River basin, concentrations of all the foregoing constituents are generally well below the maximum concentrations recommended by the U.S. Public Health Service.

IRRIGATION

The extent to which chemical quality limits the suitability of a water for irrigation depends on a number of factors: the nature and composition of the soil and subsoil; the topography of the land; the amount of water used and the methods of applying it; the types of crops grown; and the climate of the region, including the amounts and distribution of rainfall.

The most important characteristics in determining the quality of irrigation water, according to the U.S. Salinity Laboratory Staff (1954, p. 69), are: (1) total concentration of soluble salts, (2) relative proportion of sodium to other cations, (3) concentration of boron or other elements that may be toxic, and (4) the bicarbonate concentration as related to the concentration of calcium plus magnesium.

The U.S. Salinity Laboratory Staff introduced the term "sodiumabsorption-ratio" (SAR) to express the relative activity of sodium ions in exchange reactions with the soil. This ratio is expressed by the equation:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}},$$

where the concentrations of the ions are expressed in equivalents per million.

The U.S. Salinity Laboratory Staff has prepared a system for classifying irrigation waters in terms of salinity and sodium hazard. Empirical equations were used in formulating a diagram which uses SAR and specific conductance in classifying irrigation waters. The diagram is reproduced in modified form as figure 9. This classification, although embodying both research and field observations, should be used only for general guidance because of the other factors which also affect the suitability of water for irrigation. With respect to salinity and sodium hazards, waters are divided into four classes—low, medium, high, and very high. The range of this classification extends from those waters which can be used for irrigation of most crops on most soils to those waters which are usually unsuitable for irrigation.

Representative water-analysis data from the Neches River at two sites and from two tributary streams are plotted on figure 9. Also shown for the two daily chemical-quality stations, Angelina River near Lufkin and Neches River at Evadale, is the percentage of time that the specific conductance exceeded the indicated value during the period 1955–63. For the daily station, Neches River near Alto, the values plotted are the discharge-weighted average values for the period 1960–63. The data show that the waters at these stations generally are low in respect to sodium hazard, and low to medium in respect to salinity hazard.

Results of a few determinations of boron for the Neches River at Evadale are available in the files of the Geological Survey. Concentrations are low, indicating that boron is not a problem in irrigation waters of the basin.

Rice-growing in the area near Beaumont is the principal use of surface water for irrigation in the Neches River basin. The concentration of chemical constituents tolerated by rice varies with its stage of growth, but investigators generally agree that water containing less than 600 ppm sodium chloride (350 ppm chloride) is not harmful to rice at any stage of growth (Irelan, 1956, p. 330). As shown on the chloride map on plate 4, concentrations are less than 100 ppm in streams draining most of the Neches River basin. Water of the basin meets all quality requirements for rice irrigation.

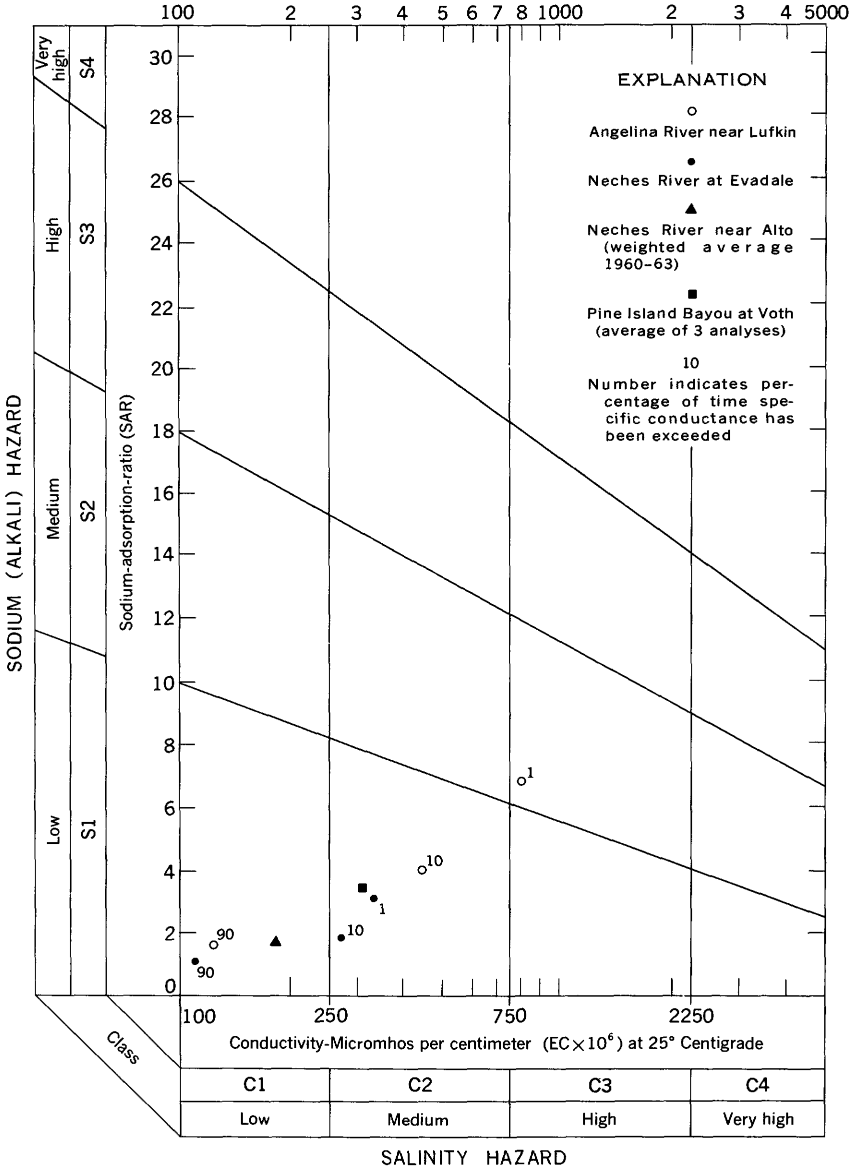


FIGURE 9.—Classification of irrigation waters.

Surface water is also used for supplemental irrigation of field crops, orchards, and truck gardens. For supplemental irrigation in humid and subhumid areas, water-quality requirements are not rigid, and surface water in the Neches River basin would be classed as excellent for this use.

INDUSTRIAL USE

Large quantities of surface water are used for industrial purposes in the Neches River basin, especially in the Beaumont-Port Arthur area. The economic feasibility of a water-development project may depend on the suitability of the water for industrial use.

The quality requirements for industrial water vary widely. For some purposes, such as cooling, water of almost any quality can be used, whereas in some manufacturing processes and in high-pressure steam boilers, water approaching the quality of distilled water may be required. The quality requirements for many types of industries are given in table 6.

Hardness is a property of water which receives great attention in evaluating an industrial water supply. This property is objectionable because it contributes to the formation of scale in boilers, pipes, water heaters, and radiators, a condition resulting in loss in heat transfer, boiler failure, and loss of flow. However, calcium carbonate in water sometimes forms protective coatings on pipes and other equipment and thus reduces corrosion.

High dissolved-solids concentration may be closely associated with the corrosive property of a water, particularly if chloride is present in appreciable quantities. Water containing high concentrations of magnesium chloride may be very corrosive because hydrolysis of this unstable salt yields hydrochloric acid.

Because the water of the Neches River basin is generally soft and low in dissolved solids, very little treatment is necessary to make it suitable for use by many industries.

TABLE 6.—*Water-quality tolerances for industrial applications* [1]

[Allowable limits in parts per million except as indicated]

Industry	Turbidity	Color	Color + O_2 consumed	D.O. (ml per l)	Odor	Hardness	Alkalinity (as $CaCO_3$)	pH	Total solids	Ca	Fe	Mn	Fe + Mn	Al_2O_3	SiO_2	Cu	F	CO_3	HCO_3	OH	$CaSO_4$	Na_2SO_4 to Na_2SO_3 ratio	General [2]
Air conditioning [3]											0.5	0.5	0.5										A, B.
Baking	10	10				(4)					.2	.2	.2										C.
Boiler feed:																							
0-150 psi (pounds per square inch)	20	80	100	2		75		8.0+	3,000-1,000					5	40			200	50	50		1 to 1	
150-250 psi	10	40	50	.2		40		8.5+	2,500-500					.5	20			100	30	40		2 to 1	
250 psi and up	5	5	10	0		8		9.0+	1,500-100					.05	5			40	5	30		3 to 1	
Brewing: [5]																							
Light	10				Low		75	6.5-7.0	500	100-200	.1	.1	.1				1				100-200		C, D.
Dark	10				Low		150	7.0→	1,000	200-500	.1	.1	.1				1				200-500		C, D.
Canning:																							
Legumes	10				Low	25-75					.2	.2	.2										C.
General	10				Low						.2	.2	.2				1						C.
Carbonated beverages [6]	2	10	10		0	250	50		850		.2	.2	.3				.2						C.
Confectionary					Low			(7)	100		.2	.2	.2										
Cooling [8]	50					50					.5	.5	.5										A, B.
Food, general	10				Low						.2	.2	.2										C.
Ice (raw water) [9]	1-5	5					30-50		300		.2	.2	.2		10								C.
Laundering						50					.2	.2	.2										
Plastics, clear, undercolored	2	2							200		.02	.02	.02										
Paper and pulp: [10]																							
Groundwood	50	20				180					1.0	.5	1.0										A.
Kraft pulp	25	15				100			300		.2	.1	.2										
Soda and sulfite	15	10				100			200		.1	.05	.1										
Light paper, HL-Grade	5	5				50			200		.1	.05	.1										B.
Rayon (viscose) pulp:																							
Production	5	5				8	50		100		.05	.03	.05	<8.0	<25	<5							
Manufacture	.3					55		7.8-8.3			.0	.0	.0										
Tanning [11]	20	10-100				50-135	135	8.0			.2	.2	.2										
Textiles:																							
General	5	20				20					.25	.25											
Dyeing [12]	5	5-20				20					.25	.25	.25										
Wool scouring [13]		70				20					1.0	1.0	1.0										
Cotton bandage [13]	5	5			Low	20					.2	.2	.2										

[1] American Water Works Association, 1950.

[2] A, *No corrosiveness*; B, *No slime formation*; C, *Conformance to* Federal drinking water standards necessary; D, NaCl, 275 ppm.

[3] Waters with algae and hydrogen sulfide odors are most unsuitable for air conditioning.

[4] Some hardness desirable.

[5] Water for distilling must meet the same general requirements as for brewing (gin and spirits *mashing water of* light-beer quality; whiskey *mashing water of* dark-beer quality).

[6] Clear, odorless, sterile water for syrup and carbonization. Water consistent in character. Most high quality filtered municipal water not satisfactory for beverages.

[7] Hard candy requires pH of 7.0 or greater, as low value favors inversion of sucrose, causing sticky product.

[8] Control of corrosiveness is necessary as is also control of organisms, such as sulfur and iron bacteria, *which tend to form slimes.*

[9] $Ca(HCO_3)_2$ particularly troublesome. $Mg(HCO_3)_2$ tends to greenish color. CO_2 assists to prevent cracking. Sulfates and chlorides of Ca, Mg, Na should each be less than 300 ppm (white butts).

[10] Uniformity of composition and temperature desirable. Iron objectionable as cellulose adsorbs iron from dilute solutions. Manganese very objectionable, clogs pipelines and is *oxidized to* permanganates by chlorine, causing reddish color.

[11] Excessive iron, manganese or turbidity creates spots and discoloration in tanning of hides and leather goods.

[12] Constant composition; residual alumina 0.5 ppm.

[13] Calcium, magnesium, iron, manganese, suspended matter, and soluble organic matter may be objectionable.

GEOGRAPHIC VARIATIONS IN WATER QUALITY

Variations of dissolved solids, hardness, and chloride with geographic locations are shown on the maps on plate 4. These maps are based on the discharge-weighted average concentrations, calculated from available chemical-quality records. All the streams will at times have concentrations exceeding those shown, but the averages on the maps are indicative of the type of water that would be stored in reservoirs obtaining water from the various areas. For some of the streams the data are limited, particularly on the chemical quality of floodflows; therefore, the boundaries of the areas are necessarily generalized.

DISSOLVED SOLIDS

The concentration of dissolved solids in surface water of the Neches River basin is generally less than 250 ppm (pl. 4). Water from the outcrop areas of the Wilcox Group and the older formations of the Claiborne Group generally has dissolved-solids concentrations ranging from 100 to 250 ppm. Water from younger formations has concentrations of less than 100 ppm. Exceptions to these general relationships were observed in three areas (Striker Creek, Beech Creek, and Pine Island Bayou subbasins) where dissolved-solids concentrations are increased by oil-field pollution.

The annual discharge-weighted average concentrations of dissolved solids in the Angelina River near Lufkin have ranged from 74 to 158 ppm, and in the Neches River at Evadale have ranged from 77 to 139 ppm. For the 9-year period from October 1954 to September 1963, for which concurrent records are available, the discharge-weighted average concentrations were 96 ppm for the Angelina River near Lufkin and 92 ppm for the Neches River at Evadale. The analyses showing the annual maximum and minimum dissolved-solids concentrations and the annual weighted averages for the daily stations are given in table 7.

Time-weighted averages are higher than discharge-weighted averages. Duration curves for concentrations of dissolved solids for both of the above stations show that (at Lufkin) 130 ppm and (at Evadale) 120 ppm dissolved solids have been equaled or exceeded 50 percent of the time (fig. 8).

HARDNESS

Surface water in the northern half of the Neches River basin is soft, having less than 60 ppm hardness (pl. 4). Water in the southern half of the basin is very soft, usually having less than 30 ppm hardness.

Waters draining from formations of the Wilcox Group and the older formations of the Claiborne Group are soft, and waters draining the younger formations are very soft.

Water in the Striker Creek subbasin is usually hard, probably because of residual effects of oil-field pollution.

CHLORIDE

The chloride concentration is less than 20 ppm in surface water from about half of the Neches River basin (pl. 4), particularly in streams draining areas underlain by Quaternary and upper Tertiary rocks. Water containing 20–100 ppm chloride in the northern half of the basin is typical of streams draining areas underlain by rocks of the Wilcox Group or by the older formations of the Claiborne Group. Chloride concentrations over 100 ppm occur in waters of the Striker Creek subbasin, and occasionally in the Pine Island Bayou subbasin, apparently because of oil-field brines.

OTHER CONSTITUENTS

Other important constituents in evaluating the chemical quality of a water include silica, sodium, bicarbonate, sulfate, fluoride, and nitrate.

Many streams in the Neches River basin contain from 10 to 30 ppm silica, and the weighted-average concentration of the Neches River at Evadale is 13 ppm. In some streams having low dissolved-solids concentrations, silica may constitute up to 40 percent of the dissolved material present.

Throughout much of the Neches River basin sodium is present in slightly larger proportions than calcium plus magnesium, and chloride is usually present in greater proportion than sulfate or bicarbonate. In unpolluted streams, sodium, bicarbonate, sulfate and chloride concentrations seldom exceed 50 ppm.

Concentration of fluoride and nitrate are low over the entire basin; fluoride concentrations range generally from 0.1 to 0.3 ppm, and nitrate from 0.0 to 1.0 ppm.

TABLE 7.—*Summary of chemical analyses at daily stations on streams in the Neches River basin*

[Analyses listed as maximum and minimum were classified on the basis of the values for dissolved solids only; values of other constituents may not be extremes. Results in parts per million except as indicated. Station numbers are located on pl. 2]

Water year	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)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: 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
11. Neches River near Alto																				
1960																				
Maximum, June 18, 1960	374	17	11	5.0	51		[1] 33	17	81	0.2	0.2	198	0.27	200	48	21	70	3.2	354	8.8
Minimum, June 13–15, 26–28	817	16	6.5	3.3	16		19	15	22	.6	1.8	90	.12	199	30	14	54	1.3	139	6.2
Weighted average	1,194	16	9.0	4.7	23		19	26	33	.1	.7	122	.17	393	42	26	54	1.5	204	------
1961																				
Maximum, Oct. 2, 1960	234	29	14	6.3	80		25	39	122	.1	1.5	304	.41	192	61	40	74	4.5	508	7.0
Minimum, June 19–20, 1961	4,400	6.4	3.0	1.6	6.4	2.0	11	8.6	7.8	.2	.5	42	.06	499	14	5	45	.7	62	6.2
Weighted average	2,327	14	7.5	3.5	17		18	19	24	.2	.5	94	.13	591	33	18	53	1.3	153	------
1962																				
Maximum, July 1–15, 1962	686	19	11	4.6	35		33	14	56	.2	1.2	165	.22	306	46	19	62	2.2	280	6.6
Minimum, May 1–2	5,385	12	4.6	2.6	12		16	12	16	.2	.5	68	.09	989	22	9	55	1.1	109	6.6
Weighted average	1,139	16	9.0	4.4	23		24	21	33	------	.7	121	.16	372	41	21	54	1.7	220	------
1963																				
Maximum, Aug. 1–5, 1963	48.6	14	17	5.7	77		34	14	135	.2	1.0	281	.38	36.9	66	38	72	4.1	548	6.5
Minimum, June 20–22	596	14	6.5	2.9	20		22	11	29	------	1.8	96	.13	154	28	10	61	1.6	158	6.9
Weighted average	418	15	11	4.8	30		28	22	46	------	.8	147	.20	166	47	24	58	1.9	245	------

[1] Includes the equivalent of 11 ppm carbonate (CO_3).

48. Angelina River near Lufkin

1955																				
Maximum, Nov. 4–18, 26–30, 1954	259	18	18	7.5	109		4	52	180	------	0.5	412	0.56	288	76	72	76	5.4	710	5.5
Minimum, May 24–29, 1955	2,843	14	3.1	2.5		7.2	16	9.3	6.8	------	1.5	53	.07	407	18	5	46	.7	80	6.3
Weighted average	693	15	7.6	4.2	32		14	22	50	------	1.0	153	.21	286	36	25	66	2.3	249	------
1956																				
Maximum, Oct. 11–20, 1955	54.1	16	12	5.0	92		24	12	154	------	.5	333	.45	48.6	50	30	80	5.6	581	7.0
Minimum, May 4–8, 11–14, 1956	4,572	13	3.7	3.1	16		19	17	16	------	1.5	80	.11	988	22	6	61	1.5	123	6.5
Weighted average	413	14	7.2	4.1	34		20	19	51	------	1.1	153	.21	171	35	18	68	2.5	249	------
1957																				
Maximum, Jan. 11–20, 1957	46.3	17	14	6.3	99		16	37	159	------	.2	365	.50	45.6	61	48	78	5.5	649	6.9
Minimum, Apr. 25–28, 30, May 1–2	12,450	11	2.5	2.1		6.3	15	6.4	5.0	------	.5	42	.06	1,410	15	3	28	.4	55	6.6
Weighted average	1,089	13	6.0	3.1	17		22	12	23	------	.8	88	.12	259	28	10	57	1.4	138	------
1958																				
Maximum, Apr. 11–13, 20–22, 1958	810	8.6	12	6.2	39		32	28	60	------	0.0	178	0.24	389	55	29	60	2.3	303	7.2
Minimum, Oct. 16–18, 1957	3,470	8.2	1.6	1.8	3.6	3.0	13	6.6	3.5	------	.5	36	.05	337	11	0	34	.5	48	6.5
Weighted average	2,096	14	5.9	2.8	14		18	14	18	------	.8	79	.11	447	26	11	54	1.2	123	------
1959																				
Maximum, Aug. 27–31, 1959	152	16	9.8	5.0	44		30	14	71	------	.8	186	.25	76.3	45	20	68	2.8	316	6.3
Minimum, Apr. 13–14, 18–23	2,214	14	4.5	2.7	8.0	1.9	18	12	10	------	1.0	63	.09	377	22	8	41	.7	98	6.7
Weighted average	994	14	7.5	4.0	22		22	19	32	------	.9	111	.15	298	35	17	58	1.6	190	------
1960																				
Maximum, Aug. 5–17, 1960	66.2	17	12	6.3	70		29	18	117	------	.2	254	.35	45.4	56	32	73	4.1	456	6.5
Minimum, Feb. 22–29	2,698	13	3.8	2.6	6.9	1.4	16	11	8.0	.1	1.0	56	.08	408	20	7	41	.7	85	5.9
Weighted average	984	15	6.6	4.1	19		19	21	26	------	.7	103	.14	274	33	18	55	1.4	166	------

TABLE 7.—*Summary of chemical analyses at daily stations on streams in the Neches River basin*—*Continued*

[Analyses listed as maximum and minimum were classified on the basis of the values for dissolved solids only; values of other constituents may not be extremes. Results in parts per million except as indicated. Station numbers are located on pl. 2]

Water year	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)	Dissolved solids			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				
48. Angelina River near Lufkin—Continued																				
1961																				
Maximum, Oct. 2–3, 1960	915	14	12	6.2	75		9	20	135	.2	.2	267	.36	660	55	48	75	4.4	509	6.4
Minimum, Mar. 18–21, 1961	4,178	11	3.8	1.8	4.1	1.4	15	5.2	6.5	------	1.0	42	.06	474	17	5	32	.4	59	6.0
Weighted average	2,353	14	5.2	3.3	12		18	13	17	------	.6	74	.10	470	26	12	50	1.0	116	------
1962																				
Maximum, Sept. 1–8, 1962	85.5	14	10	5.6	56		33	15	90	.2	.2	209	.28	48.2	48	21	72	3.5	376	5.9
Minimum, May 1–8	5,321	7.2	3.3	1.9	4.3	1.9	11	6.8	7.8	.1	.0	38	.05	546	16	7	34	.5	60	8.2
Weighted average	1,372	14	6.2	3.6	15		19	16	21	------	.5	87	.12	322	30	14	51	1.1	142	------
1963																				
Maximum, Sept. 1–6, 1963	60.0	13	18	9.0	137		25	30	232	.3	.8	452	.61	73.2	82	62	78	6.6	870	6.9
Minimum, Apr. 7–9	1,673	11	5.0	1.8	14		15	14	16	------	.8	70	.10	316	20	8	60	1.4	102	6.6
Weighted average	365	15	9.0	5.3	36		19	29	53	------	.3	158	.21	156	44	29	65	2.4	275	------

63. Neches River at Evadale

1948																				
Maximum, Nov. 1–10, 1947	572	18	18	6.2	40	6.4	39	14	78	1.2	1.5	212	0.29	327	70	38	59	2.1	337	6.9
Minimum, Feb. 14–20, 1948	18,610	11	5.8	3.6	15		8	15	28	------	.2	115	.16	5,780	29	23	53	1.2	110	------
Weighted average	4,802	--------	7.8	4.1	20		17	22	30	------	.5	96	.19	1,820	36	22	55	1.4	179	------
1949																				
Maximum, Dec. 11–20, 1948	962	19	11	3.4	51		24	25	75	------	0.2	218	.30	566	41	22	73	3.5	348	------
Minimum, Mar. 21–31, 1949	15,600	9.9	4.4	1.5	14		15	14	14	------	.8	96	.13	4,040	17	5	64	1.5	107	6.9
Weighted average	5,030	13	6.2	2.9	17		20	16	22	------	.7	122	.17	1,650	27	11	57	1.4	144	------
1950																				
Maximum, Oct. 23–29, 1949	4,874	16	8.5	4.0	33		21	15	53	0.0	1.0	173	.24	2,280	38	20	65	2.3	226	6.8
Minimum, June 4–18, 1950	36,160	12	4.9	3.8	2.1		18	5.4	8.0	.0	1.0	46	.06	4,490	28	13	14	.2	65	7.3
Weighted average	11,370	16	6.6	3.6	11		20	12	18	.0	.9	83	.11	2,550	31	15	43	.9	115	------
1951																				
Maximum, July 21–31, 1951	835	26	14	5.2	38		58	14	54	.3	1.5	206	.28	464	56	9	60	2.2	310	7.7
Minimum, Sept. 22–25, 27	1,770	6.0	2.8	2.1	7.5		11	11	7.5	.1	1.0	56	.08	268	16	7	51	.8	75	6.6
Weighted average	2,042	16	8.8	4.3	29		27	23	39	.2	.9	139	.19	766	40	18	62	2.0	222	------
1952																				
Maximum, Dec. 1–10, 1951	692	20	11	3.8	42		47	22	51	.2	.5	180	.24	336	43	5	68	2.7	290	7.6
Minimum, Apr. 20–30, 1952	12,090	10	5.1	2.7	14		18	17	15	.1	1.2	78	.11	2,550	24	9	57	1.3	111	6.7
Weighted average	3,718	15	7.6	3.7	22		23	22	27	.1	1.3	115	.16	1,150	34	15	59	1.7	174	------
1953																				
Maximum, Nov. 1–10, 1952	196	23	11	3.8	42		70	8.1	47	.5	1.5	171	.23	90.5	43	0	68	2.8	292	7.3
Minimum, May 5–12, 26–27, 1953	47,180	6.1	4.7	1.4	4.8		17	5.9	4.5	.3	.8	36	.05	4,590	18	4	36	.5	58	6.8
Weighted average	8,177	10	5.8	2.4	11		19	11	13	.3	1.5	66	.09	1,460	24	9	49	1.0	109	------

TABLE 7.—*Summary of chemical analyses at daily stations on streams in the Neches River basin*—*Continued*

[Analyses listed as maximum and minimum were classified on the basis of the values for dissolved solids only; values of other constituents may not be extremes. Results in parts per million except as indicated. Station numbers are located on pl. 2]

Water year	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)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: 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
63. Neches River at Evadale—Continued																				
1954																				
Maximum, Sept. 1-10, 1954	255	28	15	5.7	36		81	8.6	44	.3	.8	188	.26	129	61	0	56	2.0	299	7.7
Minimum, May 18-31	7,512	16	6.2	2.3	17		17	14	21	.8	2.5	88	.12	1,780	25	11	60	1.5	139	7.0
Weighted average	2,114	17	8.1	3.4	24		25	17	32	.5	1.5	127	.17	704	34	14	60	1.8	194	------
1955																				
Maximum, Oct. 1-10, 1954	191	26	14	5.2	46		86	9.7	52	.4	2.8	203	.28	105	56	0	64	2.7	330	7.6
Minimum, Apr. 13-19, 21-26, 1955	1,903	8.6	5.0	2.0	12		16	11	14	.5	.5	62	.08	319	21	8	55	1.1	101	6.8
Weighted average	3,149	13	7.8	2.8	21		22	17	27	.4	1.0	107	.15	910	31	13	59	1.6	169	------
1956																				
Maximum, Nov. 21-30, 1955	498	19	11	3.1	46		48	14	60	.5	1.0	199	.27	268	40	0	72	3.2	299	7.0
Minimum, Feb. 11-21, 1956	7,018	12	6.4	1.7	17		14	14	22	.7	.8	82	.11	1,550	23	12	61	1.5	138	6.2
Weighted average	1,608	14	8.6	2.9	26		28	17	33	.5	1.1	117	.16	508	34	10	63	2.0	198	------
1957																				
Maximum, Oct. 21-31, 1956	169	22	13	3.6	61		99	10	61	0.5	1.8	222	0.30	101	48	0	73	3.8	369	7.2
Minimum, May 3-15, 1957	43,430	10	3.0	1.6	6.7	3.3	10	9.2	9.0	.7	1.2	50	.07	5,860	14	6	45	.8	76	6.1
weighted average	4,607	12	6.2	2.5	15		21	12	17	.6	1.4	78	.11	970	26	9	56	1.3	127	------

1958																			
Maximum, Sept. 1-10, 1958	480	18	11	3.9	29		60	14	30	.3	1.5	138	.19	179	44	0	60	1.9	230	7.3
Minimum, Sept. 21-22, 24	7,937	4.0	4.0	1.0	4.9	1.5	9	8.4	6.0	.1	1.0	35	.05	750	14	6	40	.6	53	6.9
Weighted average	8,465	11	7.0	2.3	16		20	16	19	.4	.6	83	.11	1,900	27	10	56	1.3	134	------
1959																			
Maximum, Mar. 6, 1959	5,660	14	13	3.8	33		16	32	50	.1	2.0	156	.21	2,380	48	35	60	2.0	273	7.1
Minimum, Oct. 1-10, 1958	17,780	10	4.8	1.5	6.6	2.8	16	9.2	8.8	.0	.5	52	.07	2,500	18	5	40	.7	76	6.9
Weighted average	5,162	12	7.5	2.8	17		22	17	21	.1	.8	89	.12	1,240	30	12	55	1.3	151	------
1960																			
Maximum, Dec. 1-10, 1959	1,870	39	12	4.1	32		42	23	40	.1	1.2	172	.23	868	47	12	60	2.0	267	6.9
Minimum, Mar. 1-10, 1960	18,060	9.6	6.2	2.5	12		10	20	16	.1	.8	72	.10	3,510	26	18	50	1.0	124	6.1
Weighted average	4,728	16	8.6	3.4	21		20	24	27	.1	.6	112	.15	1,430	36	19	56	1.5	180	------
1961																			
Maximum, Oct. 1-10, 1960	1,966	15	8.8	3.8	28		35	18	36	.2	.8	128	.17	679	38	9	62	2.0	223	6.8
Minimum, Jan. 11-20, 1961	35,650	8.7	3.5	1.5	6.7	1.7	9	11	8.5	.1	.2	46	.06	4,430	14	7	47	.8	75	5.9
Weighted average	10,410	11	5.8	2.4	15		17	16	18	.2	.4	77	.10	2,160	24	10	57	1.3	126	------
1962																			
Maximum, Aug. 1-31, 1962	1,216	19	10	4.5	34		42	19	44	.2	.8	161	.22	529	44	9	63	2.2	251	6.2
Minimum, Dec. 20-26, 1961	20,510	8.3	3.5	2.0	11		12	12	12	.2	.8	56	.08	3,100	16	6	59	1.2	91	6.7
Weighted average	5,174	13	7.9	3.3	20		20	21	26	------	.7	102	.14	1,420	33	16	56	1.5	171	------
1963																			
Maximum, June 1-20, 1963	1,290	14	12	4.4	36		44	25	45	.2	.8	159	.22	554	48	12	62	2.3	264	6.7
Minimum, Sept. 17-21	5,163	.0	2.5	.0	2.3	.9	6	2.8	2.0	.0	.5	14	.02	195	6	1	42	.4	29	5.7
Weighted average	2,153	12	9.2	3.6	26		25	25	33	------	.5	122	.17	709	38	18	59	1.8	203	------

QUALITY OF WATER IN RESERVOIRS

Most of the reservoirs in the Neches River basin were sampled during this reconnaissance study. The chemical analyses are given in table 3; locations where water samples were collected are shown on plates 2 and 3.

FLAT CREEK RESERVOIR

Outflow samples from Flat Creek Reservoir were collected from Flat Creek (site 3) about 4 miles below the dam. These samples indicate that the water in Flat Creek Reservoir is soft, with a dissolved-solids concentration of about 100 ppm.

LAKE PALESTINE

In addition to analyses for Lake Palestine (site 7) by the Geological Survey, representative analyses made by the Texas State Department of Health are included in table 3. This water is soft and at times has contained from 94 to 178 ppm dissolved solids and from 21 to 48 ppm chloride. When the planned enlargement of Lake Palestine (fig. 6) is completed, the quality of the water stored will probably be improved and subject to less variation, because volumes of flood runoff can be stored and the effects of low-flow water will be minimized.

LAKE JACKSONVILLE

The water in Lake Jacksonville (site 10) is very soft and low in all dissolved constituents. Chloride concentrations and dissolved-solids concentrations usually have been less than 10 ppm and 70 ppm, respectively.

STRIKER CREEK RESERVOIR

Inflow into Striker Creek Reservoir (site 40) during periods of high runoff has been of good quality, but low flows carry high concentrations of sodium chloride from areas of oil production. From October 1962 to March 1964, a period of below-normal runoff, the chloride concentration in the water of the reservoir increased from 171 to 272 ppm and the dissolved-solids concentration from 342 to 525 ppm. The factors affecting the quality of water in Striker Creek Reservoir were discussed on page 20.

LAKE TYLER

The water in Lake Tyler (site 43) is of excellent chemical quality. It is low in all dissolved constituents and contains less than 70 ppm dissolved solids.

LAKE KURTH

The quality of the water available for storage in Lake Kurth, an off-channel reservoir, can be inferred from the chemical-quality data for the daily station, Angelina River near Lufkin. Weighted-average dissolved solids at the Lufkin station have not exceeded 250 ppm and were usually less than 150 ppm.

SAM RAYBURN RESERVOIR

Impoundment of water in Sam Rayburn Reservoir began in 1965. The quality of the water can be predicted from chemical-quality data for Attoyac Bayou near Chireno (site 52), for the Angelina River at the damsite (site 56), and near Horger (site 57). The water impounded in Sam Rayburn Reservoir should be of acceptable quality for most uses. Municipal and industrial wastes released into the Angelina River near Lufkin could cause significant changes in the quality, especially during extended periods of low flow, but the large volumes of water normally available for storage should be adequate to dilute the wastes.

DAM B RESERVOIR

The chemical quality of the water in Dam B Reservoir can be inferred from the records for the daily sampling stations on the Neches and Angelina Rivers. The weighted-average dissolved-solids concentration of the Neches River near Alto (site 11) has ranged from 94 to 147 ppm and of the Angelina River near Lufkin (site 48) from 74 to 158 ppm. Water in Dam B Reservoir probably has dissolved-solids concentration ranging from 100 to 150 ppm.

QUALITY OF WATER AT POTENTIAL RESERVOIR SITES

One of the principal purposes of the reconnaissance study of the Neches River basin was to appraise the quality of the water available for storage at potential reservoir sites. Many sites studied by various Federal, State, and local agencies are indicated on figure 6. Some of the sites are alternate proposals, and the construction of one reservoir might preclude the construction of another.

The reconnaissance study has shown that the quality of water is generally good throughout the Neches River basin. In the absence of local pollution, reservoirs, wherever constructed, will store water low in dissolved solids and suitable for municipal, industrial, and irrigation uses. The water quality at several of the sites is discussed below. The evaluations are based on 1964 conditions; industrial influences in the basin may cause significant changes in water quality before some of the reservoirs are built.

LAKE PONTA

A permit has been issued by the Texas Water Commission for construction of a dam at the Ponta site on the Angelina River in Nacogdoches and Cherokee Counties. When completed, this dam will impound enough water to form one of the larger reservoirs in the basin. Stored water will be low in all dissolved constituents, with dissolved solids ranging from 100 to 150 ppm.

MUD CREEK RESERVOIR

A permit has been issued for construction of a reservoir on Mud Creek in Smith County. The damsite is a few miles east of Lake Tyler, and the drainage areas are similar. Water which will be stored in Mud Creek Reservoir will contain probably less than 100 ppm dissolved solids.

WECHES AND FASTRILL DAMSITES

Two sites are being considered for reservoirs in the reach of the Neches River bordering Houston and Cherokee Counties. Water stored at either of these sites will consist of the outflow from Lake Palestine and the runoff from a few tributaries below Lake Palestine. Releases or spills from Lake Palestine generally will contain not more than 150 ppm dissolved solids, and tributary inflow will probably contain slightly lower concentrations. The Weches site is near the chemical-quality station Neches River near Alto (site 11) where, for the 4 water years 1960–63, the weighted-average dissolved-solids concentration has ranged from 94 to 147 ppm.

VILLAGE CREEK DAMSITE

A reservoir on Village Creek at the potential damsite near Kountze in Hardin County will store water very low in dissolved constituents. Analyses of 11 samples collected at the gaging station near Kountze (site 78) at low, medium, and high discharge rates have shown a range of 21–118 ppm dissolved solids. According to the evidence, slight pollution from oil fields exists in the Beech Creek drainage area, but effects on water quality in Village Creek apparently have been minor.

PINE ISLAND BAYOU DAMSITE

At present, salt water produced with oil in the Batson, Saratoga, and Sour Lake oilfields is discharged into surface streams in the Pine Island Bayou drainage area, principally during periods of flooding following heavy rains. The construction of a water-supply reservoir on Pine Island Bayou will not be feasible until an alternate method for disposal of the salt water is adopted. The natural runoff, which from that area is of good quality, will not at all times be adequate to dilute the oil-field waste.

SALT-WATER BARRIER

Several plans have proposed the construction of a dam on the Neches River below the mouth of Pine Island Bayou to prevent salt-water encroachment into the lower river and to make unnecessary the wastage of much fresh water into the Gulf of Mexico. Water available for storage at the site would be very similar in quality to the water sampled at the daily quality station at Evadale (site 63, table 7), where the weighted-average dissolved-solids concentration has ranged from 77 to 139 ppm. Additional inflow will be received from Village Creek, which is very low in dissolved solids, and from Pine Island Bayou. If the present practice of brine disposal into surface streams in the Sour Lake, Saratoga, and Batson oil-fields is continued, it could at times seriously deteriorate water quality in the Pine Island Bayou arm of the reservoir.

CONCLUSIONS AND RECOMMENDATIONS

This reconnaissance study showed that the Neches River basin has an abundance of water of good quality and is remarkably free of water-quality problems; however, two areas—Striker Creek and Pine Island Bayou—require further study.

Water in the Striker Creek drainage area is being polluted by oil-field brine. Most of the brine produced is reinjected underground; but some surface storage pits are used, and small quantities of brine also reach the streams as the result of leaks in the collection systems and from accidental spills. The results of this reconnaissance study show that the disposal of brine on the surface in years past still affects the chemical quality of the surface water. An extensive research project is needed to define these effects. Such a project should include the study of the base-exchange capacity of the various clays, the study of the quality of the shallow ground water, an inventory of the production and disposal of the brine, and the detailed geological mapping of the area.

Oil-field brines also pollute the surface streams in the Pine Island Bayou drainage area. Brine is stored in unlined surface pits and released to streams during flood-runoff periods. This practice interferes with use of surface water at present, and will be even more detrimental when water-supply storage projects are built downstream. Some of the brine seeps into the ground, and further study is needed to determine the effects this seepage will have on the shallow ground water in the area.

Continued municipal and industrial growth in the Neches River basin will increase the waste-disposal burdens of the stream systems and will require continuous effort by water-pollution control agencies to keep deterioration of water quality at a minimum.

Encroachment of sea water from the Gulf of Mexico through Sabine Lake at times makes the water of the lower reach of the Neches River unsuitable for irrigation or for municipal or industrial use. During summer low-flow periods the Lower Neches Valley Authority has had to construct a temporary barrier across the Neches River below the mouth of Pine Island Bayou to prevent salt water from reaching the Voth pumping plant (Lower Neches Valley Authority, oral commun., 1964). Further depletion of sustained flow as a result of increased consumptive use and upstream storage will aggravate the encroachment problem until the proposed salt-water barrier is built. The effect of the decreased flow on the marine life in bays and estuaries should be anticipated and studied.

The quality of water may be either improved or degraded by impoundment. Beneficial effects include reduction of turbidity, silica, color, and coliform bacteria, stabilization of sharp variations in chemical quality, entrapment of sediment, and reduction in temperature. Detrimental effects of impoundment include increased growth of algae, reduction of dissolved oxygen, and increases in the concentration of dissolved solids and hardness as a result of evaporation. Further study is needed to determine the significance of these changes in water quality and their relation to the intended uses of the water.

SELECTED REFERENCES

American Water Works Association, 1950, Water quality and treatment [2d ed.]: Am. Water Works Assoc. Manual, tables 3, 4, p. 66, 67.

Austin Oil and Gas Co., 1962, Texas wildcat Maps, May 1962: Austin, Tex.

Baker, B. B., Peckham, R. C., Dillard, J. W., and Souders, V. L., 1963, Reconnaissance investigation of the ground-water resources of the Neches River basin, Texas: Texas Water Comm. Bull. 6308, 67 p., 10 figs., 11 pls.

Baker, E. T., Jr., 1964, Geology and ground-water resources of Hardin County, Texas: Texas Water Comm. Bull. 6406, 179 p., 26 figs., 8 pls.

Broom, M. E., Alexander, W. H., and Myers, B. N., 1965, Ground-water resources of Camp, Franklin, Morris, and Titus Counties, Texas: Texas Water Comm. Bull. 6517, 153 p., 13 figs., 3 pls.

Burnitt, S. C., 1962, Henderson oil field area, Rusk County, Texas; investigation of ground-water contamination: Texas Water Comm. Pub. LD–0262–MR, 13 p., 2 figs., 1 pl.

Darton, N. H., Stephenson, L. W., and Gardner, Julia, 1937, Geologic map of Texas: U.S. Geol. Survey, Geol. Map, Scale 1:500,000.

Dillard, Joe W., 1963, Availability and quality of ground water in Smith County, Texas: Texas Water Comm. Bull. 6302.

East Texas Salt Water Disposal Co., 1958, Salt water disposal, East Texas oil field: Texas Univ. Petroleum Extension Service, 131 p., 79 figs.

Hughes, L.S., and Leifeste, D. K., 1965, Reconnaissance of the chemical quality of surface waters of the Sabine River basin, Texas and Louisiana: U.S. Geol. Survey Water-Supply Paper 1809–H, 71 p., 1 pl., 14 figs.

Irelan, Burdge, 1956, Quality of water, *in* Jones, P. H., Hendricks, E. L., Irelan, Burdge, and others, Water resources of southwestern Louisiana: U.S. Geol. Survey Water-Supply Paper 1364, p. 323–441.

Kelley, Walter P., 1948, Cation exchange in soils: New York, Reinhold Publishing Co., 144 p.

Langbein, W. B., and Iseri, Kathleen T., 1960, General introduction and hydrologic definitions: U.S. Geol. Survey Water-Supply Paper 1541–A, p. 1–29.

Maier, F. J., 1950, Fluoridation of public water supplies, Jour. Am. Water Works Assoc., v. 42, pt. 1, p. 1120–1132.

Plummer, F. B., 1945, Investigations dealing with disposal of East Texas oil-field water: Texas Univ. Bur. Eng. Research unpub. rept., 104 p., 35 figs.

Texas Board of Water Engineers, 1958, Compilation of surface water records in Texas through September 1957: Texas Board Water Engineers Bull. 5807A, 503 p., 4 pls.

——— 1961, A plan for meeting the 1980 water requirements of Texas: Texas Board of Water Engineers, 198 p., 25 pls.

Texas State Department of Health, 1960, Chemical analyses of public water systems: 99 p.

Texas Water Commission and Texas Water Pollution Control Board, 1963, A statistical analysis of data on oil field brine production in Texas for the year 1961 from an inventory conducted by the Texas Railroad Commission: Summary volume, 81 p.

U.S. Bureau of Reclamation, 1953, Water supply and the Texas economy, an appraisal of the Texas water problem: U.S. 83d Cong., 1st sess., Doc. 57, 91 p.

U.S. Geological Survey, 1939, Summary of records of surface water of Texas, 1898–1937: U.S. Geol. Survey Water-Supply Paper 850, 154 p.

——— 1960, Compilation of records of surface waters of the United States through September 1950, Part 8, Western Gulf of Mexico basins: U.S. Geol. Survey Water-Supply Paper 1312, 633 p., 1 pl., 2 figs.

——— 1961, Surface water records of Texas: U.S. Geol. Survey open-file rept.

——— 1962, Surface water records of Texas: U.S. Geol. Survey open-file rept.

——— 1963, Surface water records of Texas: U.S. Geol. Survey open-file rept.

——— 1964, Compilation of records of surface waters of the United States, October 1950 to September 1960, Part 8, Western Gulf of Mexico basins: U.S. Geol. Survey Water-Supply Paper 1732, 574 p., 1 pl., 2 figs.

U.S. Public Health Service, 1962, Drinking water standards 1962: U.S. Public Health Service Pub. 956, 61 p.

U.S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Dept. of Agr. Handb. 60, 160 p.

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