TEXAS WATER DEVELOPMENT BOARD

REPORT 92

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

By

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Prepared by the U.S. Geological Survey
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ABSTRACT

The Lavaca River basin has an abundant supply of surface water of very good quality. The basin area of about 2,410 square miles receives an average of about 38 inches of rainfall per year, of which about 5 inches enters Lavaca Bay as runoff.

The surface streams probably obtain most of their chemical characteristics from the geologic formations that crop out within the basin. The exposed rocks range in age from Miocene to Holocene and crop out in bands nearly parallel to the coast. Both the Lavaca River and its principal tributary, the Navidad River, traverse all of the formations; therefore, these streams contain chemical constituents dissolved from each formation. Usually, the streams carry water containing less than 200 ppm (parts per million) dissolved solids, less than 25 ppm chloride, and less than 100 ppm hardness. Other important chemical constituents are found in concentrations well below the recommended limits for most water uses. Although the water is very similar throughout the basin, water quality is slightly better in streams draining the eastern half of the basin than in those draining the western half.

Oil is produced in the central and southern parts of the basin, and irrigation is practiced extensively in the southern half. Surface streams are probably degraded from time to time by oil-field brine and by return flow from irrigation. Municipal wastes may also affect water quality in some streams during extreme low flow. However, these detrimental effects are minimized because runoff is usually sufficient for dilution.

The Lavaca River basin has no major reservoirs, but a dam has been proposed on the Navidad and Lavaca Rivers below Ganado and Edna to create Palmetto Bend Reservoir. Storage in this reservoir would provide water of very good quality for domestic supply, irrigation, and industrial use.

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

INTRODUCTION

The investigation of the chemical quality of the surface waters of the Lavaca River basin was made by the U.S. Geological Survey in cooperation with the Texas Water Development Board as part of a statewide reconnaissance study. This report is one in a series that was begun in 1961. Reports that have been prepared are listed in the references, and the area of this report is shown in Figure 1. Future reports are planned for each remaining major river basin in Texas.

The purpose of this report is to present available data and interpretations on the quality of surface waters in the Lavaca River basin. These data are essential in planning reservoirs and other water-use projects because the chemical character of the water determines its suitability for domestic supply, irrigation, or industrial use. If raw water is not satisfactory for a specific use, then chemical analyses are necessary to determine the type and extent of treatment needed.

Agencies that cooperated in the collection of chemical-quality and streamflow data include the U.S. Army Corps of Engineers and the Texas State Department of Health.

LAVACA RIVER DRAINAGE BASIN

General Description

The Lavaca River basin is in the central part of the Gulf Coastal Plain of Texas (Figure 1). The fan-shaped basin, drained by the Lavaca River in the west and the Navidad River in the east, is about 80 miles long and about 55 miles across at its widest point. The basin is bounded on the southeast by the Colorado-Lavaca coastal basin, on the northeast by the Colorado River basin, on the northwest by the Guadalupe River basin, and on the southwest by the Lavaca-Guadalupe coastal basin. The drainage area, which includes all or part of eight counties, is about 2,410 square miles, or about 0.9 percent of the area of the State.

The Lavaca River rises in southern Fayette County at an elevation of about 400 feet and flows south-southeastward through Lavaca and Jackson Counties to Lavaca Bay (Figure 2). The Navidad River, the principal tributary to the Lavaca River, rises in central Fayette County and flows southward into Jackson County where it joins the Lavaca River about 10 miles north of Lavaca Bay. The Navidad River drains a total area of about 1,430 square miles.

The terrain of the northernmost area of the Lavaca River basin is rolling to level and is moderately wooded with hardwood and pecan trees. The drainage pattern in this area is fairly well defined and surface water runs off quickly. In the middle section of the basin, the topography changes to a slightly rolling or level prairie covered with native grasses and groves of hardwood. Pecan trees grow profusely along the streams. In the southernmost part of the basin, the terrain becomes a flat, grassy prairie with live oaks, mesquite, and huisache. Because the slope of the streams in this area is very flat, surface water runoff is slow.

The climate in the Lavaca River basin is subhumid and is characterized by moderate summers and mild winters.

Population and Economic Development

The population of the Lavaca River basin in 1960 was 45,000, which was about 0.7 percent of the State total. Yoakum (5,761) and Edna (5,038) are the only two cities with a population of more than 5,000.

The economy of the Lavaca River basin is based chiefly on agriculture and livestock. Corn and cotton are major crops in the northern half of the basin, and rice, cotton, truck produce, and grain sorghums are the major crops in the southern half.

Oil production and oil field supply are the major nonagrarian sources of income. The greatest concentration of oil fields is in the central and southern parts of the basin (Figure 6). Natural gas and other minerals also contribute to the local economy.

Figure 1.--Index Map of Texas Showing River Basins and Coastal Areas

SURFACE WATER

Streamflow Records

The U.S. Geological Survey has four streamflow stations in the Lavaca River basin. These stations and the date they were established are: Lavaca River at Hallettsville (July 1939), Lavaca River near Edna (August 1938), Navidad River near Ganado (May 1939), and Navidad River near Hallettsville (October 1961). The station at Hallettsville was operated by the U.S. Army Corps of Engineers from August 1938 to July 1939. In addition to the four gaging stations, periodic discharge measurements were made on Sandy and West Mustang Creeks. Locations of these stations are shown on Figure 9.

Records of discharge and flow of streams in the Lavaca River basin from 1939 to 1960 have been published in the annual series of U.S. Geological Survey Water-Supply Papers (see table at end of list of references). Beginning with the 1961 water year, streamflow records have been released by the Geological Survey in annual reports for each state (U.S. Geological Survey, 1961-66). Summaries of discharge records have been published giving monthly and annual totals (U.S. Geological Survey, 1960, 1964a; Texas Board of Water Engineers, 1958).

Occurrence

Low flow in some streams in the basin may be maintained for indefinite periods of time by return flow from irrigation, local waste water, seepage from bank storage (water stored in stream banks during high flow), and seepage into streams that have cut below the water table. However, almost all of the flow in streams in the basin is surface runoff, which is dependent on the quantity and intensity of local precipitation.

Precipitation

Average precipitation ranges from about 35 inches in the west to about 41 inches in the east. The annual average for the basin is about 38 inches. Average annual precipitation in the basin, average monthly precipitation at Hallettsville and Edna, and annual precipitation for the period 1931-65 at Hallettsville and Edna are shown in Figure 2.

Rainfall is fairly evenly distributed throughout the year. In the northern half of the basin, average monthly rainfall is usually at a peak in May and again in September. In the southern half of the basin, the rainfall generally peaks during the summer season (see average monthly precipitation data for Hallettsville and Edna, Figure 2). However, rainfall throughout the basin is subject to much greater variations than indicated by the annual and monthly averages. For example, during the 1931-65 period, precipitation at Hallettsville ranged from a low of 0.00 inches in October 1934 to a high of 24.68 inches in July 1936. Similarly, precipitation at Edna ranged from a low of 0.00 inches during several months to a high of 14.38 inches in June 1960. Precipitation so unevenly distributed in time does not sustain streamflow; therefore, flow in most tributaries in the basin is intermittent, and periods of no flow have occurred in both the Lavaca and Navidad Rivers.

Runoff

Runoff is defined as that part of precipitation appearing in surface streams, and is the same as streamflow unaffected by artificial diversions, storage, or other works of man in or on stream channels (Langbein and Iseri, 1960, p. 17). The natural runoff pattern of some streams in the Lavaca River basin is presently altered by diversions for irrigation and by the importation of water from the Colorado River basin.

The average annual runoff for the years 1940-66 from the Lavaca River near Hallettsville and near Edna and the Navidad River near Ganado was 5.8, 4.2, and 5.9 inches respectively (Figure 2). Annual runoff expressed as mean discharge in cfs (cubic feet per second) and inches per year is shown on Figure 2 for the Lavaca River near Edna and Navidad River near Ganado station. Total runoff for the basin is about 5 inches or about 2 percent of the State total (Figure 3). As the basin makes up only about 0.9 percent of the area of the State, available surface water is considerably greater than the average for the State.

Runoff, like rainfall, in the Lavaca River basin is highly variable. Discharge of the Lavaca River near Edna has ranged from no flow to 73,000 cfs. Similarly, discharge of the Navidad River near Ganado has ranged from no flow to 64,500 cfs. The magnitude and frequency of high and low flows can best be shown by flow-duration curves. A curve with a steep slope throughout indicates a highly variable stream whose flow is largely from direct runoff, whereas a curve with a flat slope shows surface or ground water storage. Flow-duration curves for the Lavaca River near Edna and the Navidad River near Ganado are shown in Figure 4. The steep slope of each curve further supports the fact that flow in the streams of the Lavaca River basin mostly comes from surface runoff.

Surface-Water Development

Because precipitation and runoff are variable in the Lavaca River basin, surface-water development is necessary to maintain an adequate supply. At present, some surface water for irrigation is imported from the Colorado River basin by way of Sandy Creek (Figure 9), and some direct diversions from the Navidad and Lavaca Rivers are being used for irrigation. No surface water is being used for industrial or municipal purposes.

To provide for a continuing supply of surface water for irrigation, the creation of Palmetto Bend Reservoir on the Navidad and Lavaca Rivers below Ganado and Edna has been proposed (Figure 9). This reservoir would have a storage capacity of about 286,000 acre-feet and a surface area of about 18,500 acres.

CHEMICAL QUALITY OF THE WATER

Chemical-Quality Records

The daily chemical-quality sampling station Navidad River near Ganado was established in October 1959 and is the only daily station in the Lavaca River basin. However, in 1959 periodic sampling was begun on the Lavaca and Navidad Rivers near Hallettsville, and in 1960 on the Lavaca River near Edna. Also, periodic samples were collected from Sandy and West Mustang Creeks near Ganado during 1967 as part of the data collection for this report.

Locations for these stations are shown in Figure 9 and the chemical-quality data for the daily station are summarized in Table 3. Results of all periodic analyses are given in Table 4. The complete records are published in an annual series of U.S. Geological Survey Water-Supply Papers and reports of the Texas Water Development Board (see table at end of list of references).

Factors Affecting Chemical Quality of Water

The chemical quality of surface water depends on a number of factors. The more important ones are geology, patterns and characteristics of streamflow, and the activities of man.

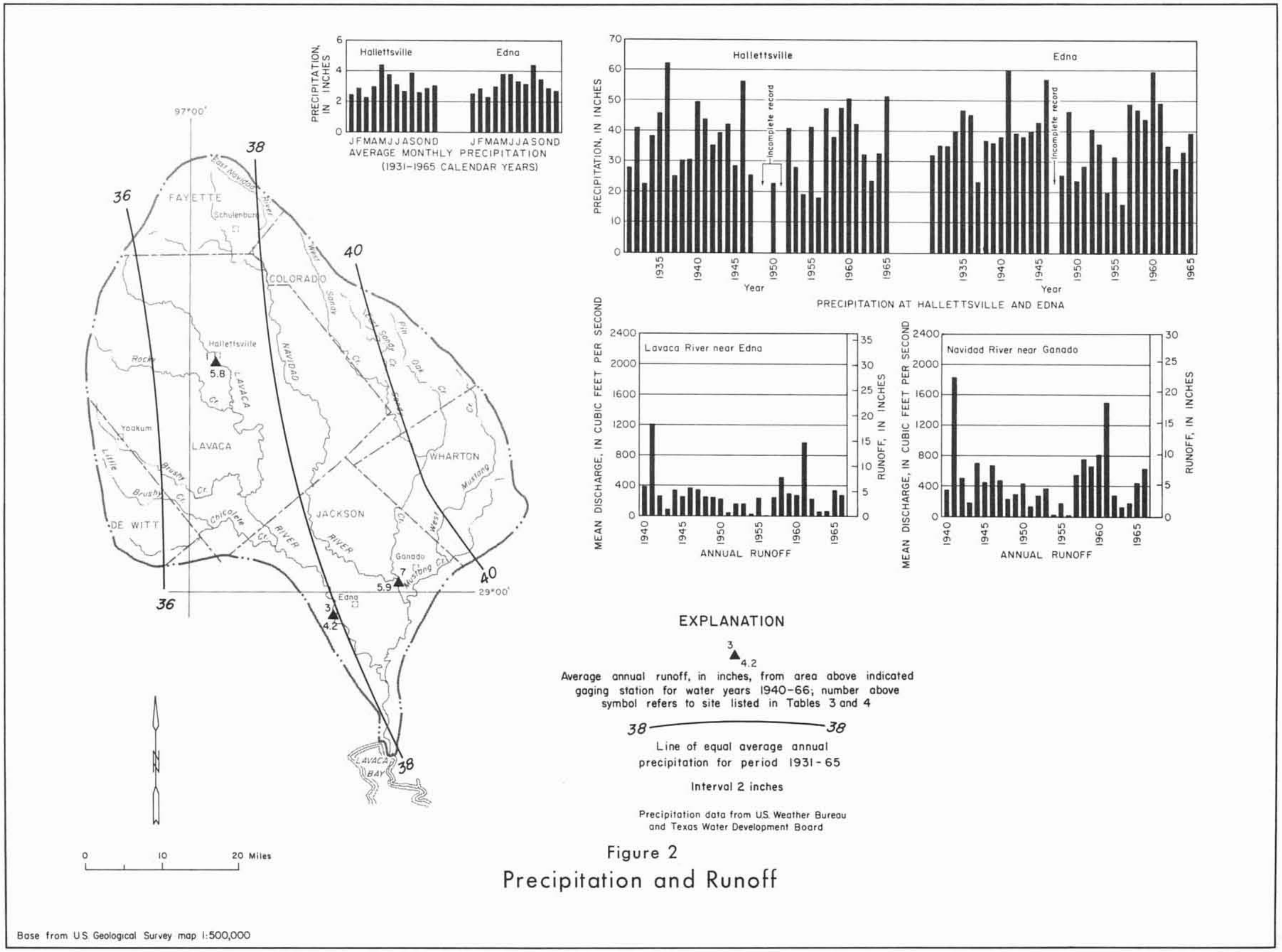

Figure 2
Precipitation and Runoff

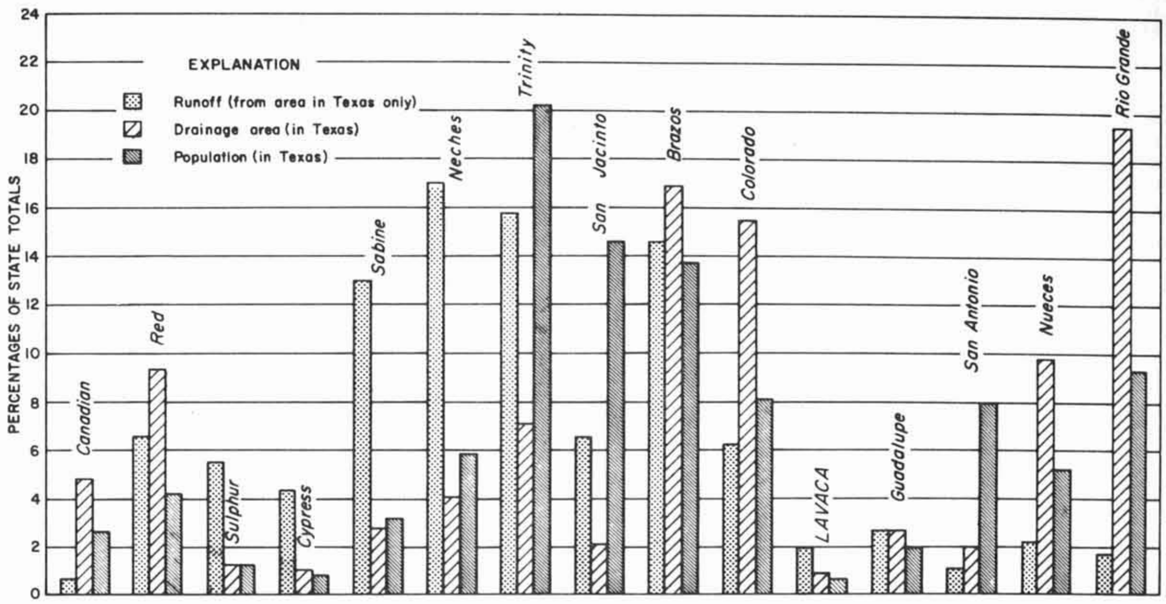

Figure 3.--Average Annual Runoff, Drainage Area, and 1960 Population of Major River Basins in Texas, as Percentages of State Totals

Geology

All water from natural sources contains minerals dissolved from the rocks and soils of the earth's crust. The amounts and kinds of minerals dissolved in water depend principally on the chemical composition and physical structure of the rocks and soils traversed by the water and the length of time the water is in contact with them.

The rocks and soils exposed in the Lavaca River basin range in age from Miocene to Holocene (Figure 9). The Catahoula Sandstone and the Fleming Formation of Miocene age, the Goliad Sand of Pliocene age, the Lissie Formation and Beaumont Clay of Pleistocene age, and alluvium of Holocene age are exposed in belts that are nearly parallel to the Gulf Coast. The younger units crop out close to the coast and successively older units crop out farther inland. The units are generally composed of similar materials in varying amounts. The main constituents are limy clay, clay, sandstone, and limy sand. The Holocene alluvium consists of beach sand, silt, clay, and gravel.

Chemical analyses (Tables 3 and 4) of water in the Lavaca and Navidad Rivers and their tributaries indicate that the streams draining all the geologic formations in the Lavaca River basin contain water of good quality. Dissolved solids are low and the water is usually of the calcium bicarbonate type. Data indicate that water drained from the eastern half of the basin is probably of slightly better quality than water drained from the western half.

Streamflow

In most streams where flow is not regulated by upstream reservoirs, the concentrations of dissolved minerals vary inversely with the flow of the stream. The sustained low flow of a stream is predominantly water that has entered the stream as ground-water effluent. This water had been in contact with the rocks and soils a sufficient time to dissolve part of their soluble minerals. At high flow a stream consists of surface runoff. This water has been in contact with the exposed rocks and soils for a short time. Therefore, the dissolved-solids concentrations of a stream is usually lowest during periods of high flow. Figure 5 shows this inverse relationship between water discharge and dissolved solids to be generally true for streams in the Lavaca River basin. The curves for the Lavaca River at Hallettsville and near Edna and the Navidad River near Hallettsville are based on periodic samples and discharge measurements. The curve for the Navidad River near Ganado was prepared from the monthly weighted averages of chemical analyses and monthly mean discharge data. The point scatter is typical of western streams, where the initial flows of each runoff event flush out the materials left by evaporation of water that remained in the drainage area after the previous runoff event.

Activities of Man

The activities of man often alter the chemical composition of surface streams. Depletion of flow by diversion, return flow of irrigation, disposal of municipal and industrial wastes into streams, and evaporation from water storage projects usually increase the dissolved-solids concentration of water in streams.

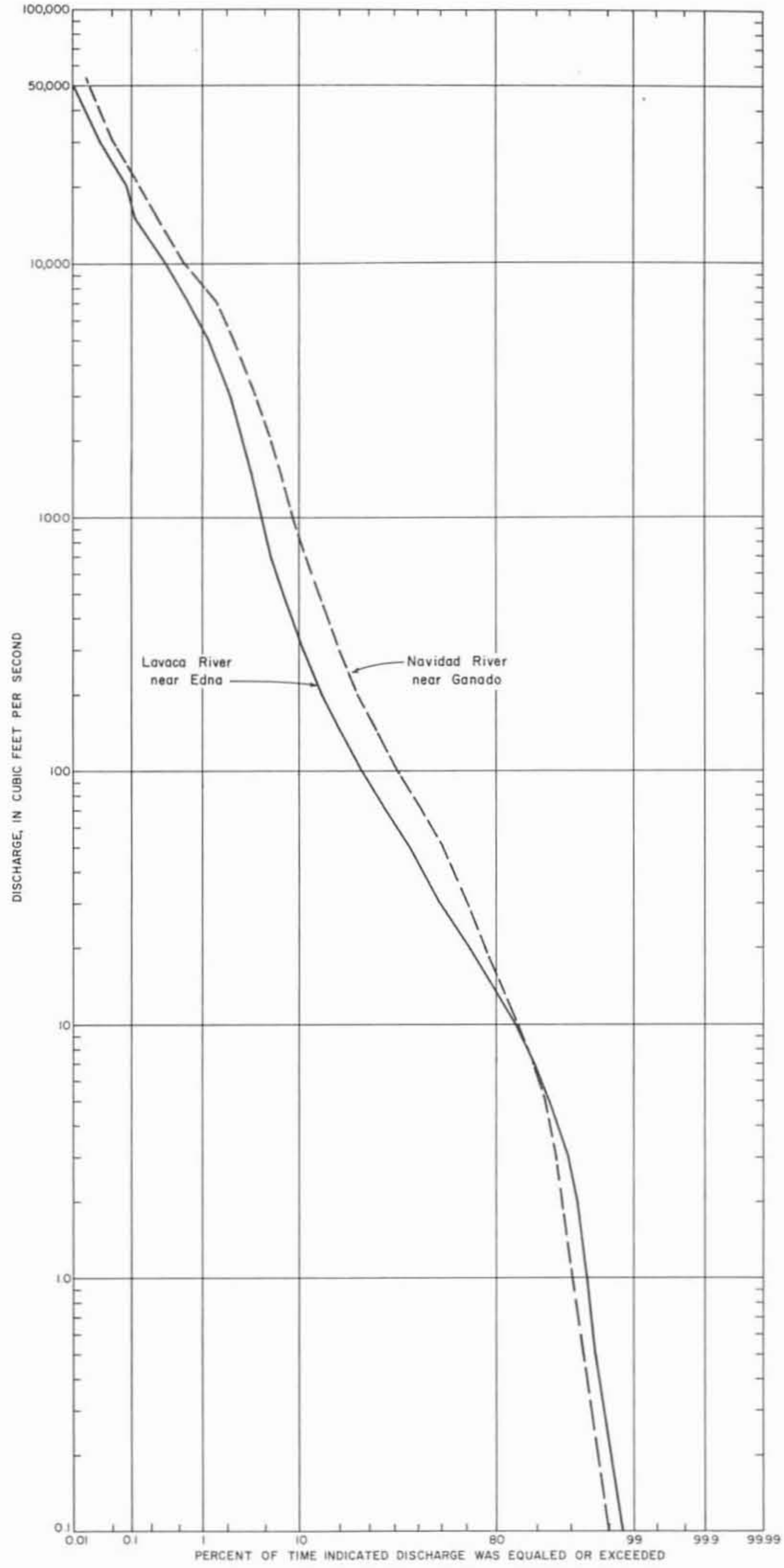

Figure 4

Duration of Daily Flows, Lavaca River Near Edna and Navidad River Near Ganado, 1940-66

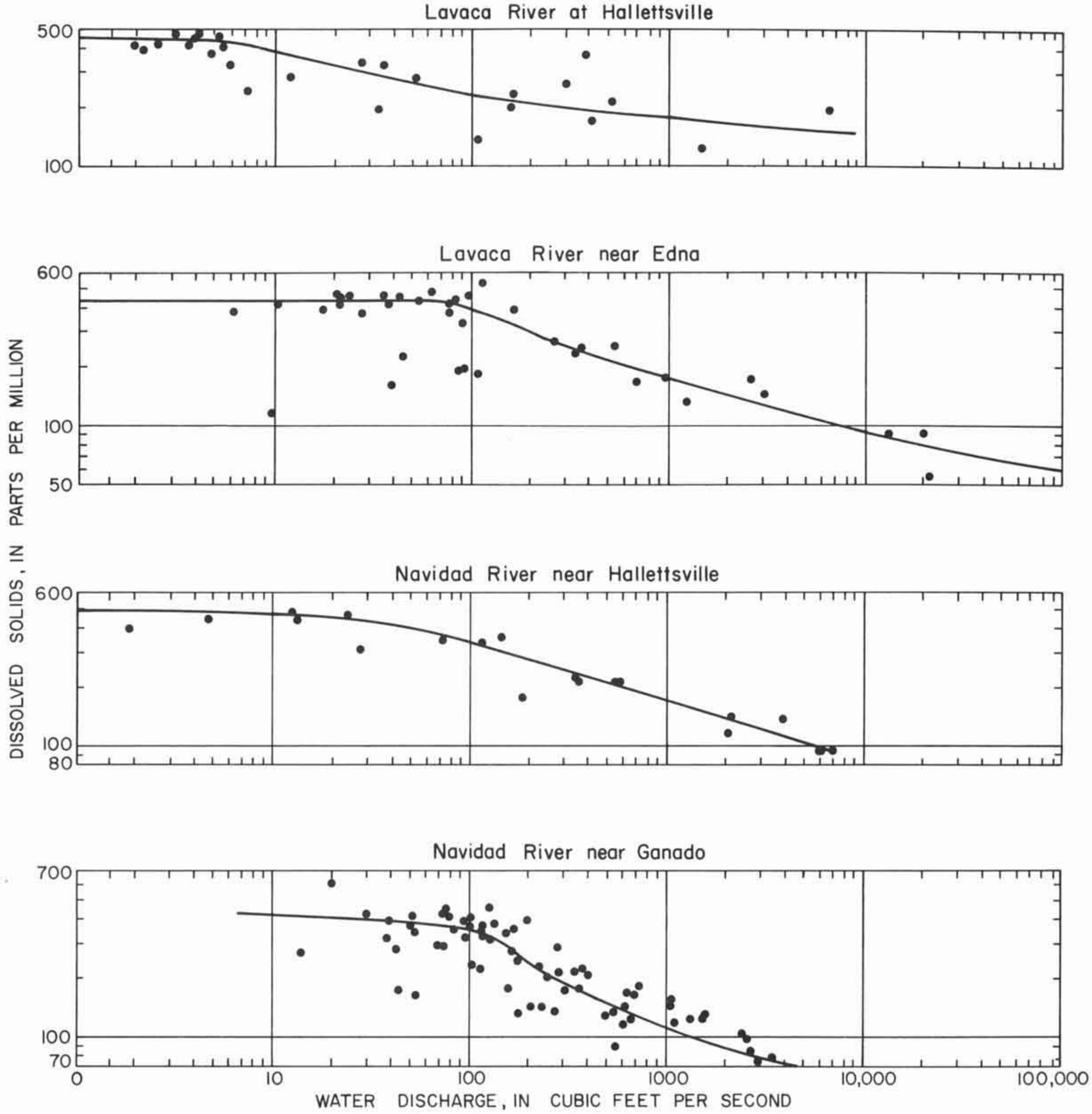

Figure 5

Relation of Concentration of Dissolved Solids to Water Discharge

Only a small amount of water is diverted from the surface streams in the Lavaca River basin. However, significant amounts of water have been diverted from the Colorado River basin. However, significant amounts of water have been diverted from the Colorado River basin into the Lavaca River basin. The quality of water in streams used to facilitate the diversion is partly dependent on the chemical quality of the imported water. The available data are insufficient to determine the extent by which the chemical quality of streams in the Lavaca River basin may be affected by imported water. However, water in the Colorado River basin is similar in quality to that in the Lavaca River basin, so the effect on total streamflow is probably negligible (Leifeste and Lansford, 1968).

Irrigation practices often affect the water quality of streams. Where surface water is diverted for irrigation, the volume of streamflow is reduced and the return flows from irrigated lands carry minerals leached from the soil. Where crops are irrigated with ground water, the drainage often differs in quality and type from water in the receiving stream. In 1964, 220,070 acre-feet of water was used for irrigation in the Lavaca River basin (Gillett and Janca, 1965, p. 43). Of this total, about 147,000 acre-feet was from ground-water supplies. Most of the 73,000 acre-feet of surface water used was diverted to the Lavaca River basin from the Colorado River.

Irrigation is practiced extensively in the southern and southeastern parts of the basin. High rainfall and good quality irrigation waters have negated any effects from irrigation return flows. At present, irrigation practices are contributing little to the degradation of basin streams.

Municipal and industrial wastes may cause some degradation of streams in the Lavaca River basin. This problem is minimized by adequate dilution of water in the stream during high flow.

Oil is produced in the central and southern parts of the basin (Figure 6), and brine, which is produced in nearly all of the fields, may, if improperly handled, eventually reach the streams. According to an inventory by the Texas Railroad Commission in 1961 (Texas Water Commission and Texas Water Pollution Control Board, 1963), about 78 percent of salt water produced in oil fields of the Lavaca River basin was reinjected underground; the remaining brine was placed in unlined surface pits or directly into surface streams. Oil-field pollution is undoubtedly occurring in these localized areas, but the available data do not indicate any brine pollution.

There are no major reservoirs in the Lavaca River basin; therefore, the quality of surface water in the basin is unaffected by water storage projects. If the proposed Palmetto Bend Reservoir is constructed, then water quality below the dam will be altered.

Quality of Water in Surface Streams

All natural water contains dissolved minerals, most of which are dissociated into charged particles or ions. Principal cations (positively charged ions) in natural water are calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), and iron (Fe). The principal anions (negatively charged ions) 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 help define the chemical and physical properties of water. In the following discussion, concentrations of the dissolved constituents are based on discharge-weighted averages. The discharge-weighted average represents approximately the chemical character of the water if all the water passing a point in the stream during a period were impounded in a reservoir and mixed with no adjustments for evaporation, rainfall, or chemical changes that may occur during storage.

Dissolved Solids

The concentration of dissolved solids in the Lavaca River basin is generally less than 200 ppm (parts per million). The discharge-weighted average dissolved solids of water from the Navidad River near Ganado for the period 1960-66 was 134 ppm. The flow at this station represents almost all the water drained from the eastern half of the basin. Also, this is the water that the Navidad River will contribute to storage in Palmetto Bend Reservoir. The discharge-weighted average dissolved solids for the Lavaca River near Edna based on partial records for the same period was 173 ppm. This station represents water from almost all the streams draining the western half of the basin. The limited data obtained from Brushy, Sandy, and West Mustang Creeks suggest that these tributary streams contain water usually having less than 200 ppm dissolved solids. The analyses showing the annual maximum and minimum dissolved-solids concentrations and the annual discharge-weighted averages for the Navidad River near Ganado are given in Table 3. Dissolved solids determined for the miscellaneous sampling sites are listed in Table 4.

A time-weighted average represents the composition of water that would be contained in a reservoir that had received equal quantities of water from the stream each day for a given period of time. Time-weighted average dissolved solids for the Navidad River near Ganado, plotted in Figure 7, are higher than the discharge-weighted average dissolved solids. The duration curve shows that 370 ppm dissolved solids have been equalled or exceeded 50 percent of the time.

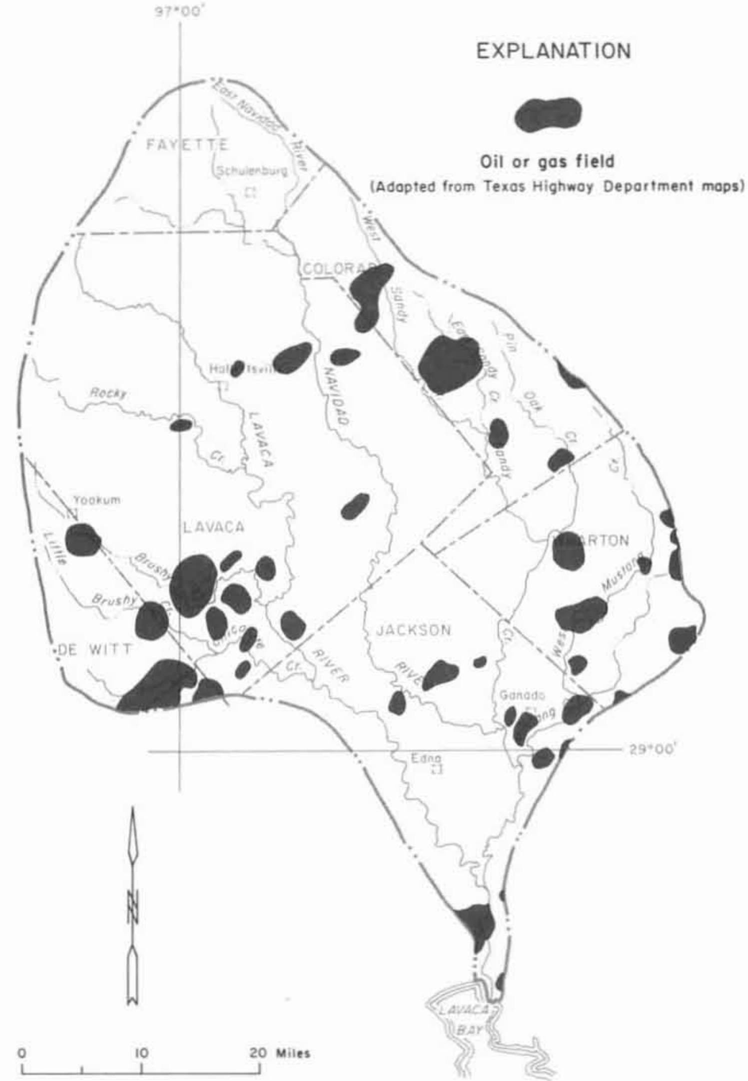

Figure 6

Oil Fields in the Lavaca River Basin

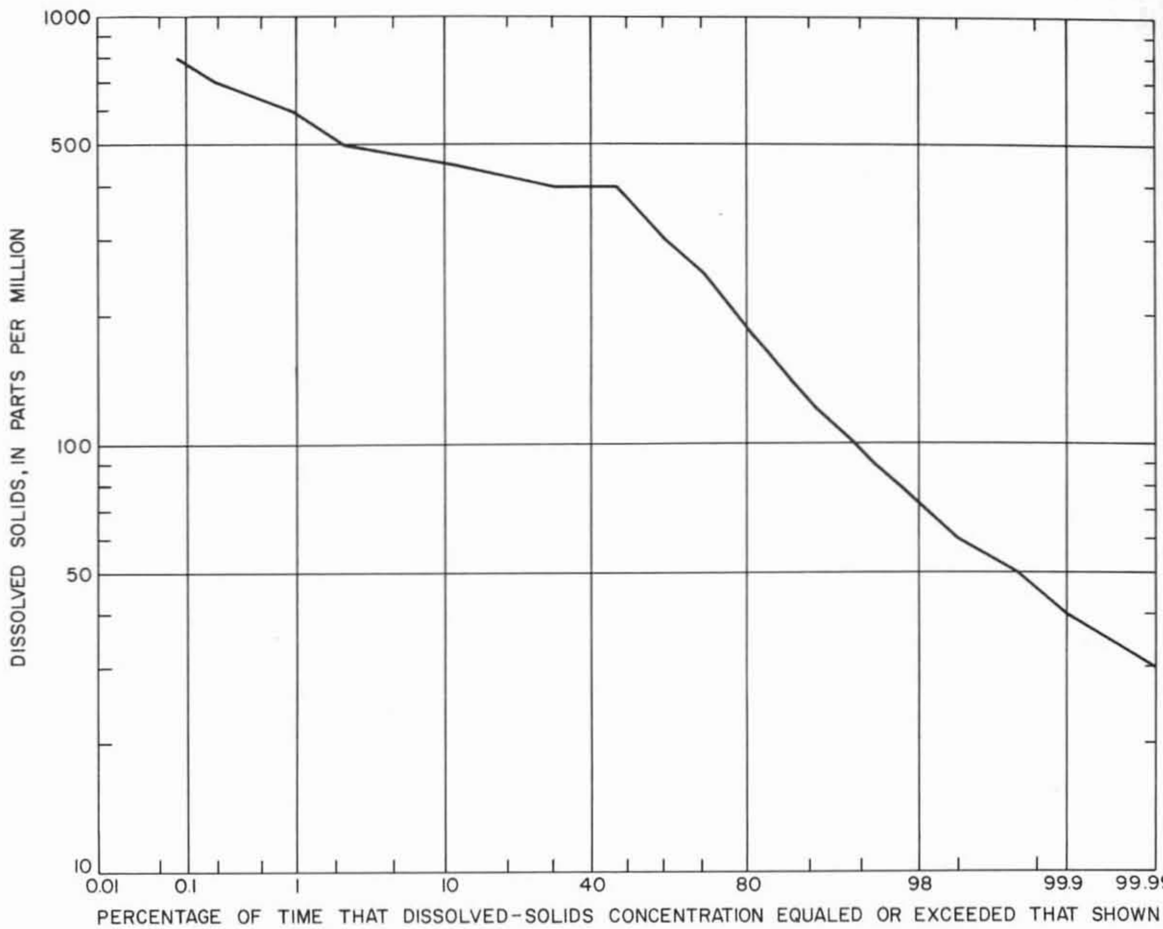

Figure 7.--Duration Curve of Dissolved Solids, Navidad River Near Ganado, Water Years 1960-66

Hardness

Surface water in the Lavaca River basin would generally be classed as moderately hard (61 to 120 ppm). The discharge-weighted average hardness for the Navidad River near Ganado and the discharge-weighted average, based on partial records, for the Lavaca River near Edna were 73 and 115 ppm, respectively. The several investigated tributary streams can usually be expected to carry water containing less than 100 ppm hardness.

Chloride

The chloride concentration in waters of the Lavaca River basin is generally less than 25 ppm. Discharge-weighted averages of chloride concentrations in the Navidad River near Ganado and Lavaca River near Edna were 23 and 18 ppm respectively. Chloride concentrations in tributary streams are probably in the same range as in the two major streams.

Other Constituents

Other important constituents in evaluating the chemical quality of water include silica, sodium, bicarbonate, sulfate, fluoride, and nitrate. Discharge-weighted averages of these constituents for the Navidad River near Ganado are: silica, 13 ppm; sodium, 18 ppm; bicarbonate, 86 ppm; sulfate, 7.5 ppm; and nitrate, 1.1 ppm. Fluoride concentrations in all streams have consistently been less than 1 ppm.

Water Quality in Potential Reservoirs

The quality of water may be improved or degraded by impoundment. Beneficial effects include reduction of silica, turbidity, color, and coliform bacteria; stabilization of sharp variations in chemical quality; entrapment of sediment; and reduction in temperature. Detrimental effects include increased algae growth, reduction of dissolved oxygen, and increases in the concentration of dissolved solids and hardness as a result of evaporation.

The proposed Palmetto Bend Reservoir should store water of very good quality. The quality of water at the two stations, Navidad River near Ganado and Lavaca River near Edna, is representative of the quality of water that would be stored in the reservoir. Combined discharge-weighted averages of dissolved solids, hardness, and chloride concentrations for the two stations are 148, 88, and 21 ppm, respectively.

Suitability of the Water for Use

Quality-of-water studies usually are concerned with determining the suitability of the water—judged by the chemical, physical, and sanitary characteristics—for its proposed use. Table 1 lists the constituents and properties commonly determined by the U.S. Geological Survey and includes a résumé of their sources and significance.

Domestic Purposes

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

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	[a] 1.0
Dissolved solids	500

[a] Based on annual average of maximum daily air temperatures at Yoakum.

In the Lavaca River basin, concentrations of all the foregoing constituents are generally well below the recommended limits.

Irrigation

The chemical composition of a water is an important factor in determining its usefulness for irrigation because the quality of the water should not adversely affect the productivity of the land. The extent to which chemical quality affects the suitability of a water for irrigation depends on many factors, such as: the nature, composition, and drainage of the soil and subsoil; the amounts of water used and the methods of applying it; the kind of crops grown; and the climate of the region, including the amounts and distribution of rainfall. Because these factors are highly variable, all methods of classifying waters for irrigation are somewhat arbitrary.

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 excess of equivalents of bicarbonate over equivalents of calcium plus magnesium.

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

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

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

A system for classifying irrigation waters in terms of salinity and sodium hazards has been prepared by the U.S. Salinity Laboratory Staff. Empirical equations were used in developing a diagram that uses SAR and specific conductance in classifying irrigation waters. The diagram is reproduced in modified form as Figure 8. This classification, although embodying both research and field observations, should be used for general guidance only, 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 waters that can be used for the irrigation of most crops on most soils to waters that are usually unsuitable for irrigation.

Representative water-analyses data from the Navidad River near Ganado and the discharge-weighted average for the Lavaca River near Edna (1960-66) are plotted on Figure 8. One point showing the probable classification of water stored in Palmetto Bend Reservoir is included in Figure 8. In the Lavaca River basin, where the sodium hazard is low, the salinity hazard is low to medium, and the annual average rainfall is 38 inches, the surface water should be excellent for irrigation of most types of crops.

Table 1.—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 stains 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 sodium 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 susceptbility 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 1000 ppm dissolved solids are unsuitable for many purposes.
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 non-carbonate hardness. Waters of hardness as much as 60 ppm are considered soft; 61 to 120 ppm, moderately hard; 121 to 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.

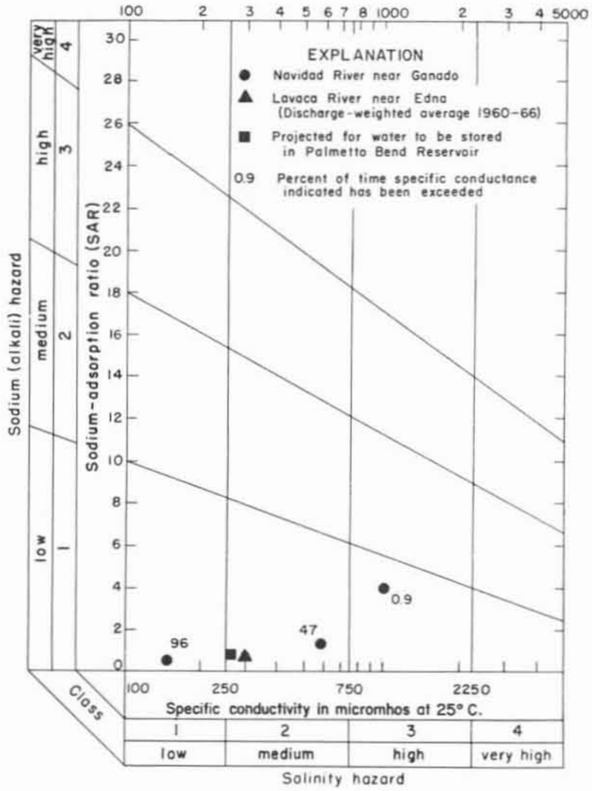

Figure 8.--Classification of Irrigation Waters

Industrial Use

The quality requirements for almost every industrial application, as indicated by the water tolerances, are given in Table 2. One requirement of most industries is that the concentrations of the various constituents of the water remain relatively constant. When concentrations of undesirable substances in water vary, constant monitoring is required, and operating expenses are increased.

Hardness is one of the more important properties of water that affect its utility for industrial purposes. Excessive hardness is objectionable because it contributes to the formation of scale in steam boilers, pipes, water heaters, radiators, and various other equipment where water is heated, evaporated, or treated with alkaline materials. The accumulation of scale increases cost for fuel, labor, repairs, and replacements, and lowers the quality of many wet-processed products. On the other hand, some calcium hardness may be desirable because calcium carbonate sometimes forms protective coatings on pipes and other equipment and reduces corrosion. The water in the Lavaca River basin, which is moderately hard, should be desirable for many industries, but for others, some treatment for hardness would probably be necessary.

The corrosive property of a water receives considerable attention in industrial water supplies. A high concentration of dissolved solids in a water may be closely associated with corrosive properites, particularly if chloride is present in appreciable quantities. Water that contains a large concentration of magnesium chloride may be highly corrosive because the hydrolysis of this salt yields hydrochloric acid. The magnesium chloride and dissolved-solids concentrations in surface waters of the Lavaca River basin are low; therefore, the corrosive properties should be low.

SUMMARY AND CONCLUSIONS

This reconnaissance of the chemical quality of surface water in the Lavaca River basin has shown that in general the basin is relatively free of water quality problems. The water is of very good quality, and any reservoir built in the basin would probably store water of very good quality for domestic supply, irrigation, and industrial use. If Palmetto Bend Reservoir is constructed, it will provide a supply of water of high quality.

The data available for this report are probably adequate to represent the chemical quality of the basin's surface water. But more data should be obtained from the many tributaries to the Lavaca and Navidad Rivers so that problem areas may be isolated and preventive or corrective measures can be taken. Of special concern should be streams in or near oil fields, municipal areas, areas of highly irrigated lands, and the waterways used for importing water.

A continuous study of streams contributing storage water to the proposed Palmetto Bend Reservoir should be maintained. Also, a continuing study is needed to determine the significance of all detrimental changes in water quality within the reservoir due to storage and to determine the relationship of these changes to the intended uses of the water.

Table 2.-Water-Quality Tolerances for Industrial Applications [1]

[Allowable Limits in Parts Per Million Except as Indicated]

INDUSTRY	TURBIDITY	COLOR	COLOR + O_2 CONSUMED	DISSOLVED OXYGEN (ml/1)	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	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.

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WATER YEAR	U.S.G.S. WATER-SUPPLY PAPER NO.	T.W.D.B. REPORT NO.
1945	--	*1938-45
1948	--	*1948
1959	--	Bull. 6205
1960	1744	Bull. 6215
1961	1884	Bull. 6304
1962	1944	Bull. 6501
1963	1950	Rept. 7

* "Chemical Composition of Texas Surface Waters" was designed only by water year from 1938 through 1955.

The following U.S. Geological Survey Water-Supply Papers contain results of stream measurements in the Lavaca River basin, 1939-60:

YEAR	WATER-SUPPLY PAPER NO.
1939	878
1940	898
1941	928
1942	958
1943	978
1944	1008
1945	1038
1946	1058
1947	1088
1948	1118
1949	1148
1950	1178
1951	1212
1952	1242
1953	1282
1954	1342
1955	1392
1956	1442
1957	1512
1958	1562
1959	1632
1960	1712

Table 3. Summary of Chemical Analyses at Daily Stations on Streams in the Lavaca 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.)

Date of collection	Discharge (cfs)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3) (a)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids			Hardness as $CaCO_3$		Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH
												Parts per million	Tons per acre-foot	Tons per day	Calcium, Magnesium	Non-carbonate			
7. NAVIDAD RIVER NEAR GANADO																			
Water year 1960																			
Maximum, Nov. 16-30, 1959.	83.4	24	115	6.3	50		356	20	77	0.2	0.2	b480	0.65	108	313	22	1.2	792	7.5
Minimum, Oct. 31.........	481	--	9.2	1.7	--		42	--	7.0	--	--	63	.09	81.8	30	0	--	98	7.5
Weighted average.........	c798	13	24	3.0	16		86	6.2	20	.2	1.1	128	.17	276	72	2	.8	212	--
Water year 1961																			
Maximum, Apr. 11-20, 1961.	106	27	96	7.3	65		310	22	93	.5	1.0	b490	.67	140	270	16	1.7	808	7.7
Minimum, Feb. 5-8, 1961..	4257	5.3	5.8	.9	5.6	2.8	19	4.8	8.5	.3	.8	44	.06	506	18	3	.6	76	6.6
Weighted average.........	1508	12	19	2.5	14		69	4.9	17	.2	1.1	107	.15	436	58	1	.8	180	--
Water year 1962																			
Maximum, Feb. 21-28, 1962	99.0	26	100	5.9	59		326	20	80	.4	1.2	b473	.64	126	274	7	1.6	791	7.0
Minimum, Nov. 14-17, 1961	5182	12	10	2.5	8.4	4.4	42	5.0	12	.3	1.0	77	.10	1080	35	1	.6	122	7.0
Weighted average.........	280	17	35	5.0	28		123	11	39	--	1.5	203	.27	154	107	7	1.1	341	7.0
Water year 1963																			
Maximum, June 1-17, 1963.	3.5	34	64	9.8	101		278	18	121	.5	.8	486	.66	4.59	200	0	3.1	804	7.7
Minimum, Jan. 18-20......	1120	8.0	16	2.8	10		52	8.2	15	.3	1.0	87	.12	263	51	9	.6	157	6.6
Weighted average.........	122	19	35	6.7	36		131	14	50	--	1.5	228	.31	75.0	116	9	1.4	393	6.8
Water year 1964																			
Maximum, Oct. 1-31, 1963.	20.4	48	56	17	138	6.4	320	21	170	.7	.2	614	.84	33.8	210	0	4.1	1020	7.8
Minimum, Jan. 31, 1964...	977	7.3	14	1.7	9.1		50	5.0	9.6	--	2.5	74	.10	195	42	1	.6	132	7.5
Weighted average.........	175	20	27	6.3	33		111	13	42	--	1.3	198	.27	94.0	92	4	1.4	338	6.9
Water year 1965																			
Maximum, Mar. 1-31, 1965.	52.0	14	84	6.0	63		262	22	94	.4	.2	413	.56	58.0	234	19	1.8	709	7.5
Minimum, Jan. 3-6........	1120	5.7	8.5	2.1	11		36	7.2	11	--	.8	64	.09	194	30	0	.9	111	7.3
Weighted average.........	448	13	26	3.5	18		94	9.9	22	--	1.0	141	.19	170	79	2	.7	240	6.7
Water year 1966																			
Maximum, Mar. 19-28, 1966.	94.3	16	87	6.0	49	2.5	274	20	74	.3	.5	375	.51	95.5	242	16	1.4	672	--
Minimum, May 5-9.........	6824	9.4	10	1.8	5.9	3.6	39	6.4	6.7	.2	.2	63	.09	1160	32	0	.5	106	6.9
Weighted average.........	634	12	25	3.5	19		90	9.5	22	--	.6	137	.19	235	76	3	.9	239	7.1
Water year 1967																			
Maximum, Apr. 2-12, 1967.	21.7	18	54	13	128	5.8	244	45	159	.7	.8	544	.74	31.9	188	0	4.1	954	7.9
Minimum, Sept. 22-24.....	22430	8.9	8.2	1.7	6.0	2.9	32	.8	9.2	.2	.5	54	.07	3270	27	1	.5	85	7.1
Weighted average.........	374	14	17	3.3	15	3.7	66	4.1	22	.3	.5	112	.15	113	55	1	.8	184	7.3

a Includes the equivalent of any carbonate (CO_3) present.

b Residue on evaporation at 180° C.

c Represents 91 percent of flow for water year 1960.

Table 4.--Chemical Analyses of Streams in the Lavaca River Basin for Locations Other Than Daily Stations

(Results in parts per million except as indicated)

Date of collection	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Non-carbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH
1. 8-1635. LAVACA RIVER AT HALLETTSVILLE																						
Apr. 10, 1959.....	1480	11		30	1.5	11		92		11	9.5	--	4.5		124	0.17		81	6	0.5	221	7.5
Sept. 24, 1962....	2.13	21		64	5.6	69		208		32	90	0.6	.2		a396	.54		182	12	2.2	652	6.9
Jan. 7, 1963......	4.15	9.0		81	6.4	77		242		42	108	.6	.5		a486	.66		228	30	2.2	790	7.0
Mar. 19...........	5.26	11		74	7.0	83		212		42	124	.6	.0		a463	.63		214	40	2.5	799	7.1
May 30............	.79	27		40	6.3	83		154		27	107	.7	.0		367	.50		126	0	3.2	627	7.2
July 1............	12.0	20		49	3.3	53		175		16	63	.6	.0		291	.40		136	0	2.0	477	7.4
July 29...........	.52	27		32	4.9	75		132		22	92	.7	.0		319	.43		100	0	3.3	543	7.3
Sept. 3...........	.85	24		41	4.7	79		166		21	95	.7	.2		348	.47		122	0	3.1	607	6.3
Nov. 12...........	1.93	14		55	6.1	90		182		38	119	.6	.0		412	.56		162	13	3.1	751	6.9
Dec. 16...........	3.65	16		77	6.3	69		238		40	93	.5	.2		419	.57		218	23	2.0	750	7.1
June 16, 1964.....	33.7	12		46	2.7	24		164		12	22	.4	.0		200	.27		126	0	.9	350	6.8
June 17...........	503	12		62	1.8	17		204		10	14	.4	1.2		218	.30		162	0	.6	380	6.9
Sept. 22..........	7.23	17		50	2.7	34		164		17	40	.4	.5		243	.33		136	1	1.3	416	7.0
Jan. 5, 1965......	5.96	12		62	3.8	57		205		24	71	.4	.5		332	.45		170	20	1.9	569	8.0
Feb. 16...........	6570	11		58	2.3	12		190		8.4	10	.4	1.8		197	.27		154	0	.4	340	7.5
Feb. 17...........	407	13		49	1.9	11		155		11	8.5	.5	2.8		174	.24		130	3	.4	297	7.0
Feb. 18...........	158	14		54	2.0	16		168		10	17	.4	6.2		203	.28		143	5	.6	350	7.2
Oct. 19...........	107	10		35	.7	14		112		10	11	.3	1.8		138	.19		90	0	.6	236	6.8
Nov. 5............	161	15		62	1.8	21		186		17	26	.4	.5		235	.31		162	10	.7	419	6.8
Nov. 6............	62.8	15		62	2.7	30		183		24	39	.4	.5		264	.36		166	16	1.0	462	7.0
Nov. 12...........	27.6	19		80	7.4	35		232		29	60	.4	.2		345	.47		230	40	1.0	612	6.8
Dec. 20...........	35.3	20		76	3.7	36	4.5	241		24	50	.4	.2		334	.45		205	8	1.1	570	7.0
Sept. 28, 1966....	2.58	23		60	6.0	85	3.1	212		38	108	.7	.5		428	.58		174	0	2.8	739	7.4
Dec. 9............	3.81	20		74	6.3	93	3.1	251		44	114	.4	.2		478	.65		210	5	2.8	829	7.2
Feb. 14, 1967.....	3.13	11		76	6.6	99	2.3	248		51	128	.6	.5		497	.68		216	14	2.9	871	7.4
Apr. 13...........	300	12		72	2.4	23	3.6	222		14	30	.6	.0		267	.36		190	8	.7	459	7.1
Apr. 14...........	51.4	11		56	2.3	42	4.2	169		24	55	.5	1.2		279	.38		149	11	1.5	493	7.1
Apr. 17...........	5.44	16		64	3.7	78	4.5	184		54	98	.7	4.0		413	.56		174	24	2.6	716	6.9
Apr. 19...........	3.74	17		68	4.6	64	3.8	214		30	86	.8	.2		379	.52		188	13	2.0	672	6.6
Apr. 19...........	4.74	12		59	4.4	72	4.2	200		32	92	.6	.2		374	.51		165	1	2.4	671	7.3
Sept. 12..........	.81	23		53	4.4	86	3.8	240		26	87	.6	1.5		403	.55		150	0	3.1	677	7.7
Sept. 26..........	--	21		77	3.2	46	4.7	224		36	64	.5	.8		363	.49		205	22	1.4	606	7.5
2. BRUSHY CREEK NEAR YOAKUM																						
Apr. 10, 1959.....	--	7.8		35	3.1	26		101		14	40	--	4.4		180	0.24		100	17	1.1	341	7.3
3. 8-1640. LAVACA RIVER NEAR EDNA																						
Aug. 21, 1945.....	--	--		71	8.0	62		260		26	74	--	0.0		a390	0.53		210	0	1.9	639	--
June 9, 1948......	--	26		82	7.5	40		272		17	58	--	1.2		a376	.51		236	12	1.1	627	--
Aug. 1............	--	27		81	8.2	47		272		17	69	--	.2		a391	.53		236	12	1.3	671	--
Oct. 27, 1960.....	21000	6.5		14	1.2	2.8	2.4	49		.2	4.0	0.2	.5		56	.08		40	0	.2	97	6.5
Apr. 4, 1961......	113	25		118	8.0	66		362		32	97	.5	2.5		a544	.74		328	31	1.6	909	7.6
Sept. 14..........	19900	7.6		24	1.7	4.2	3.4	82		3.6	7.5	.2	.0		92	.13		67	0	.2	152	6.6
Nov. 5............	10300	9.2		22	1.6	6.7	4.0	71		.8	11	.3	.8		92	.13		62	3	.4	161	6.7
Jan. 6, 1962......	95.4	16		101	7.1	59		312		29	85	.5	2.8		a460	.63		281	26	1.5	784	7.0
June 12...........	77.7	20		90	5.0	43		285		20	58	.4	.0		376	.51		245	12	1.2	663	7.0
July 17...........	37.5	25		92	6.5	50		303		22	66	.4	.0		411	.56		256	8	1.4	711	7.3

a Residue on evaporation at 180°C.

Table 4.--Chemical Analyses of Streams in the Lavaca River Basin for Locations Other Than Daily Stations--Continued

(Results in parts per million except as indicated)

Date of collection	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Dissolved solids: Tons per day	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Non-carbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH
3. 8-1640. LAVACA RIVER NEAR EDNA--Continued																						
Oct. 30, 1962.....	947	13		39	2.6	19		130		10	20	0.4	4.0		a177	.24		108	1	0.8	299	7.0
Jan. 8, 1963......	35.1	17		99	6.5	52		304		27	75	.5	1.0		a464	.62		274	24	1.4	747	7.1
Mar. 20...........	43.3	10		64	6.6	61		212		29	82	.4	.0		357	.49		186	13	1.9	637	7.4
May 28............	23.7	25		94	7.2	69		328		21	86	.5	.2		464	.63		264	0	1.8	773	7.3
July 2............	685	5.2		50	1.8	9.7	2.9	176		4.8	7.0	.3	.2		169	.23		132	0	.4	286	6.4
July 30...........	10.3	23		86	6.7	61		300		19	76	.4	.0		420	.57		242	0	1.7	710	7.1
Sept. 4...........	6.04	23		67	6.8	68		256		15	82	.5	.0		388	.53		195	0	2.1	676	6.8
Nov. 13...........	17.6	20		68	6.4	69		270		17	76	.4	.2		390	.53		196	0	1.5	688	6.9
Dec. 17...........	39.1	11		28	3.0	26		105		13	27	.3	.5		161	.22		82	0	1.2	292	6.4
Feb. 25, 1964.....	86.6	8.9		40	3.0	28		137		13	32	.4	.2		192	.26		112	0	1.2	359	6.6
May 5.............	44.8	14		52	3.0	26		180		12	26	.4	.8		223	.30		142	0	.9	389	7.0
June 16...........	2600	9.8		52	1.5	7.1	3.8	172		5.6	6.5	.3	.0		172	.23		136	0	.3	299	6.9
June 17...........	3020	9.4		40	2.2	12		138		5.8	9.2	.2	.0		147	.20		109	0	.5	260	6.6
June 18...........	1260	11		37	1.9	10		126		5.2	8.4	.2	1.0		137	.19		100	0	.4	240	6.7
Sept. 23..........	108	20		33	3.3	28		138		10	22	.3	.5		185	.25		96	0	1.2	303	7.1
Jan. 6, 1965......	90.8	9.4		36	3.2	29		134		18	25	.4	1.0		188	.26		103	0	1.2	303	8.2
Jan. 25...........	356	11		62	3.2	28		216		15	25	.3	.0		250	.34		168	0	.9	423	7.3
Feb. 18...........	9.54	9.1		32	1.3	5.3	3.3	109		4.8	4.3	.3	2.2		117	.16		85	0	.3	199	7.9
Mar. 16...........	76.6	9.9		93	6.8	59		304		29	77	.4	.0		424	.58		260	11	1.6	638	7.7
Apr. 19...........	89.5	17		72	5.2	44		237		21	55	.5	2.2		334	.45		201	7	1.4	576	7.9
May 23............	538	18		62	4.7	26		214		13	28	.3	.5		258	.35		174	0	.9	447	7.2
June 29...........	83.2	25		100	6.9	51		334		23	64	.3	.8		435	.59		278	4	1.3	747	7.4
Nov. 16,..........	162	24		105	8.3	29		328		23	46	.3	1.0		398	.54		295	27	.7	683	7.0
Dec. 21...........	261	17		61	3.3	25	4.5	201		18	31	.3	.2		260	.35		166	1	.8	439	7.0
Jan. 26, 1966.....	333	10		50	3.1	30	3.6	158		17	41	.3	1.0		234	.32		138	8	1.1	418	6.8
Apr. 7............	62.1	20		108	5.8	54	2.6	338		31	74	.6	.5		462	.63		294	16	1.4	800	7.2
May 11............	300	--		68	4.7	--	--	217		--	41	--	.0		--	--		189	11	--	500	7.2
June 16...........	88.1	22		88	6.1	60	1.9	302		29	72	.4	.2		428	.58		244	0	1.7	740	7.5
July 20...........	53.4	24		80	7.3	70	2.4	294		20	81	.1	.0		430	.58		230	0	2.0	735	7.8
Dec. 7............	20.6	15		100	6.0	70	3.2	345		27	80	.3	.2		472	.64		274	0	1.8	815	7.6
Jan. 10, 1967.....	27.5	4.2		73	5.6	62	2.6	254		29	72	.9	.2		374	.51		205	0	1.9	665	7.4
Feb. 15...........	21.1	6.9		78	5.6	70	2.2	275		30	84	.5	.2		412	.56		218	0	2.1	726	7.8
Apr. 28...........	21.5	21		90	6.3	65	4.5	325		22	80	.6	.2		450	.61		250	0	1.8	763	7.7
July 6............	1.93	26		78	8.6	97	4.1	336		17	106	.5	.5		503	.68		230	0	2.8	858	7.7
Aug. 24...........	123	17		40	3.7	32	4.6	164		9.2	30	.4	.2		218	.30		115	0	1.3	365	6.9
Sept. 24..........	8240	--		28	.6	--	--	99		5.4	5.0	--	--		--	--		72	0	--	169	8.8
Sept. 25..........	84.2	17		50	2.0	13	4.3	168		9.6	14	.4	.5		194	.26		133	0	.5	323	7.1
Sept. 26..........	--	19		51	2.8	21	4.3	173		14	25	.4	1.0		224	.30		139	0	.8	370	7.4
4. NAVIDAD RIVER NEAR SCHULENBURG																						
Apr. 10, 1959.....	--	11		30	1.2	6.6	3.9	97		6.6	6.5	--	2.5		116	0.16		80	0	0.3	200	7.5

a Residue on evaporation at 180°C.

Table 4.--Chemical Analyses of Streams in the Lavaca River Basin for Locations Other Than Daily Stations--Continued

(Results in parts per million except as indicated)

Date of collection	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids			Hardness as $CaCO_3$		Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH
															Parts per million	Tons per acre-foot	Tons per day	Calcium, Magnesium	Noncarbonate			
5. 8-1643. NAVIDAD RIVER NEAR HALLETTSVILLE																						
Apr. 26, 1959.....	--	23		138	2.7	65	3.8	409		30	95	0.4	1.2		560	0.76		356	20	1.5	915	--
Mar. 19, 1963.....	23.8	15		100	6.2	68		305		20	106	.5	.8		466	.63		275	25	1.8	819	6.9
Sept. 22, 1964....	185	11		45	2.4	17		144		11	19	.3	2.5		179	.24		122	4	.7	312	6.9
Jan. 25, 1965.....	17.2	16		75	4.9	48		249		13	66	.4	.2		346	.47		207	3	1.4	598	7.7
Feb. 16...........	6350	8.6		27	1.1	2.3	3.0	89		2.4	2.4	.2	.8		92	.13		72	0	.1	156	7.5
Feb. 17...........	7020	7.3		28	1.5	2.7	2.7	96		.4	3.8	.2	.2		94	.13		76	0	.1	164	7.5
Feb. 18...........	2120	12		36	1.8	11		122		6.6	8.0	.3	2.0		138	.19		97	0	.5	232	7.9
Oct. 19...........	2050	7.7		32	1.3	6.5	3.5	105		6.0	7.6	.2	1.5		118	.16		85	0	.3	203	6.8
Nov. 5............	2900	11		38	1.5	7.9	3.7	122		5.4	10	.2	.5		138	.19		101	1	.3	245	7.1
Nov. 5............	6130	10		28	.8	3.3	3.6	94		.4	3.4	.2	.2		96	.13		73	0	.2	170	6.8
Nov. 6............	545	16		61	2.4	13		194		8.2	15	.3	.2		211	.29		162	3	.4	380	6.7
Nov. 6............	353	16		58	2.5	17		187		10	19	.3	.8		216	.29		155	2	.6	374	7.1
Nov. 12...........	144	22		105	6.8	17		328		18	27	.3	.2		357	.49		290	21	.4	720	6.9
Dec. 21...........	114	20		81	3.7	30	4.0	266		14	39	.3	.8		324	.44		218	0	.9	548	7.3
Sept. 28, 1966....	4.65	22		102	5.8	54	3.8	328		13	85	.5	.2		447	.61		278	10	1.4	770	7.6
Dec. 9............	12.5	23		104	5.2	67	3.7	338		14	95	.3	.2		478	.65		281	4	1.7	830	7.6
Feb. 14, 1967.....	13.2	7.9		94	5.2	69	2.5	310		18	99	.4	.2		448	.61		256	2	1.9	795	7.7
Apr. 14...........	576	10		56	2.1	18	3.9	172		11	24	.3	2.2		212	.29		148	7	.6	374	7.2
Apr. 14...........	345	11		60	2.0	18	4.1	182		12	25	.4	1.5		223	.30		158	9	.6	395	7.0
Apr. 17...........	27.5	17		70	3.4	37	4.8	213		16	55	.5	1.0		310	.42		188	14	1.2	540	7.1
May 17............	1.85	26		72	5.9	63	3.8	236		11	97	.5	.4		396	.54		204	10	1.9	688	7.9
Aug. 25...........	8.40	12		42	1.5	26	4.0	130		18	30	.6	1.2		199	.27		111	4	1.1	333	7.7
Sept. 26..........	75.8	22		102	3.7	45	4.3	294		23	73	.4	1.8		420	.57		270	28	1.2	706	7.6
6. SANDY CREEK NEAR GANADO																						
Sept. 13, 1967....	92.3	12		9.0	2.5	7.2	3.0	41		3.0	9.8	0.2	0.5		67	0.09		33	0	0.5	105	7.0
Oct. 25...........	104	17		17	3.4	16	4.2	70		7.6	21	.3	.8		121	.16		56	0	.9	199	7.1
8. WEST MUSTANG CREEK NEAR GANADO																						
Aug. 24, 1967.....	1160	30		32	6.1	25	7.3	108		9.6	48	0.3	1.0		212	0.29		105	16	1.1	351	6.9
Sept. 12..........	61.8	46		60	12	46	5.5	200		16	88	.4	.5		372	.51		199	35	1.4	609	7.8
Sept. 24..........	3940	15		13	2.7	7.1	3.5	51		4.0	11	.2	.2		82	.11		44	2	.5	125	7.0
Oct. 25...........	34.4	19		25	4.2	14	4.8	93		7.6	22	.2	.5		143	.18		80	3	.7	234	7.2

a Residue on evaporation at 180°C.

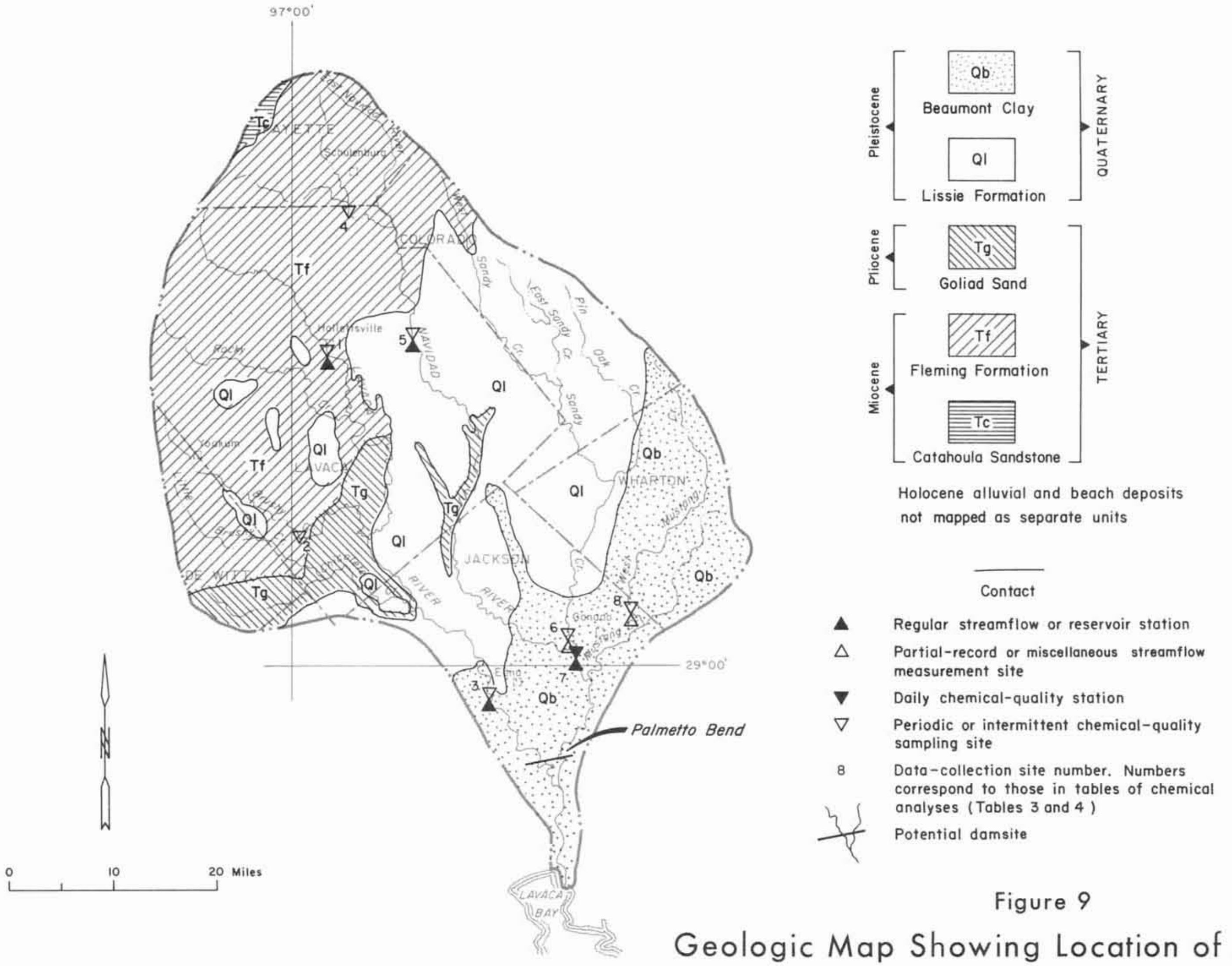

Figure 9

Geologic Map Showing Location of Streamflow and Chemical Quality Data-Collection Sites

Base from U.S. Geological Survey map 1:500,000