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REPORT 93

RECONNAISSANCE OF THE CHEMICAL QUALITY OF SURFACE WATERS OF THE SAN ANTONIO RIVER BASIN, TEXAS

By

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ABSTRACT

The kinds and quantities of minerals dissolved in surface waters of the San Antonio River basin are related principally to the geology of the area and to rainfall and streamflow characteristics. Municipal and industrial wastes have degraded the natural quality of water in some streams.

Rocks exposed in the basin range in age from Cretaceous to Quaternary. The upper part of the basin is underlain by the Edwards and associated limestones and Glen Rose Limestone. Streams that traverse these outcrops usually contain less than 325 mg/l (milligrams per liter) dissolved solids but are very hard. Principal chemical constituents are calcium and bicarbonate. Dissolved-solids content of water in the lower reach of Medina River averages more than 325 mg/l because of municipal and industrial pollution.

The chemical composition of water in streams that traverse younger formations in the central and lower part of the basin is variable. However, the dissolved-solids content of most streams not appreciably affected by pollution averages less than 200 mg/l. Water in these streams usually is moderately hard. Although the chemical quality of water in the mainstem San Antonio River and the lower reach of Cibolo Creek is being degraded by municipal, industrial, and irrigation wastes, the discharge-weighted concentration of dissolved solids in both streams averages less than 500 mg/l. Water in both streams usually is very hard.

The chloride content of surface waters in the basin generally averages less than 20 mg/l, except in areas where the chemical quality is being degraded considerably by pollution.

The concentration of chemical constituents in surface waters throughout much of the basin is within limits recommended by the U.S. Public Health Service for domestic use. The waters also are suitable for most irrigation uses. However, the water throughout much of the basin is moderately hard or very hard and will require softening for most industrial uses.

RECONNAISSANCE OF THE CHEMICAL QUALITY OF SURFACE WATERS OF THE SAN ANTONIO RIVER BASIN, TEXAS

INTRODUCTION

The investigation of the chemical quality of surface waters of the San Antonio River basin, Texas, is a part of a statewide reconnaissance. The chemical quality of surface waters in each of the major river basins is being studied, and a series of reports summarizing the results of the study is being prepared by the U.S. Geological Survey in cooperation with the Texas Water Development Board. (See list of references.)

The purpose of this report is to present available data and interpretations on the quality of surface waters that will aid in the proper development, management, and use of the water resources of the San Antonio River basin. In the study, the following factors were considered: the nature and concentrations of mineral constituents in solution; the geologic, hydrologic, and cultural influences that determine the water quality; and the suitability of the water for municipal supply, industrial use, and irrigation.

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 and with federal and local agencies. However, this network has not been adequate to inventory completely the chemical quality of surface waters in the State. To supplement the information being obtained by the network, a cooperative statewide reconnaissance by the U.S. Geological Survey and Texas Water Development Board was begun in September 1961. Samples for chemical analysis are collected periodically at numerous sites throughout Texas so that some quality-of-water information will be available for locations where water-development projects are likely to be built. These data aid in the delineation of areas having water-quality problems and in the identification of probable sources of pollution, thus indicating areas in which more detailed investigations are needed.

During the reconnaissance, water-quality data were collected for the principal streams and several of their tributaries, Medina Lake, and a number of potential reservoir sites.

Agencies that have cooperated in the collection of chemical quality and streamflow data include the U.S. Army Corps of Engineers, Guadalupe-Blanco River Authority, Edwards Underground Water District, Bexar Metropolitan Water District, city of San Antonio, and Texas State Department of Health.

THE SAN ANTONIO RIVER BASIN AND ITS ENVIRONMENT

Physical Features

The San Antonio River basin comprises an area of more than 4,100 square miles in south-central Texas and includes parts of two physiographic sections—the Edwards Plateau of the Great Plains province and the West Gulf Coastal Plain of the Coastal Plain province (Figure 1). These physiographic sections within the basin are separated by the Balcones Escarpment. Although both the Edwards Plateau and the top of the Balcones Escarpment are partly protected from erosion by a cap of very resistant limestone, streams that rise in the plateau have cut broad valleys below the upland surface. Between these valleys, remnants of the resistant limestone form steep cliffs. The resulting terrain is rough and rugged and the soil mantle is very thin—except along the major stream valleys.

The West Gulf Coastal Plain section within the basin extends from the Balcones Escarpment to the Gulf of Mexico. In this section the rolling to moderately hilly country merges with the level, nearly featureless prairie of the Gulf Coast.

The principal stream that drains the Edwards Plateau section of the basin is the Medina River, which rises in the northwestern part of Bandera County, flows southeastward across the Edwards Plateau, and joins the San Antonio River about 15 miles south of the city of San Antonio (Figure 2).

The mainstem San Antonio River rises in the city of San Antonio near the center of Bexar County, flows southeastward across the West Gulf Coastal Plain, and

Figure 1.—River Basins in Texas and Physiographic Sections of the San Antonio River Basin

joins the Guadalupe River about 11 miles upstream from San Antonio Bay, an arm of the Gulf of Mexico. Another report (Rawson, 1968) describes the quality of water in the Guadalupe River basin.

Cibolo Creek, the principal tributary to the San Antonio River, rises in Kendall County in the Edwards Plateau section, flows southeastward across the Balcones Escarpment and West Gulf Coastal Plain section, and joins the San Antonio River in Karnes County.

Springflow from the Edwards and associated limestones in the Edwards Plateau contributes to the base flow of Medina River and Cibolo Creek. In turn, most of the base flow and a part of the floodflow infiltrates into the Balcones Fault zone on the outcrop of the Edwards and associated limestones (Garza, 1962, p. 4). Consequently, south of the Balcones Fault zone, these streams are often dry.

Climate

The San Antonio River basin has a dry subhumid climate (Thornthwaite, 1952, p. 32) characterized by mild winters and hot summers. Daily minimum temperatures during the winter are seldom less than 0°C (32°F); daily maximum temperatures during the summer usually exceed 32°C (90°F) and occasionally are greater than 38°C (100°F).

Mean annual precipitation in the basin is about 31 inches and ranges from about 26 inches in the west to about 37 inches in the southeast. Mean annual precipitation in the basin and annual and average monthly precipitation at two U.S. Weather Bureau stations for the 1931-60 period are shown on Figure 2. These data indicate that rainfall varies considerably from year to year but that the average monthly rainfall is fairly constant. However, much of the rainfall occurs during thunderstorm activity; consequently, a few days of high intensity rainfall often account for much of the rainfall that occurs in any given month.

Cultural Features and Economic Development

The population of the San Antonio River basin in 1960 was about 700,000, more than 85 percent of which was urban. Three cities, all within the San Antonio metropolitan area, had more than 5,000 inhabitants in 1960 (San Antonio—587,718, Alamo Heights—7,552, and Terrell Hills—5,572).

Agriculture contributes substantially to the economy of the basin. Principal agricultural and livestock products include wool and mohair from the Edwards Plateau section, and poultry, beef cattle, dairy products, cotton, grain, grain sorghum, and vegetables from the West Gulf Coastal Plain section.

Although most of the basin is agriculturally oriented, the San Antonio area is a combined military, commercial, and light industrial center. Food processing, breweries, and tourism are also mainstays of the San Antonio economy.

The production of cement is an important industry in the basin because large deposits of limestone are abundant.

Surface-Water Resources Development

Three reservoirs in the San Antonio River basin have storage capacities of 5,000 acre-feet or more (Figure 8). (In the following discussion, total capacity is that capacity below the lowest uncontrolled outlet or spillway and is based on the most recent reservoir survey available.)

Medina Lake, owned and operated by the Bexar-Medina-Atascosa Counties Water Improvement District No. 1, is the largest reservoir in the basin. This 254,000 acre-foot reservoir on the Medina River supplies water for irrigation, mostly in the Nueces River basin.

Olmos Reservoir, which has a storage capacity of 15,500 acre-feet, is owned and operated by the city of San Antonio for flood protection of the city's business district. The reservoir, located on Olmos Creek in San Antonio, is maintained empty and the area is used for parks and playgrounds—except when needed for floodwater storage.

Victor Braunig Lake, constructed on Arroyo Seco by the City Public Service Board of San Antonio to supply cooling water for a steam-electric generating plant, has a storage capacity of 26,500 acre-feet. Inflow to the lake consists of runoff from the drainage area of Arroyo Seco supplemented by water pumped from the San Antonio River.

CHEMICAL QUALITY OF SURFACE WATER

Chemical-Quality Records

The systematic collection of chemical-quality data on surface waters of the San Antonio River basin by the U.S. Geological Survey was begun in 1942 when a daily sampling station was established on the San Antonio River at Goliad. This station was discontinued in 1946 but was reestablished in 1958. Data obtained from the station until it was discontinued in 1946 consisted of chemical analyses of filtrates from samples collected by the U.S. Soil Conservation Service for the determination of suspended matter. Usually only specific conductance and chloride determinations were made on these filtered samples. Since reestablishment of the station in 1958, chemical analyses have been more comprehensive, and the discharge-weighted averages of analyses have been computed annually. The only other station in the basin for which daily chemical-quality records are available is San Antonio River near Elmendorf, which was established in October 1966. However, periodic or miscellaneous chemical-quality data are available for several additional sites in the basin. Locations of selected data-collection sites are shown on Figure 8. Chemical-quality data for the daily station San Antonio River at Goliad are summarized in Table 5, and the complete records are published in an annual series of U.S. Geological Survey water-supply papers and in reports of the Texas Water Development Board and predecessor agencies. (See table in the list of references.) Results of selected periodic and miscellaneous analyses are given in Table 6. Included in Table 6 are results of analyses of samples collected periodically from the station San Antonio River near Elmendorf before its conversion to a daily station.

The Texas State Department of Health since 1957 has maintained a statewide stream-sampling program which includes the periodic determination of pH, dissolved solids, chloride, and sulfate at eight sites in the San Antonio River basin. Data from this program were made available to the Geological Survey and were studied during the preparation of this report.

Factors Affecting Chemical Quality of Water

All natural waters contain dissolved minerals, most of which are dissociated into charged particles (ions). Principal cations (positively charged ions) are calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), and iron (Fe). Principal anions (negatively charged ions) are carbonate (CO_3), bicarbonate (HCO_3), sulfate (SO_4), chloride (Cl), fluoride (F), and nitrate (NO_3). These and

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 mg/l. High concentrations, as much as 100 mg/l, 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 mg/l of iron in surface waters generally indicate 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 mg/l 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 mg/l. 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 mg/l.
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 mg/l.
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 mg/l. 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 mg/l dissolved solids not be used if other less mineralized supplies are available. Waters containing more than 1000 mg/l dissolved solids are unsuitable for many purposes.

Table 1.—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 non-carbonate hardness. Waters of hardness as much as 60 mg/l are considered soft; 61-120 mg/l, moderately hard; 121-180 mg/l, hard; more than 180 mg/l, 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, 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.

other constituents and properties are determined to evaluate the chemical quality of water. Table 1 lists the constituents and properties commonly determined by the U.S. Geological Survey and includes a resume of their source and significance.

Waters are classified usually in various ways to demonstrate similarities and differences in chemical composition. In the following discussion which relates chemical quality of water to environmental factors, waters are classified on the basis of chemical type and degree of hardness. As to chemical type, water is classified according to the predominant cations and anions in milliequivalents per liter. For example, a water is referred to as a calcium bicarbonate type if the calcium ion constitutes 50 percent or more of the cations and the bicarbonate ion constitutes 50 percent or more of the anions. Waters in which one cation and one anion are not clearly predominant are recognized as mixed types and are identified by names of all important ions.

On the basis of hardness, waters are classified as soft, moderately hard, hard, or very hard. (See tabulation on page 15.)

Geology

The kinds and amounts of dissolved constituents in unpolluted surface waters are determined to a large extent by the geologic environment. All rocks and soils contain soluble minerals, but the amount of minerals available for solution is decreased by leaching. Therefore, rocks and soils in areas of high rainfall usually are well leached and yield water of low mineralization, whereas rocks and soils in arid regions are poorly leached and often yield large quantities of minerals to circulating waters.

Mean annual precipitation in the San Antonio River basin is about 31 inches; consequently, many of the more soluble minerals have been leached from the surface rocks and soils. The dissolved-mineral content of unpolluted surface runoff in the basin usually averages less than 325 mg/l (milligrams per liter).

Most streams in the basin traverse more than one geologic formation; consequently, water in some of these streams is a composite of several different chemical types. Moreover, the chemical composition of water in some streams is altered by municipal or industrial pollutants. For these reasons, the following discussion which relates chemical composition of surface waters to geology is very general.

The geology of the San Antonio River basin has been described by Alexander, Myers, and Dale (1964, p. 29-50). Rocks exposed in the basin consist of sediments that range in age from Cretaceous to Quaternary; the outcrop areas of the various geologic units are shown in Figure 3.

A few chemical analyses of surface water are represented diagrammatically (Stiff, 1951) in Figure 3 to relate chemical composition to geology. The shape of each diagram indicates the relative concentration of the principal chemical constituents; the size of the diagram indicates roughly the degree of mineralization. Most of the samples for which diagrams are shown on Figure 3 were collected during low flow periods when the flow was sustained by the inflow of ground water.

The Edwards Plateau section of the basin is underlain by the Edwards and associated limestones and Glen Rose Limestone of Cretaceous age. These rocks consist largely of limestone, dolomitic limestone, marl, and shale. Chemical analyses of samples collected from Medina Lake indicate that runoff from these rocks averages less than 325 mg/l dissolved solids and is very hard. The water is a calcium bicarbonate type and is typical of water that drains a terrane of impure limestone (Figure 3, site 2).

In the West Gulf Coastal Plain section of the San Antonio River basin, successively younger formations crop out in narrow belts roughly parallel to the coast of the Gulf of Mexico. Rocks from the Grayson Shale of Late Cretaceous age to the Wills Point Formation of the Midway Group of Paleocene age were considered as a unit by Alexander, Myers, and Dale (1964, p. 41) and are mapped together on Figure 3. These rocks, which crop out in a belt from 10 to 15 miles wide in the upper part of the West Gulf Coastal Plain section, consist largely of clay, marl, limestone, and sandstone. Data on the chemical character of surface runoff from these rocks in the San Antonio River basin are lacking. However, in the adjoining Guadalupe River basin, low flows of streams that traverse these rocks usually contain less than 500 mg/l dissolved solids and are calcium bicarbonate or mixed calcium sodium bicarbonate sulfate types.

Other rocks that crop out in the upper and central part of the West Gulf Coastal Plain section include the Wilcox Group, Claiborne Group, Jackson Group, Catahoula Tuff, and the lower part of the Fleming Formation of Tertiary age. These rocks consist largely of sand, sandstone, silt, clay, and gravel. The chemical character of water in streams that traverse these rocks is variable. The dissolved-solids content of low flows in Ecleto Creek near Runge has ranged from less than 100 mg/l to more than 750 mg/l. Principal chemical constituents in the more highly mineralized low flows usually are sodium, calcium, and bicarbonate (Figure 3, site 10).

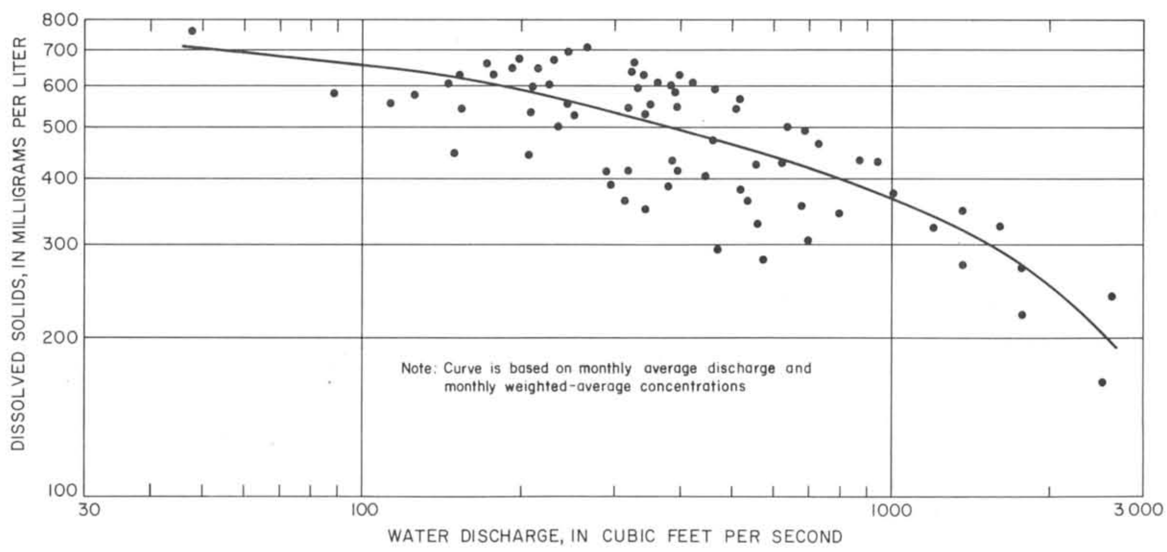

Figure 4.—Relation of Concentration of Dissolved Solids to Water Discharge, San Antonio River at Goliad, Water Years 1959-66

During high flow periods, the water usually contains less than 200 mg/l dissolved solids and is the calcium bicarbonate type.

The dissolved-solids concentration of water in Escondido Creek, which traverses outcrops of Catahoula Tuff and the lower part of the Fleming Formation, usually is less than 250 mg/l. Principal chemical constituents are calcium and bicarbonate, and the water is moderately hard or hard (Figure 3, site 12).

Formations that crop out in the lower part of the San Antonio River basin, in downstream order, are the upper part of the Fleming Formation and Goliad Sand of Tertiary age and the Lissie Formation and Beaumont Clay of Quaternary age. Chemical-quality data for streams that traverse these rocks are lacking; consequently, no generalization about the chemical character of runoff can be made. However, since rainfall in this area averages more than 32 inches annually, the dissolved-solids content of surface runoff probably is low.

Streamflow

The dissolved-solids concentration of streams not regulated by upstream reservoirs usually varies inversely with the water discharge. The concentration usually is minimum during floods when most of the water is surface runoff that has been in contact with the rocks and soils for a short time. Conversely, the concentration is maximum during low flow periods when the flow is sustained by ground-water effluent that has been in contact with the rocks and soils for a sufficient time to dissolve more of the soluble minerals. Figure 4 shows this general relationship to be true for the San Antonio River at Goliad. However, the scatter of points in Figure 4 shows that the inverse relationship between streamflow and concentration of dissolved solids is not precise. Obviously, the concentration of dissolved solids has varied somewhat at all rates of water discharge. Although part of the variation is related to the diverse geology and pattern of runoff from subbasins, the intermittent disposition of municipal and industrial wastes into the river is responsible for much of the variation.

Activities of Man

The activities of man often debase the chemical quality of surface water. Depletion of flow by diversion and consumptive use, and the return flow of irrigation, municipal, and industrial wastes into a stream increase the concentration of dissolved constituents.

According to an inventory by the Texas Water Commission (Gillett and Janca, 1965, p. 39), about 78,600 acre-feet of water was used for irrigation in the San Antonio River basin in 1964. (This does not include water diverted from Medina Lake for irrigation in the Nueces River basin.) Surface-water sources supplied about 32,200 acre-feet, much of which was effluent from San Antonio waste-disposal facilities. The return flow of water used for irrigation has degraded the quality of water in some streams. However, the use of municipal waste water for irrigation has reduced the waste-disposal burden of streams in the San Antonio area.

Chemical-quality data indicate that the return flow of municipal, industrial, and irrigation wastes from the San Antonio area has caused a considerable increase of dissolved minerals in the San Antonio River and the lower reach of the Medina River. Available data for miscellaneous sites indicate that the concentration of dissolved solids in tributary inflow, downstream from the mouth of Medina River, averages less than 300 mg/l, whereas the discharge-weighted concentration of dissolved solids in the San Antonio River at Goliad during the 1959-66 water years averaged 413 mg/l.

Similarly, the quality of water in Cibolo Creek is being degraded by municipal, industrial, and irrigation return flows, especially during periods when natural streamflow is low (Holland and Welborn, 1965, p. 7). During low flow periods, water in Cibolo Creek at Falls City has contained as much as 796 mg/l dissolved solids. Elm Creek, a small tributary to Cibolo Creek, has contained as much as 3,010 mg/l dissolved solids, of which 1,120 mg/l was chloride. Elm Creek drains one of the largest oil fields in the area, and the high concentrations of dissolved solids and chloride indicate that some oil-field brine has reached the stream (Holland and Welborn, 1965, p. 6). Although the inflow of wastes has caused some deterioration of the chemical quality of water in Cibolo Creek, available data indicate that the discharge-weighted concentration of dissolved solids averages less than 300 mg/l.

Daily Variations of Water Quality

The amount of dissolved constituents in a stream is ever changing. Because one or more constituents sometimes may exceed the limit recommended for a specific use, a knowledge of the daily variations of chemical constituents at a particular site is desirable. Table 2 provides this information for selected chemical constituents in water that passed the daily chemical-quality station San Antonio River at Goliad during the 1959-66 water years.

Table 2.—Concentrations of Selected Constituents (in Milligrams per Liter) That Were Equaled or Exceeded for Indicated Percentage of Days of Flow, San Antonio River at Goliad, Water Years 1959-66

CONSITUENT	PERCENT OF DAYS				
	10	25	50	75	90
Sulfate (SO_4)	120	110	100	80	50
Chloride (Cl)	145	130	115	90	50
Dissolved solids	685	640	585	490	345
Hardness as $CaCO_3$	355	335	310	270	200

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Although daily samples were collected from the San Antonio River at Goliad, a complete chemical analysis of each daily sample was not feasible. Therefore, two or more daily samples usually were composited for chemical analysis on the basis of specific conductance, supplemented by data on river stage. For this study, the dissolved-solids content of each daily sample was estimated from the relation of specific conductance to dissolved solids. These data were used to prepare a dissolved-solids duration curve (Figure 5) from which the dissolved-solids values in Table 2 were compiled. Next, curves of relation between dissolved solids and concentrations of sulfate, chloride, and hardness were prepared (Figure 6). Then, for each value of dissolved solids in Table 2, corresponding concentrations of sulfate, chloride, and hardness were tabulated. The resulting Table 2 shows that the concentrations of sulfate, chloride, dissolved solids, and hardness are fairly constant in the mainstem San Antonio River.

Although data in Table 2 and Figure 6 can be used as a rough guide for estimating the percentage of days that a particular concentration will be exceeded in the future, excessively dry or wet years or radical changes in land use or industrial development may cause significant changes in concentrations of some constituents.

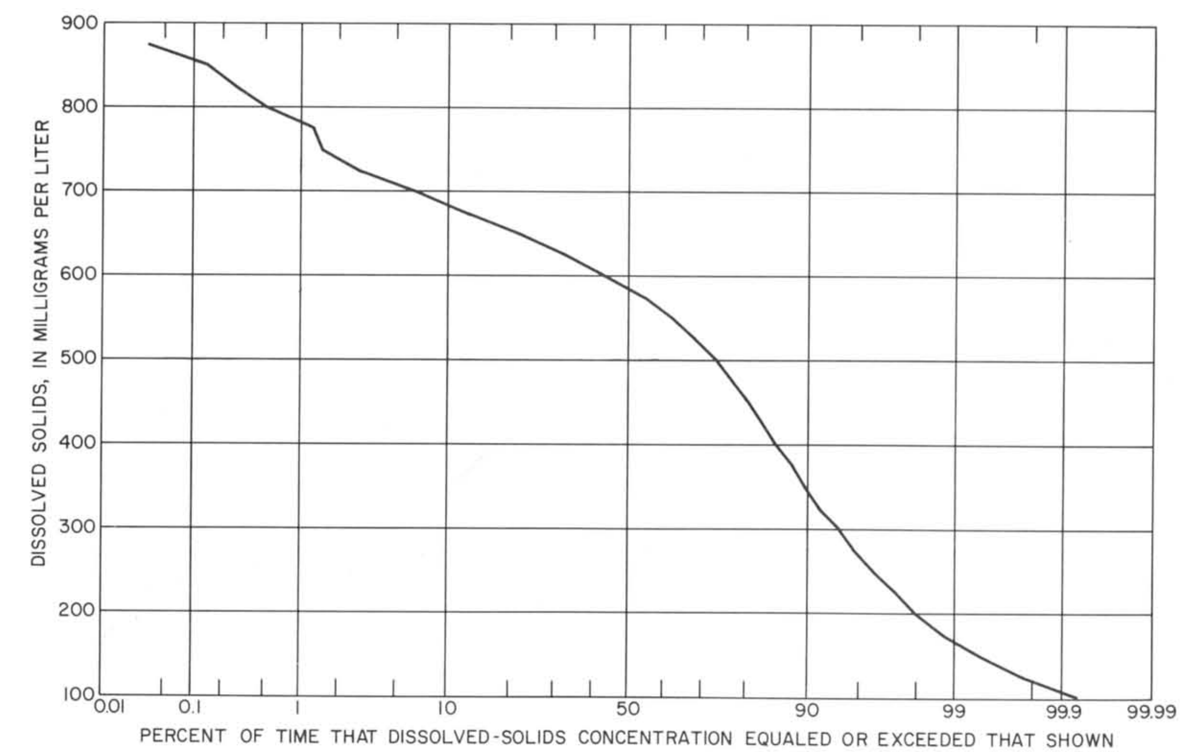


Figure 5.—Duration Curve of Dissolved Solids, San Antonio River at Goliad, Water Years 1959-66

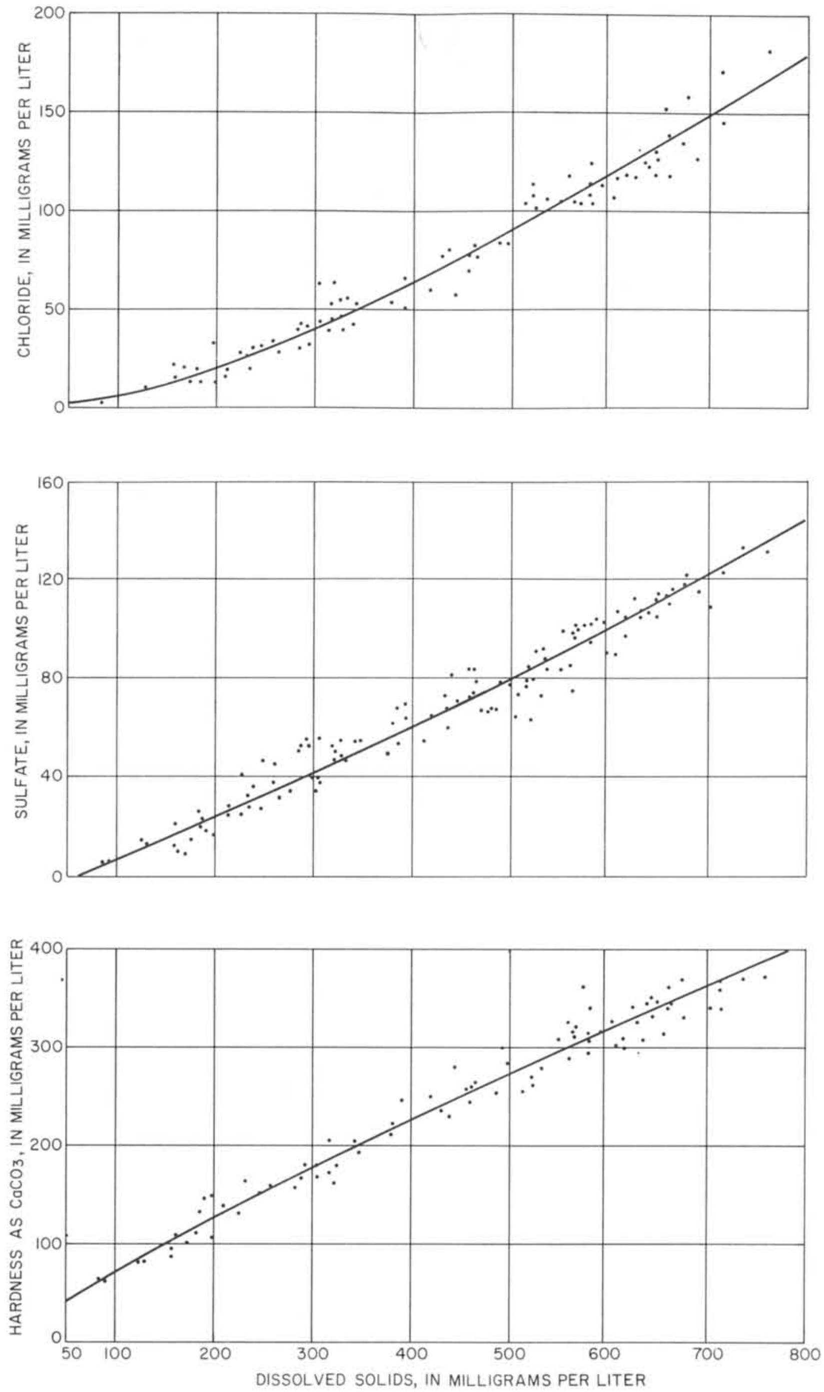


Figure 6

Relation of Dissolved Solids to Chloride, Sulfate, and Hardness, San Antonio River at Goliad

Areal Variations of Water Quality

Some of the previous sections have shown that the concentrations of dissolved constituents vary from stream to stream and from site to site on the same stream. The areal variations of the discharge-weighted average concentrations of dissolved solids, chloride, and hardness are shown in Figure 9. The discharge-weighted average represents approximately the concentration that would be present if all water passing a point in the stream during a period were impounded in a reservoir and mixed, with no adjustment for evaporation, rainfall, or chemical change that might occur during storage. Chemical-quality data for some streams in the basin are meager, especially for floodflows; therefore, the boundaries of the areas in Figure 9 are general. All of the streams will at times have concentrations greater than those shown for their respective areas, but the averages shown in Figure 9 are indicative of the water that would be stored in reservoirs.

Dissolved Solids

The discharge-weighted concentration of dissolved solids in streams that traverse the Edwards Plateau section of the basin averages less than 325 mg/l. Tributary streams that traverse the West Gulf Coastal Plain section of the basin and join the mainstem San Antonio River downstream from the mouth of Medina River generally contain less than 200 mg/l dissolved solids.

Cibolo Creek rises in the Edwards Plateau section and traverses the West Gulf Coastal Plain section. Available data indicate that flow in Cibolo Creek originating in the Edwards Plateau contains about 300 mg/l dissolved solids. However, as Cibolo Creek crosses the Balcones Fault zone, part of this flow is lost as recharge to the Edwards and associated limestones. As the flow remaining in Cibolo Creek moves downstream, its quality is degraded somewhat by the inflow of municipal, industrial, and irrigation wastes. However, natural runoff from the West Gulf Coastal Plain section of the drainage area is low in dissolved solids. Thus, the discharge-weighted concentration of dissolved solids in the lower reach of Cibolo Creek averages about 280 mg/l.

Flow in the mainstem San Antonio River and the lower reach of the Medina River is sustained partly by the inflow of municipal and industrial wastes from the San Antonio area. Nevertheless, the discharge-weighted concentration of dissolved solids in water throughout the mainstem and in the lower reach of Medina River averages less than 500 mg/l. During the 1959-66 water years, for example, the dissolved-solids content of the San Antonio River at Goliad averaged 413 mg/l.

Hardness

Surface runoff from the limestone terrane of the Edwards Plateau section of the basin is very hard. For example, available data indicate that the discharge-weighted concentration of hardness in the upper reaches of Medina River averages more than 200 mg/l.

Surface runoff from the West Gulf Coastal Plain section of the basin generally is moderately hard; the discharge-weighted averages of hardness in most tributaries that join the San Antonio River downstream from the mouth of Medina River are less than 100 mg/l. However, available data indicate that the hardness of water in Cibolo Creek averages more than 180 mg/l.

Water throughout the mainstem San Antonio River is very hard. The discharge-weighted hardness in the San Antonio River at Goliad averaged 228 mg/l during the 1959-66 water years.

Chloride

The chloride content of surface waters in the San Antonio River basin is low—the discharge-weighted concentration in most streams averages less than 20 mg/l. However, the chloride content of water in the mainstem San Antonio River and the lower reaches of Medina River and Cibolo Creek averages more than 20 mg/l because of the inflow of municipal and industrial wastes. Available data indicate that the discharge-weighted chloride concentration averages about 50 mg/l in the lower reach of the Medina River and about 25 mg/l in the lower reach of Cibolo Creek. During the 1959-66 water years, the discharge-weighted concentration of chloride in the San Antonio River at Goliad averaged 68 mg/l.

Other Constituents

Other constituents of importance in the evaluation of the quality of a water include silica, sodium, bicarbonate, sulfate, fluoride, and nitrate.

The silica content of surface water in the San Antonio River basin generally averages less than 20 mg/l. During the 1959-66 water years, the discharge-weighted silica concentration in the San Antonio River at Goliad averaged 17 mg/l.

The sodium content of surface water throughout the basin generally averages less than 20 mg/l—except in areas where pollution is occurring. Available data indicate that the sodium content of water in the lower reach of Cibolo Creek averages about 35 mg/l. The discharge-weighted sodium plus potassium concentration (calculated as sodium) in water of the San Antonio River at Goliad averaged 55 mg/l during the 1959-66 water years.

Bicarbonate is the principal anion in streams that traverse the Edwards and associated limestones and Glen Rose Limestone. Available data indicate that the bicarbonate content of these streams averages more than 175 mg/l. The bicarbonate content of most streams that traverse younger formations is somewhat variable but generally averages less than 150 mg/l. However, the discharge-weighted concentration of bicarbonate in water of the San Antonio River at Goliad averaged 215 mg/l during the 1959-66 water years.

The sulfate content of surface water in the Edwards Plateau section of the San Antonio River basin generally averages less than 75 mg/l. The sulfate content of most streams in the West Gulf Coastal Plain section averages less than 20 mg/l; however, the inflow of pollutants has increased the average sulfate content in some streams. Available data indicate that the sulfate content of water in the lower reach of Cibolo Creek averages about 50 mg/l. During the 1959-66 water years, the discharge-weighted concentration of sulfate in the San Antonio River at Goliad averaged 67 mg/l.

Although the nitrate content of most streams in the San Antonio River basin seldom exceeds 4.0 mg/l, the disposition of municipal wastes has caused a considerable increase in the nitrate content of the mainstem San Antonio River. During the 1959-66 water years, for example, the discharge-weighted concentration of nitrate in the San Antonio River at Goliad averaged 8.2 mg/l. Similarly, the nitrate content of water in Cibolo Creek is fairly high during some periods—water collected from Cibolo Creek near Falls City has contained as much as 7.6 mg/l nitrate.

The concentration of fluoride in surface waters of the San Antonio River basin seldom exceeds 0.7 mg/l. The discharge-weighted concentration of fluoride in the San Antonio River at Goliad averaged 0.4 mg/l during the 1959-66 water years.

Water Quality in Medina Lake

Medina Lake stores water of the calcium bicarbonate type that is hard or very hard. The dissolved-solids content of six samples collected from the reservoir during the period from November 1950 to June 1965 averaged 303 mg/l, of which 14 mg/l was chloride and 75 mg/l was sulfate.

Water Quality at Potential Reservoir Sites

One of the principal objectives of this reconnaissance was to appraise the quality of water available for storage at potential reservoir sites. The locations of three potential reservoir sites are shown on Figure 8. In the following discussion, evaluations of the water quality at these sites are based on present conditions. Municipal and industrial growth in some areas may increase the waste-disposal burdens of the streams and may cause significant changes in water quality before some of the reservoirs can be built.

Cibolo.—Chemical analyses of samples collected from Cibolo Creek near Falls City indicate that water stored in Cibolo Reservoir would contain about 280 mg/l dissolved solids, 25 mg/l chloride, and 50 mg/l sulfate. The water usually would be very hard.

Goliad.—Discharge-weighted average analyses of water collected from the daily station San Antonio River at Goliad indicate that water stored in Goliad Reservoir would contain about 420 mg/l dissolved solids, 70 mg/l chloride, 70 mg/l sulfate, and 230 mg/l hardness.

Confluence.—Confluence Reservoir would store water from both the San Antonio and Guadalupe Rivers. Daily chemical-quality records for the San Antonio River at Goliad and Guadalupe River at Victoria (Rawson, 1968) indicate that the stored water would contain less than 350 mg/l dissolved solids, 50 mg/l chloride, and 50 mg/l sulfate and would be very hard.

Relation of Water Quality to Use

Although other water-quality criteria are important, the suitability of a water for most uses is often dependent on its chemical quality. To present chemical-quality criteria for all purposes would be an endless task. Because surface water in the San Antonio River basin is being used or developments are being planned primarily for municipal supply, industrial use, and irrigation, only these uses will be considered.

Municipal Supply

Because of differences in individuals, amounts of water used, and other factors, defining the safe limits for mineral constituents in water to be used for municipal supply is difficult. The criteria usually accepted in the United States are those recommended by the U.S. Public Health Service. 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). The limits recommended by these standards for some of the more commonly determined constituents are included in the following table.

CONSTITUENT	MAXIMUM CONCENTRATION MG/L
Sulfate	250
Chloride	250
Nitrate	45
Fluoride	0.8 1/
Iron	0.3
Dissolved solids	500

1/ Based on temperature records for San Antonio.

The concentrations of sulfate, chloride, nitrate, and fluoride throughout much of the San Antonio River basin are within limits recommended by the U.S. Public Health Service. Although the concentration of dissolved solids in the mainstem San Antonio River and some of the tributaries often exceeds the recommended limit of 500 mg/l (Tables 2 and 6), a considerable number of water supplies containing more than 500 mg/l dissolved solids have been used for municipal supply without adverse effects. Moreover, the discharge-weighted concentration of dissolved solids in surface waters throughout the basin averages less than 500 mg/l.

Iron determinations usually were not included in the chemical analyses of surface-water samples collected from the San Antonio River basin. However, chemical analyses of water from shallow wells and Medina Lake indicate generally that iron concentrations in surface waters of the basin are within the U.S. Public Health Service recommended limit of 0.3 mg/l.

Hardness is another property usually considered in evaluating a water for municipal supply. Soaps and synthetic detergents react with calcium, magnesium, and other hardness components to form an insoluble curd; thus, the effective concentration of soaps and detergents is decreased in hard water. Surface waters in the Edwards Plateau section of the San Antonio River basin and in Cibolo Creek and San Antonio River are very hard and probably will require softening for domestic use.

Industrial Use

The quality requirements vary greatly for many industrial applications. A few of the maximum limits for chemical constituents in water to be used in industry are given in Table 3; for more detailed information on the requirements of specific industries, the reader is referred to Nordell (1961).

Corrosion is the most widespread and probably the most costly water-caused difficulty with which industry must cope. Consequently, the suitability of a water for many industrial applications is determined partly by its corrosiveness. Large concentrations of dissolved solids, chloride, and sulfate; small concentrations of calcium; and a low or high pH usually are conducive to corrosion. The concentrations of dissolved solids, chloride, and sulfate in surface waters in the San Antonio River basin are not excessive; the pH usually ranges between 6.5 and 8.0; and the waters usually are moderately hard or very hard. On the basis of these properties or constituents, the corrosive potential of surface waters in the basin is low.

Although some calcium hardness may be desirable for the prevention of corrosion, excessive hardness is objectionable for most industrial applications 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 material. The accumulation of scale increases cost for fuel, labor, repairs, and replacements, and lowers the quality of many wet-processed products. A comparison of hardness-duration data for the San Antonio River at Goliad (Table 2) and chemical analyses of water from miscellaneous sites (Table 6) with the classification of hardness in the following table shows that surface waters in the San Antonio River basin will require softening for some industrial applications. Otherwise, the waters are suitable for many industrial applications—or can be made suitable with a minimum of treatment.

HARDNESS (MG/L)	RATING	USABILITY
0 to 60	Soft	Suitable for many uses without further softening.
61 to 120	Moderately hard	Usable except in some industrial applications.
121 to 180	Hard	Softening required by some industries.
181+	Very hard	Softening desirable for most purposes.

Table 3.—Water-Quality Tolerances for Industrial Applications[1]

[Allowable Limits in Milligrams Per Liter Except as Indicated]

INDUSTRY	TURBIDITY	COLOR	COLOR $+O_2$ CONSUMED	DISSOLVED OXYGEN (ml/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	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[7]	--	--	--	--	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 mg/l.
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 mg/l (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.)lor.
11/ Excessive iron, manganese, or turbidity creates spots and discoloration on tanning of hides and leather goods.
12/ Constant composition; residual alumina 0.5 mg/l.
13/ Calcium, magnesium, iron, manganese, suspended matter, and soluable organic matter may be objectionable.

Irrigation

The suitability of a water for irrigation depends primarily on its chemical composition. However, the extent to which chemical quality limits 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 application; the kind of crops grown; and the climate of the region, including the amounts and distribution of rainfall. Because these factors are highly variable, every method of classifying waters for irrigation is somewhat arbitrary.

According to the U.S. Salinity Laboratory Staff (1954, p. 69) the most important characteristics in determining the quality of irrigation water 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 carbonate plus bicarbonate over equivalents of calcium plus magnesium.

High concentrations of dissolved salts in irrigation water may cause a buildup of salts in the soil solution and may make the soil saline. The increased soil salinity may reduce crop yields drastically by decreasing the ability of the plants to take up water and essential plant nutrients from the soil solution. This tendency of irrigation water to cause a high buildup of salts in the soil is called the salinity hazard of the water. The specific conductance of the water is used as an index of the salinity hazard.

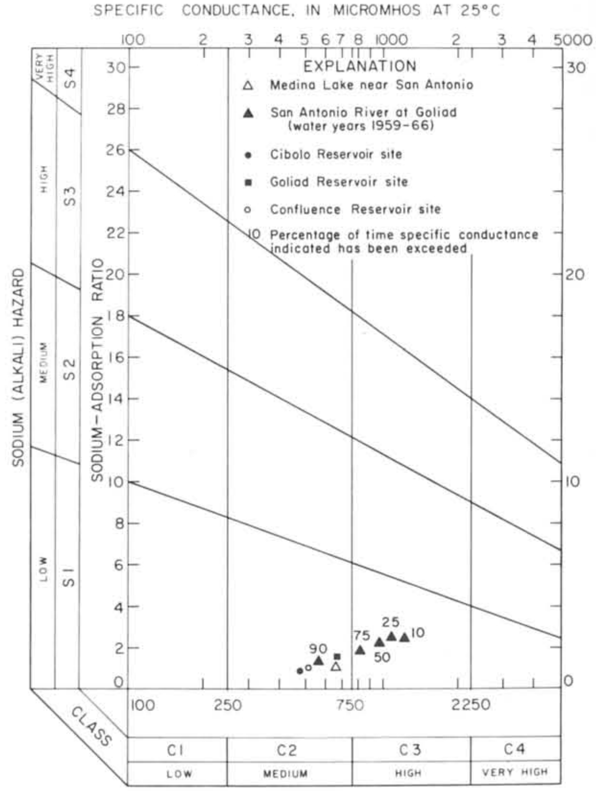
High concentrations of sodium relative to the concentrations of calcium and magnesium in irrigation water can adversely affect soil structure. Cations in the soil solution become fixed on the surface of the soil particles; calcium and magnesium tend to flocculate the particles, whereas sodium tends to deflocculate them. Deflocculation of the soil particles by sodium decreases the permeability of the soil. This tendency to deflocculate soil particles by high sodium concentrations in an irrigation water is called the sodium hazard of the water. An index used for predicting the sodium hazard is the sodium-adsorption ratio (SAR), which is defined by the equation:

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

where the concentrations of the ions are expressed in milliequivalents per liter.

The U.S. Salinity Laboratory Staff has prepared a classification for irrigation waters in terms of salinity and sodium hazards. Empirical equations were used in developing a diagram, reproduced in modified form as Figure 7, which uses SAR and specific conductance in classifying irrigation waters. This classification, although embodying both research and field observations, should be used only for general guidance because many additional factors (such as availability of water for leaching, ratio of applied water to precipitation, and crops grown) affect the suitability of water for irrigation. With respect to both salinity and sodium hazards, waters are divided into four classes—low, medium, high, and very high. The classification range encompasses those waters that can be used for irrigation of most crops on most soils as well as those waters that are usually unsuitable for irrigation. Selection of class demarcation is discussed in detail in the publication by the U.S. Salinity Laboratory Staff (1954).

The salinity and sodium hazards of water at selected sites in the San Antonio River basin are given in Table 4 and Figure 7. Because the concentrations of dissolved solids and individual constituents vary somewhat with change in water discharge, Table 4 shows the sodium and salinity hazards for both low and high flows. These data show that the sodium hazard of surface waters throughout the basin is low. The salinity hazard is somewhat variable but usually ranges from medium to high during low-flow periods when rainfall is deficient and irrigation is desirable. The salinity hazard of water that passed the daily station San Antonio River at Goliad during the 1959-66 water years was high more than 75 percent of the time. The salinity hazard of water stored in Medina Lake usually is medium; the sodium



(Adapted from U.S. Salinity Laboratory Staff, 1954, p. 80)

Figure 7.—Classification of Irrigation Waters

hazard is low. Available data indicate that the salinity hazard of water that would be stored in Cibolo, Goliad, and Confluence Reservoirs would be medium.

Surface water for irrigation in the San Antonio River basin is being used principally for the supplemental irrigation of pastures and fields producing feed, forage, and vegetables. Water-quality requirements for water used for supplemental irrigation of these crops are not stringent. Thus, the medium and high salinity hazards of surface water in the basin do not preclude the use of water for irrigation.

Other criteria for evaluating the suitability of water for irrigation include the boron content and residual sodium carbonate (excess of equivalents of carbonate plus bicarbonate over equivalents of calcium plus magnesium). Although small quantities of boron are essential for normal plant growth, concentrations that are required for the optimum growth of some plants are toxic to others. Water with residual sodium carbonate causes irrigated soils to become alkaline and thus reduces the soil's permeability.

Boron determinations usually were not included in the analyses of surface-water samples collected from the San Antonio River basin. However, the boron content of surface waters in the adjoining Guadalupe River basin is low. During the 1951-56 water years, for example, the discharge-weighted concentration of boron in the Guadalupe River at Victoria averaged 0.20 mg/l. Streams in the Guadalupe and San Antonio River basins traverse the same geologic formations; thus, the boron content of surface waters in the San Antonio River basin probably is low.

With regard to residual sodium carbonate, surface waters in the San Antonio River basin usually contain an excess of equivalents of calcium plus magnesium over equivalents of bicarbonate plus carbonate. Consequently, the residual sodium carbonate is usually zero.

Table 4.—Suitability of Waters for Irrigation

STATION (FIGURE 8)	STREAM AND LOCATION	DATE	WATER DISCHARGE (cfs)	SALINITY HAZARD	SODIUM HAZARD
2	Medina Lake near San Antonio	Nov. 28,1950	—	medium	low
		Oct. 9,1964	—	do	Do.
4	San Antonio River near Elmendorf	May 18,1964	15,200	do	Do.
		Apr. 30,1965	226	high	Do.
6	Calaveras Creek near Elmendorf	Feb. 23,1965	1.11	low	Do.
		May 18,1965	1,340	do	Do.
7	San Antonio River near Falls City	Apr. 10,1959	433	high	Do.
		May 19,1956	5,010	medium	Do.
9	Cibolo Creek near Falls City	Aug. 7,1962	4.81	high	Do.
		May 18,1965	8,190	medium	Do.
10	Ecleto Creek near Runge	Jan. 30,1961	1.1	high	Do.
		Jan. 22,1965	2,650	low	Do.
12	Escondido Creek at Kenedy	Feb. 15,1965	.1	medium	Do.
		Feb. 16,1965	1,360	~~medium~~ do	Do.

Be consistent

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WATER YEAR	U.S.G.S. WATER-SUPPLY PAPER NO.	T.W.D.B. REPORT NO.
1943-45	—	*1938-45
1946	1050	*1946
1959	1644	Bull. 6205
1960	—	Bull. 6215
1961	—	Bull. 6304
1962	1944	Bull. 6501
1963	1950	Rept. 7

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

Table 5.--Summary of Chemical Analyses at Daily Stations on Streams in the San Antonio 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 milligrams per liter except as indicated.)

Date of collection	Mean 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 (calculated): Milligrams per liter	Dissolved solids (calculated): Tons per acre-foot	Dissolved solids (calculated): Tons per day	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH
14. SAN ANTONIO RIVER AT GOLIAD																						
Water year 1942																						
Maximum, Aug. 25, 1942....	281	--		--	--	--		--		--	192	--	--		--	--	--	--	--	--	1210	--
Minimum, July 6...........	6910	--		--	--	--		--		--	9.0	--	--		--	--	--	--	--	--	174	--
Water year 1944																						
Maximum, Feb. 25, 1944....	263	--		--	--	--		--		--	--	--	--		--	--	--	--	--	--	1270	--
Minimum, May 4............	6070	--		--	--	--		--		--	12	--	--		--	--	--	--	--	--	250	--
Water year 1945																						
Maximum, June 30, 1945....	344	--		--	--	--		--		--	132	--	--		--	--	--	--	--	--	959	--
Minimum, Apr. 22..........	2350	--		--	--	--		--		--	20	--	--		--	--	--	--	--	--	328	--
Water year 1946																						
Maximum, Sept. 11-12, 28, 1946....................	1724	--		91	17	57		280		75	77	--	6.2		a560	0.76	2610	297	68	--	801	--
Minimum, May 17-18........	5220	--		36	4.0	13		122		15	11	--	3.0		a175	.24	2470	106	6	--	248	--
Water year 1959																						
Maximum, Sept. 18, 1959...	199	--		--	--	--		269		--	216	--	--		808	1.10	434	290	70	--	1300	8.1
Minimum, Oct. 30-31, Nov. 1, 1958............	4403	15		31	4.5	17		102		21	16	0.2	4.2		159	.22	1890	96	12	0.7	271	7.8
Weighted average..........	597	18		77	16	57		242		73	70	.4	10		457	.62	737	258	60	1.5	732	--
Water year 1960																						
Maximum, June 11-24, 1960.	124	23		105	23	106		314		122	139	.5	5.2		a726	.99	243	356	99	2.4	1100	8.0
Minimum, July 21..........	3070	9.8		25	6.6	21		109		20	15	.4	4.0		156	.21	1290	90	1	1.0	265	7.3
Weighted average..........	429	18		73	15	65		232		74	78	.5	9.8		460	.63	533	244	54	1.8	745	--
Water year 1961																						
Maximum, June 1-10, 1961..	226	23		104	23	109		310		127	141	.6	6.9		a725	.99	442	354	100	2.5	1140	7.9
Minimum, Oct. 27, 1960....	9230	--		--	--	--		75		--	3.0	--	--		85	.12	2120	57	0	--	138	7.4
Weighted average..........	994	16		60	11	43		188		55	52	.4	6.1		347	.47	931	194	40	1.3	564	--
Water year 1962																						
Maximum, Apr. 1-10, 1962..	252	20		105	23	102		308		125	133	.5	8.9		a718	.98	489	356	104	2.3	1100	7.8
Minimum, June 3...........	5190	--		--	--	--		89		8.6	16	--	--		137	.19	1920	74	1	--	218	7.4
Weighted average..........	374	20		75	16	69		237		79	84	--	9.3		488	.66	493	253	59	1.9	761	7.7
Water year 1963																						
Maximum, Aug. 1-31, 1963..	47.9	24		106	26	132		316		132	182	.6	3.5		761	1.03	98.4	372	112	3.0	1290	7.6
Minimum, Dec. 22, 1962....	1060	--		--	--	--		99		12	22	--	--		158	.21	452	86	5	--	262	7.4
Weighted average..........	196	18		81	17	79		239		91	102	--	11		524	.71	277	271	75	2.1	863	7.5
Water year 1964																						
Maximum, Aug. 1-8, 1964...	144	19		86	24	117		268		114	157	.6	7.0		657	.89	255	313	94	2.9	1100	8.2
Minimum, Aug. 9-10........	3885	16		38	3.2	136		10		13	--	--	.2		162	.22	1700	108	0	.6	276	8.0
Weighted average..........	289	16		71	15	62		219		73	78	--	8.4		431	.59	336	236	57	1.7	732	7.5
Water year 1965																						
Maximum, July 1-31, 1965..	231	20		110	23	97	6.3	320		118	135	.6	6.8		674	.92	420	369	107	2.2	1140	7.5
Minimum, Feb. 17-19.......	5537	10		29	2.3	14		98		13	11	--	2.8		130	.18	1940	82	2	.8	225	7.8
Weighted average..........	676	14		64	11	43		198		54	53	--	6.7		343	.47	626	204	42	1.2	582	7.3
Water year 1966																						
Maximum, Feb. 1-10, 1966..	287	14		107	21	94	5.9	304		112	120	.3	21		648	.88	502	354	105	--	1090	7.8
Minimum, Oct. 20-22, 1965.	3097	11		41	5.3	13		102		28	26	--	3.0		177	.24	1480	124	40	--	328	7.5
Weighted average..........	390	15		75	14	64		222		74	81	.4	8.6		445	.61	469	246	64	1.8	769	7.6

a Residue at 180°C.

Table 6.--Chemical Analyses of Streams and Reservoirs in the San Antonio River Basin for Locations other than Daily Stations

(Results in milligrams per liter 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 (calculated): Milligrams per liter	Dissolved solids (calculated): Tons per acre-foot	Dissolved solids (calculated): 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. SAN ANTONIO RIVER AT SAN ANTONIO																						
June 7, 1965......	39.4	12		66	13	23		206		42	36	0.3	5.8		299	0.41		218	49	0.7	531	6.9
2. MEDINA LAKE NEAR SAN ANTONIO																						
Nov. 28, 1950.....		9.9		78	16	47		234		134	20	--	3.5		a455	0.62		260	69	1.2	655	7.9
Oct. 19, 1951.....		11	0.00	58	21	8.5	3.6	168		93	13	0.1	2.2	0.61	a350	.48		235	0	.2	484	8.1
Apr. 8, 1954......		7.0		66	15	10		209		57	12	--	2.0		a303	.41		226	55	.3	462	8.1
Sept. 15, 1964....		9.8		62	22	12		191		84	18	.4	.5		303	.41		245	88	.3	500	7.3
Oct. 9...........		6.4		44	8.1	3.1	2.6	132		31	5.9	.3	6.2		173	.24		143	40	.1	296	7.0
July 16, 1965.....		7.8		52	15	6.4	2.0	170		52	12	.2	1.2		233	.32		191	52	.2	405	7.1
3. MEDINA RIVER NEAR SAN ANTONIO																						
June 7, 1965......	306	12		76	16	29		250		52	39	0.3	5.0		352	0.48		256	50	0.8	625	7.2
4. SAN ANTONIO RIVER NEAR ELMENDORF																						
Sept. 28, 1964....	333	11		73	10	32		240		45	34	0.4	0.8		324	0.44		223	26	0.9	554	7.0
Nov. 4...........	5,630	13		63	7.0	12		238		3.8	8.6	.2	.5		225	.31		186	0	.4	397	6.8
Nov. 5...........	3,730	11		69	6.8	21		234		25	19	.3	1.2		268	.36		200	8	.6	468	6.9
Apr. 30, 1965.....	226	16		88	18	74		281		86	84	.6	17		522	.71		294	63	1.9	870	7.1
May 17...........	4,660	12		56	5.7	15		191		22	11	.3	.5		216	.29		163	7	.5	377	7.6
May 17...........	5,380	13		60	4.9	14		204		18	9.6	.4	.5		220	.30		170	3	.5	380	7.1
May 18...........	15,200	7.4		47	4.3	11		153		22	6.3	.3	2.2		176	.24		135	10	.4	309	7.0
May 19...........	10,400	9.9		64	6.4	18		206		28	17	.1	2.5		247	.34		186	17	.6	436	6.9
June 4...........	406	14		88	20	54		278		82	68	.4	12		475	.65		302	74	1.4	800	7.6
5. CALAVERAS CREEK SUBWATERSHED NO. 6 NEAR ELMENDORF																						
Sept. 6, 1962.....		7.8		56	13	57		137		126	50	0.7	0.0		a382	0.52		193	80	1.8	614	6.9
Apr. 29, 1963.....		4.6		50	9.6	28		133		86	18	.5	.2		262	.36		164	55	1.0	437	6.9
Mar. 1, 1965......		6.8		24	2.9	4.6	5.2	87		12	2.7	.3	2.0		104	.14		72	1	.2	183	6.7
6. CALAVERAS CREEK NEAR ELMENDORF																						
Apr. 5, 1963......	23.5	6.2		24	2.4	3.9	6.7	76		13	6.0	0.4	1.2		101	0.14		70	7	0.2	172	6.4
Sept. 13..........	43.9	8.5		39	3.6	11		126		23	5.1	.5	1.5		154	.21		112	9	.5	281	6.5
Feb. 23, 1965.....	1.11	6.7		30	3.7	11		109		15	5.6	.3	.8		127	.17		90	1	.5	227	7.5
May 18...........	1340	8.2		32	2.7	2.8	4.2	116		4.8	2.6	.1	.2		115	.16		91	0	.1	203	6.6
7. SAN ANTONIO RIVER NEAR FALLS CITY																						
Apr. 10, 1959.....	433	16		90	20	61		b264		94	75	0.3	22		508	0.69		306	90	1.5	852	8.5
May 19, 1965......	5010	8.9		62	4.4	13		204		19	8.2	.2	1.8		218	.30		173	6	.4	383	7.0
June 3............	547	13		100	21	60		302		95	77	.4	14		529	.72		336	88	1.4	897	7.2
8. ELM CREEK NEAR LAVERNIA																						
Mar. 6, 1963......	0.1	--		--	--	--		249		344	750	--	0.0		--	--		920	716	--	3140	6.8
Mar. 11, 1964.....	c.05	10		410	101	517		298		708	1120	--	1.5		3010	4.09		1440	1190	5.9	4700	7.0
Mar. 21...........	1.17	12		64	11	58		129		86	94	0.4	1.0		389	.53		204	99	1.8	692	6.9
Feb. 18, 1965.....	92.4	11		21	2.8	3.6	5.5	62		19	3.1	.3	3.2		100	.14		64	13	.2	160	7.2

See footnotes at end of table.

Table 6.--Chemical Analyses of Streams and Reservoirs in the San Antonio River Basin for Locations other than Daily Stations--Continued

(Results in milligrams per liter 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 (calculated): Milligrams per liter	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
9. CIBOLO CREEK NEAR FALLS CITY																						
Oct. 25, 1961	28.7	16		83	15	77		211		147	76	0.5	1.8		a545	0.74		268	96	2.0	831	7.5
Jan. 5, 1962	34.6	11		101	21	111		258		196	112	.3	7.1		a727	.99		338	127	2.6	1130	7.1
Jan. 30	34	13		107	19	112		275		190	112	.3	7.6		a714	.97		345	120	2.6	1130	7.1
Apr. 18	26.4	12		86	24	135		187		203	170	.3	2.2		a738	1.00		313	160	3.3	1200	7.4
June 4	32	11		44	7.6	54		139		73	47	.3	.8		a326	.44		142	28	2.0	532	6.7
Aug. 1	8.15	17		70	21	133		168		216	132	.4	.0		672	.91		261	124	3.6	1090	7.3
Sept. 5	8.22	18		83	19	125		218		192	126	--	.2		670	.91		285	106	3.2	1100	7.5
Oct. 18	10.2	15		82	18	118		218		190	112	.3	.2		648	.94		278	100	3.1	1030	7.6
Nov. 26	14.0	16		87	21	123		236		205	115	.3	.2		684	.93		304	110	3.1	1090	7.6
Jan. 3, 1963	19.2	14		98	19	103		226		198	110	.4	.0		a661	.90		322	138	2.5	1030	7.5
Mar. 7	17.2	8.8		95	18	100		212		197	104	.5	2.2		a637	.87		311	138	2.5	1020	7.2
Aug. 7	4.81	19		82	21	169		216		226	173	.5	.0		796	1.08		291	114	4.3	1270	7.3
Nov. 10	312	6.8		38	3.7	11		114		23	8.8	.3	4.2		152	.21		110	17	.5	271	6.6
Jan. 28, 1964	12.9	17		108	21	124		250		220	135	.2	.0		748	1.02		356	151	2.9	1200	7.8
June 19	688	9.4		46	4.2	7.0	5.4	150		15	6.5	.3	4.8		173	.24		132	9	.3	295	7.0
July 21	5.36	13		82	16	103		213		158	110	.4	.0		587	.80		270	96	2.7	964	7.1
Aug. 25	28.9	6.1		42	7.3	27		99		73	25	.4	.8		231	.31		135	54	1.0	399	6.7
Sept. 29	2700	11		68	5.4	2.6	3.8	226		9.6	3.2	.3	.0		215	.29		192	7	.1	367	7.1
Sept. 29	2400	7.9		58	4.4	2.9	4.4	187		10	3.6	.4	4.8		188	.26		163	10	.1	327	7.2
Oct. 1	126	8.4		59	5.1	11		184		24	8.8	.4	3.5		210	.29		168	17	.4	361	7.1
Nov. 2	17.7	9.6		52	7.4	39		160		57	36	.6	1.5		282	.38		160	29	1.3	479	7.1
Feb. 17, 1965	2790	11		63	5.1	8.1	4.1	205		18	6.1	.3	2.5		219	.30		178	10	.3	382	7.1
Apr. 29	75.3	15		87	15	85		254		134	80	.3	1.0		542	.74		278	70	2.2	891	7.2
May 18	8190	6.3		47	3.6	2.9	4.1	159		8.8	3.0	.1	1.2		155	.21		132	2	.1	276	7.0
May 20	5540	3.8		60	4.0	5.4	4.4	201		14	5.1	.2	.2		196	.27		166	1	.2	351	7.3
May 21	1320	11		57	5.8	12		188		21	9.3	.1	3.2		211	.29		166	12	.4	367	7.0
June 4	110	12		97	16	52		296		87	59	.3	4.8		474	.64		308	66	1.3	802	6.8
10. ECLETO CREEK NEAR RUNGE																						
Oct. 24, 1961	1.03	12		32	3.4	43		144		17	35	0.5	0.5		214	0.29		94	0	1.9	371	7.0
Jan. 2, 1962	1.36	20		72	9.9	119		314		64	108	.5	.5		a570	.78		220	0	3.5	928	7.6
Jan. 30	1.1	17		76	12	148		342		79	139	.5	.0		a647	.88		239	0	4.2	1080	7.5
June 2	971	12		50	1.6	6.1	5.3	168		4.4	6.0	.2	.0		169	.23		131	0	.2	292	6.9
June 4	75.0	12		23	2.4	28		96		14	23	.3	1.5		151	.21		67	0	1.5	262	6.5
June 5	15.9	11		22	3.5	33		92		26	26	.4	2.0		169	.23		69	0	1.7	304	6.3
Sept. 27	.01	19		36	3.1	13		134		6.8	8.5	.2	1.2		154	.21		103	0	.6	246	6.6
Dec. 18, 1963	1.03	10		20	2.2	15		74		13	12	.2	1.0		109	.15		59	0	.8	197	6.5
Apr. 3, 1964	c.21	16		56	5.5	91		264		23	84	.4	.5		406	.55		162	0	3.1	719	7.3
Aug. 8	194	18		40	2.5	10		147		5.6	2.8	.2	2.0		153	.21		110	0	.4	254	6.7
Jan. 22, 1965	2650	12		26	2.2	10		102		5.2	3.0	.3	2.2		111	.15		74	0	.5	178	7.4
Jan. 23	459	9.8		14	2.4	13		60		11	7.2	.2	3.5		91	.12		45	0	.8	157	6.6
Feb. 16	67.8	13		44	3.5	15		141		15	17	.1	2.2		179	.24		124	9	.6	324	7.1
Apr. 29	.10	20		125	16	131		296		119	209	.4	.2		767	1.04		378	136	2.9	1360	7.2
May 21	82	11		16	1.7	13		65		9.0	7.3	.2	1.0		91	.12		47	0	.8	153	6.1
May 22	29.9	12		20	2.2	12		76		9.4	8.3	.1	2.5		104	.14		59	0	.7	177	6.5
May 25	4.41	19		36	4.9	26		138		17	24	.3	.8		196	.27		110	0	1.1	331	7.6

See footnotes at end of table.

Table 6.--Chemical Analyses of Streams and Reservoirs in the San Antonio River Basin for Locations other than Daily Stations--Continued

(Results in milligrams per liter 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 (calculated): Milligrams per liter	Dissolved solids (calculated): Tons per acre-foot	Dissolved solids (calculated): Tons per day	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH
11. ESCONDIDO CREEK SUBWATERSHED NO. 1 NEAR KENEDY																						
Jan. 11, 1955....		--		--	--	--		110		--	3.5	--	--		--	--		74	0	--	241	7.5
June 1..........		--		--	--	7.5		120		2.0	3.5	--	--		--	--		89	0	--	229	7.2
July 13.........		10		32	1.5	4.5	4.9	114		2.9	2.0	0.4	3.8		a123	0.17		86	0	0.2	230	7.9
Jan. 4, 1956.....		3.0		24	2.7	12		108		1.5	3.8	.5	1.4		a115	.16		72	0	.6	184	7.3
July 10..........		--		--	--	--		190		--	3.5	--	--		--	--		138	0	--	295	7.2
Dec. 17..........		--		--	--	--		156		--	4.0	--	--		a160	.22		117	0	--	279	7.5
Feb. 25, 1957....		5.0		21	1.7	12		83		7.2	4.5	.5	3.5		96	.13		59	0	.7	143	7.5
Mar. 12..........		11		22	1.3	10		87		3.4	3.2	.5	3.0		97	.13		61	0	.6	164	7.8
Apr. 17..........		12		30	1.6	4.9	6.2	111		2.8	2.5	.5	3.2		119	.18		81	0	.2	166	6.9
Apr. 22..........		18		42	2.3	14		143		5.4	10	.8	5.0		a183	.25		113	0	.6	285	7.5
Apr. 27..........		7.8		19	.8	4.9		71		.6	.0	.5	2.0		71	.10		51	0	.3	127	7.9
Sept. 30.........		6.0		23	1.6	6.8	8.0	96		3.8	4.5	.2	1.0		102	.14		64	0	.4	174	7.4
Nov. 18, 1957....		--		--	--	--	--	118		--	2.5	--	--		--	--		88	0	--	205	7.2
Jan. 6, 1958.....		--		--	--	--	--	104		--	2.2	--	--		--	--		77	0	--	170	7.6
Jan. 27..........		--		--	--	--	--	106		--	3.0	--	--		--	--		75	0	--	155	8.2
May 28...........		--		--	--	--	--	104		--	3.0	--	--		--	--		77	0	--	180	7.9
Feb. 10, 1959....		1.9		33	2.8	6.8	6.5	120		7.2	4.8	.4	3.2		126	.17		94	0	.3	236	7.5
Oct. 26..........		12		36	2.0	3.8	7.4	131		.6	3.0	.4	.8		a143	.19		98	0	.2	233	7.0
Mar. 10, 1960....		8.7		36	2.0	5.0	6.3	126		3.8	3.0	.2	4.0		131	.18		98	0	.2	228	7.0
Aug. 2...........		8.0		43	2.2	12		163		.6	4.8	.3	.2		151	.21		116	0	.5	271	7.0
Mar. 9, 1961.....		1.0		42	3.0	15		134		6.8	22	.2	.8		157	.21		117	7	.6	303	7.0
Sept. 4, 1962....		11		57	3.0	26		224		10	9.0	--	5.6		232	.32		155	0	.9	379	7.0
Mar. 7, 1963.....		6.6		43	2.4	4.3	5.6	153		.2	2.8	.3	.2		140	.19		117	0	.2	256	6.9
Feb. 15, 1965....		10		30	1.3	3.5	4.0	108		.8	1.2	.3	.2		104	.14		80	0	.2	180	7.0
May 20...........		10		33	1.4	11		124		4.2	1.9	.3	2.2		125	.17		88	0	.5	211	7.9
May 21...........		12		33	2.3	5.6	4.5	122		5.2	2.0	.2	2.8		128	.17		92	0	.3	211	7.5
May 24...........		11		33	2.1	6.0	4.6	124		4.6	2.3	.3	2.2		127	.17		91	0	.3	215	7.8
12. ESCONDIDO CREEK AT KENEDY																						
May 3, 1959......	0	10		54	4.8	38		168		17	56	0.4	1.0		264	0.36		154	17	1.3	487	7.4
Apr. 30, 1963....	82.7	23		28	2.1	16		100		11	11	.6	2.2		143	.19		78	0	.8	221	6.9
May 1............	11.2	16		36	2.9	27		145		20	12	1.0	1.0		187	.25		102	0	1.2	309	6.8
Feb. 15, 1965....	c.1	16		40	2.7	32		145		18	29	.6	.2		210	.29		111	0	1.3	351	7.4
Feb. 16..........	1360	14		52	2.7	6.1	4.5	182		7.2	3.0	.4	.2		179	.24		141	0	.2	299	7.4
Feb. 17..........	200	11		50	3.2	23		173		12	23	.6	.0		208	.28		138	0	.9	363	7.3
13. ESCONDIDO CREEK SUBWATERSHED NO. 11 (DRY ESCONDIDO CREEK) NEAR KENEDY																						
Sept. 14, 1962...		1.7		23	3.2	28		118		4.8	21	0.3	0.0		140	0.19		71	0	1.4	263	6.5
Oct. 30, 1964....		3.3		29	9.1	104		273		8.4	72	.5	.5		361	.49		110	0	4.3	697	6.6
Feb. 15, 1965....		9.6		26	3.4	29		119		7.8	24	.4	1.2		160	.22		79	0	1.4	285	7.3
Feb. 19..........		9.4		25	1.4	21		106		6.4	14	.3	.5		130	.18		68	0	1.1	229	7.0

a Residue at 180°C.
b Includes the equivalent of a milligrams per liter carbonate (CO_3).
c Field estimate.