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Potential Impact of the Development of Lignite Reserves on Water Resources of East Texas

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POTENTIAL IMPACT OF THE DEVELOPMENT OF LIGNITE RESERVES ON WATER RESOURCES OF EAST TEXAS

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ABSTRACT

This study was conducted for the Office of Water Resources Research and Technology in the U.S. Department of the Interior by the Texas Engineering Experiment Station at Texas A&M University. The project was concerned with identifying potential adverse effects of lignite strip mining and lignite utilization on the hydrology and water quality of the area. Both field and desk studies were conducted to evaluate the potential impact of lignite development on water resources of the area. Field studies included (1) monthly water sampling for a one-year period of streams, lakes and wells near the strip-mined areas at Fairfield and Rockdale and at control stations located away from the lignite development; (2) leaching studies of the lignite and overburden at Fairfield and Rockdale; (3) precipitation samples collected under the airborne waste plume from the lignite-fueled electric generating plant at Fairfield; and (4) a limited trace element enrichment study in the soils around the plant at Fairfield.

Potential lignite reserves, as defined by the Bureau of Economic Geology, include about 41 percent of the outcrop area of the Wilcox Aquifer. Strip mining can change the hydrologic characteristics of the area and full development of the near-surface lignite reserves in east and east central Texas could have a significant impact on the groundwater resources of the region. Changes in the recharge rate of the Wilcox aquifer should be considered when identifying new lignite deposits for development. Also hydrologic characteristics should be considered when developing reclamation plans for the spoil area.

Lignite-fired power plants cause environmental modifications of considerable magnitude and consume a significant quantity of water.

During the 35-year expected life of a 1,000-megawatt, lignite-fired power plant, about 21,000 acres of land would typically be strip mined. Approximately 25 percent of the identified near-surface lignite deposits are committed to existing and presently planned lignite-fired power plants in Texas. The Development of deep-basin lignite deposits in the near future appear inevitable.

Lignite can contain elevated concentrations of certain trace elements and power plants tend to concentrate these elements. A 1,000-megawatt plant requires approximately six million tons of lignite per year. When the lignite is fired at the plant some trace metals are concentrated in the fly ash (arsenic, iron, manganese and lead), while others are discharged from the stack primarily as a vapor (mercury and selenium). Improper handling and disposal of fly ash could result in pollution of water supplies. Precipitation samples collected at Fairfield under the airborne waste plume from the Big Brown plant had elevated concentrations of chromium, iron, manganese, selenium and phosphate when compared to background precipitation samples. A trace element enrichment study of the soils around the plant should be conducted to monitor the concentrations of those elements that could adversely affect the plant and animal life of the area.

Small surface streams near Rockdale and Fairfield had elevated levels of zinc, selenium, manganese and sulfate as compared to other surface waters observed in the study. Strip mining or power generation was probably not the primary source of the elevated levels of these parameters. A water quality study should be initiated to accurately identify the source of these elevated parameters.

Water quality in the cooling lakes at the Alcoa plant near Rockdale and the Big Brown plant near Fairfield was generally good. Highest observed values of many of the surface water quality parameters were in the spoil lake in the strip-mined area at Alcoa. Since there appears to be a direct hydraulic connection between water in the spoil lake and the shallow groundwater aquifer in the area, poor water quality in the lake could adversely affect the groundwater. Additional groundwater studies were recommended for both the Rockdale area and the Fairfield area.

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CHAPTER I

INTRODUCTION

The energy crisis has produced a dramatic increase in demand for coal. The value of coal has significantly increased to the point where deposits which were previously uneconomical can now be profitably developed. The discovery and development of oil and gas has fallen behind consumption and increased development of lignite will be necessary.

Near-surface Texas lignite depoists are found throughout the Texas Gulf Coastal Plain. Main deposits occur in the Calvert Bluff Formation of the Wilcox Group, with minor deposits in the Yegua and Jackson Formation. Recent mapping of lignite lands in the Texas Gulf Coastal Plain by the Bureau of Economic Geology indicates approximately 1,000,000 acres are possibly underlain by recoverable lignite (within 200 feet of the ground surface). The location of the near-surface lignite reserves are shown in Figure 1.

The objectives of this study are:

(1) Define existing, proposed and potential lignite development activities,
(2) estimate strip mining land requirements and water consumption for power generation,
(3) collect and develop grounwater and surface water baseline data that might be affected by lignite development in East Texas,
(4) estimate the impact of the proposed and potential activities on the quality and quantity of surface and grounwater in East Texas and
(5) identify potential water resources problem associated with development and make recommendations to minimize the adverse impacts.

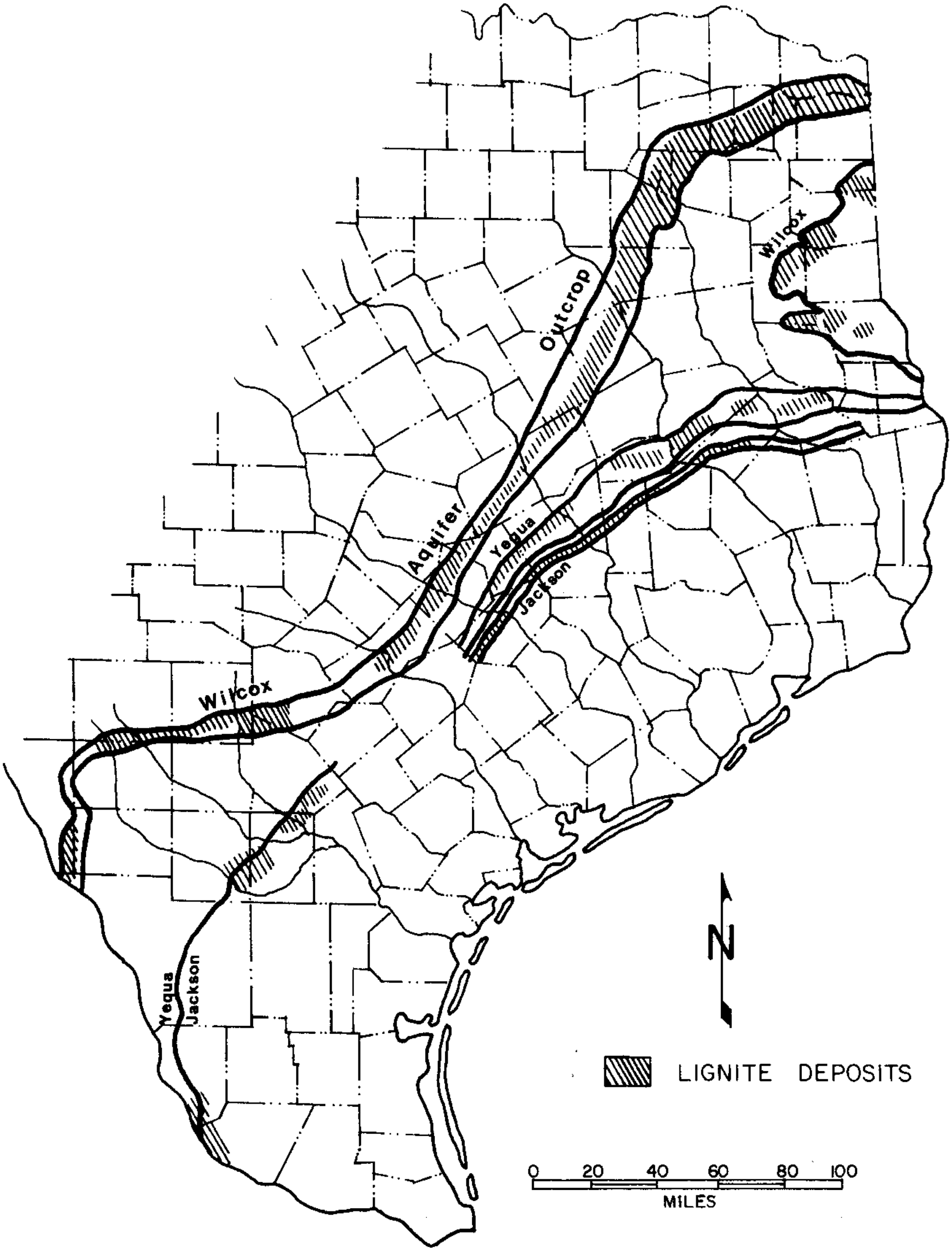


Figure 1. Near-Surface Lignite Deposits in Texas.

CHAPTER II

LIGNITE DEVELOPMENT ACTIVITIES

Texas Lignite

Lignite represents an early stage of coal formation and contains more or less clearly separable pieces of plant material. Nature and composition of the lignite depends on the type of accumulated plant remains and duration and character of natural processes. Most lignite is brownish black, soft and friable with a low specific gravity and is comparatively porous.

Lignite seams generally have a lenticular cross-section and irregular areal shape with individual seams seldom exceeding ten square miles. In general the strata that includes the lignite deposits dip towards the Gulf of Mexico.

Studies at the Center for Energy and Mineral Resources at Texas A&M University indicate that Texas lignite could be a major fuel both for generating electricity and as a source of raw material for producing synthetic fuels and petrochemicals. As of 1974, the total amount of oil located in Texas (146 billion barrels) was about half that of the lignite reserves.

Lignite reserves in Texas can be divided into near-surface and deep-basin categories. Near-surface lignite is within 200 feet of the ground surface and is considered capable of being recovered by traditional strip-mining methods. According to Bureau of Economic Geology studies, total near-surface deposits are estimated at 10 billion short tons (equivalent to about 30 billion barrels of oil) with about 80 percent of these reserves in the Wilcox Group.

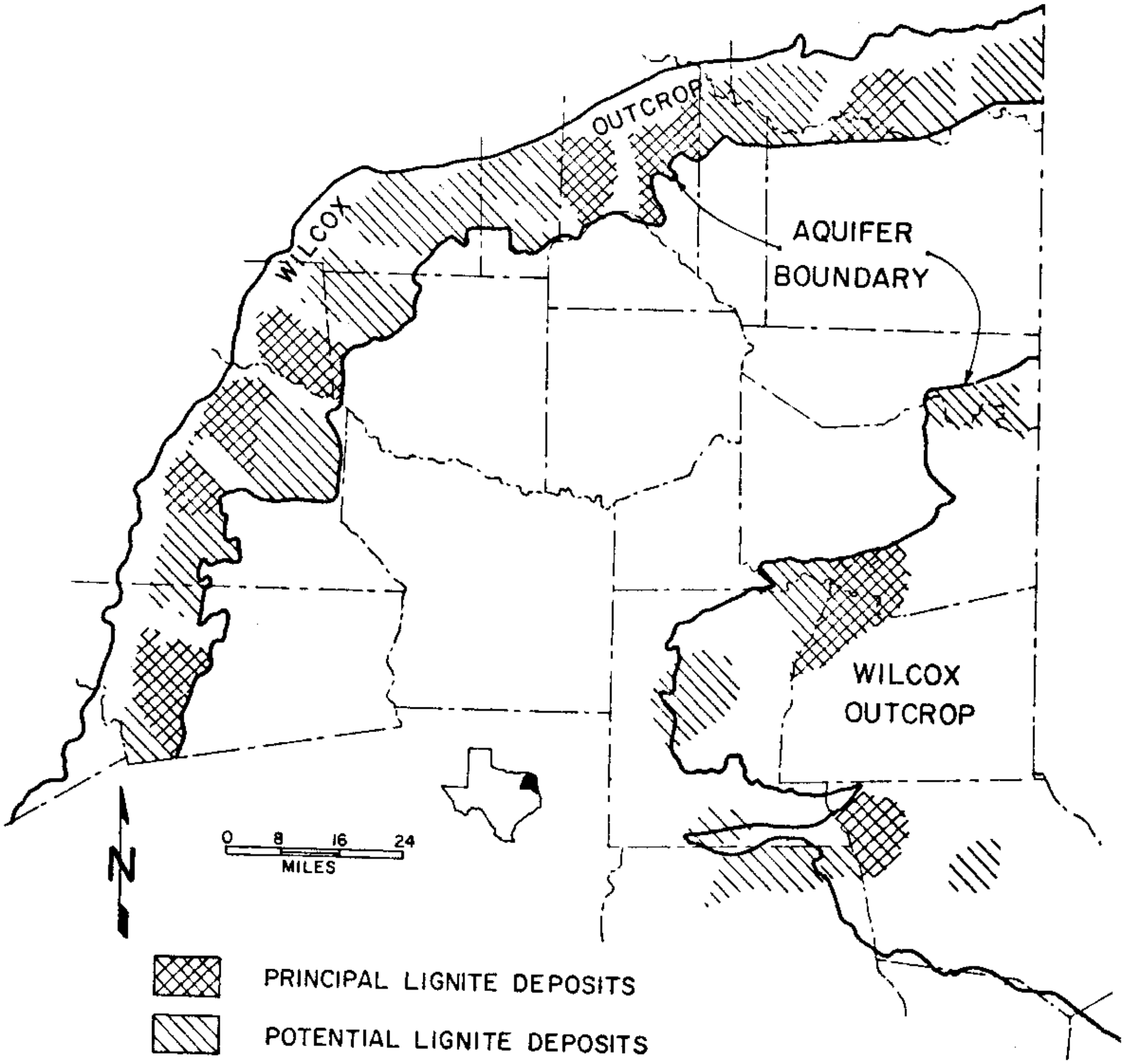
Deep-basin deposits of lignite are at depths between 200 and 5000 feet below the surface and were estimated by the Bureau at 100 billion short tons (equivalent to 270 billion barrels of oil). Deep-basin lignite deposits occur coastward and downdip from the near-surface deposits. A major challenge in lignite recovery is developing economically feasible and environmental acceptable methods for utilizing deep-basin deposits.

According to Kaiser (1975) lignite deposits in East Texas were mainly formed in the backswamp areas along ancient river systems. Fluvial lignite has a high percentage of woody material, low sulfur content (1.0 ± 0.4 percent dry basis) and an ash content of 13.8 ± 5.6 percent.

Deltaic lignite occurs mainly in central Texas in the Wilcox and in Yegua-Jackson outcrops. These deposits were primarily formed from marshes associated with ancient deltas and have a low ash content (12.2 ± 3.3 percent), moderate sulfur (1.4 ± 0.7 percent) and a wide lateral extent (up to 10 miles) (Kaiser, 1975).

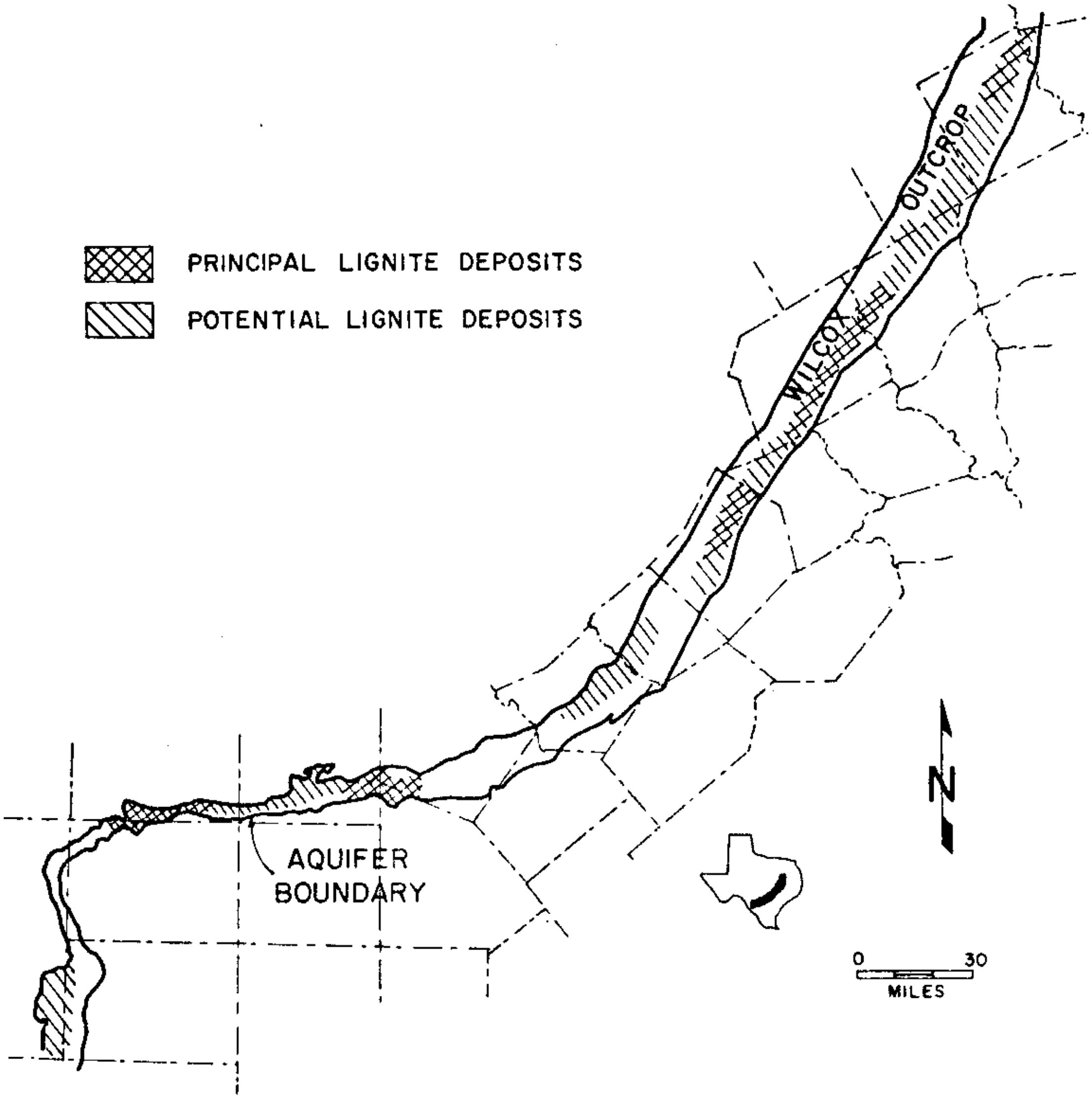
Lagoonal lignite was formed from salt marshes associated with ancient lagoon systems and occur primarily in the South Texas Wilcox formation and in the Yegua and Jackson formation. Lagoonal lignites are characterized by high ash content and high sulfur content. In the South Texas Wilcox formation, lagoonal lignite ash content is 16.5 ± 8.3 percent and sulfur content is 1.7 ± 0.5 percent while the lagoonal deposits of the Yegua and Jackson formations have ash and sulfur contents of 40.8 ± 14.3 percent and 1.9 ± 0.8 percent, respectively (Kaiser, 1975).

Figures 2, 3 and 4 show the lignite deposits for the east Wilcox, the south and central Wilcox and the Yegua and Jackson outcrops. Principal and potential lignite deposits as delineated by Kaiser (1974) cover about 42 percent of the Wilcox recharge area.



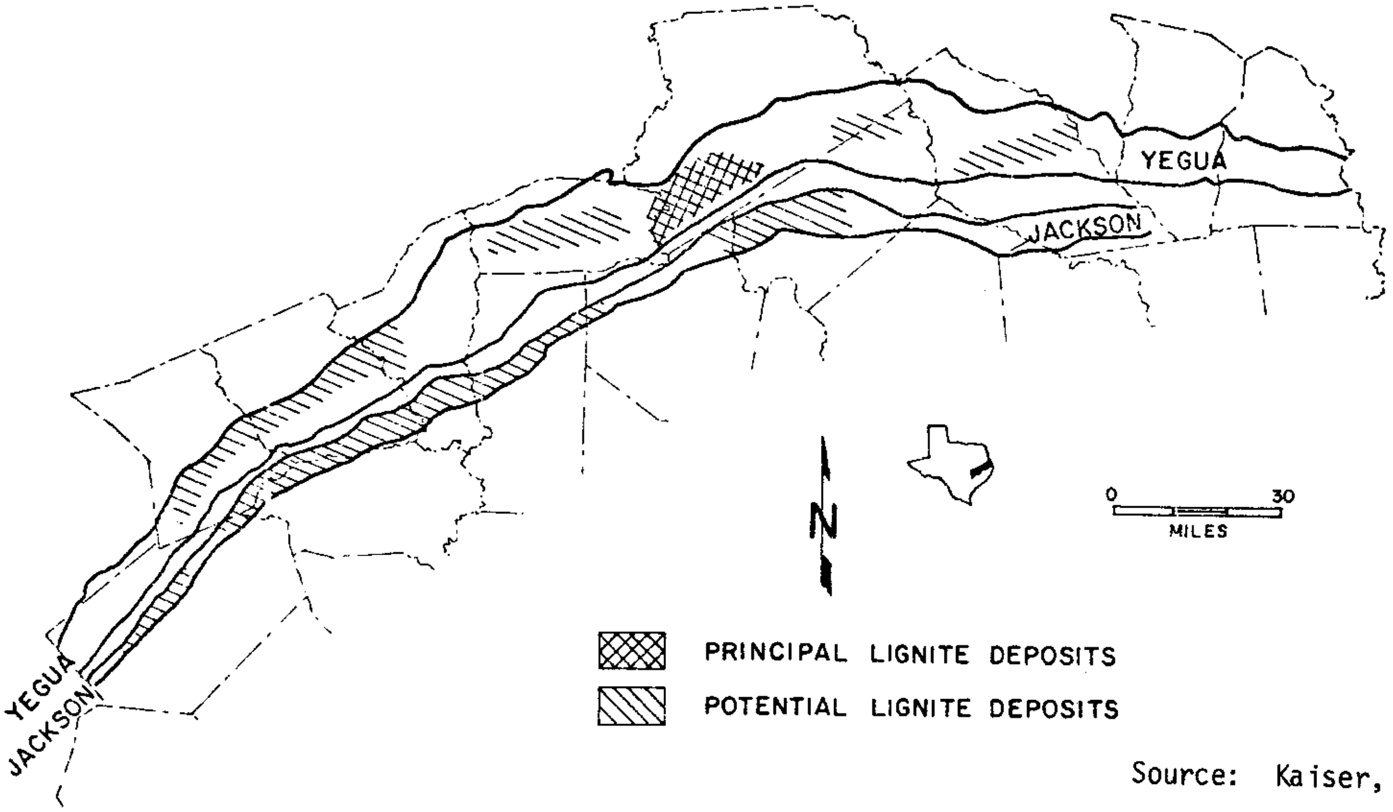
Source: Kaiser, 1974

Figure 2. Lignite Deposits in the East Wilcox Outcrop



Source: Kaiser, 1974

Figure 3. Lignite Deposits in the South and Central Wilcox Outcrop



Source: Kaiser, 1974

Figure 4. Lignite Deposits in the Yegua and Jackson Outcrops

Mining in Texas

During the early development of the coal industry in Texas, lignite was mined primarily for local industrial use. Federal Government records for coal production began in 1884 when 125,000 tons were produced. Annual production reached 1.4 million tons in 1914. After World War II, production declined through 1950 when less than 20,000 tons were mined. According to the Bureau of Mines report (1971), accurate data have not been available since 1950, but production has increased in recent years.

Lignite is being mined near Rockdale, Fairfield, Marshall, and Mt. Pleasant. The first major lignite surface mine was opened in 1954 by Alcoa near Rockdale (Texas Energy Report, 1976). The lignite is used to generate electricity primarily to be used in aluminum processing. Sixty megawatts of the 360-megawatt plant is utilized by Texas Power and Light. The Darco Plant near Marshall, Texas uses lignite to product activated carbon and coal chemicals.

The Big Brown Plant near Fairfield was the first lignite-fired power plant built exclusively by Texas Utilities. It consists of two 575-megawatt units. A third, 750-megawatt unit is scheduled for completion in 1978.

The third and largest of the Texas Utilities lignite plants is the Martin Lake Plant near Henderson. It will consist of four 750-megawatt generating units. Three additional lignite plants are under consideration by Texas Utilities. These include the 750-megawatt Forest Grove Plant near Athens, the 1500-megawatt Twin Oaks Plant near Franklin and 1150-megawatt un-named plant required by 1985.

Texas Municipal Power Pool is planning a 1,200-megawatt plant near Bryan which will utilize lignite from the Yegua-Jackson Formation. A joint project of the South Texas and Medina Electric Cooperative Pool and the Texas Municipal Power Pool is being built near Tilden to utilize lignite from the Yegua-Jackson Formation in South Texas. Existing and proposed lignite plants are summarized in Table 1.

In 1975 Texas lignite represented approximately 9 percent of fuel used by the electric utility industry. It is projected that by 1985 approximately 23 percent of the state's electricity needs will be met by lignite and 20 percent by coal (Texas Energy Report, 1976). The Texas Utilities System consists of Dallas Power and Light, Texas Electric Service and Texas Power and Light. Ninety-nine counties and about one-third the population of Texas are served by the three-company system. In 1973 lignite-fueled, Big Brown generating plant met 15 percent of the power requirements for the system. By 1985, 50 to 60 percent of the power production of Texas Utilities will be based on lignite (Texas Energy Report, 1976).

Lignite Requirements

An electrical power generating plant will require a considerable amount of lignite during its life. Annual lignite requirements and mining area are shown in Figure 5 for various size plants. This plot was based on a 35 percent plant efficiency and a lignite density of 73 pounds per cubic foot. For example, a 1,140-megawatt plant operating at 80 percent capacity throughout the year would require 6.5 million tons of lignite (6,000 BTU/lb) per year. If the lignite seam is six feet thick, 700 acres of land would be required each year or 24,000 acres during the 35-year life of the plant. Using the same assumptions, the nine existing or proposed electric

Table 1. Existing and Proposed Lignite Plants in Texas

Name	Location	Company	Total Capacity MW	Start Operation	Source Lignite
Alcoa	Rockdale	Texas Utilities	360	1954	Wilcox
Big Brown	Fairfield	Texas Utilities	1150	1971	Wilcox
Darco	Marshall	ICI America	-		Wilcox
Monticello	Mt. Pleasant	Texas Utilities	1900	1975	Wilcox
Martin Lake	Henderson	Texas Utilities	3000	1977	Wilcox
Forest Grove	Athens	Texas Utilities	750	1981	Wilcox
Twin Oaks	Franklin	Texas Utilities	1500	1982	Wilcox
- - - -	- - - -	Texas Utilities	1150	1985	Wilcox
- - - -	Tilden	STMEC & TMP	800	1979	Yegua-Jackson
- - - -	Bryan	TMP	1200	1982	Yegua-Jackson

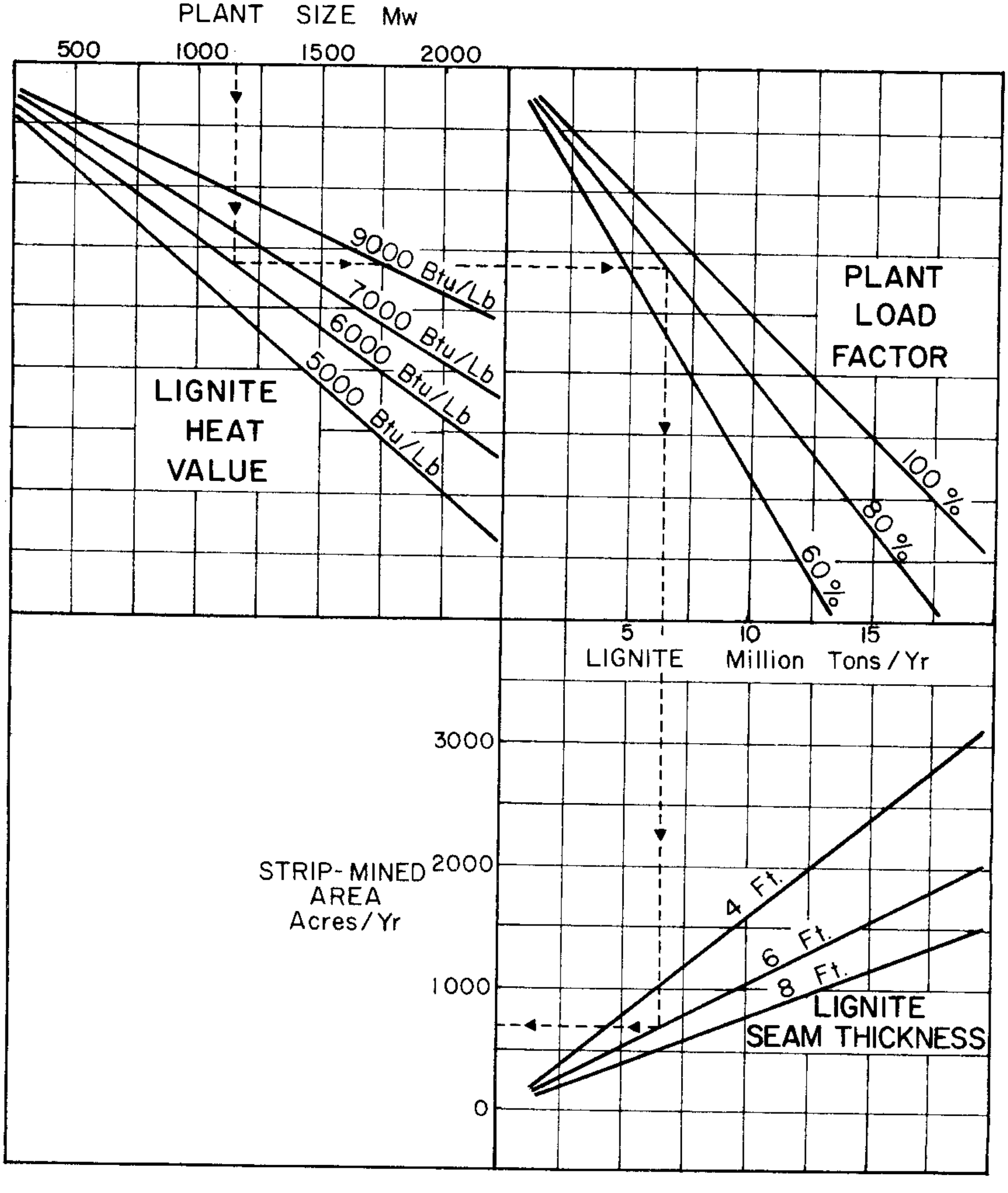


Figure 5. Lignite and Strip-Mined Area Required for Electric Generating Plants

generating plants listed in Table 1 would require approximately 7,000 acres of mine area per year (72 million tons) or 240,000 acres (2.5 billion tons) during the 35-year life expectancy of the plants. Approximately 25 percent of estimated near-surface lignite deposits as defined by the Bureau of Economic Geology are committed to these plants.

Water Requirements

As a result of the large increase in electricity consumption, more water is needed to dissipate waste heat from the power plants. In Texas about 13,600 acre-feet of water was used in 1970 by power plants. The Texas Water Development Board (Hoffman and Chandler, 1974) estimated that in the year 2000, water consumption by the power industry will reach 1.2 million acre-feet per year. The is approximately equivalent to the conservation storage capacity of Lake Livingston.

A typical 1,000-megawatt, fossil-field power plant operating at 38 percent thermal efficiency will require approximately 2.5 million BTU per second of input energy and will dissipate 1.5 million BTU per second of waste heat. Approximately 10 percent of the heat will be lost through the stack in the flue gas and 5 percent lost to the atmosphere by in-plant radiation. The remaining 85 percent of the waste heat (1.3 million BTU per second) can be dissipated by one of several methods including (a) once-through or flow-through cooling, (b) cooling lake or pond, (c) wet-tower cooling or (d) dry-tower cooling. The four methods of heat dissipation are briefly discussed in the following sections.

Flow-through Cooling. The 1973 Texas Water Quality Board Water Quality Standards restrict the maximum temperature rise to 5 degrees F over ambient for fresh water streams, 3 degrees F over ambient for fresh water impoundments and 1.5 degrees F during the summer for tidal and Gulf waters. Since natural high temperatures occur regularly in Texas waters, the Water Quality Board has established a maximum temperature for the various streams in addition to the maximum rise in temperature. For many streams during the summer months the allowable temperature rise will probably be less than 5 degrees F.

Because of the large flow rates of cooling water required to limit temperature rise to 5 degrees F in streams, flow-through cooling can only be used where large volumes of water are available. For example, a 1,000-megawatt plant dissipating 1.3 million BTU per second of heat would require a flow rate of 700 cfs to limit the temperature rise to 30 degrees F, 4,000 cfs for a 5 degrees F rise and 14,000 cfs for a 1.5 degrees F rise. Since no streams in the area have the minimum flow required to limit the temperature rise to 5 degrees F, flow-through cooling has limited application for lignite-fueled power plants in East Texas.

Cooling Lake. A cooling lake is an open body of water designed to dissipate waste heat from the power plant. Cooling lakes are simple, easy to operate and maintain and can be used for other purposes such as recreation and aquaculture. Water is withdrawn from the cooling lkae and pumped through the condenser in the plant where the water absorbs the waste heat from the plant.

If the dissolved gases in the intake water are near saturation, after heating in the condenser the discharge water may be supersaturated. Levels of dissolved gases (Cresluk, 1974) monitored in the intake and discharge water of the Big Brown Steam Electric Plant at Fairfield indicated that gas saturation levels increased after passing through the condenser and ranged from 100.5 to 115 percent. The study also indicated that some golden shiners, longear sunfish and channel catfish held in cages, exhibited external symptoms of gas-bubble disease after exposure to the gas-supersaturated effluent water.

As heated water from the plant is discharged into the cooling lake, the temperature in the lake will rise until the increase in the heat loss rate from the lake to the atmosphere by evaporation, convection and back radiation is equal to the rate heat is added by the power plant. The effectiveness of a cooling lake depends on the depth, surface area and meteorological conditions such as solar radiation, air temperature, relative humidity and wind velocity. Figure 6 is based on average meteorological conditions for East Texas and shows the effect of increased cooling lake temperatures on heat dissipation rates (see Appendix A for computations). The size of the cooling lake is generally based on the capacity of the plant. Typically about 1.5 acres of cooling lake surface area is provided per megawatt of plant capacity. A 1,000-megawatt plant with a 1,500-acre cooling lake would have an average temperature rise of about 9 degrees F in the summer and about 12 degrees F in the winter. The temperature rise can be reduced to about 3 degrees F by providing a 5,000-acre cooling lake for a 1,000-megawatt plant. Temperature requirements of the Texas Water Quality Board do not apply to privately-owned reservoirs, constructed primarily for cooling purposes.

As shown in Figure 7, about 65 percent of the heat is lost by evaporation in the summer while in the winter only about 45 percent of the heat is lost by evaporation. The remainder of the heat is lost by convection and back radiation. Since heat dissipation by evaporation increases with the temperature rise, it would appear desirable to limit the temperature rise by using a large cooling lake. However, a cooling lake also loses water by natural evaporation. For example, a 1,000-megawatt plant operating

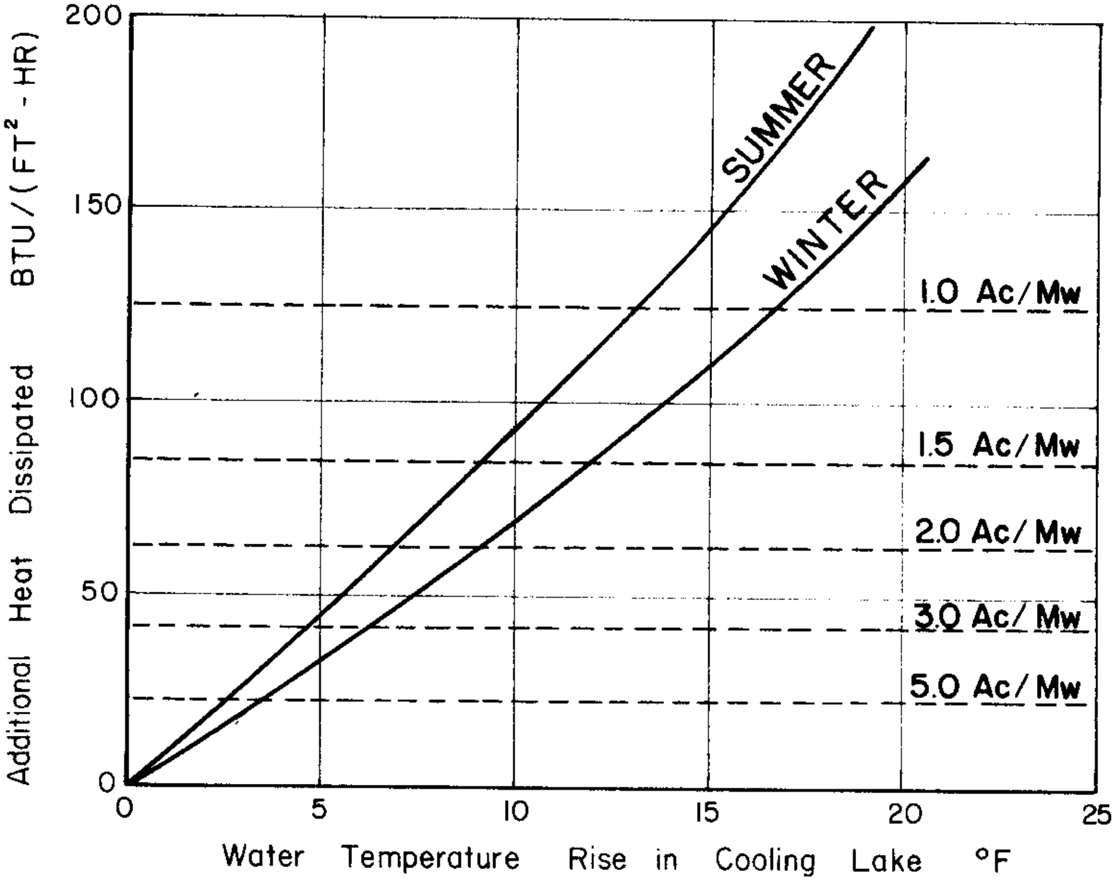


Figure 6. Temperature Rise in a Cooling Lake in East Texas.

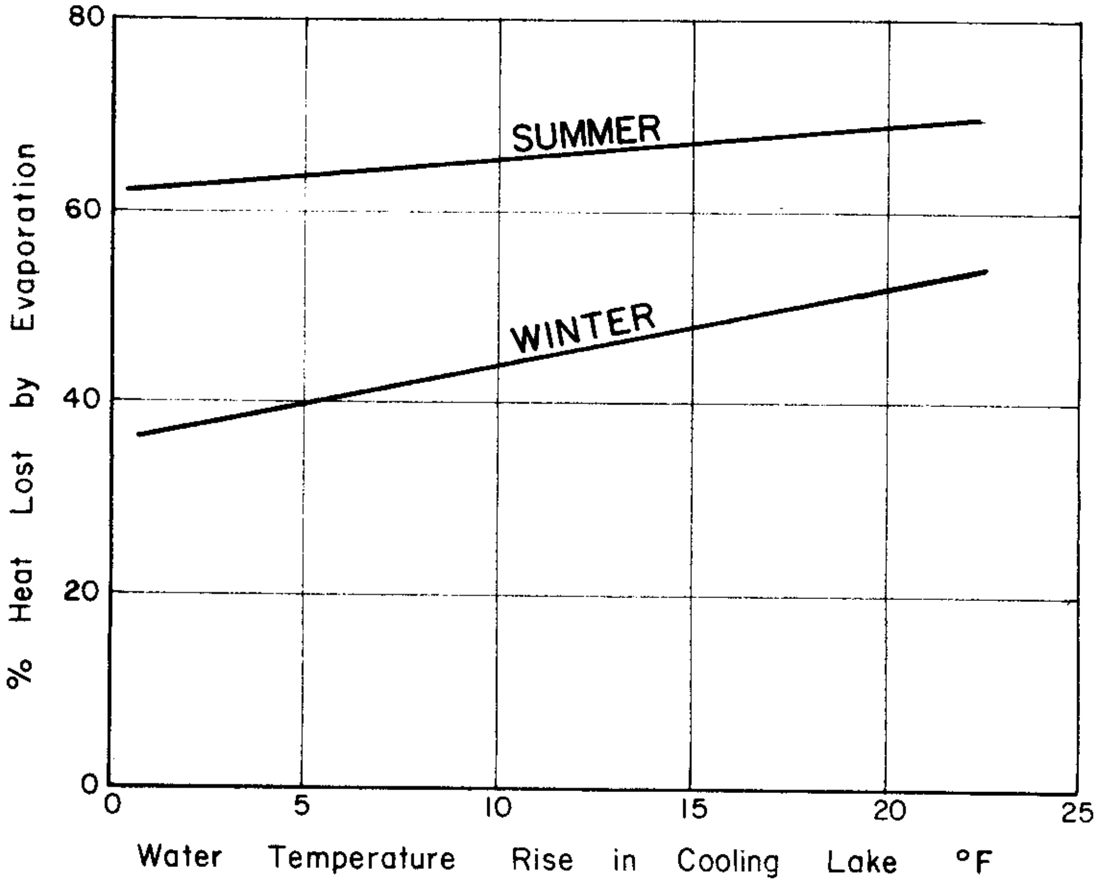


Figure 7. Amount of Heat Lost by Evaporation for a Cooling Lake.

at a 75 percent load factor with a 1,500-acre lake would lose 9.5 cubic feet per second (cfs) to the atmosphere to dissipate the heat from the plant and 2.0 cfs to the atmosphere by natural excess evaporation. Excess evaporation as defined is the evaporation minus 90 percent (assuming a 10 percent runoff coefficient prior to building the lake) of the precipitation. If the same plant has a 5,000-acre cooling lake, 8.8 cfs would be required to dissipate heat and 6.9 cfs would be lost by natural excess evaporation. Increasing the cooling lake size from 1,500 acres to 5,000 acres would cause the evaporation to increase from 11.5 cfs to 15.7 cfs (8,400 to 11,500 acre-feet per year).

Figure 8 shows the water lost by cooling lakes for various size plants. Water lost includes both natural excess evaporation and evaporation for heat dissipation but does not include that required for dilution. If only enough water was added to replace the water lost to evaporation, the dissolved solids would continue to increase. Additional water is required to flush the dissolved solids from the cooling lake. If the dissolved solids of the inflow (Q) is 100 ppm (concentration of inflow (C_i) includes that of the direct precipitation on the reservoir) and the amount of dilution water (Q_d) is equal to that lost to evaporation, the concentration of the lake and the outflow (C_o) is given by:

$$\begin{aligned} C_o &= \frac{Q}{Q_d} C_i \\ &= 200 \text{ ppm} \end{aligned}$$

for a completely mixed, steady state condition.

The water consumption (not including water for dilution) for the existing and proposed lignite-fueled electric generating plants listed in Table 1 (1.5 acres cooling lake per megawatt capacity, 75 percent load factor

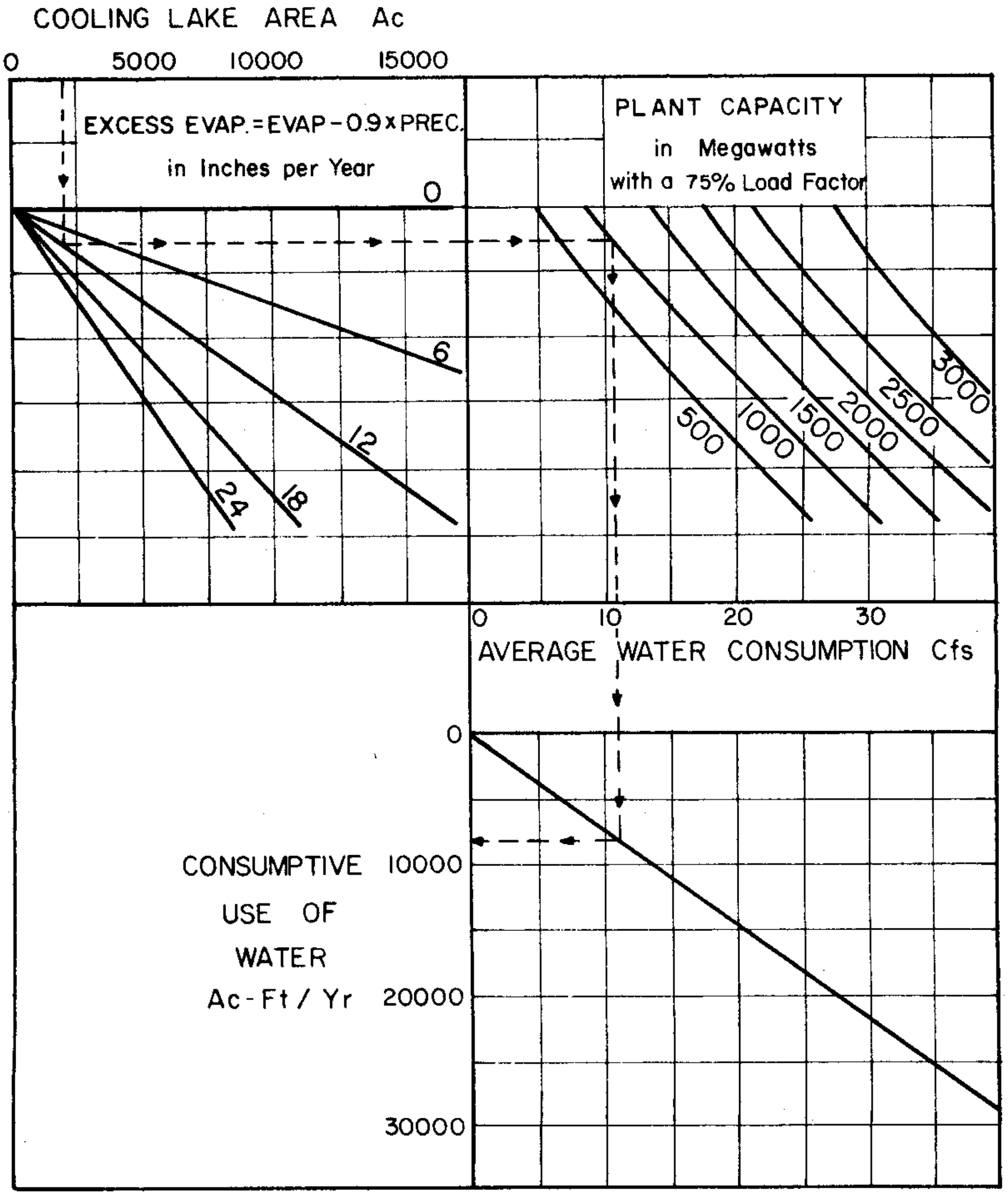


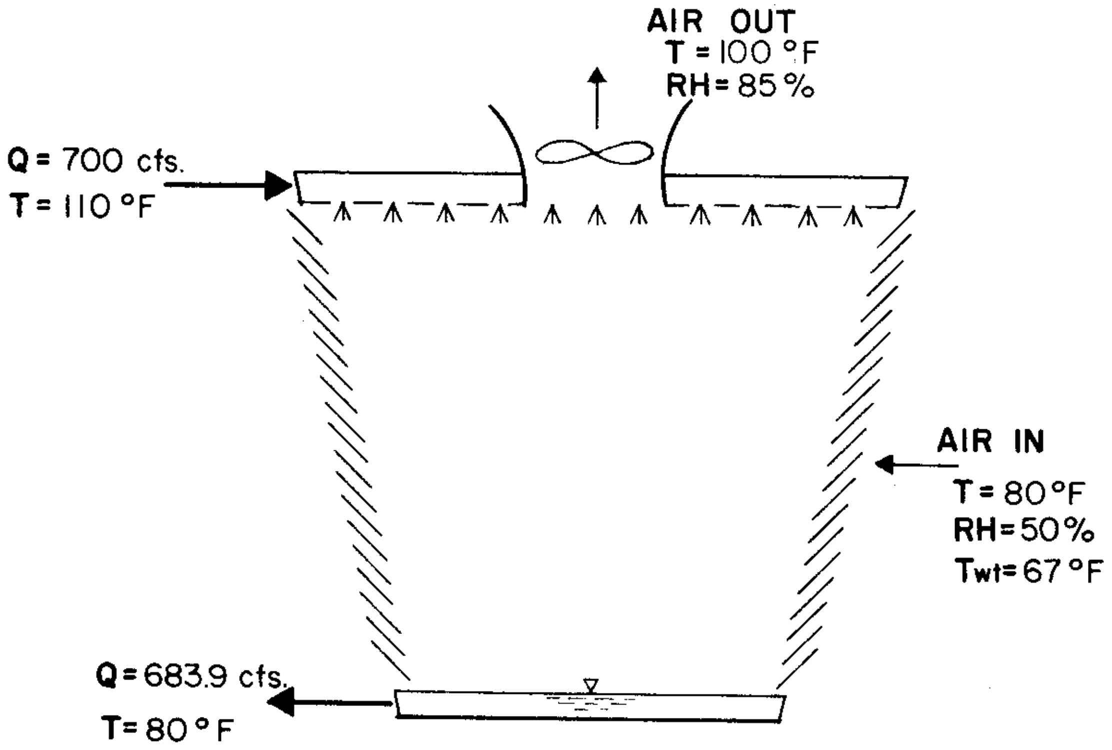
Figure 8. Water Lost by Cooling Lake.

and 12 inches per year of excess natural evaporation) would amount to approximately 100,000 acre-feet per year. Because of small differences in the overall plant efficiencies, the water consumption for lignite-fueled plants would be slightly higher than that required for gas - or oil - fueled plants and less than that for nuclear-fueled plants.

Wet-type Cooling Tower. In the wet-type cooling tower both the air and the water serve as coolants. Water is circulated through the heat exchanges of the power plant where it absorbs the waste heat. The heated water is then sprayed at the top of the tower and as it falls it breaks into small water droplets. Part of the waste heat is dissipated to the air by evaporation and part by direct heat conduction between the air and water droplets. Since the cooling is mainly by evaporation, part of the water circulating through the system is lost by evaporation. The rest of the water is collected at the bottom of the tower and returned to the cooling cycle. A large volume of air is required and most wet towers in the U.S. are equipped with draft fans to draw air through the tower rather than natural-draft towers often used in Europe.

An example of a wet tower is shown in Figure 9 for a 1,000-megawatt power plant. Under the conditions listed in the figure, 82 percent of the cooling is by evaporation and 18 percent by conduction. When the plant is operating at full capacity 16.1 cfs of water is required to make up the water lost by evaporation. With a 75 percent load factor, the plant would use about 8,800 acre-feet per year.

Another loss from the cooling tower is that water carried away as very fine droplets with the air leaving the tower. This is called drift and can amount to as much as 0.2 percent of the water circulated. However, modern



Assume

1000-megawatt plant
1,270,000 BTU/sec heat dissipation
30° F temperature change in cooling water
Ambient Air
  T = 80° F, RH = 50%, Specific heat 0.24 BTU/lb-°F
Effluent Air
  T = 100° F, RH = 85%

Required Air Flow

Water in Air
  Ambient 0.00078 lbs/ft^3 dry air
  Effluent 0.00241 lbs/ft^3 dry air
Dry Air Flow Rate = 46,000 lbs/sec

Heat Balance

Evaporation - 1,040,000 BTU/sec
Conduction - 230,000 BTU/sec

Figure 9. Typical Conditions for a Wet-Type Cooling Tower

design of cooling towers can reduce drift to 0.005 percent of the circulating water.

Blowdown while not a consumptive use of water is required to flush the dissolved solids from the system. As a general rule, blowdown amounts to about 0.1 to 0.3 percent of the circulated water for each 10 degrees F of cooling. In the example in Figure 9, approximately 4 cfs of water would be required to flush the dissolved solids from the system. The dissolved solids in the blowdown water would be about five times that of the makeup water.

Dry-type Cooling Towers. The dry cooling tower operates similar to a car radiator and consumes little or no water. The cost of this type of system is about three times that of a wet-type tower (Woodson, 1971) and approximately five percent of the plant output is required to operate the cooling system (Hoffman and Chandler, 1974).

Numerous dry cooling towers are located in Europe. In the United States, a 330-megawatt, coal-fired unit is being built at Wyodak, Wyoming. When completed in 1978, it will be the world's largest, single-unit power plant employing the direct system, dry-type cooling tower.

At least for the near future, it appears that economics will continue to limit the application of the dry-type cooling tower for lignite-fueled power plants in Eastern and Central Texas.

Solid Waste

In a lignite-fueled power plant, pulverized lignite is combusted in the furnace to produce heat. Some of the ash which is formed in the process is a fine dust which is relatively light and is carried out the top of the furnace with the flue gas. This ash, referred to as fly ash, is removed from the hot flue gas with air pollution control devices such as electrostatic precipitators, fabric filters or liquid scrubbers. Fly ash generally amounts to 70 to 90 percent of the total ash output of the furnace.

The heavier ash, which does not travel upward with the hot flue gas, is the bottom ash. The bottom ash ranges from 10 to 30 percent of the total ash output of the furnace. Major factors affecting the separation of ash into fly ash or bottom ash are the ash fusion temperature of the lignite and type of furnace and firing employed. Figure 10 is based on a 38 percent plant efficiency and a 75 percent load factor and shows the amount of ash generated from a lignite-fueled power plant. A typical 1,000-megawatt power plant utilizing Wilcox lignite would produce about 100,000 tons of bottom ash and 400,000 tons of fly ash per year.

In the production of heat, sulfur in the coal is converted to sulfur oxides which is discharged primarily in the flue gas as SO_2. The fly ash in the flue gas is basic while the sulfur oxides are acidic. Sulfur oxides can combine with water in the atmosphere to form an acid. Removal of the basic components in the air waste stream may cause the pH of the rainfall to drop. A significant reduction in pH has been observed in the rivers of south Norway and acid precipitation is apparently becoming a problem in some areas in northeastern United States.

Some lignite-fueled power plants may be required to install sulfur oxide stack gas control systems. According to Cooper (1975) wet limestone and wet lime scrubbers have SO_2 removal efficiency of about 80 and 90 percent respectively. Approximately 1.4 moles of calcium is required to remove 1.0 mole of sulfur in the wet limestone scrubbing process while 1.2 moles of calcium is required in the wet lime process to remove 1.0 mole of sulfur.

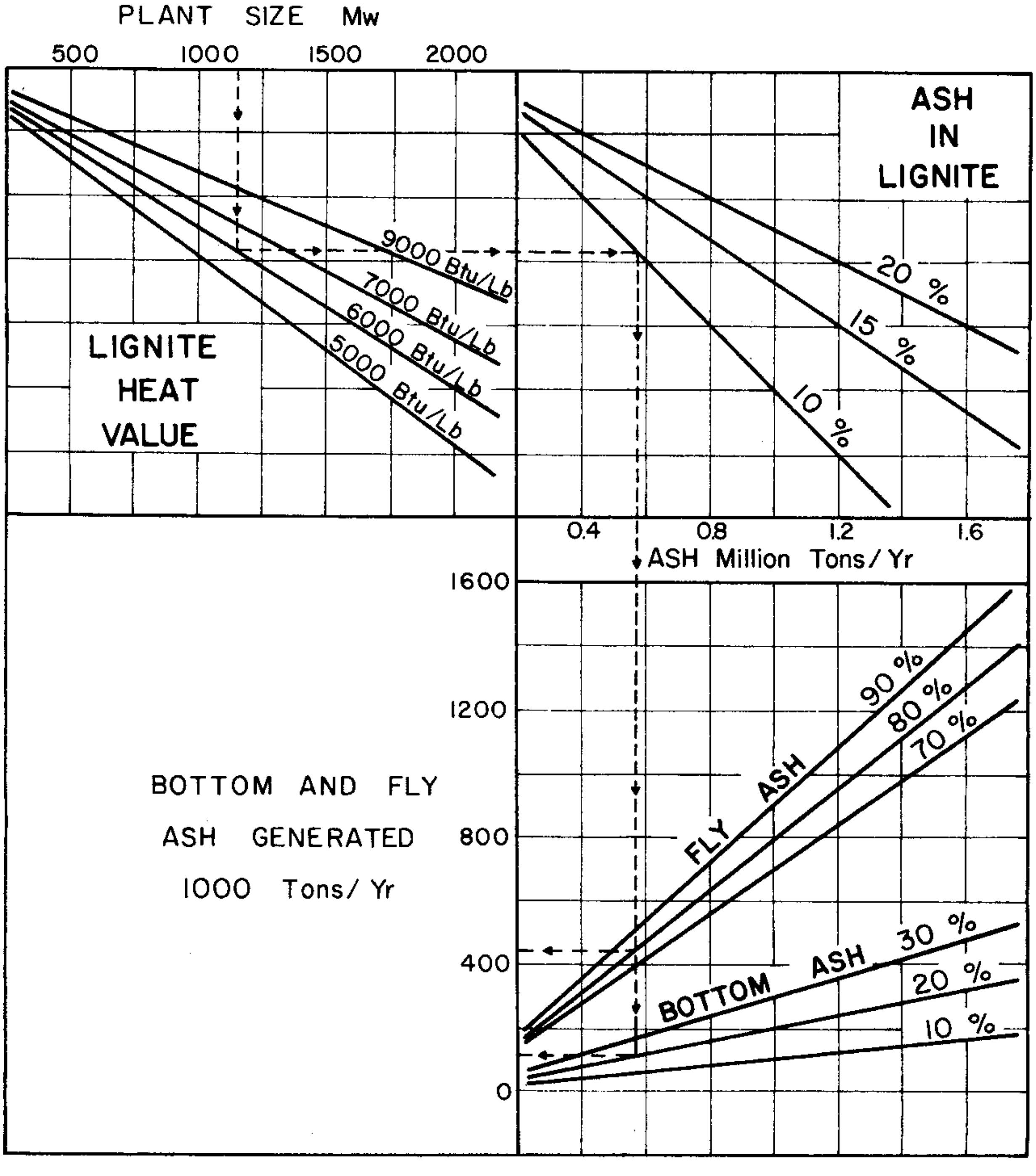


Figure 10. Bottom and Fly Ash Generation from Lignite Power Plants

In the scrubber, flue gas is contacted with a recirculating slurry of lime or limestone where the following reaction takes place.

$$SO_2 + Ca(OH)_2 \rightarrow H_2O + CaSO_3 \text{ for lime or}$$

$$SO_2 + CaCO_3 \rightarrow CO_2 + CaSO_3 \text{ for limestone}$$

Sulfite is converted to sulfates by oxidation.

$$2CaSO_3 + O_2 \rightarrow 2CaSO_4$$

Water is required for wet bottom furnace, precipitator units and lime or limestone scrubber systems. Total water inputs can range from 0.7 to 1.5 gallons per minute per megawatt capacity (Cooper, 1975). Approximately 75 percent of the water added to the scrubber system is evaporated. The evaporation losses are approximately 10 percent of the wet-type cooling tower makeup water (Ottmers, Lowell and Noblett, 1975). The effluent water from the scrubber system contains the solids at a concentration of about 20 percent and flows at a rate of 0.1 to 0.3 gallons per minute per megawatt. The sludge usually passes to a clarifier, a thickner and then to a pond for sedimentation to about 40 percent solids (Cooper, 1975). Sludge generation and storage requirements are shown in Figure 11. The figure was based on a 38 percent plant efficiency and a 75 percent load factor. The large volume of sludge associated with sulfur control can be seen in Figure 11. For example, a 1,150-megawatt power plant utilizing 6,000-BTU per pound lignite with 1.0 percent sulfur would generate 260,000 tons of sludge per year requiring about 260 acre-feet of storage. During the 35-year life of a plant, 9,000 acre-feet of sludge storage would be required. Fly ash and bottom ash are relatively easy to de-water while lime or limestone scrubber sludge is more difficult to de-water.

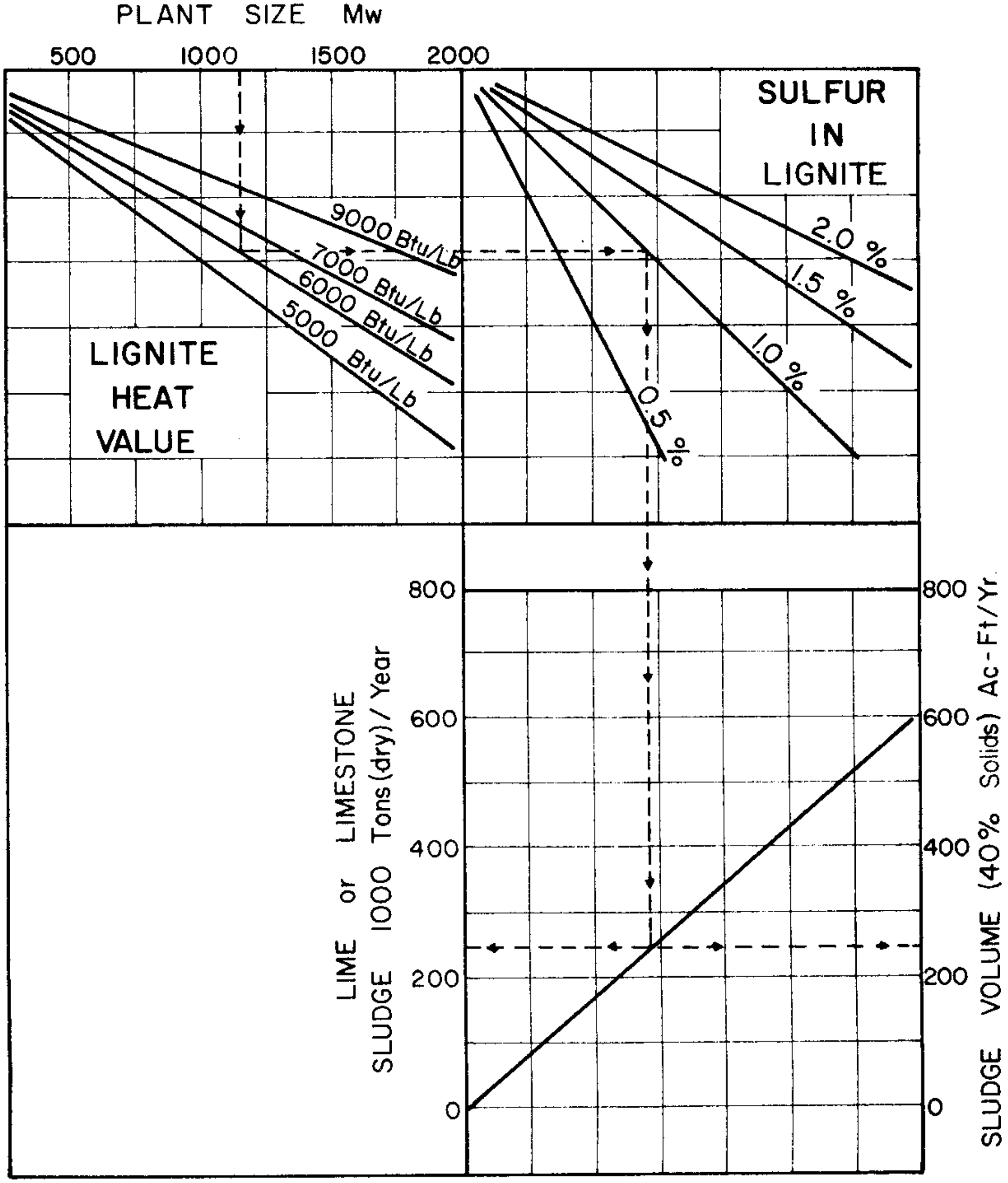


Figure 11. Sulfur Control Sludge Generation from Lignite Plant.

Supernatant waters from ash disposal and scrubber sludge de-watering stages have dissolved solids concentrations of 5,000 to 7,000 ppm consisting primarily of sodium, calcium, potassium and magnesium sulfate and sulfite (Cooper, 1975). Sulfite ion will exert an oxygen demand on the receiving waters and may require oxidization to sulfate ion before discharging. Scrubber effluent water normally has a pH of 5.0 to 5.5 and may require neutralization. According to Cooper (1975) water pollution problems may result from trace metals such as lead, copper, arsenic, selenium and other heavy metals concentrated in the fly ash or scrubber sludge. These materials could pose a potential problem by leaching or overflows caused by rain resulting in discharge to surface or ground water.

The Big Brown plant at Fairfield generates about 350,000 tons per year of fly ash and 150,000 tons per year of bottom ash. The lignite at Fairfield is low in sulfur content and SO_2 scrubbers are not required. Currently at Big Brown part of the fly ash is slurried out of the plant into ponds and part is conveyed dry to silos where it is processed. Once fly ash is wet and drys, it loses some of its cementious properties. An increasing larger percent of the ash produced at Big Brown is being used as concrete admixture, synthetic aggregate and road surface material.

Coal Gasification and Coal Liquefaction

According to Davis and Wood (1974), there are no modern-design, commercial-scale coal gasification or liquefaction plants in the United States to accurately estimate water consumption. The Synthetic Gas-Coal Task Force (1973) estimated the water consumption for a typical coal-gasification plant using lignite to produce 250 billion BTU per day (equivalent to approximately 250 million standard cubic feet (scf) per day of pipeline quality gas or a 3,000-megawatt electrical plant) to range from 9,000 to 37,000 acre-feet per year depending primarily on the type of cooling employed. Process and boiler make-up water amounted to 2,000 gpm or 4.5 cfs (3,000 acre-feet per year with 90 percent load factor) while cooling water accounted for the balance of the water used. Approximately 6,000 acre-feet per year of water is required for cooling when 85 percent of the cooling requirements are met by nonevaporative air cooling while 34,000 acre-feet per year of cooling water (including blowdown) is required when the cooling requirements are met primarily by evaporative cooling. On a BTU basis, water consumption required for converting lignite to pipeline gas is comparable to that required to convert lignite to electricity. If the gas produced from the lignite is used as fuel for electrical power generation, the water requirements for the two processes are additive in the total fuel cycle. If the energy is used for space heating, the water consumption for gasification and electricity are comparable or perhaps slightly less for gasification. However, if the energy is used to produce work using motors, electrical motors are about three times as efficient as fossil-fueled engines and water consumption in generating electricity would be less than that required for gasification.

In-situ gasification processes involve extraction of low-BTU gas through boreholes linked to a seam of lignite. Combustion of the lignite begins along one portion of the seam while product gases are removed. Air or other gases are forced down the first set of boreholes to aid in combustion and product gases are removed from the second set of boreholes. The processed product gases can be used as low-BTU gas fuel or upgraded to pipeline quality through the process of methanation (Governor's Energy Advisory

Council, 1976). While <u>in-situ</u> gasification involves no strip-mining, it creates the possibility of groundwater pollution and subsidence.

Unit water consumption estimates for coal liquefaction range from 0.2 acre-feet per year per barrel of daily (bpd) capacity to as much as 1.3 acre-feet per year bpd capacity (Davis and Wood, 1974). The National Petroleum Council (1973) adopted a unit consumptive-use value of 0.2 acre-feet per year per bpd capacity.

CHAPTER III

WILCOX AQUIFER

Texas is very fortunate to have large quantities of high quality groundwater in many parts of the state. In 1965, 5,820,000 Texans were served by groundwater supplies, and 3,630,000 Texans took their water from surface supplies. Many cities have been able to use groundwater supplies in the past with little or no treatment other than adding chlorine as a safeguard against bacterial contamination. Most of the minerals present in groundwater are dissolved from the outer layer of the earth's crust by the passage of water over or through the soil and rocks. In general, the greater distance the water travels, the greater will be the mineral content. Therefore, water from deep wells usually have more minerals in solution than water from shallow wells.

The Wilcox aquifer supplies substantial quantities of water to wells in the East and Central Texas. The following is a list of 44 municipalities that obtained at least part of their water supply from this source in 1948 (Sundstrom, Hastings, and Broadhurst, 1948): Alba, Arp, Athens, Altanta, Avinger, Bremond, Buffalo, Calvert, Carthage, Como, Daingerfield, Elgin, Eustace, Fairfield, Garrison, Gilmer, Gladewater, Hearne, Henderson, Hughes Springs, Jefferson, Karnack, Kilgore, Kosse, Lindale, Linden, Malakoff, Marshall, Mineola, Mount Vernon, Naples, Omaha, Palestine, Pittsburg, Quitman, Rockdale, San Augustine, Tatum, Tenaha, Timpson, Trinidad, Troup, Tyler and Waskom.

Soils

Land Resource areas are units of lands similar in soils, climate, natural vegetation, and physiography. Resource units associated with the Wilcox are shown in Figure 12. Soils of the East Texas Timberlands, Claypan area in Central Texas and the Rio Grande Plain in South Texas have formed from stratified clayey and sandy deposits of tertiary age. Table 2 lists the soil series on the Wilcox along with the Unified Soils Classification and permeability of several horizons for typical profiles. The hydrologic group (group A, B, C or D) which reflects the runoff potential is also listed for each soil series. The general characteristics of each group are:

A. soils that have rapid infiltration rates even when thoroughly wetted (low runoff potential),

B. soils that have moderate infiltration rates when thoroughtly wetted,

C. soils that have slow infiltration rates when thoroughly wetted, and

D. soils having very slow infiltration rates when thoroughly wetted (rapid runoff potential).

To estimate the relative recharge potential of the hydrologic soil groups, the amount of deep percolation was estimated for soils in each group for a 6-hour, 2.5-inch rainfall. The return period of this rainfall is about one year. For the calculation, the deep percolation was equal to the rainfall minus the sum of the direct surface runoff, interflow, soil moisture storage increase, and evapotranspiration. Prior to the rainfall, the surface soil moisture content was assumed to be half way between the field capacity and wilting point while the subsurface soils were assumed to be at field capacity. It can be seen in Table 2 that many of the soils have a relatively pervious surface layer but a relatively impervious subsurface layer. In general, the infiltration of water through the soil surface was not the limiting factor for deep percolation but the subsurface permeability restricted the deep percolation.

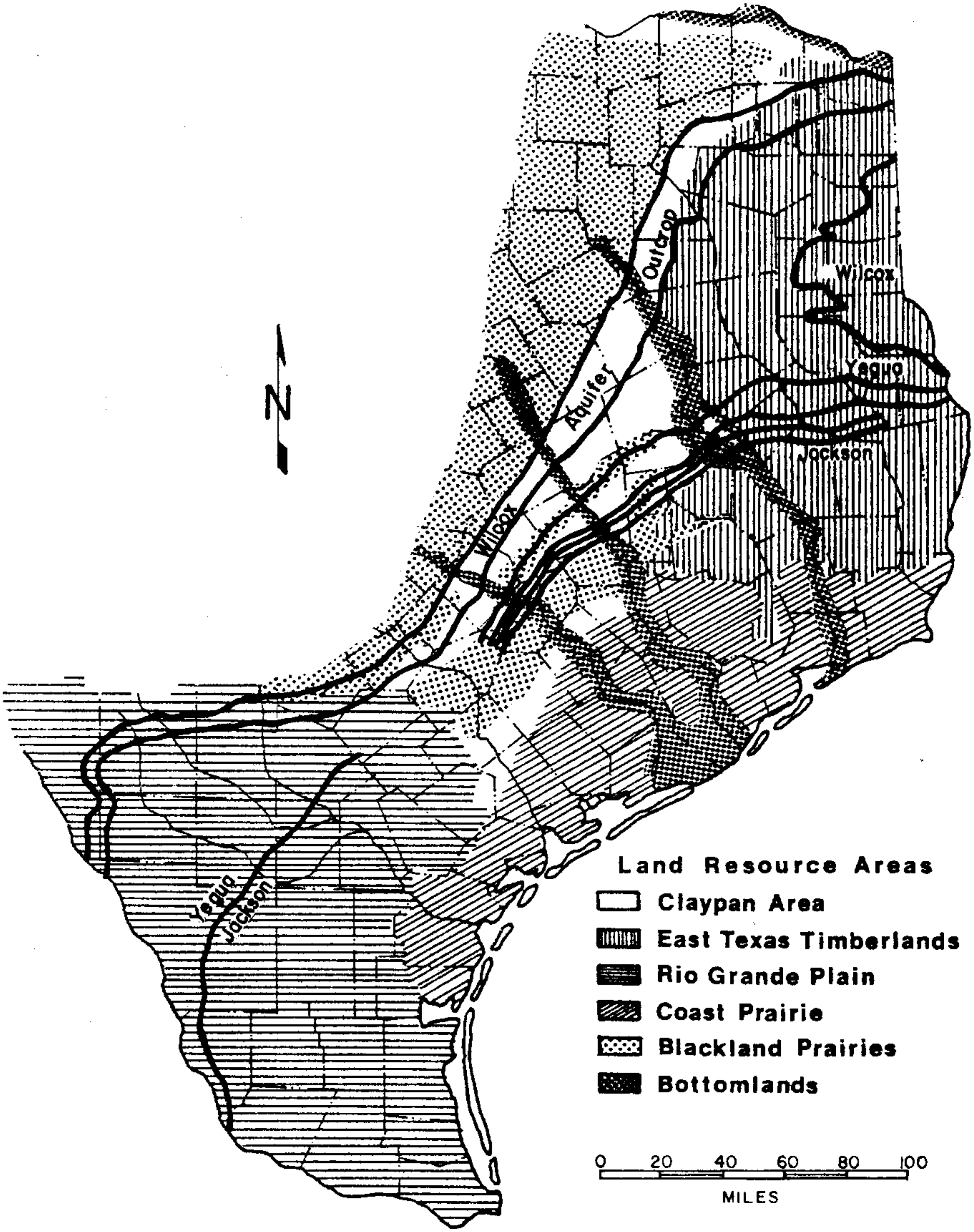


Figure 12. Land Resource Areas Associated with the Wilcox and Yegua-Jackson Formations

Table 2. General Soils on the Wilcox

Land Resource Area	Soil Association	Soil Series	Depth in.	Classification Unified	Permeability in/hr	Hydrologic Group
CLAYPAN AREA	1-A	Lufkin	0-7	SM or ML	0.63-2.0	D
			7-38	CH	< 0.06	
			38-64	CL or CH	< 0.06	
		Axtell	0-6	SM	0.63-2.0	D
			6-82	CH	< 0.06	
		Tabor	0-15	SM, CL-ML	0.63-2.0	D
			15-48	CH, CL	≤ 0.06	
			48-66	CH,CL,SC	0.06-0.20	
			66-80	CL or CH	0.06-0.20	
	1-B	Patilo	0-66	SM or SP-SM	6.3-20	C
			66-132	SC	0.20-0.63	
			132-140	SM	2.0-6.3	
		Stidham	0-26	SM	6.3-20	A
			26-72	SC or CL	0.63-2.0	
	1-C	Wrightsville	0-16	ML, CL	0.20-0.63	D
			16-65	MH, CH	< 0.06	
		Susquehanna	0-8	SM	0.63-2.0	D
			8-68	CH	< 0.06	
		Muskogee				C
EAST TEXAS TIMBERLANDS	2-A	Bowie	0-12	SM, SM-SC	2.0-6.3	B
			12-42	SC, CL	0.63-2.0	
			42-78	SC, CL	0.20-0.63	
		Kirvin	0-10	SM	2.0-6.3	C
			10-42	SM, MH, CL	0.20-0.63	
			42-48	CL, SC	0.63-2.0	
		Troup	0-53	SM	6.3-20.0	A
			53-80	SC	0.63-2.0	
	2-B	Freestone	0-12	SM or ML	0.63-2.0	C
			12-46	SC or CL	0.20-0.63	
			46-100	CL or CH	0.06-0.20	
		Boxwell				D
		Kenney	0-44	SM or SP-SM	6.3-20	A
			44-72	SC or CL	0.63-2.0	
	2-C	Nacogdoches	0-6	SC-SM, SC	0.6-2.0	C
			6-70	CH, CL, MH	0.2-0.6	
		Ruston	0-9	SM, ML	0.63-2.0	B
			9-74	SC, CL, ML	0.63-2.0	
		Bub	0-4	SM, SC, GM	0.20-0.63	C
			4-18	GC, CL	0.20-0.63	
			18-28	CL, CH		

Table 2. General Soils on the Wilcox (continued)

Land Resource Area	Soil Association	Soil Series	Depth in	Classification Unified	Permeability in/hr	Hydrologic Group
RIO GRANDE PLAIN	3-A	Miguel	0-10	SM, SM-SC	2.0-6.0	C
			10-33	CL, SC, CH	<0.06	
		San Antonio	0-8	CL	0.8-1.0	C
			8-28	CH	0.7-0.8	
			28-60	CL	0.6-0.8	
			60-120	CL	0.8-1.0	
	3-B	Knippa	0-35	CH, CL	0.2-0.6	A
			35-60	CH, CL	0.2-0.6	
		Castrovile	0-52	CL	0.6-2.0	A
			52-84	CL	0.6-2.0	
		Atco	0-9	CL, CL-ML	0.6-2.0	C
			9-72	CL, CL-ML	0.6-2.0	
	3-C	Uvalde	0-34	CL	0.6-2.0	A
			34-80	CL	0.6-2.0	
		Montell	0-30	CH	<0.06	C
			30-72	CH	<0.06	
		Zapata	0-8	SC, CL	0.6-2.0	B
	3-D	Catarina	0-48	CH	<0.06	C
			48-60	CH, CL	<0.06	
		Montell	0-30	CH	<0.06	C
			30-72	CH	<0.06	
		Jimenez	0-9	GC, GM-GC	0.6-2.0	B
BLACKLAND PRAIRIES	4-A	Wilson	0-6	CL	0.20-0.63	D
			6-108	CL or CH	<0.06	
		Crockett	0-7	SM, SC, or ML	2.0-6.3	D
			7-68	CH or CL	<0.06	
			68-92	CL or CH	<0.06	
		Burleson	0-70	CH	<0.06	D
	4-B	Houston Black	0-104	CH	<0.06	D
		Heiden	0-56	CH	<0.06	D
		Austin	0-34	CH, CL	0.20-0.63	C
			34-48	CL	0.20-0.63	
BOTTOM LANDS	5-A	Miller	0-70	CH	<0.06	D
			70-120	CH	<0.06	
		Norwood	0-18	CL	0.63-2.0	B
			18-60	CL or ML	0.63-2.0	
		Pledger	0-5	CH, CL	0.06-0.2	A
			5-50	CH, CL	<0.06	
	5-B	Kaufman	0-72	CH	<0.06	D
		Trinity	0-75	CH	<0.06	D
		Tuscumbia	0-4	CL	0.06-0.2	A
			4-50	CH	<0.06	

The direct runoff was estimated using the Soil Conservation Service Curve Number procedure for range lands in fair hydrologic condition. Storage capacity for gravity water of the surface soils was taken as the difference between field capacity and saturation. Water in excess of that required to saturate the surface layer was considered to contribute to the runoff. Interflow was assumed to occur where there was a pervious layer on top of an impervious layer (hydrologic group D) and was estimated at 20 percent of the gravity water.

At the end of the rain, the gravity water stored in the surface soils continued to move downward while some gravity water was also lost to evapotranspiration. The evapotranspiration was estimated as being equal to the average lake evaporation of 55 inches per year or 0.006 inches per hour. When the permeability value of the soil was listed as less than 0.06 inches per hour it was assumed to be equal to the evapotranspiration rate (0.006 in./hr.).

Under the conditions listed above, the approximate contributions to deep percolation for the hydrologic soil groups are listed in Table 3. For this preliminary analysis, calculations were based on Darcy's law for saturated flow rather than the equations for unsaturated flow. From these calculations, it appears that areas in the Wilcox outcrop with soils in hydrologic groups A, B, or C could contribute significant quantities of water to groundwater recharge.

Soil maps from the Soil Conservation Service of the counties along the Wilcox outcrop were reviewed to identify areas of recharge potential. When the dominant hydrologic soil group of the several soil series in an association was A, B, or C, the soil association was considered to have fair to

Table 3. Estimated Contribution to Deep Percolation for the Hydrologic Soil Groups*

Soil Series	Hydrologic Group	Direct Runoff inches	Change soil Moisture inches	Gravity Water inches	Inter-Flow inches	Evapo-transpiration inches	Deep Percolation inches
Tabor	D	1.2	0.8	0.5	0.1	0.4	0.0
Freestone	C	0.8	0.8	0.9	0.0	0.1	0.8
Bowie	B	0.5	0.8	1.2	0.0	0.0	1.2
Stidham	A	0.1	1.0	1.4	0.0	0.0	1.4

* Computations are for a one-year, six-hour, 2.5-inch rainfall.

good recharge potential. Figures 13 through 16 show the areas of pervious soils with recharge potential in the Wilcox outcrop for Freestone, Limestone, Robertson and Milam counties. The maps also show the area of principal and potential lignite deposits (Kaiser, 1974). Soil maps were also reviewed for other counties in the Wilcox and Jackson-Yegua outcrops. Information for the Wilcox outcrop is summarized in Table 4 and shown in Figure 17. Approximately 40 percent of the previous soils in the Wilcox outcrop are located in areas of potential lignite strip mining.

The Bureau of Economic Geology (1970) on the Waco Sheet divides the Wilcox outcrop into Calvert Bluff Formation, the Simsboro Formation and the Hooper Formation. Of the three formations the Simsboro typically contains more coarse-grained sands. However, from well logs it is difficult to differentiate the formations of the Wilcox group (Guyton, 1972). Major lignite deposits in the Wilcox are located in Calvert Bluff Formation. Formations of the Wilcox outcrop are shown in Figures 18 and 19 for Freestone and Milam Counties, respectively.

Aquifer

Wilcox consists mainly of interbedded sands, silts and clays. The sands are mostly thin-bedded, fine-grained and silty. Particularly in the middle to lower part of the Wilcox, some sands are fine - to coarse-grained and thick bedded. Individual beds within the Wilcox Group generally cannot be correlated from well to well due to lateral changes in the formation.

Typical profiles of the Wilcox are shown in Figure 20 through 26. From these figures it can be observed that while the lignite is often

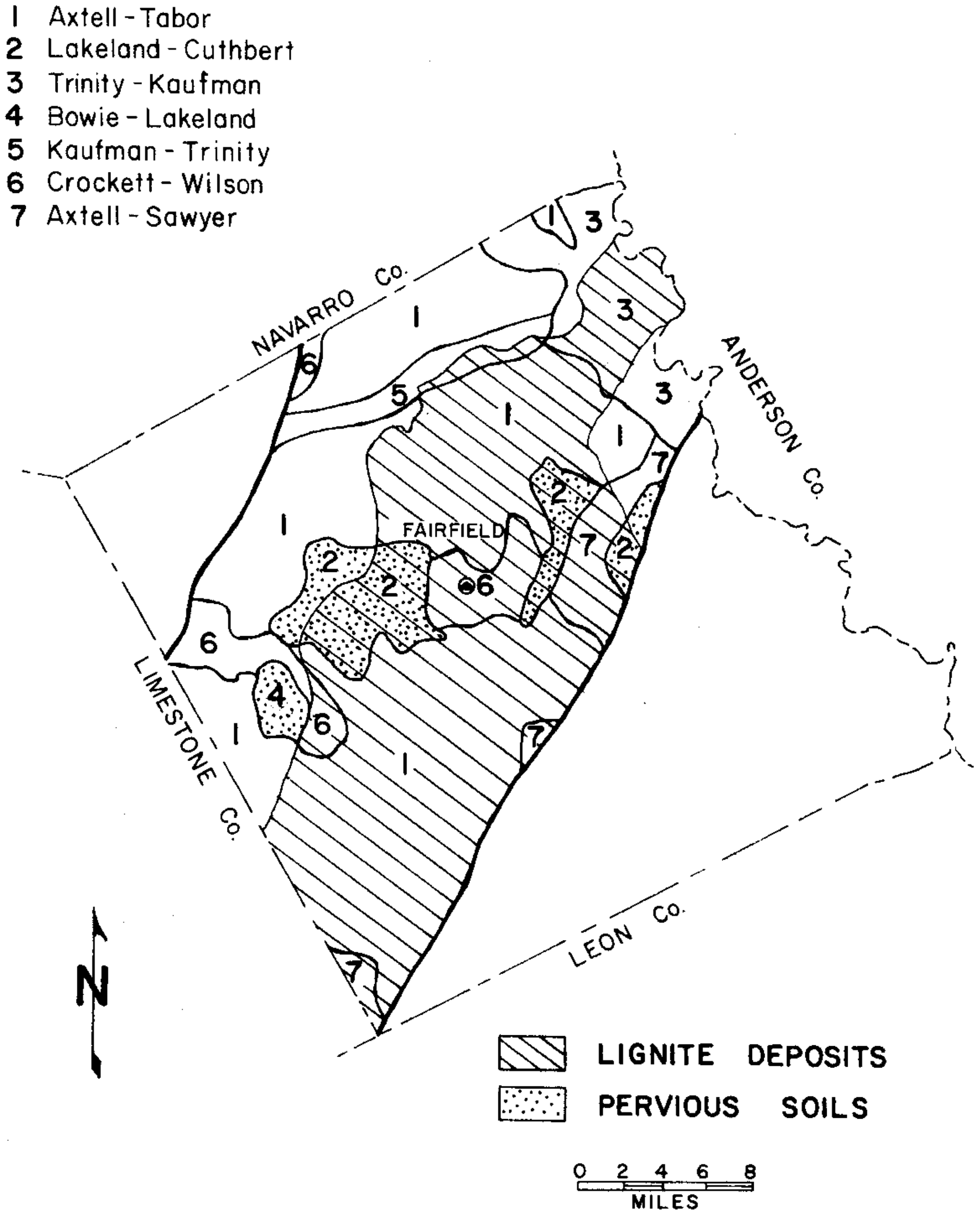


Figure 13. Pervious Soils and Lignite Deposits in the Wilcox Outcrop, Freestone County

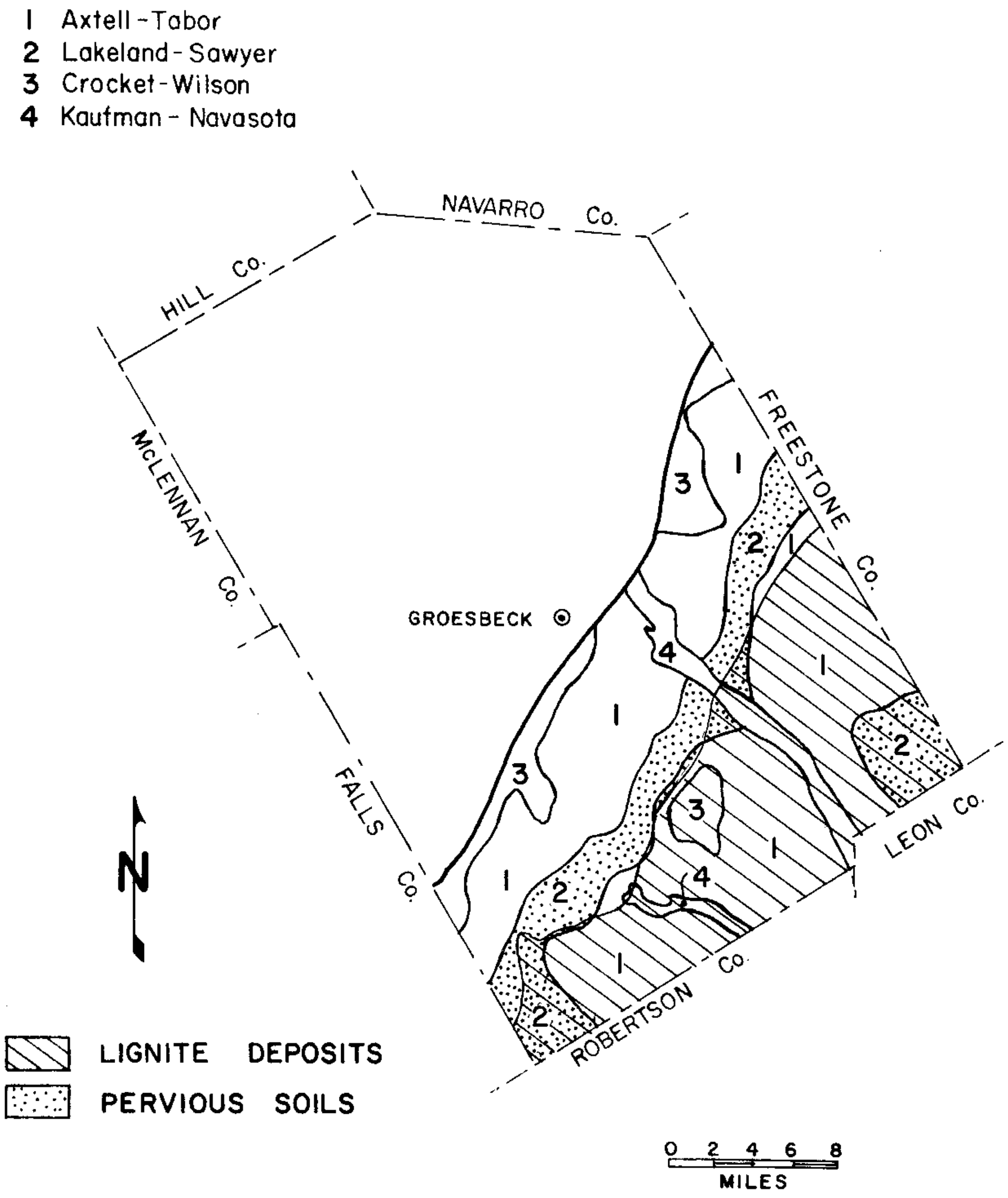


Figure 14. Pervious Soils and Lignite Deposits in the Wilcox Outcrop, Limestone County

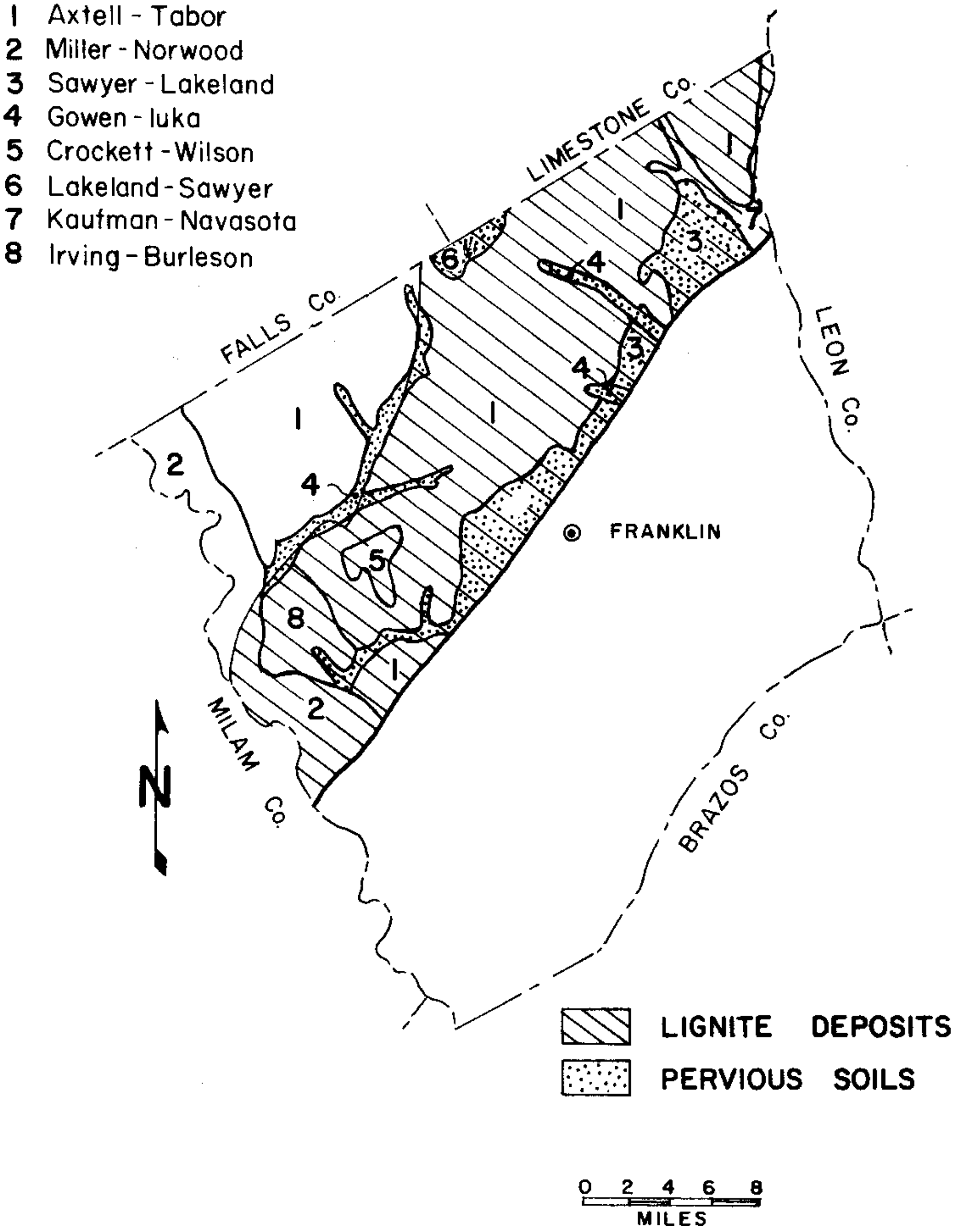


Figure 15. Pervious Soils and Lignite Deposits in the Wilcox Outcrop, Robertson County

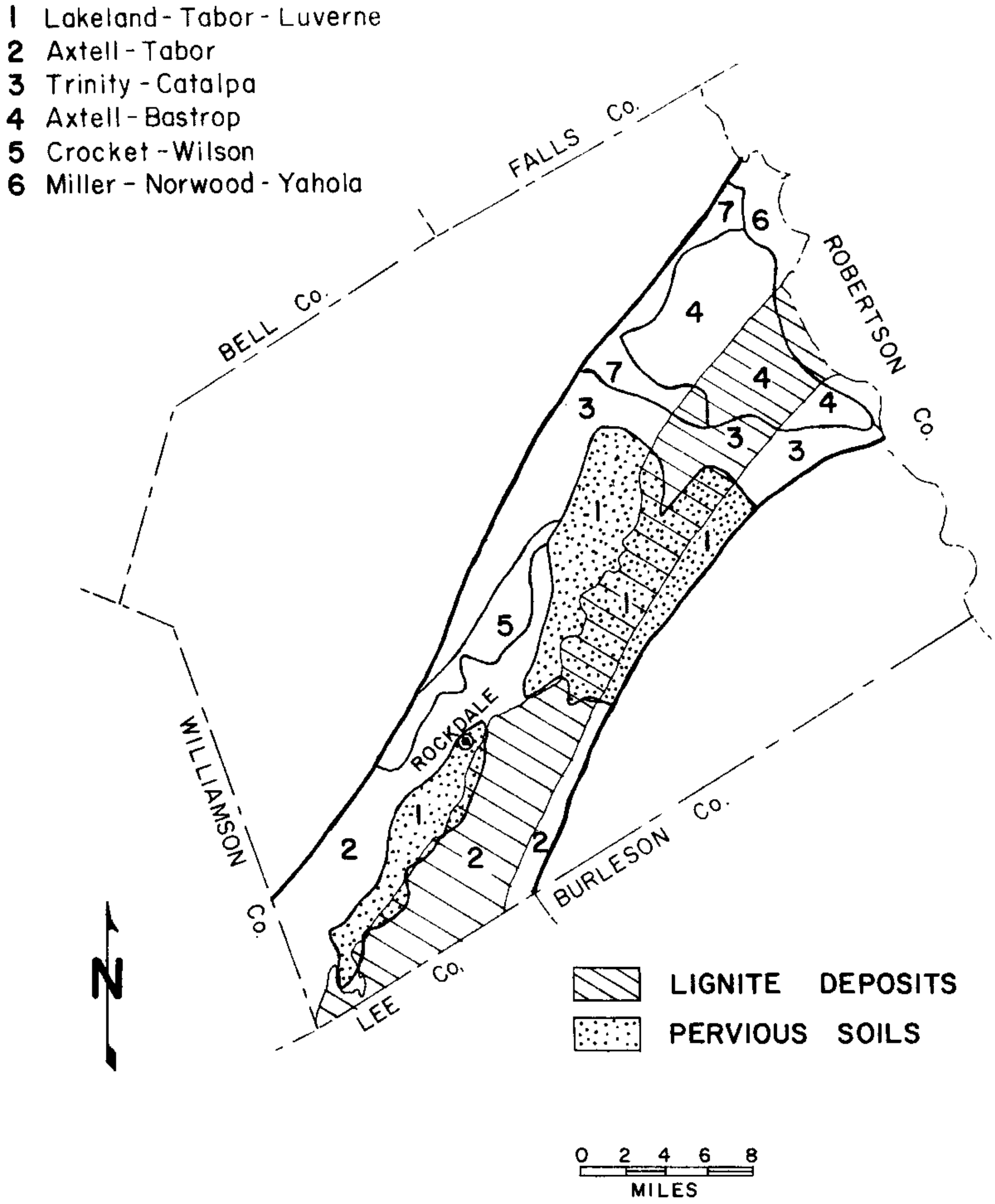


Figure 16. Pervious Soils and Lignite Deposits in the Wilcox Outcrop, Milam County

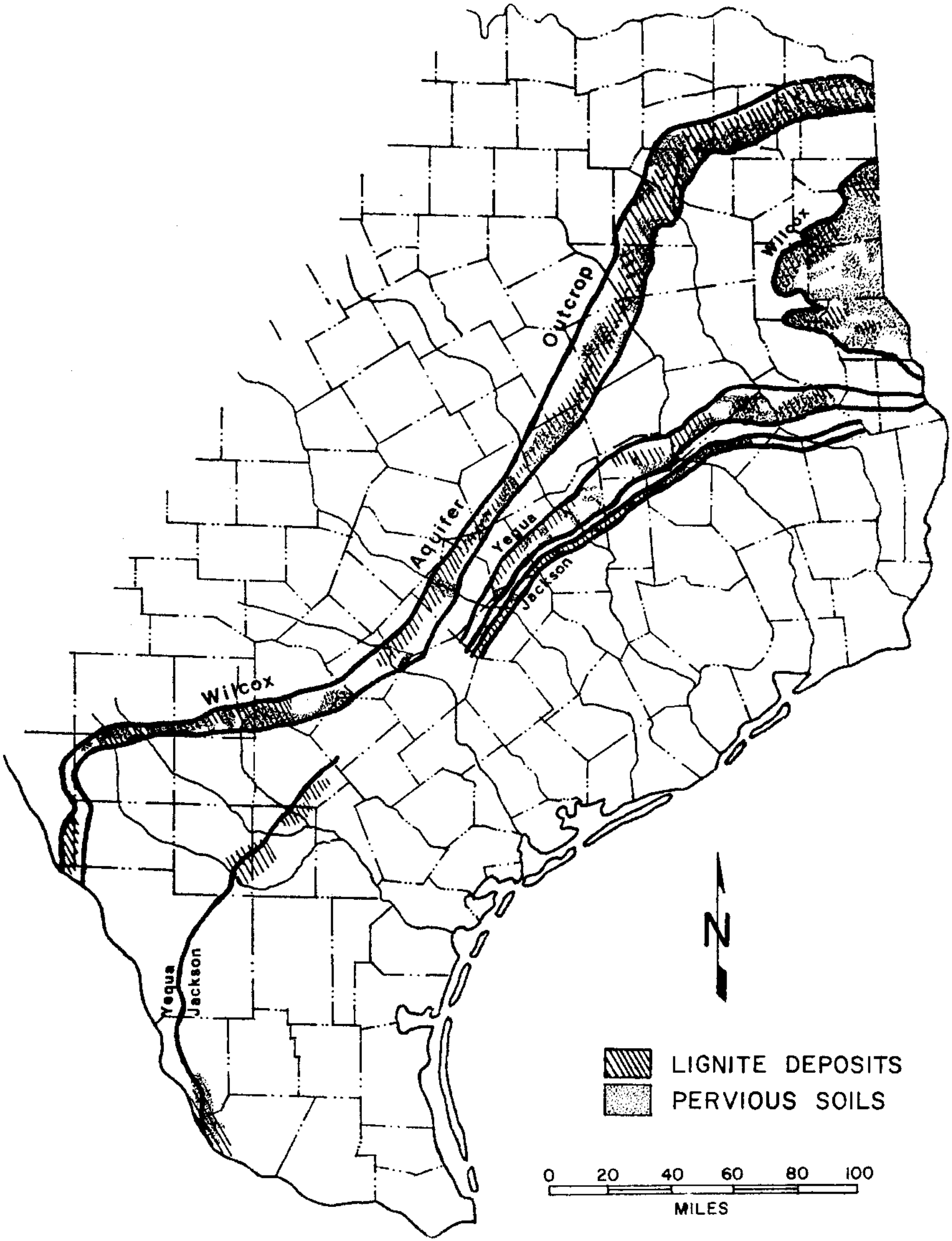


Figure 17. Lignite Deposits and Pervious Soils in the Wilcox and Jackson-Yegua Formations

Table 4. Pervious Soils Located in Potential Strip-Mining Areas in the Wilcox Outcrop.

County (1)	Wilcox Outcrop sq. mi. (2)	Lignite* Deposits sq. mi. (3)	Pervious Soils** Wilcox sq. mi. (4)	Pervious Soils** Lignite sq. mi. (5)	Col. (5)*** / Col. (4) % (6)
Shelby	740	200	450	130	29
Nacogdoches	60	30	-	-	-
Rusk	480	145	325	145	45
Panola	870	80	600	80	13
Harrison	530	120	530	120	23
Marion	95	85	95	85	89
Cass	70	50	70	50	71
Bowie	440	265	230	140	61
Morris	65	60	35	35	100
Titus	315	185	80	65	81
Franklin	165	120	90	75	83
Hopkins	315	180	95	35	37
Rains	180	85	75	40	53
Wood	120	70	55	40	73
Van Zandt	520	320	120	70	58
Henderson	370	210	115	95	83
Freestone	635	235	100	85	85
Limestone	430	100	110	0	0
Leon	40	40	-	-	
Robertson	340	290	90	30	33
Milam	470	215	105	65	62
Lee	90	40	15	15	100
Bastrop	410	215	40	20	50
Caldwell	315	75	20	0	0
Guadalupe	310	125	-	-	-
Bexar	340	80	275	80	29
TOTALS	8715	3620	3720	1500	40%

* Principal and potential lignite deposits from Kaiser, 1974

** See text for definition of pervious soils

***Percent of pervious soils in the Wilcox Outcrop that are underlaid by lignite deposits.

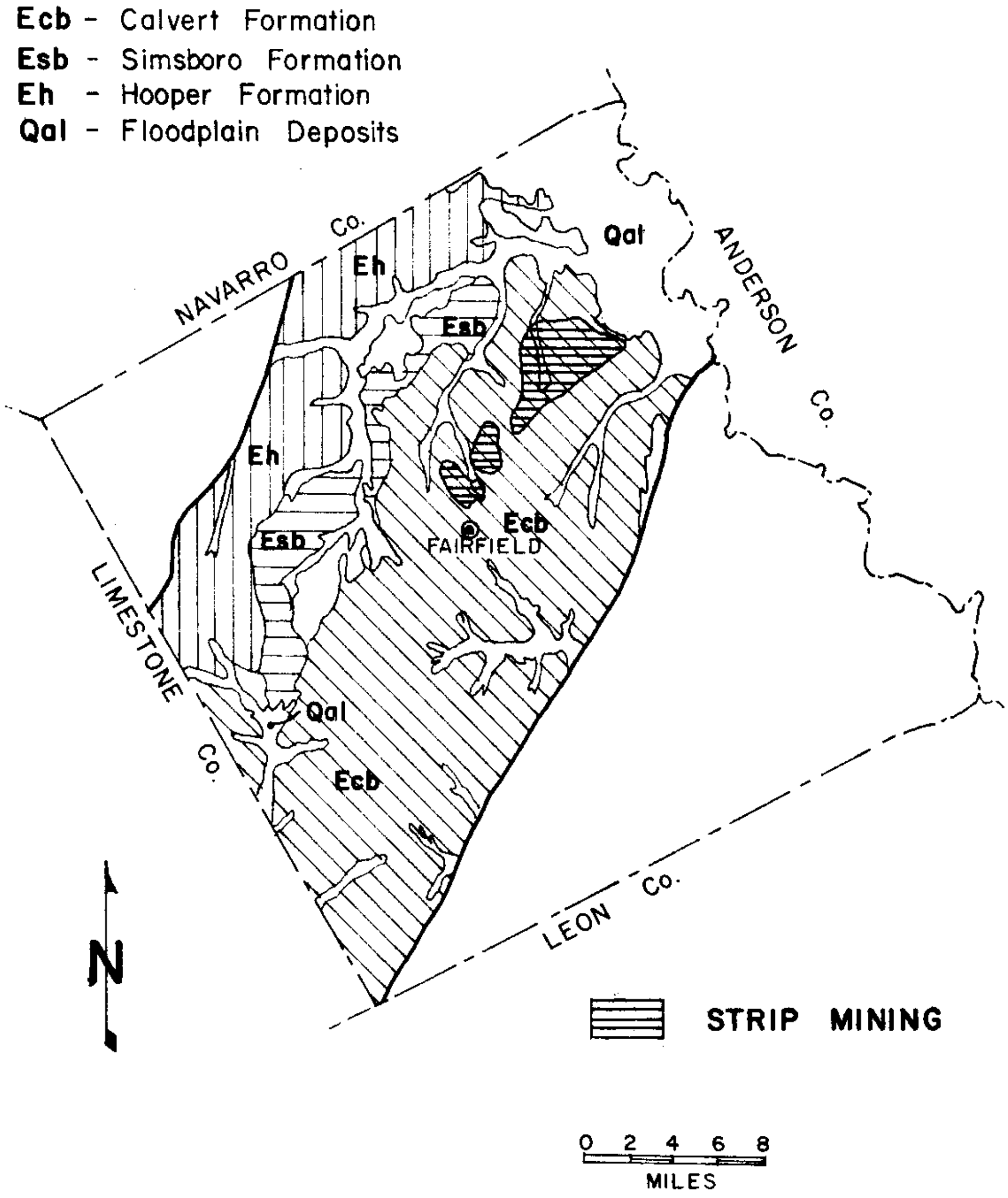


Figure 18. Formation of the Wilcox Outcrop in Freestone County

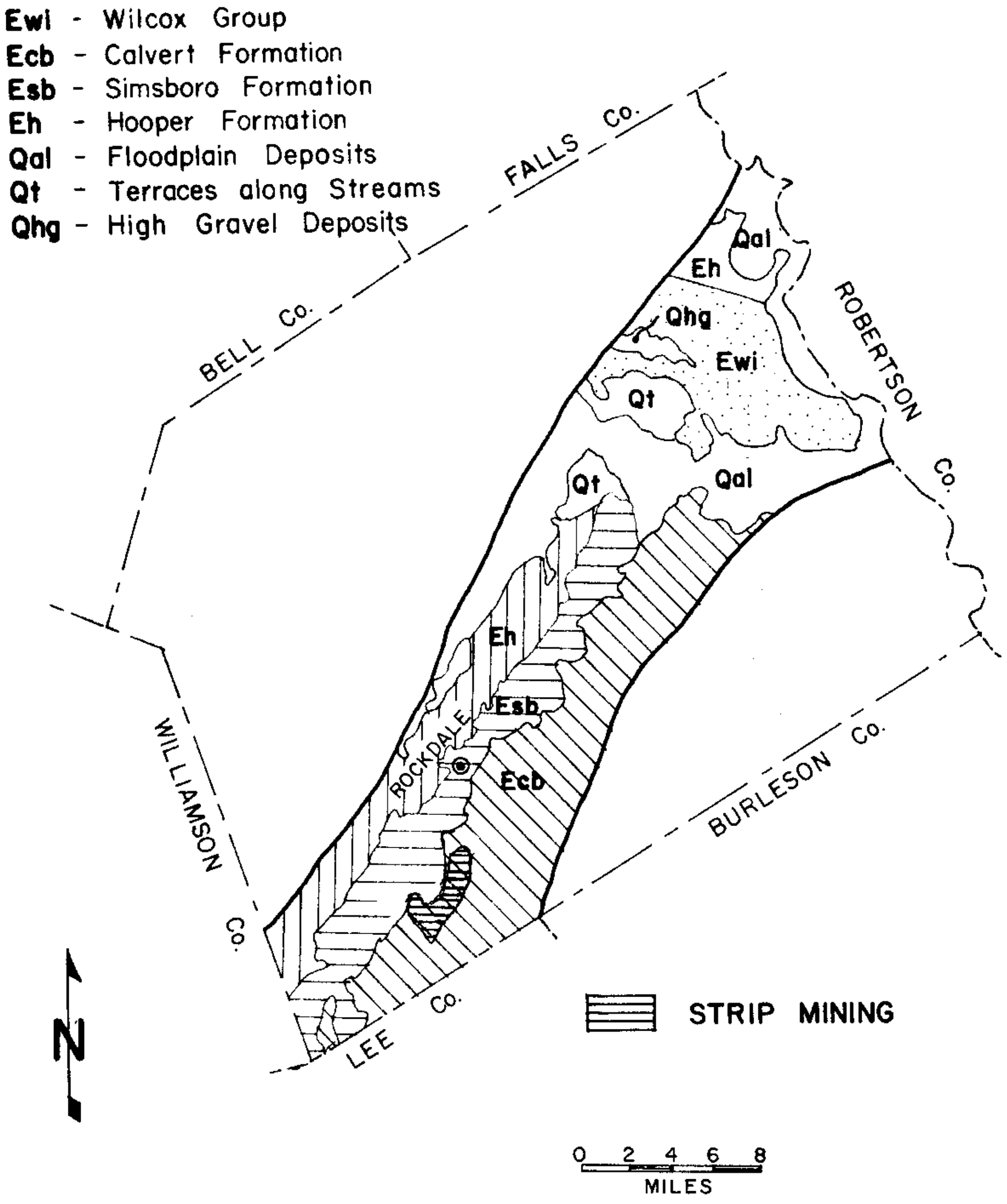


Figure 19. Formation of the Wilcox Outcrop in Milam County

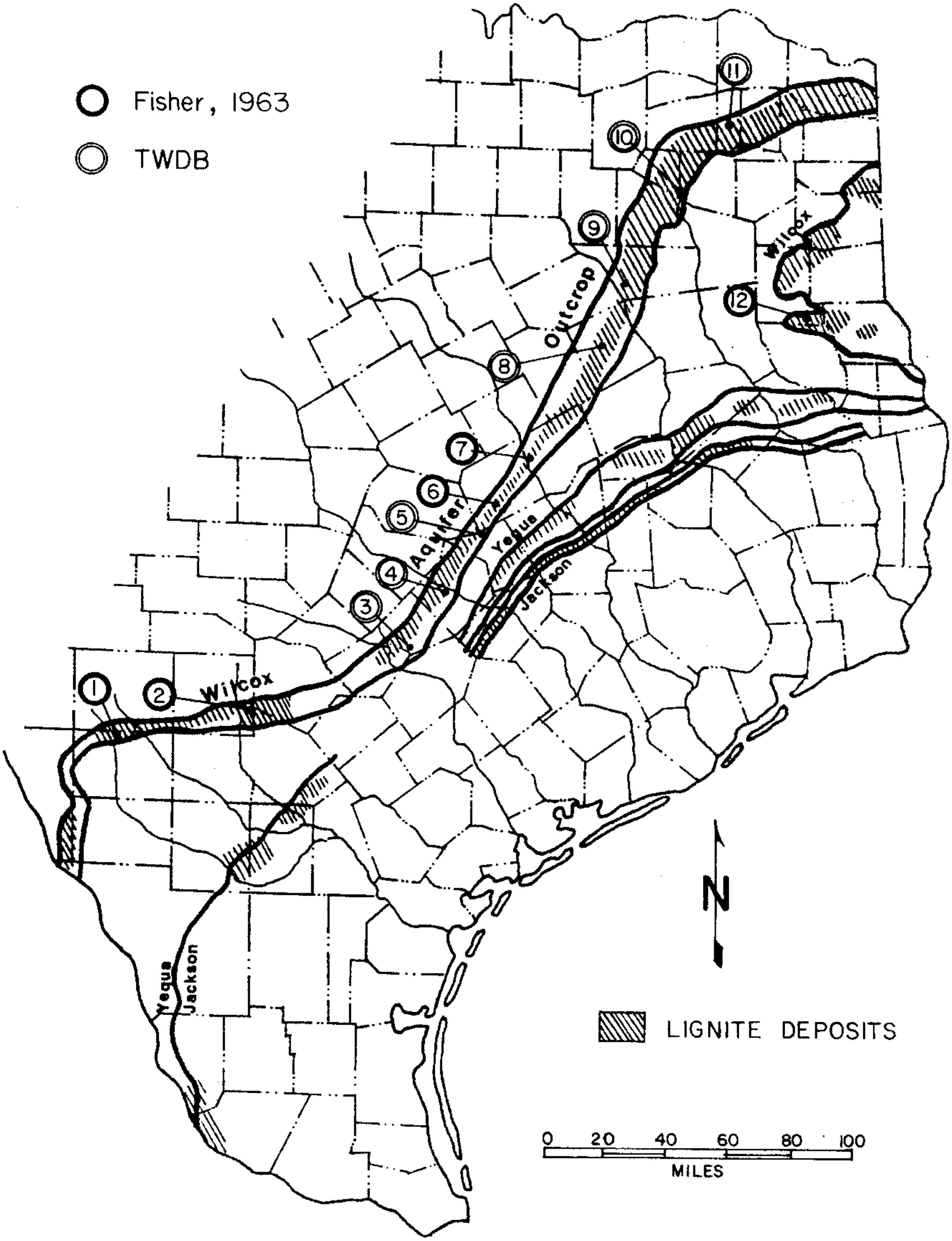


Figure 20. Location of Profiles in Lignite Areas of the Wilcox Outcrop

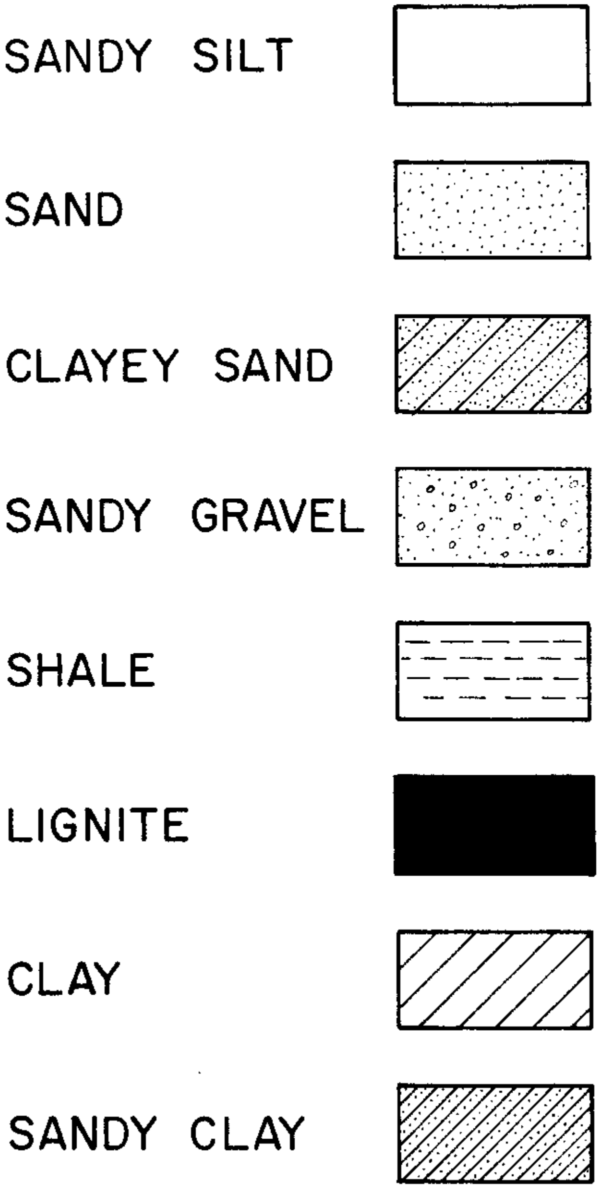
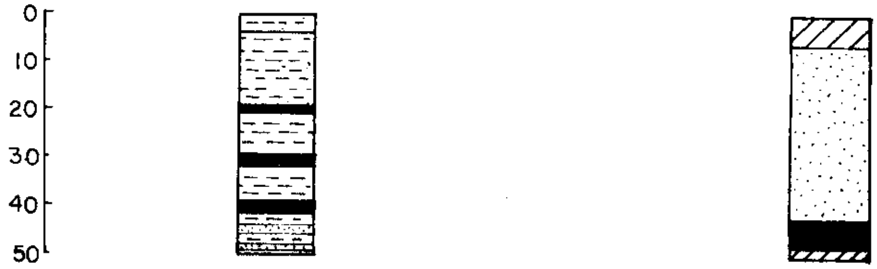


Figure 21. Symbols used on Profiles

* Source: Fisher, 1963

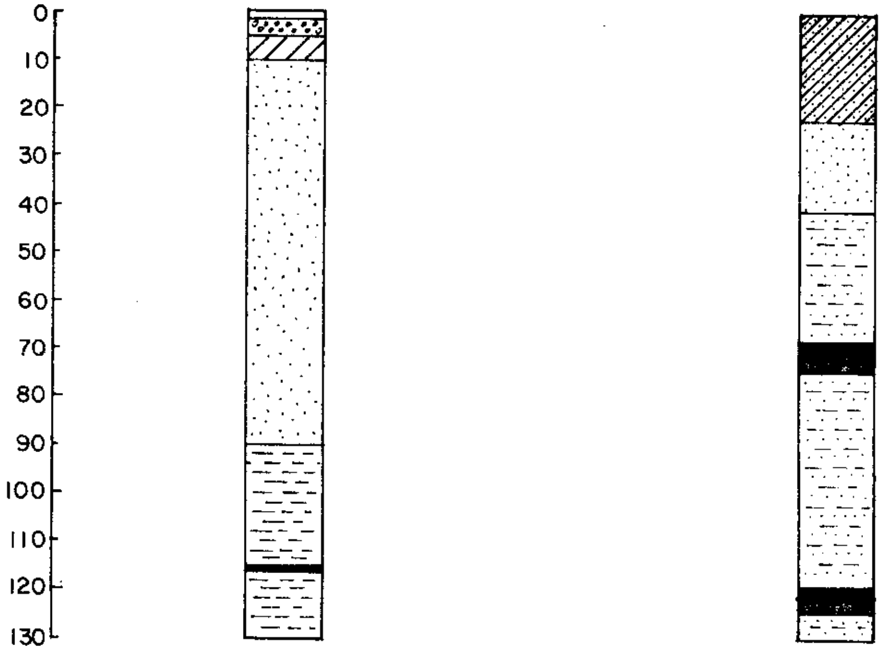


1
ZAVALA Co.

2
MEDINA Co.

* East Bank of Nueces River

* Mine Shaft West of Lytle



3
CALDWELL Co.

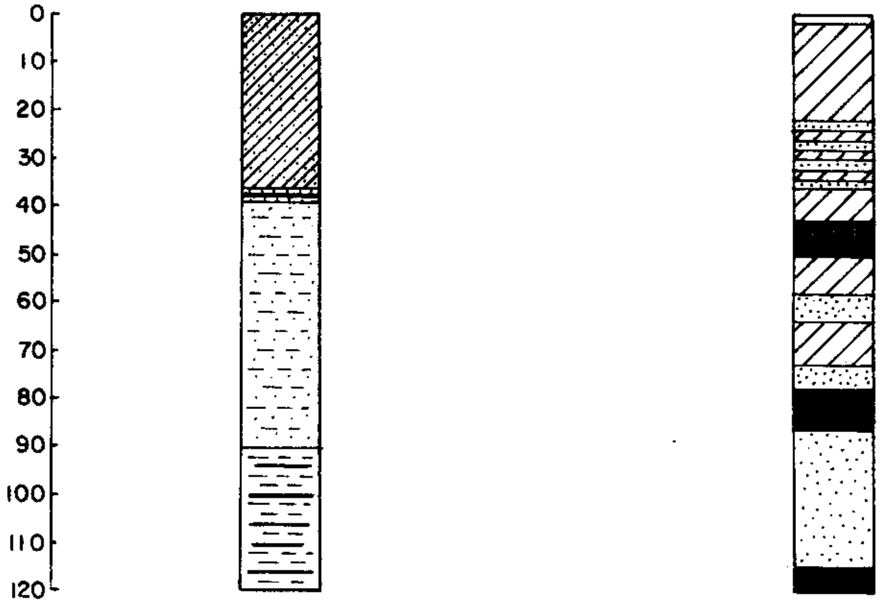
4
BASTROP Co.

Log of Well BU 67-19-503

Log of Well AT 58-62-109

Figure 22. Profiles in South Wilcox Outcrop

* Source: Fisher, 1963

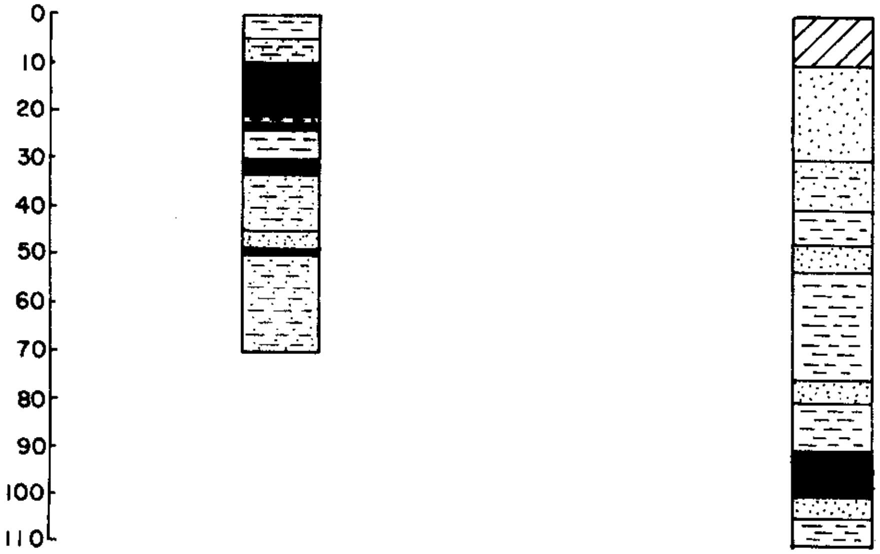


5
LEE Co.

6
MILAM Co.

Log of Well RZ 59-25-702

* Mine Shaft Near Rockdale



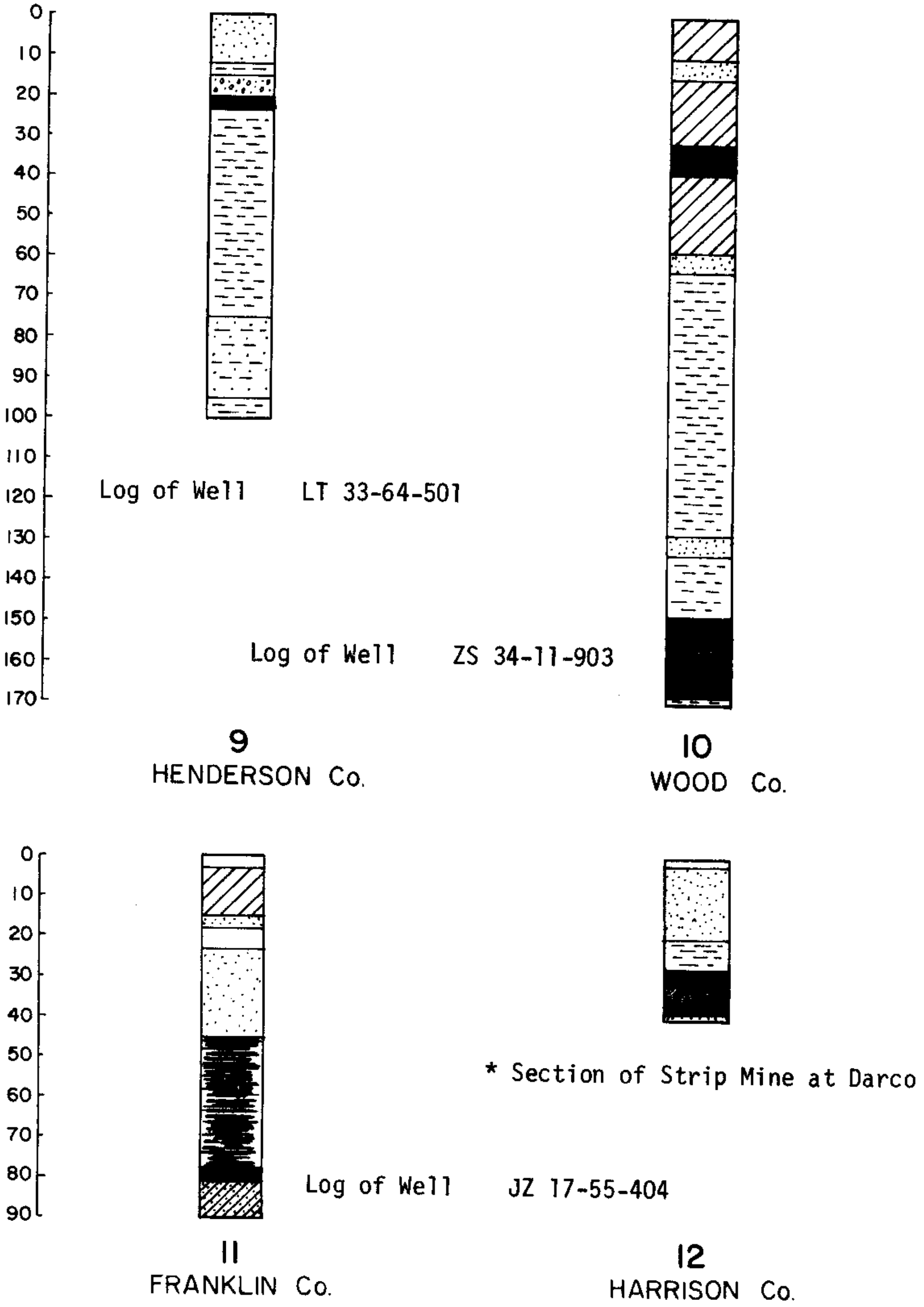
7
ROBERTSON Co.

8
FREESTONE Co.

* East Side of Brazos River

Log of Well KA 39-23-407

Figure 23. Profiles in Central Wilcox Outcrop



* Source: Fisher, 1963

Figure 24. Profiles in East Wilcox Outcrop

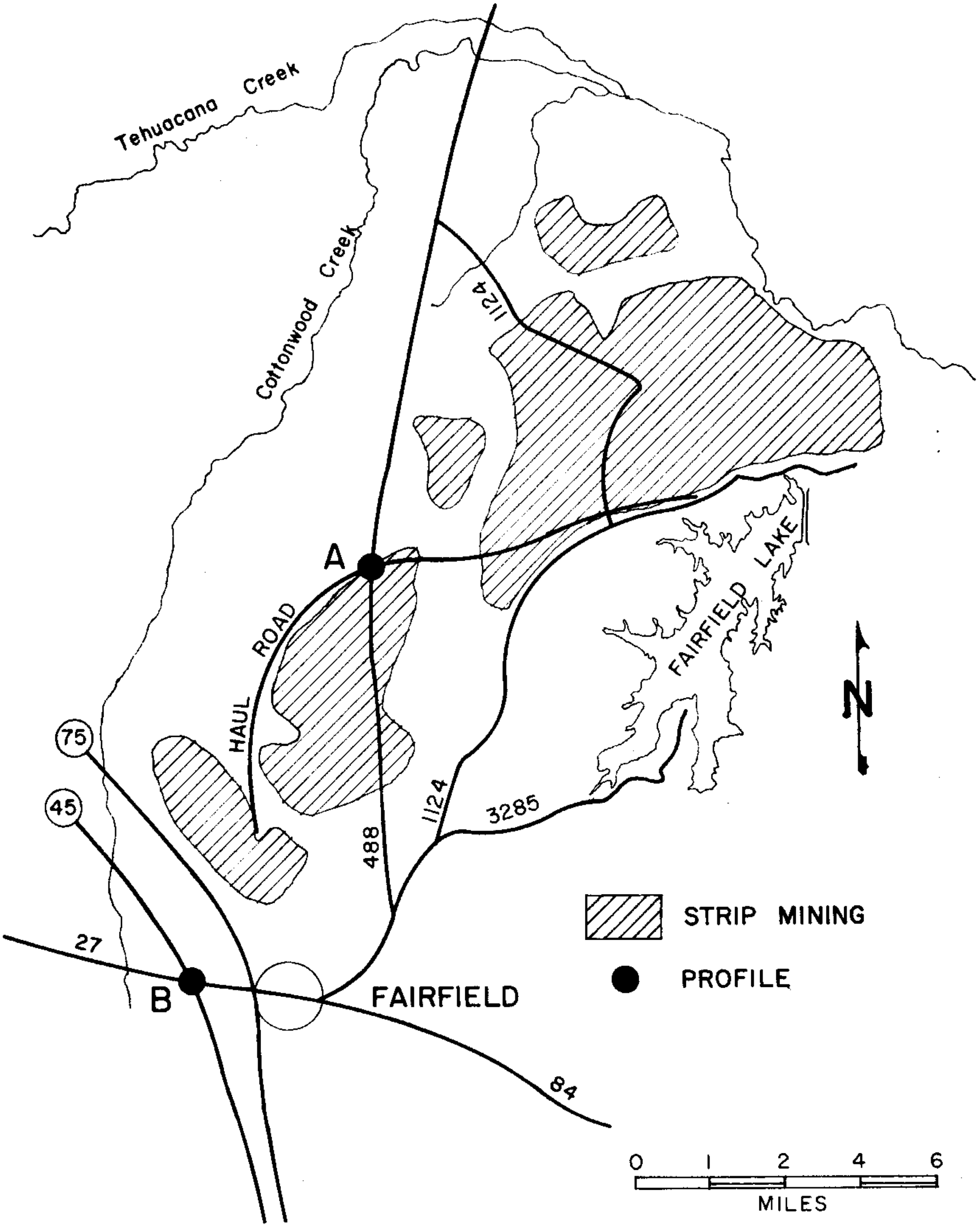


Figure 25. Strip-Mined Areas and Location of Profiles near Fairfield

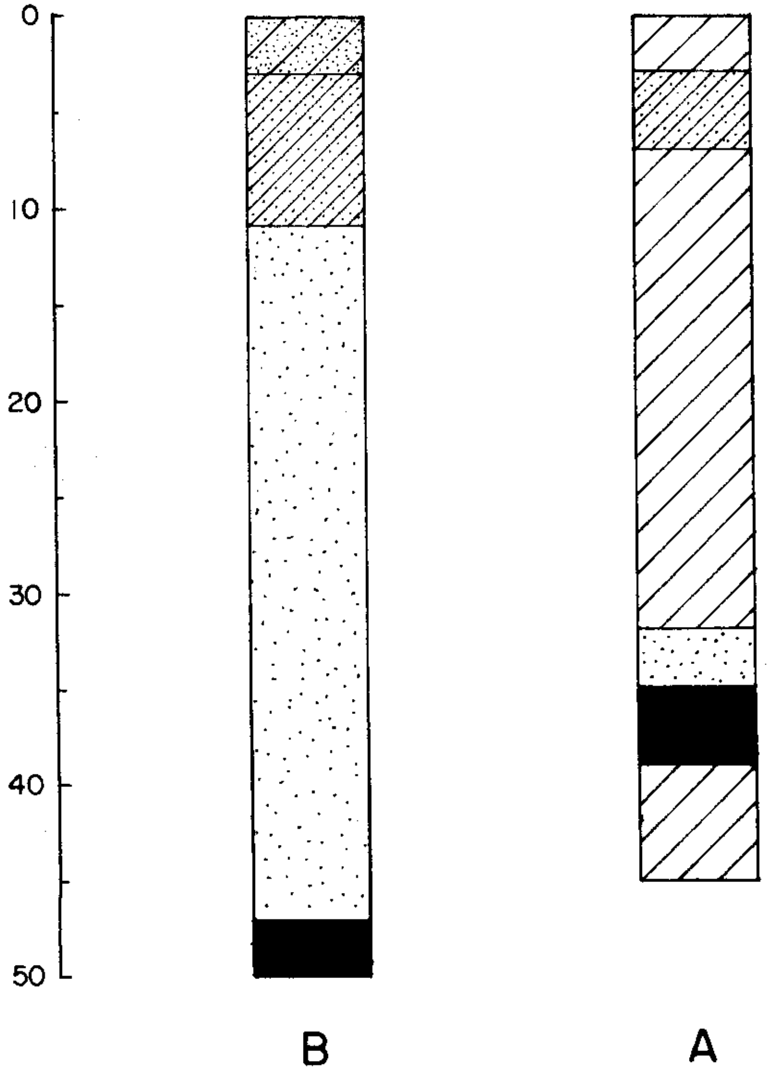


Figure 26. Texas Highway Department Profiles near Fairfield

associated with clay deposits, the overburden which would be disturbed in the mining operation often contains layers which are capable of transmitting water.

A summary of the Wilcox Aquifer characteristics is provided in Table 5 for 12 counties in East and Central Texas. Typically the Wilcox formation is about 1000 feet thick, has a slope of about one percent and permeability of 50 gallons per day per square foot. If the slope of the piezometric surface is assumed to equal the slope of the aquifer and the porosity is 20 percent, the actual velocity of groundwater flow would be about 100 feet per year. Strip-mining operations which have been in progress for five years such as those at Fairfield would not be expected to affect the groundwater for much over 500 feet from areas first mined. This makes it difficult to monitor groundwater about strip-mining operations utilizing existing wells.

If the average rainfall on the recharge area is 40 inches per year and the runoff coefficient is 20 percent, 32 inches would infiltrate into the soil. As shown in Figure 27, the recharge would be about 2.8 inches per year (based on the assumptions listed in the preceding paragraph and provided water available throughout the year for recharge). Approximately 30 inches per year would be consumed by evapotranspiration or rejected by seepage to surface streams. If the supply of water to plants is not limited, the free-water evaporation (approximately 55 inches per year) is ofted assumed to indicate potential evapotranspiration from a vegetated soil surface. Monthly rainfall values for Fairfield in Freestone County are shown in Figure 28 for the last 10 years. It can be observed that most precipitation occurs in spring and fall with minor amounts falling in summer and winter. According to Guyton (1972) in the counties of high precipitation, the factor generally limiting recharge is the transmissibility of the aquifer.

Table 5. Characteristics of the Wilcox Aquifer

County	Recharge Area miles^2	Rainfall in./yr	Evaporation in./yr	Aquifer Thickness ft	Storage Coeff.	Permeability Coeff. GPD/ft^2	Aquifer Slope	Velocity* ft/yr	Refer.** Report	yr
Gregg		46	44	<600	0.00006	80	0.0036	70	101	69
Nacogdoches	34	48		900-2000	-	45	0.016	180	110	70
Upshur	-	46	44	<600	-	80	0.0012	20	101	69
Wood	108	44	-	550-900	0.0005	50	0.006	70	79	68
Rains	119	43	30	-	0.0004	47	0.005	60	169	73
Van Zandt	413	43	30	960	0.0003	47	0.005	60	169	73
Henderson	161	40	-	800-1100	-	54	0.006	80	150	72
Smith	-	44	-	-	-	50		-	6302	63
Freestone	433	38	-	800-1100	-	42	0.005	50	150	72
Lee	99	37	59	2050-3000	-	-	0.03	2200	70	66
Bastrop	323	37	60	1400-2600	0.0004	-	0.03	166	109	69
Caldwell	214	32	73	1200-2000	0.001	-	0.03	800	12	66

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* Velocity was estimated assuming a porosity of 20% and the slope of the piezometric surface equal to the slope of the formation.

** Reference reports of the Texas Water Development Board.

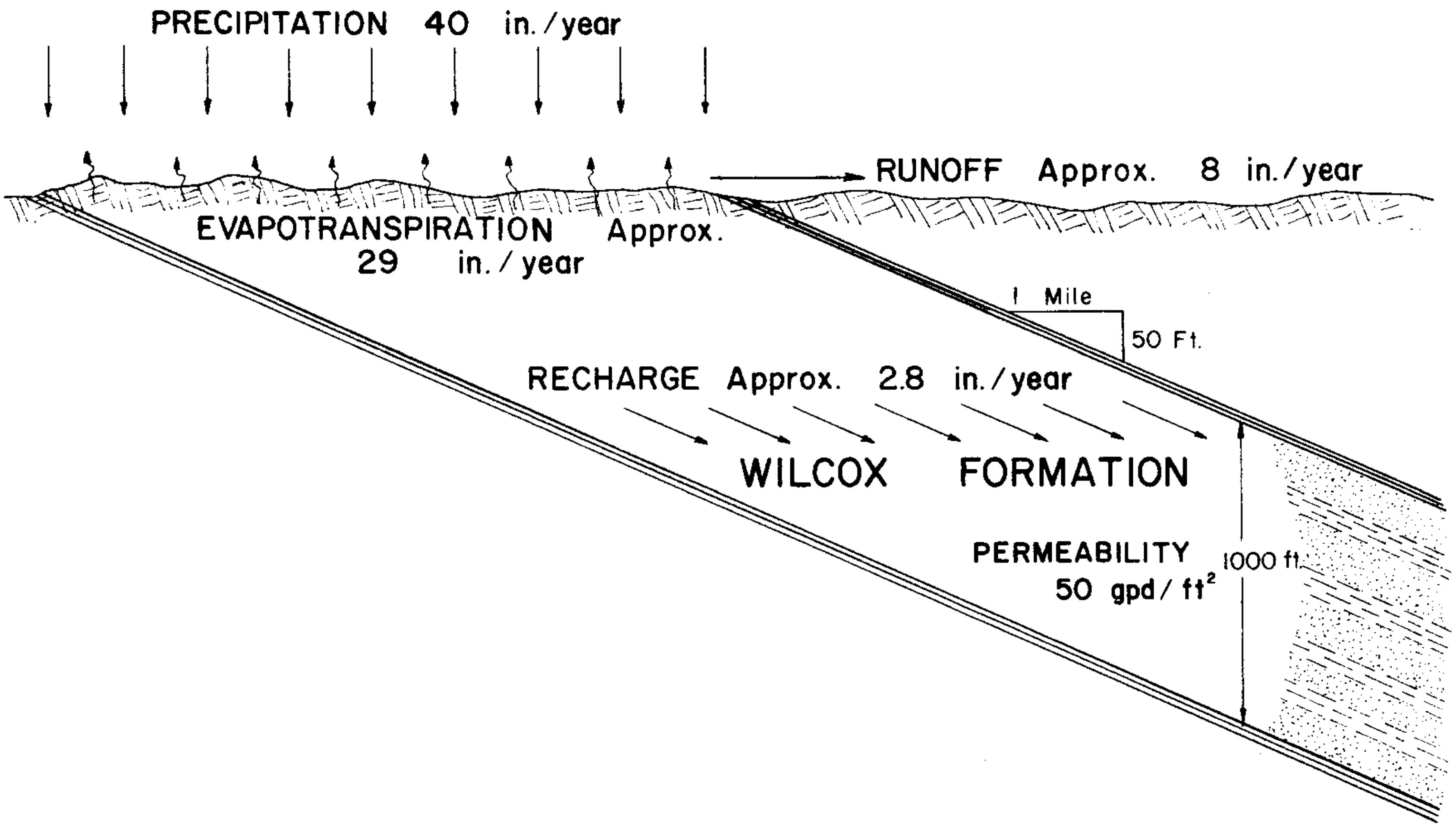


Figure 27. Recharge Potential for the Wilcox Formation

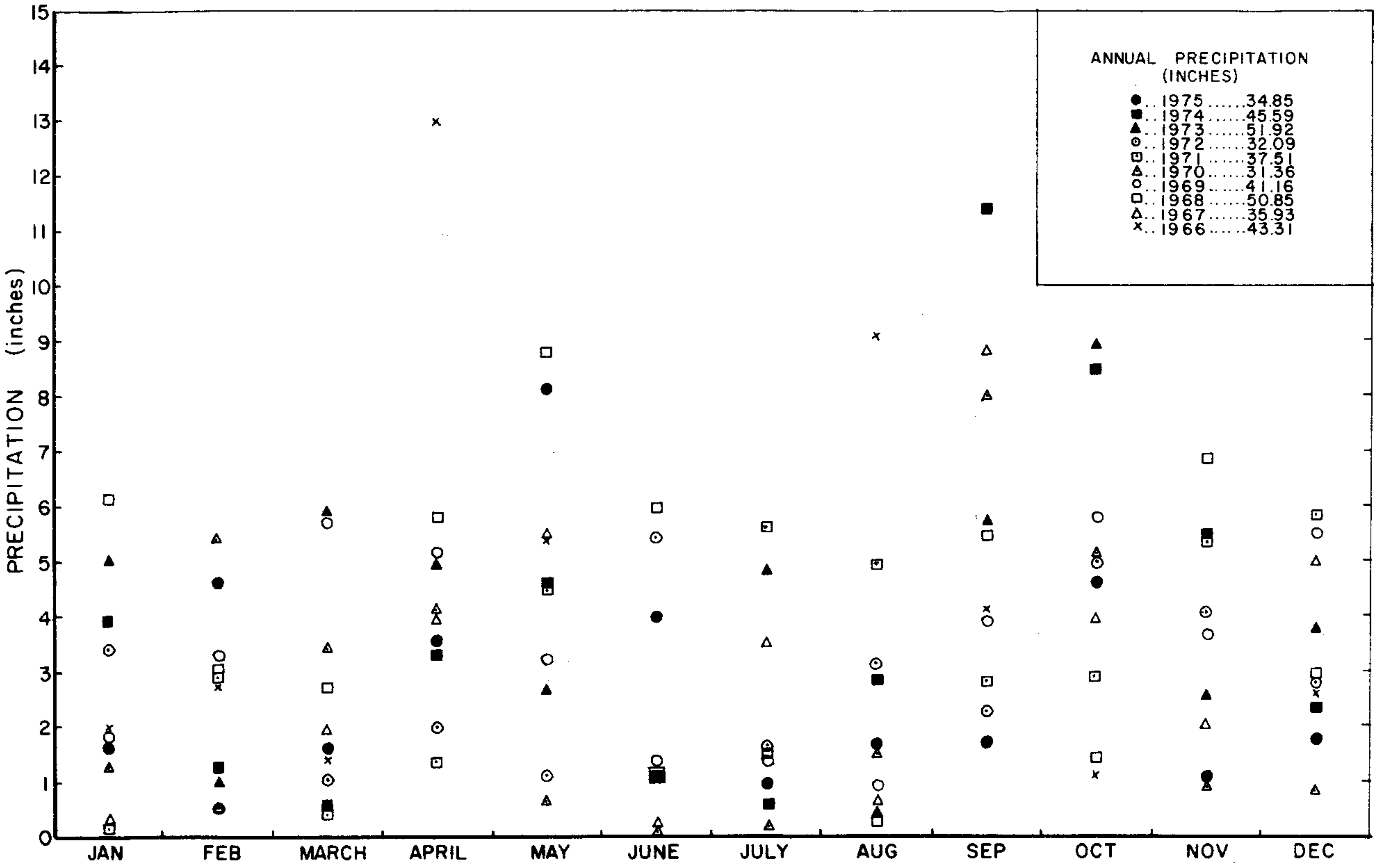


Figure 28. Monthly Precipitation for Fairfield.

If only 43 percent of the Wilcox outcrop area has soils which allow significant recharge, the recharge in the pervious soils becomes more important and about 6.5 inches of recharge per year is required for the pervious soils to equal the transmissibility of the aquifer.

The water table in the recharge area is controlled by the base level of the streams and during wet periods slopes toward the streams causing seepage into the streams. During a dry period there is little flow in the streams indicating only a small part of the recharge is rejected by seepage.

Strip-Mined Areas

In the lignite strip-mining operation, the overburden is removed, lignite extracted and the spoil reshaped to approximately its original shape. The overburden expands about 15 percent in the mining operation. Thus additional voids are available for storage of water in the strip-mined area. If the porosity of the overburden was 20 percent before mining, it could increase to about 30 percent after mining. The additional void space would be provided as noncapillary porosity and could be used to store gravity water. A 1,000-megawatt plant operating for 35 years would strip mine about 20,000 acres. If the average depth of overburden is 50 feet, approximately 150,000 acre-feet of additional subsurface void space would be provided. As shown in Figure 29, subsurface water storage would be limited by seepage which depends on the slope of the formation and the location and elevation of streams in the recharge area. Perhaps 20 percent of the total volume or 30,000 acre-feet of subsurface storage could be utilized. As pH does not appear to be a problem associated with the low sulfur lignite in East Texas, subsurface storage would have the advantages of (1) limiting water loss to evapotranspiration,

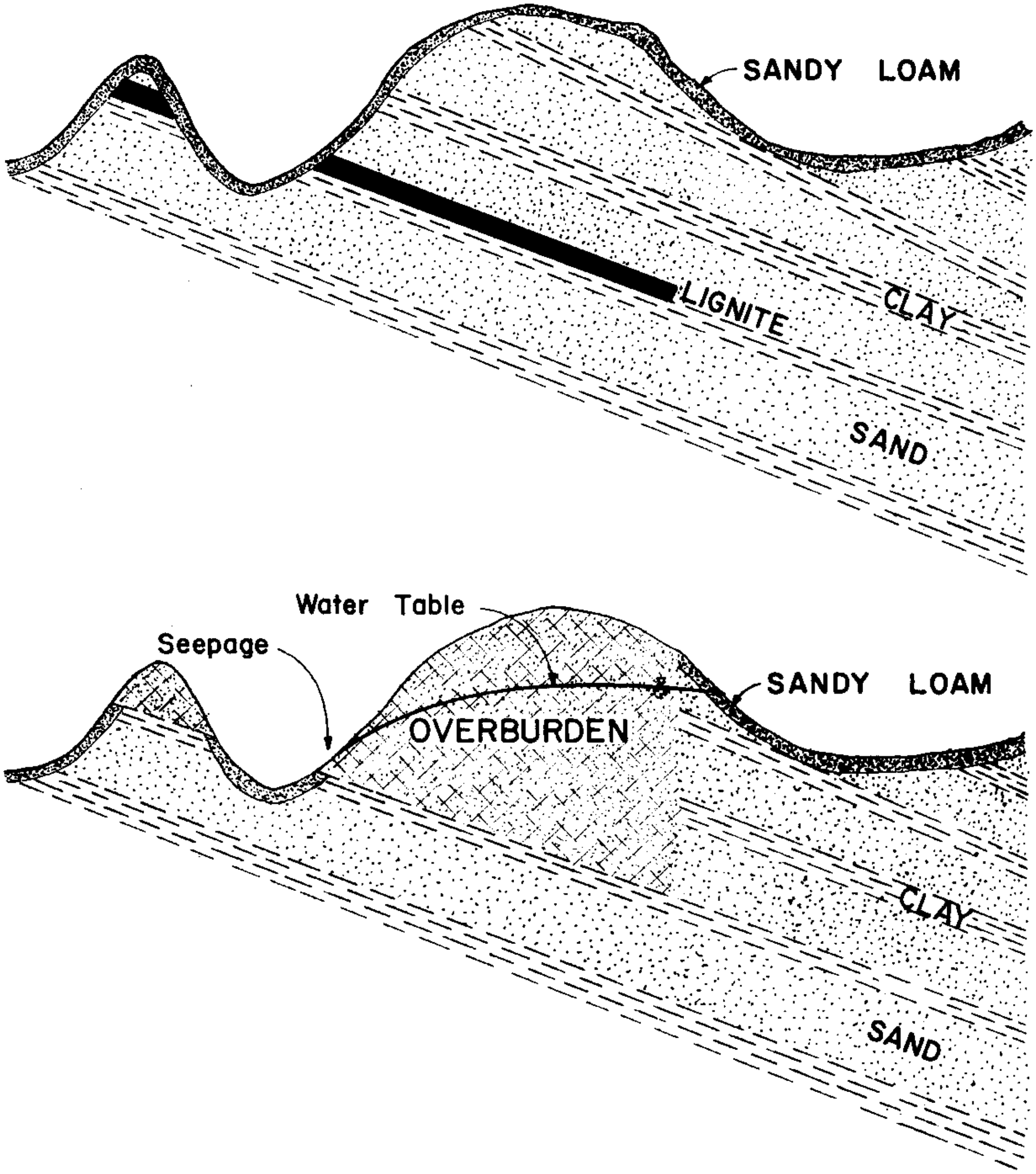


Figure 29. Subsurface Water Storage Potential of Strip-Mined Areas

(2) providing more uniform flow in the surface streams by increasing seepage, (3) increasing recharge to the aquifer by providing a continuous supply of recharge water and (4) providing a large volume water supply from shallow wells. After many years when the overburden has reconsolidated to its original density, the additional porosity will be lost and the permeability of the overburden will probably be reduced from its original value.

Musgrave and Holtan (1965) considered infiltration to be affected by three main factors: surface entry, transmission through the soil and depletion of storage capacity in the soil, in addition to the characteristics of the permeable medium and percolating fluid. Prior to mining, transmission through the soil would probably be the limiting factor while after mining when the top soil is not replaced, surface entry will probably be the limiting factor.

Wisler and Brater (1956) listed eleven major factors affecting infiltration rate as follows: (1) depth of surface detention and thickness of saturated layer where gravity is the principal force on infiltration, (2) soil moisture, (3) compaction due to rain, (4) clogging of pores with fine particles from the surface, (5) compaction due to man and animals, (6) development of permeable structure in the soil by natural conditions such as by burrowing animals and insects, decay of vegetable matter, frost heaving, and by sun checking, (7) vegetative cover, (8) changes in viscosity of water, (9) freezing of water in soil, (10) reduction of infiltration by the compression of entrapped air, (11) annual and seasonal changes in land use and vegetation.

Most of the factors affecting infiltration rates are modified during strip mining and land reclamation. During the mining operation the various layers of the soil (sand, clay, etc.) are mixed together (sandy clay, clayey sand, etc.) and the porosity of the overburden is increased. Reclamation tends to smooth the surface reducing surface detention and causes compaction of the surface by heavy equipment which reduces the noncapillary pore space and the permeability of the surface soil. If the top soil is not replaced in the reclamation operation, the surface soil will probably change from a silty to clayey material, storage capacity of the surface layer will decrease and direct runoff will probably increase. Vegetation cover protects the soil surface from the impact of raindrops, reduces the clogging of pores with fine particles through erosion protection and provides root penetration and organic matter for the soil. During the summer deep soil cracking might occur and improve the infiltration prior to the fall rains. The permeable structure of the reclaimed area should improve with time because of burrowing animals and insects, increased organic matter, root penetration, surface cracking and development of vegetative cover.

Impoundments are required for controlling the turbidity of surface runoff from the overburden and could also serve as infiltration basins for groundwater recharge. How effective they are for this function will depend on the type of material lining the bottom of the reservoir.

Four satellite views of the Fairfield area are shown in Figure 31. Landsat imagery (red band) was taken in August 1972, May 1973, June 1974 and March 1975. Figure 30 includes tracings of the imagery in Figure 31 and shows the strip-mined area, and for reference and scale, Fairfield Lake and Interstate 45. The first dragline operation and associated strip mining began in April 1971. In March 1975, the outline of the strip-mined area is clearly visible including the area that was mined in 1972. Revegetation of

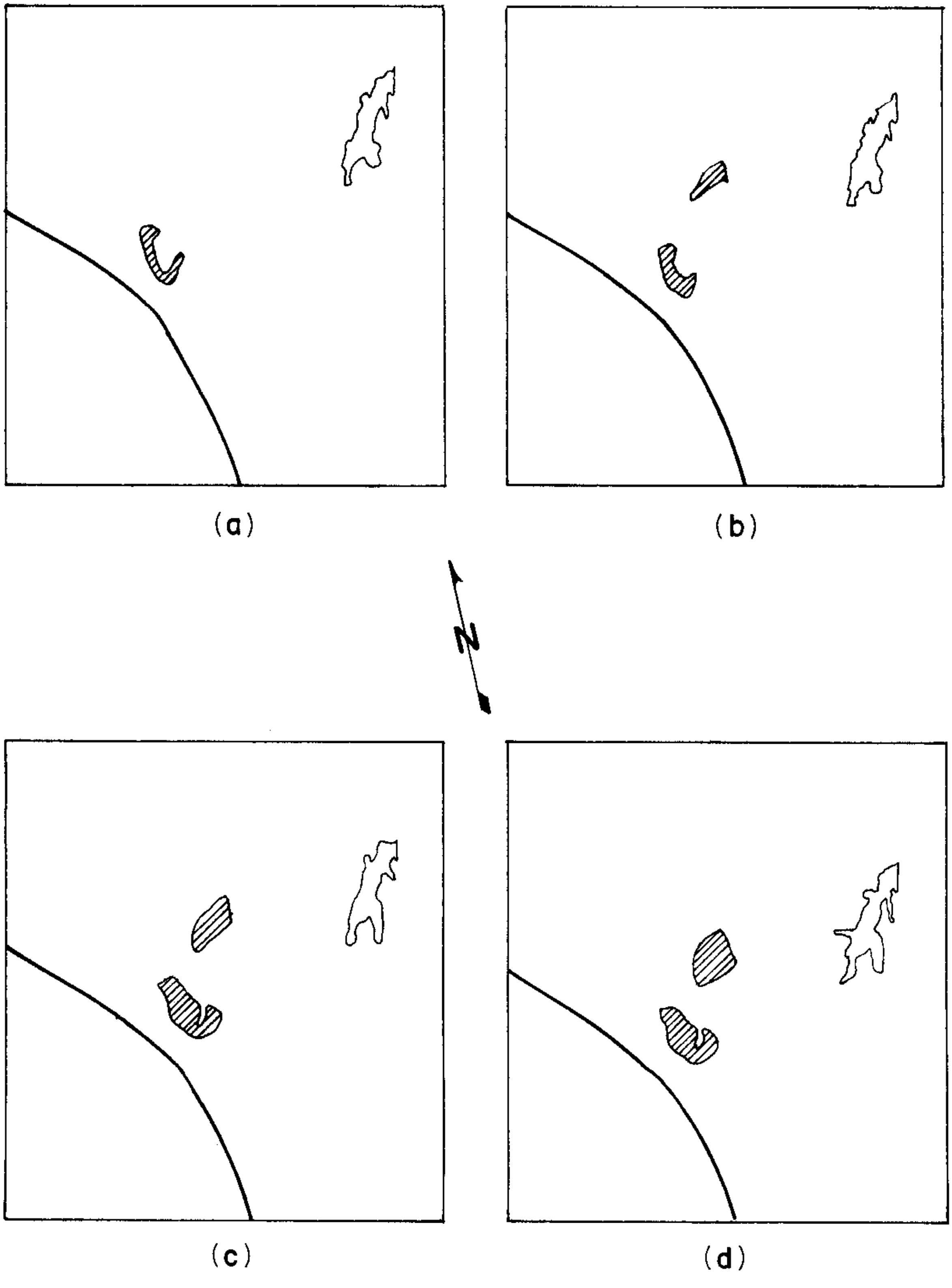
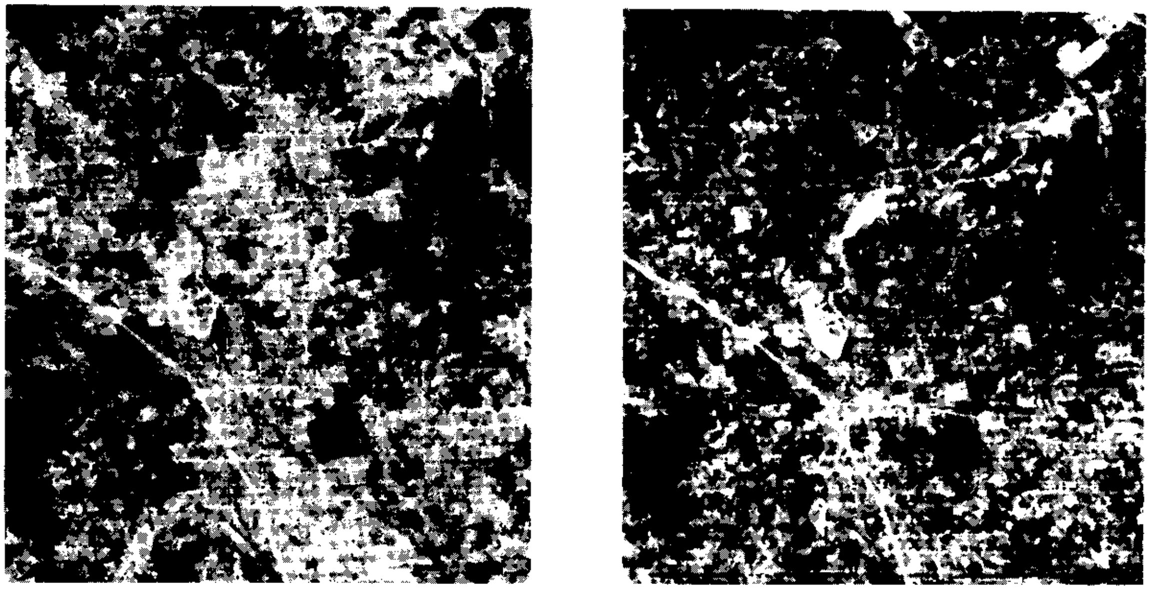


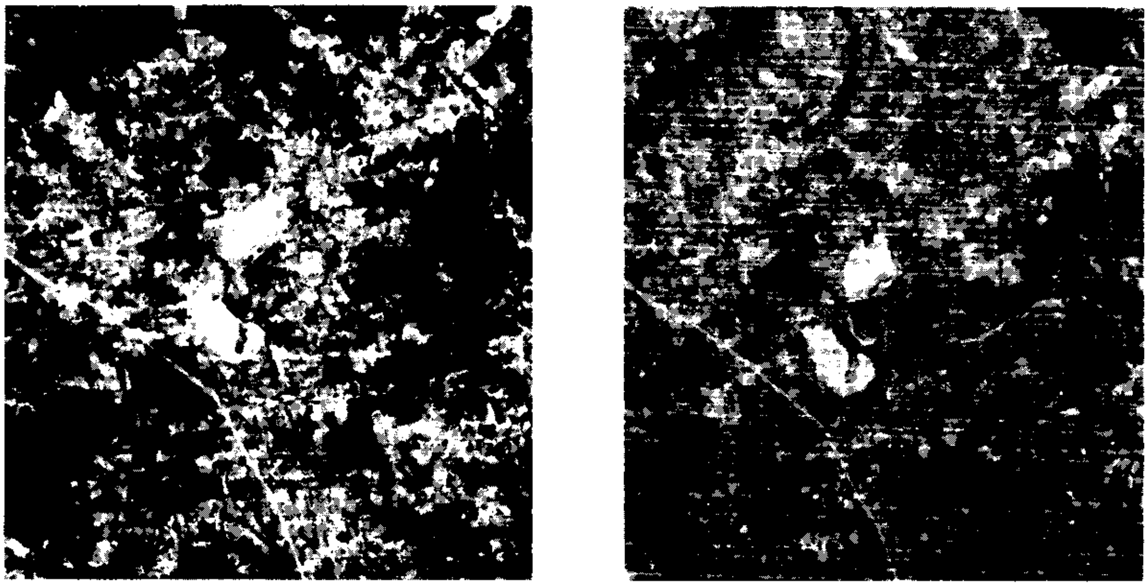
Figure 30. Sketch of Strip-Mined Area and Cooling Lake near Fairfield



a. August 30, 1972

b. May 9, 1973

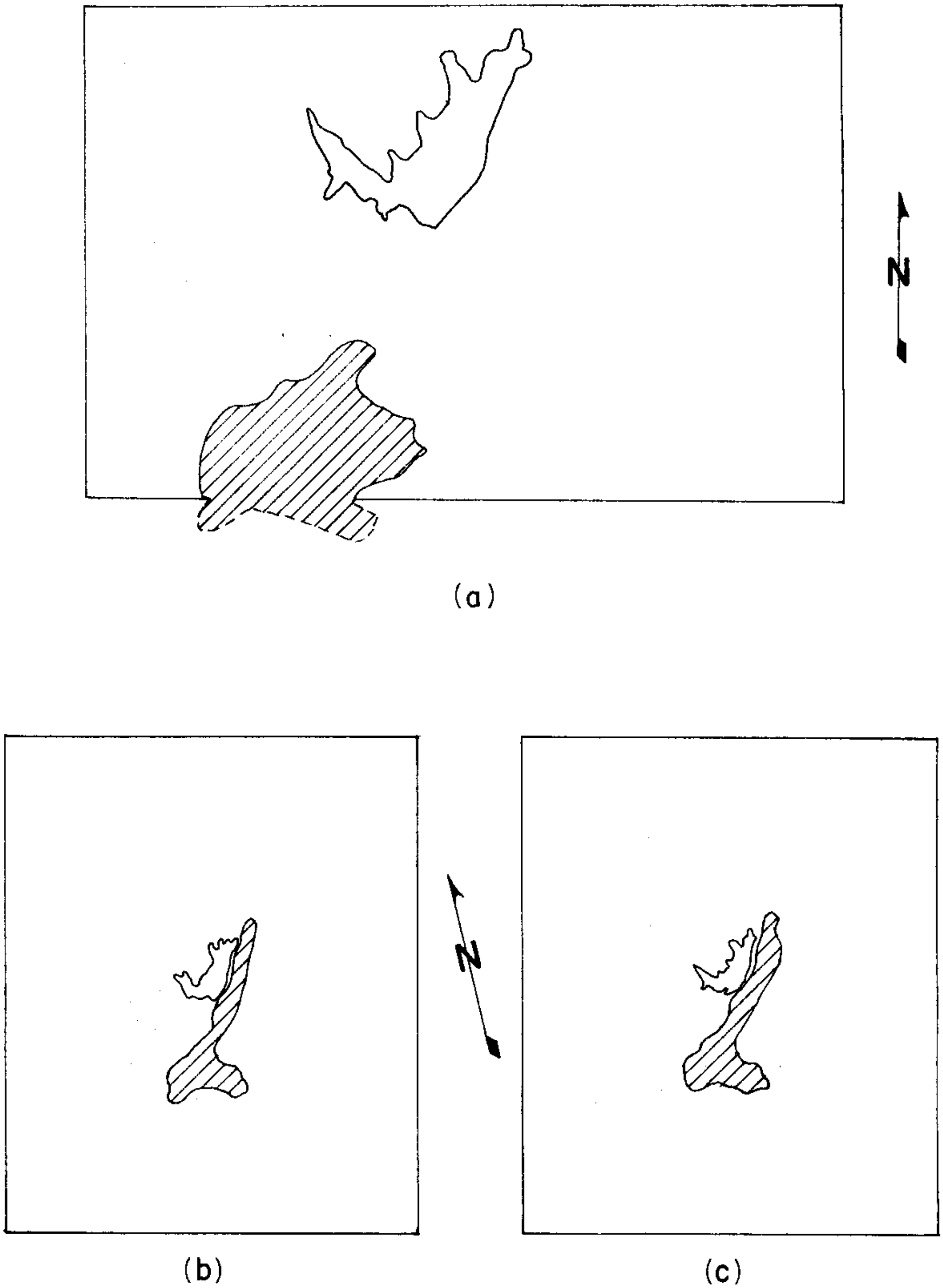
Scale 1 inch to 5.5 miles



c. June 27, 1974

d. March 24, 1975

Figure 31. Landsat Imagery of Fairfield Area

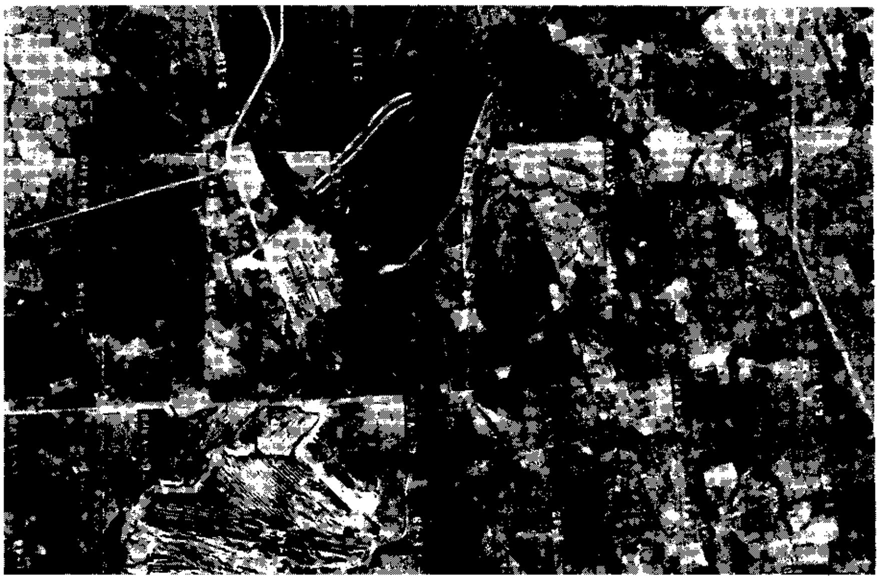


(a)

(b)

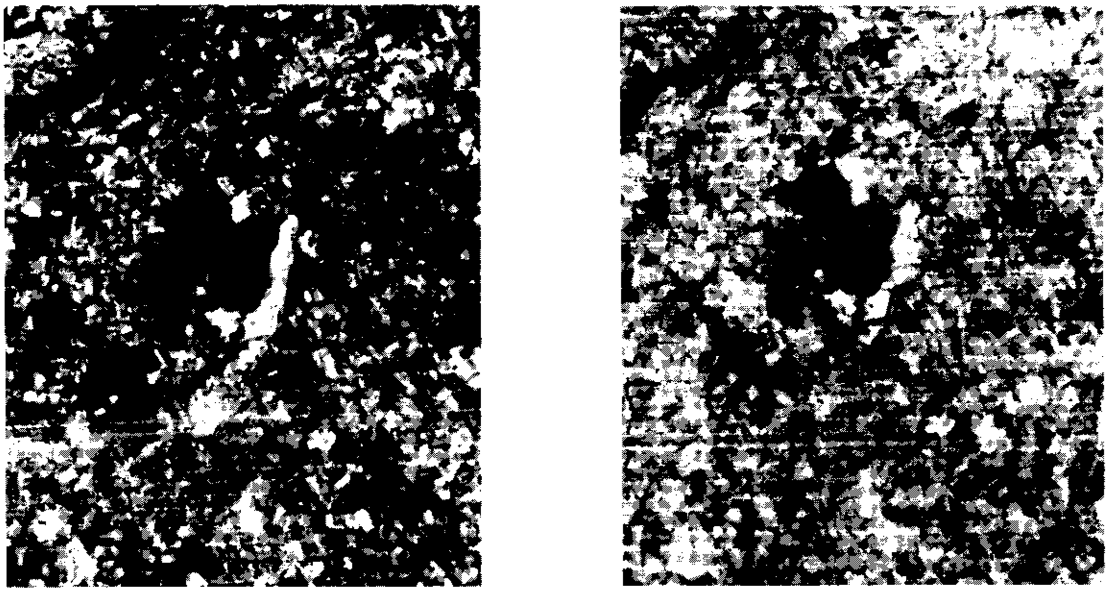
(c)

Figure 32. Sketch of Strip-Mined Area and Cooling Lake near Rockdale



a. February 3, 1963 - Aerial Mosaic

Scale 1 inch to 1.4 miles



b. May 9, 1973

c. February 25, 1975

Satellite

Scale 1 inch to 4.4 miles

Figure 33. Aerial Mosaic and Landsat Imagery of Rockdale Area

the area nearest Interstate 45 has been completed and the area is presently being utilized for pasture.

Figure 33 includes an aerial mosaic and two satellite views of the Rockdale area. Tracings of these scenes are shown in Figure 32 and include the strip-mined area and Alcoa Lake. The strip-mined area begins about 3 miles southwest of Alcoa Lake and extends along the southeast side of the lake. The spoil in the northern part is being reclaimed while that in the southern part is not. Spoil lakes in the southern part of the strip-mined area indicate a high water table. After strip mining began at Rockdale, one well located southeast of the mine dried up apparently due to de-watering pits in the mining operation (Crump, 1975). According to the Water Quality Board records (Freeman, 1970), mine de-watering averages about 1,242,000 gallons per day (1,400 acre-feet per year).

CHAPTER IV

SPECIAL STUDIES

The primary purpose of the study was to identify potential problems associated with the development of lignite reserves on the water resources of East Texas. The main questions to be answered were (1) what water quality parameters might be affected by lignite development and (2) are changes in these parameters measureable in the surface water and groundwaters around existing lignite developments. To help answer these questions, special studies were conducted and are described in this chapter. These included trace element enrichment study, precipitation study, leaching study and water quality study. Samples were collected in the field and analyzed according to the procedures described in Appendix B.

Trace Element Enrichment Study

Background. Trace elements in lignite are similar to those in the earth's crust and consist of nearly all the elements in the periodic chart. Because of the chemical environment during the formation of the lignite, it can contain elevated levels of certain trace elements relative to the average concentration in the earth's crust. Lignite may contain elements that have undesirable physiological affects on plant and animal life such as As, Be, Cd, F, Hg and Se. Illinois State Geological Survey (Ruch, Gluskoter and Shimp, 1976) conducted an investigation of trace elements in coal and found As, Cd, and Hg to be inorganically combined in coal while Be was organically combined in the coal.

Large amounts of lignite are being used at single locations in the environment which might tend to concentrate these elements in harmful concentrations. For example, a 1,000-megawatt plant would utilize about 6 million tons per year of lignite. If the concentration of arsenic in the lignite is 3 ppm, 18 tons per year of arsenic would be released from the plant with bottom ash and fly ash or discharged from the stack. There are potential health risks associated with those elements which are highly volatilized (mercury, selenium and arsenic) and those discharged principally as submicron particulates (lead, cadmium and nickel) (Piperno, 1975). The process of lignite combustion releases trace elements to the atmosphere as vapors and particles, small particles which pass through the air pollution control devices have relatively greater concentrations of certain trace elements than the feed lignite or the collected fly ash. Studies conducted by Kaakinen et al., (1975) indicated that the enrichment of As, Pb and Se was related to specific surface areas of the ash.

Bolton, et al (1973), conducted a trace element mass balance for the coal-fired Allen Steam Plant in Memphis. The study indicated that electrostatic precipitators were effective in removing most trace elements in the flue gas. Exceptions were those elements (mercury, selenium and arsenic) forming volatile compounds and discharged with the flue gas as a vapor. For example, more than 80 percent of the mercury entering with the coal was emitted with the flue gas as a vapor.

Airborne trace metals resulting from fossil-fuel combustion is frequently cited as a source of metals in lakes. Bertine and Goldberg (1971) consider fossil fuel consumption to be a potentially significant source of atmospheric discharge of many trace metals.

In a study designed to detect fallout from a major coal burner equipped with a precipitator, Klein and Russell (1973) showed that many trace elements were deposited in the surrounding soil. They were able to correlate the enrichment with the wind rose pattern around the plant. Except for mercury, the highest surface soil concentration occurred about 1.5 miles downwind from the plant.

Given, *et al*., (1975) conducted a study on major, minor and trace elements in the liquid products and solid residue from catalytic hydrogenation of coals. This study indicated that the oil produced from the coal was a cleaner fuel than the original coal as most trace elements concentrated in the residual material from the process. However, some of the more toxic elements such as mercury, selenium, fluorine and cadmium were not considered in the study.

Figure 34 illustrates potential contamination from the combustion of lignite. Chemical binding of certain trace elements with the soil may inhibit the transport to streams, lakes or groundwater.

Trace Elements in Lignite, Fly Ash, Lake Sediments and Overburden. Recent studies have indicated that significant amounts of trace elements might be concentrated and redistributed in the surrounding environment while mining and utilizing lignite for generating electricity. Acid extractable trace metals were analyzed for two lignite samples from the Big Brown plant near Fairfield and two samples from the Alcoa plant near Rockdale. These values are summarized in Table 6. For comparison average trace element concentrations for seven coals from Arizona, Montana, Colorado and Utah were included in the table. It can be observed that the Texas

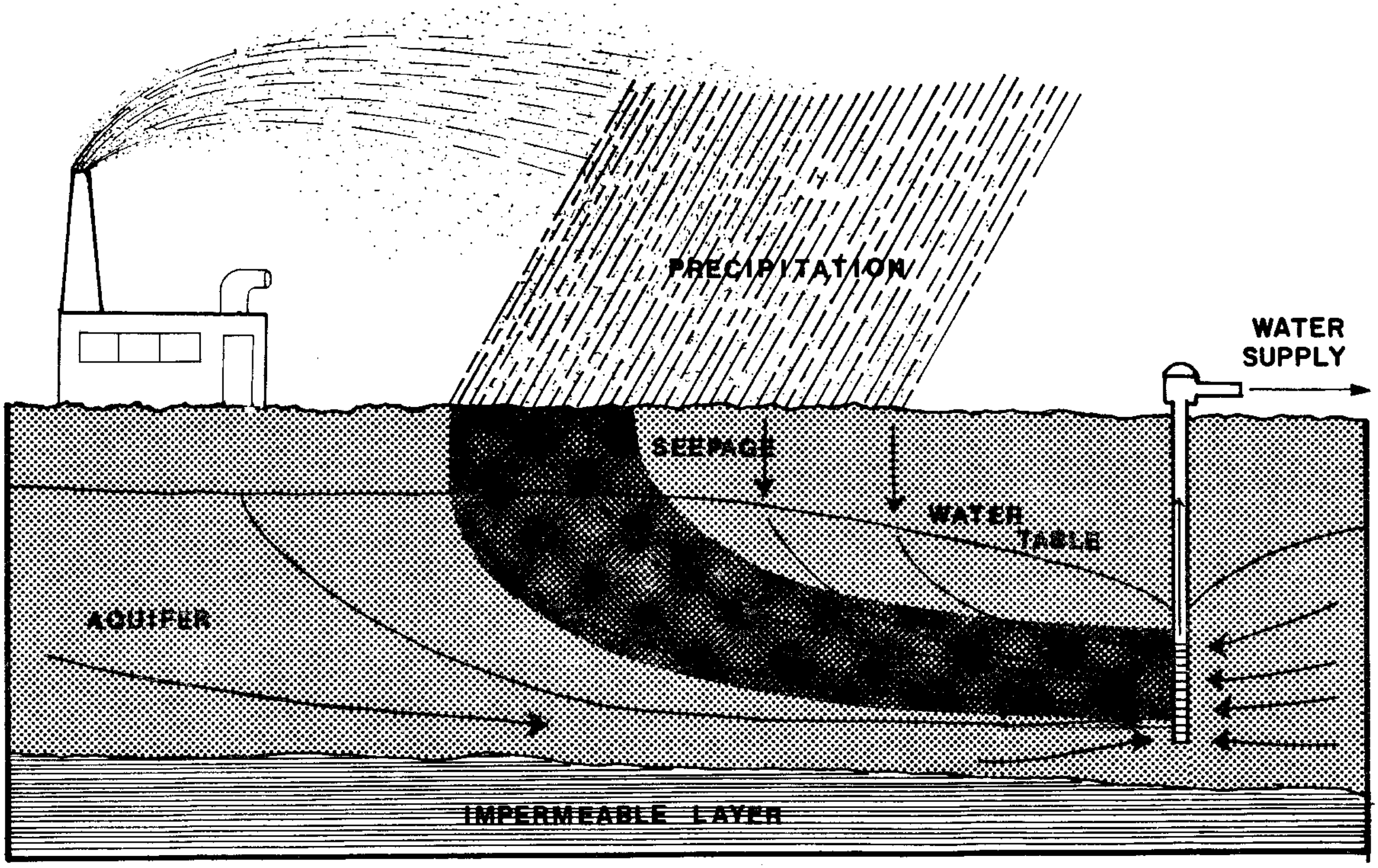


Figure 34. Potential Contamination from Combustion of Lignite

Table 6. Concentration of Trace Elements in Coal, Lignite and Fly Ash (mg/kg)

Trace Element (1)	Coal[a] (Literature) (2)	Texas[b] Lignite (3)	Overburden[c] (4)	Ratio (3)/(4) (5)	Fly Ash Literature (6)	Texas[f] Fly Ash (7)	Ratio (7)/(3) (8)
As	1.1	1.7	2.8	0.6	60[d]	106	62
Be	0.8	0.3	0.6	0.5		-	-
Cd	<0.4	<2.0	<2.0	-		5	>2
Cr	6.0	10.0	6.4	1.4	120[e]	70	7
Cu	15.0	15.0	6.1	2.5	122[e]	50	3
Fe	6000.0	700.0	8800.0	0.1	60000[e]	13600	19
Hg	0.05	0.4	0.06	6.7		<0.01	<0.03
Mn	36.0	160.0	240.0	0.7	490[e]	2050	13
Ni	5.3	4.0	9.2	0.4	94[e]	20	5
Pb	5.6	1.5	7.9	0.2	70[e]	43	29
Se	1.3	6.8	2.8	2.4	9[d]	33	4.8
Zn	10.8	6.3	37.0	0.2	210[e]	22	3

a. Average of seven western coals, 2 AZ, 2 MT, 2 CO, and 1 UT. Ruch, Gluskoter, and Shimp, 1974.

b. Average of four samples, two from Big Brown and two from Alcoa (see Table 7).

c. Average of eight surface overburden samples from the Big Brown reclaimed strip-mined area (see Table 12).

d. Kaakinen and Jorden, 1975.

e. Fisher, 1976.

f. Results of one sample of Fly Ash from Big Brown.

lignite was lower in Fe and Pb but higher in Mn, Hg and Se than the average values for the seven western coals.

Comparing the concentrations of the trace elements in the lignite (column 3) to overburden (column 5) indicates that the concentration of Cu, Cr, Hg and Se are greater in the lignite than in the overburden.

The concentration of trace elements in fly ash from the literature and from the Big Brown plant are also included in the table. It can be observed that the sample of fly ash from the Big Brown plant was lower in Cr, Cu, Fe, Ni, Pb and Zn but higher in As, Mn and Se than the average values reported by Fisher (1976) and Kaakinen and Jordan (1975). The final column is the ratio of concentration in the fly ash to that in the lignite. Since about 10 percent by weight of the lignite is converted to fly ash, it appears that most of the As, Fe, Mn and Pb leaves the plant with the fly ash.

Trace metals in the cooling lake sediments were also analyzed. Trace metals in Fairfield Lake and Alcoa Lake sediments are compared with Springfield Lake and Somerville Lake sediments in Table 7. No significant difference in trace metal concentrations were observed for cooling lakes and non-cooling lakes. Rather than being associated with burning of lignite and cooling, trace metal concentrations in sediments appeared to be associated with age and were generally higher in the older lakes (Springfield and Alcoa) than in the younger lakes (Somerville and Fairfield).

Surface overburden samples were collected in the reclaimed strip-mined areas at both the Big Brown plant near Fairfield and the Alcoa plant near Rockdale. While collected at the surface, the overburden samples prior to mining were probably located near the lignite seam. For control, surface

Table 7 . Acid Extracted Metals in mg/kg

Sample	As	Be	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Zn
Lignite												
Alcoa 1	1.4	0.2	<2	5	9	1000	0.47	192	4	1	5	2
Alcoa 2	1.7	0.3	<2	12	23	800	0.43	96	3	3	8	14
Big B 1	2.1	0.3	<2	15	22	400	0.34	56	5	2	9	7
Big B 3	1.5	0.5	<2	8	6	600	0.39	302	5	1	5	2
$\overline{X}$	1.68	0.33	<2	10.0	15.0	700.0	0.41	161.5	4.3	1.8	6.8	6.3
$\sigma_{\overline{x}}$	0.15	0.06	-	2.2	4.4	129.1	0.03	54.8	0.4	0.3	1.0	2.8
Cooling Lake Sediments												
Fairfield 1	1.7	0.1	<2	2	1	2000	0.18	65	<1	1	1	4
Fairfield 2	0.8	-	<2	4	2	5000	0.08	137	4	3	2	16
Alcoa 1	2.8	-	<2	9	3	1100	0.04	335	14	18	8	26
Alcoa 2	2.1	-	<2	6	7	1200	0.18	260	18	21	7	63
$\overline{X}$	1.85	0.1	<2	5.3	3.3	2325.0	0.12	199.3	9.1	10.8	4.5	27.3
$\sigma_{\overline{x}}$	0.42	-	-	1.5	1.3	914.1	0.04	60.6	4.1	5.1	1.8	12.7
Lake Sediments (control)*												
Springfield	5.5	1.0	<2	8	5	8000	<0.02	154	3	13	5	27
Springfield	5.5	1.3	<2	10	8	8000	0.03	660	8	21	8	32
Somerville 1	0.6	-	<2	2	2	1600	0.08	92	<2	<3	1	6
Somerville 2	0.7	-	<2	5	2	5200	0.11	218	3	8	1	6
$\overline{X}$	3.08	1.15	<2	6.3	4.3	5700	0.06	281	3.75	10.9	3.8	17.8
$\sigma_{\overline{x}}$	1.40	0.15	-	1.8	1.4	1517.7	0.02	128.9	1.49	4.1	1.7	6.9

Table 7 . Acid Extracted Metals in mg/kg (continued)

Sample	As	Be	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Zn
Big Brown Spoil												
FDSP-1	3.7	0.8	<2	9	9	9800	0.08	280	13	12	4	46
FDSP-4	2.1	0.5	<2	4	4	10800	0.19	210	6	5	2	32
FDSP-6	1.9	0.5	<2	4	5	5800	0.04	110	6	8	2	28
FDSP-7	3.3	0.4	<2	4	3	5000	0.02	90	5	3	2	24
FDSP-9	2.7	0.6	<2	9	8	7700	0.06	140	8	7	3	48
FDSP-11	2.6	0.6	<2	7	7	12600	<0.02	390	8	6	3	37
FDSP-12	2.7	0.6	<2	7	6	12400	0.08	340	11	9	3	32
FDSP-14	3.2	0.6	<2	7	5	7400	0.05	190	14	8	3	44
FDSP-15	3.3	0.8	<2	7	8	7800	<0.02	370	12	13	3	41
$\overline{X}$	2.83	0.6	<2	6.4	6.1	8811	0.06	235.6	9.2	7.9	2.8	36.9
$\sigma_{\overline{X}}$	0.20	0.04	-	0.7	0.7	913	0.02	37.9	1.1	1.1	0.2	2.8
Big Brown Surface Soil (control)*												
FDSP-3	1.7	0.1	<2	4	2	2400	0.08	70	1	6	1	7
FDSP-5	3.4	0.4	<2	3	1	3200	0.06	140	6	5	2	4
FDSP-8	1.3	-	<2	6	1	4700	<0.02	80	4	6	1	6
FDSP-10	3.0	0.5	<2	8	2	16400	<0.01	120	4	6	3	13
FDSP-13	3.1	0.2	<2	6	1	4200	0.02	140	1	5	2	9
FDSP-16	1.3	0.2	<2	6	4	5900	<0.02	130	4	4	1	9
$\overline{X}$	2.30	0.28	<2	5.5	1.8	6133	0.03	113.3	3.3	5.3	1.7	8.0
$\sigma_{\overline{X}}$	0.40	0.07	-	0.7	0.5	2112	0.01	12.6	0.8	0.3	0.3	1.3

Table 7 . Acid Extracted Metals in mg/kg (continued)

Sample	As	Be	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Zn
Alcoa Spoil												
ALSP-2	4.6	-	<2	<2	3	4600	0.06	74	4	3	1.2	6
ALSP-4	7.5	-	<2	4	5	7500	0.08	207	9	4	1.5	29
ALSP-5	4.0	-	<2	5	2	4000	0.08	28	6	3	1.7	13
ALSP-7	0.4	-	<2	<2	2	1300	0.02	70	3	2	1.2	14
$\overline{X}$	4.13	-	<2	2.8	3.0	4350	0.06	94.8	5.5	3.0	1.4	15.5
$\sigma_{\overline{X}}$	1.46	-	-	1.0	1.4	1271.8	0.01	38.8	1.3	0.4	0.12	4.8
Alcoa Surface Soil (control)*												
ALSP-1	1.0	-	<2	<2	3	1000	0.04	74	4	4	0.9	5
ALSP-3	2.0	-	<2	3	1	2000	0.05	72	<2	4	0.9	5
ALSP-6	0.6	-	<2	5	2	3000	0.07	150	3	5	1.4	6
ALSP-8	0.5	-	<2	5	2	9600	0.10	184	5	5	1.4	11
$\overline{X}$	1.03	-	<2	3.5	2	3900	0.07	120	3.3	4.5	1.15	6.8
$\sigma_{\overline{X}}$	0.34	-	-	1	0.4	1943.3	0.01	28	0.9	0.3	0.14	1.4
Fly Ash (Big Brown)												
Fine	108	-	3	70	54	14300	0.03	2100	21	45	23	23
Total	106	-	5	70	50	13600	<0.01	2050	20	43	33	22

* Control samples collected outside the strip-mined area.

soil samples of the 'A' horizon were collected adjacent to but outside of the strip-mined area. The overburden samples were clayey material while the control samples were sandy material. Trace metals in the soil and overburden samples are given in Table 7. It appears that Cu, Mn, Ni, Se, and Zn are significantly higher in the spoil than in the adjacent surface soil at the Big Brown plant and only As is significantly higher in the spoil at the Alcoa plant.

Soil Trace Element Enrichment Study. As discussed previously, the burning of large amounts of lignite at a single location has the potential of concentrating contaminants. The fallout from the airborne waste could be deposited in the surrounding area. If the plant is a significant source of contaminants the concentration of those elements found in the lignite should be increased in the surface soils about the plant and the pattern of increased concentration should be related to the dominant wind direction.

Surface soil samples were collected at various locations about the Big Brown Power Plant near Fairfield. Sample locations are shown in Figure 35 and the acid extractable concentration of the various metals are listed in Table 8. Only the top one inch of soil was sampled and analyzed according to the precedures listed in Appendix B. Approximately half the time the wind is from the SE, SSE, S, SSW or SW (Orton, 1964). Plotting the surface soil concentrations of the parameters listed in Table 8 on maps of the plant area did not reveal any definite patterns related to the plant location or wind patterns. It appears that the natural variation in concentration of these parameters in the surface soils is greater than the increased

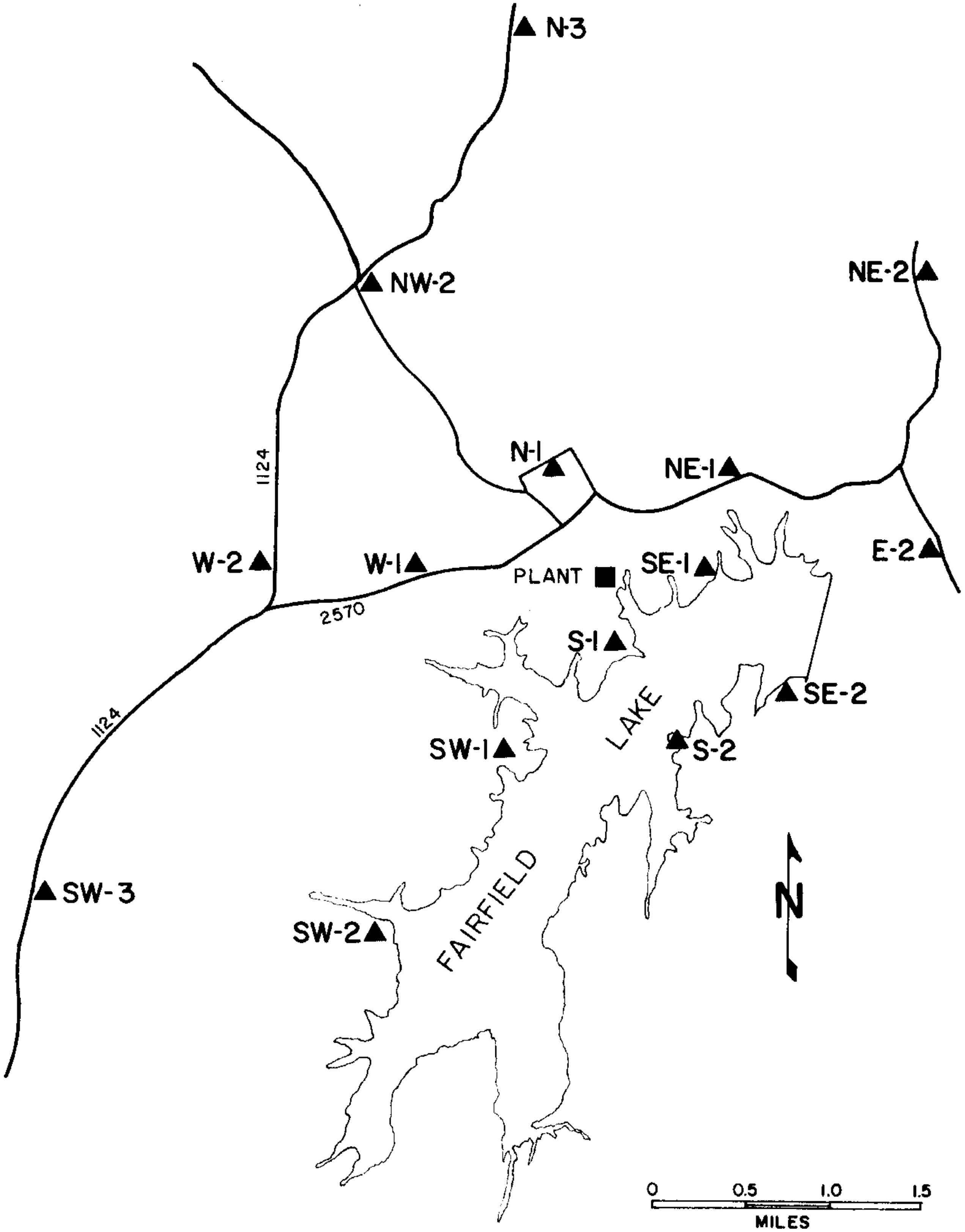


Figure 35. Soil Sample Locations for Trace Element Enrichment Study

Table 8. Acid Extracted Metals from Surface Soil Samples about Big Brown Plant (mg/kg) and Soil Type and pH.

Sample	As	Cd	Cr	Cu	Hg	Mn	Ni	Pb	Se	Zn	pH	Soil
W1	1.8	<2	2	<1	<0.01	32	1	2	1.1	3	5.9	sandy
N1	2.0	<2	3	1	0.01	140	1	3	1.3	3	5.3	sandy
NE1	2.5	<2	3	1	<0.01	155	<1	5	1.6	4	5.8	clayey sand
SE1	1.9	<2	3	4	<0.01	35	<1	2	1.0	3	5.8	sandy
S1	1.6	<2	-	2	<0.02	130	3	5	-	10	5.7	sandy
SW1	2.1	<2	2	<1	<0.01	86	4	4	1.6	9	5.9	clay
W2	1.2	<2	4	1	0.02	90	1	5	1.4	4	5.5	clay
NW2	2.8	<2	6	2	0.03	129	2	6	2.5	11	5.8	sandy
NE2	2.3	<2	3	1	0.02	116	1	2	1.0	5	5.9	sandy
E2	2.0	<2	2	2	<0.01	95	<1	5	1.3	9	6.4	sandy
SE2	2.3	<2	6	2	<0.01	108	1	2	1.3	6	7.5	sandy
S2	3.0	<2	6	1	0.02	45	2	2	1.5	5	6.5	sandy
SW2	2.2	<2	2	<1	<0.01	44	1	1	1.2	10	7.2	sandy
N3	1.9	<2	7	1	<0.01	57	<1	3	1.5	2	6.9	sandy
SW3	1.3	<2	2	1	0.01	169	1	4	1.2	4	6.4	sandy

concentrations which may have occurred as a result of the plant being in operation since 1971. In order to measure any increase in concentration caused by the operation of the plant, a more extensive sampling program would be required.

Precipitation Study

pH Rainfall. The importance of the carbon dioxide-biocarbonate system in determining the pH of rainfall has been recognized by various investigators (Reuss, 1975). The reaction of CO_2 and water can be represented by

$$CO_2 + H_2O \leftrightarrows H^+ + HCO_3^-$$

The logarithm to the base 10 of the equilibrium constant at 77° F is -7.81. The natural CO_2 concentration in the atmosphere is approximately 316 parts per million or a partial pressure of 3.16×10^{-4} atmospheres.

$$\frac{[H^+]\,[HCO_3^-]}{[CO_2]g} = 10^{-7.81}$$

where $[H^+]$ and $[HCO_3^-]$ are considered to be the concentration in moles per liter and $[CO_2]g$ is the partial pressure of CO_2 in atmospheres.

If CO_2 is the only source of HCO_3^-

$$[H^+]^2 = 10^{-11.31}$$

$$[H^+] = 10^{-5.65}$$

The pH of pure rainwater in equilibrium with atmospheric CO_2 at 77° F would be about 5.6. CO_2 can be shown to be an effective buffer in preventing the pH from increasing but is not effecting in preventing a drop in pH (Reuss, 1975).

Sulfur may be released from the power plant stack as sulfur dioxide. The sulfur dioxide could form with water to give

$$SO_2 + \tfrac{1}{2}O_2 + H_2O \rightarrow 2H^+ + SO_4^=$$

which would result in a decrease in pH.

Precipitation Samples. Rainfall samples were collected both under the airborne waste plume from the discharge stack at the Big Brown plant near Fairfield and away from the influence of the plant. The samples were collected on a 4 feet by 8 feet polyethylene sheet suspended in a rectangular frame 3 feet above the ground. Prior to collection samples the sheet was washed with a 4 percent hydrochloric acid solution and rinsed with deionized distilled water. At the start of the rainfall, the polyethylene sheet was rinsed thoroughly with the rain. Samples were collected in quart cubitainers at one corner of the polyethylene sheet. The cubitainers were also rinsed with 4 percent hydrochloric acid solution, deionized distilled water and rain before sampling. Although attempts were made to collect samples on eight separate days in the spring, sampling was completed twice. The weather was exceptionally dry until April 1976 and sampling was accomplished one in May and once in July 1976. Results are shown in Table 9 for both filtered and unfiltered samples. The duration of the May rain was too short to obtain adequate samples. The July sampling results show the pH

Table 9. Rain Samples Near Fairfield

Sample	As ppb	Be ppb	Cd ppb	Cr ppb	Cu ppb	Fe ppb	Hg ppb	Mn ppb	Ni ppb	Pb ppb	Se ppb	Zn ppb	NO_3-N ppm	PO_4-P ppm	SO_4 ppm	pH
Under plume from stack (May)																
R 1M	3	<0.1	3	7	26	700	<0.2	<50	10	72	<2	31	-	-	-	-
R 1M(f)*	3	<0.1	2	<2	16	<200	<0.2	<50	6	40	<2	29	-	-	-	-
Away from plume (control)** May																
R 3M	4	<0.1	2	3	18	700	<0.2	<50	8	54	<2	26	-	-	-	-
R 3M(f)*	<2	<0.1	2	<2	9	<200	<0.2	<50	8	18	<2	23	-	-	-	-
Under plume from stack - unfiltered (July)																
R 1J	4	-	3	4	7	480	0.7	80	7	8	7	32	0.16	0.04	15	4.6
R 2J	4	-	4	3	7	640	0.3	80	11	8	9	40	0.15	0.06	<10	4.8
R 3J	7	-	<1	7	3	1190	0.9	100	3	<1	5	14	0.10	0.06	<10	5.4
R 4J	7	-	<1	23	5	4250	1.2	200	<1	2	7	17	0.11	0.12	<10	5.6
R 5J	24	-	<1	21	4	4350	0.6	300	2	1	6	8	0.05	0.09	<10	-
$\bar{X}$	9.2		1.7	11.6	5.2	2182	0.74	152	4.7	3.9	6.8	22.2	0.11	0.07	7	
$\sigma_{\bar{x}}$	3.8		0.8	4.3	0.8	873	0.15	43	1.9	1.7	0.7	6.0	0.02	0.01	2	
Away from plume (control)** - unfiltered (July)																
R 6J	7	-	<1	<2	3	<100	0.3	<50	4	3	5	8	0.07	0.02	<10	4.1
R 7J	4	-	<1	<2	4	<100	0.4	<50	3	1	2	6	0.10	0.02	<10	4.1
R 8J	3	-	<1	<2	7	<100	-	<50	5	<1	5	20	0.19	0.04	<10	4.0
R 9J	<2	-	<1	<2	4	<100	0.7	<50	7	1	<2	9	0.18	0.01	<10	4.1
$\bar{X}$	3.8	-	<1	<2	4.5	<100	0.47	<50	4.8	1.4	3.3	10.8	0.14	0.02	<10	
$\sigma_{\bar{x}}$	1.3	-	-	-	0.9	-	0.12	-	0.9	0.6	1.0	6.3	0.06	0.01	-	

Table 9. Rain Samples Near Fairfield (continued)

Sample	As ppb	Be ppb	Cd ppb	Cr ppb	Cu ppb	Fe ppb	Hg ppb	Mn ppb	Ni ppb	Pb ppb	Se ppb	Zn ppb	NO_3-N ppm	PO_4-P ppm	SO_4 ppm	pH
Under plume from stack - filtered (July)																
R 1J(f)*	3	-	2	-	7	-	-	<50	7	4	7	32	-	-	-	-
R 2J(f)*	<2	-	4	-	7	-	-	<50	8	5	7	36	-	-	-	-
R 3J(f)*	3	-	<1	-	3	-	-	80	3	<1	5	14	-	-	-	-
R 4J(f)*	5	-	<1	-	5	-	-	<50	<1	<1	7	17	-	-	-	-
R 5J(f)*	12	-	<1	-	4	-	-	<50	<1	1	6	8	-	-	-	-
$\overline{X}$	4.8		1.5		5.2				3.8	2.2	6.4	21.4				
$\sigma_{\overline{X}}$	1.9		0.7		0.8				1.6	1.0	0.4	5.4				
Away from plume (control)* - filtered (July)																
R 6J(f)*	<1	-	<1	-	3	-	-	<50	<1	<1	5	8	-	-	-	-
R 7J(f)*	<1	-	<1	-	3	-	-	<50	<1	<1	<2	6	-	-	-	-
R 8J(f)*	<1	-	<1	-	3	-	-	<50	2	<1	5	20	-	-	-	-
R 9J(f)*	<1	-	<1	-	2	-	-	<50	4	<1	<2	9	-	-	-	-
$\overline{X}$	<1		<1		2.8			<50	1.8	<1	3.0	10.8				
$\sigma_{\overline{X}}$	-		-		0.3			-	0.8	-	1.2	3.1				

* Sample filtered.

** Rain samples collected away from the influence of the airborne waste emissions of the stack.

to be lower under the plume and away from the influence of the plume than the expected value of pure rainwater in equilibrium with atmospheric CO_2 (5.6). Cr, Fe, Mn, Se, PO_4 and pH were all significantly higher under the plume than away from the influence of the plume for the unfiltered samples. For the filtered samples, the precipitation collected under the plume had a significantly higher concentration of As, Cu and Se than the precipitation collected away from the influence of the plume.

Leaching Studies

To determine the potential of contaminants in the lignite, overburden and fly ash to be transferred to the water, leaching studies were conducted in accordance with the procedures of the Texas Water Quality Board except that triplicate runs were not conducted on all samples. The procedures are summarized in Appendix C. Chemical parameters are listed in Table 10 and trace elements are listed in Table 11.

There does not appear to be a large difference between the concentration in the leachates for the three lignites (Alcoa, Big Brown and Darco), but there does appear to be a significant difference in the leachates from the spoil.

Surface soil samples for control were collected adjacent to but outside the strip-mine area at both Big Brown and Alcoa. Comparison of the chemical parameters of the leachate for the spoil and control samples shows only the sulfate to be higher in the spoil at both locations. In general the trace metals concentrations were higher in the leachate from the surface soil samples than the spoil at Big Brown while the trace metals were higher in the leachate from the spoil samples than the soil samples at Alcoa.

Table 10. Seven-Day Leachate Study, Chemical Parameters

Sample	NO_2-N ppm	NO_3-N ppm	K_j-N ppm	TOTAL PO_4-P ppm	SO_4 ppm	pH	Alkalinity ppm
Lignite							
Alcoa 1	<0.05	<0.05	1.3	<0.01	<10	5.9	9
Alcoa 2	<0.05	<0.05	0.6	<0.01	<10	5.8	29
Alcoa 3	<0.05	<0.05	-	<0.01	<10	-	-
Big 1	<0.05	<0.05	0.4	<0.01	<10	6.6	45
Big 2	<0.05	<0.05	0.8	<0.01	<10	5.8	14
Big 3	<0.05	<0.05	0.5	<0.01	<10	6.4	55
Darco 1	<0.05	0.18	-	<0.01	<10	5.9	18
Darco 2	<0.05	0.16	-	<0.01	<10	-	-
$\overline{X}$	<0.05	0.06	-	<0.01	-		28.3
$\sigma_{\overline{X}}$	-	0.02	-	-			7.5
Fly Ash (Big Brown)							
Fine	<0.05	0.06	0.4	<0.01	260	12.	1000.
Total	<0.05	0.07	3.9	<0.01	70	12.	1560.

Table 10. Seven-day Leachate Study, Chemical Parameters (continued)

Sample	NO_2-N ppm	NO_3-N ppm	K_j-N ppm	TOTAL PO_4-P ppm	SO_4 ppm	pH	Alkalinity ppm
Big Brown Spoil							
FDSP-1	<0.05	0.06	1.9	<0.01	28	6.7	30
FDSP-4	<0.05	-	-	<0.01	162	7.0	162
FDSP-6	<0.05	0.36	1.7	0.02	<10	6.7	38
FDSP-7	<0.05	-	4.3	0.15	<10	7.0	81
FDSP-9	<0.05	1.23	<0.1	<0.01	80	6.5	45
FDSP-11	<0.05	0.74	0.4	0.02	38	7.3	53
FDSP-12	<0.05	0.50	0.7	0.02	<10	7.2	49
FDSP-14	<0.05	-	1.6	<0.01	330	6.8	24
FDSP-15	<0.05	<0.05	-	0.02	50	4.9	4
$\overline{X}$	<0.05	0.49	1.52	0.03	78.1		54.0
$\sigma_{\overline{x}}$	-	0.19	1.41	0.02	35.6		15.2
Big Brown Surface Soil (control)*							
FDSP-2	<0.05	0.46	1.6	0.02	15	6.5	24
FDSP-3	<0.05	<0.05	2.0	0.03	<10	6.8	28
FDSP-5	<0.05	-	-	0.03	<10	4.8	4
FDSP-8	<0.05	1.11	1.4	0.03	<10	4.6	-
FDSP-10	<0.05	-	3.2	0.14	<10	6.0	20
FDSP-13	<0.05	-	3.4	0.04	<10	6.9	59
FDSP-16	<0.05	0.29	0.3	0.02	<10	5.7	10
$\overline{X}$	<0.05	0.48	1.98	0.04	6.0		24.2
$\sigma_{\overline{x}}$	-		0.48	0.02	1.4		8.1

Table 10. Seven-day Leachate Study, Chemical Parameters (continued)

Sample	NO_2-N ppm	NO_3-N ppm	K_j-N ppm	TOTAL PO_4-P ppm	SO_4 ppm	pH	Alkalinity ppm
Alcoa Spoil							
ALSP 2	<0.05	0.07	1.4	-	<10	6.0	6
ALSP 4	<0.05	0.16	1.4	0.02	30	4.5	6
ALSP 5	<0.05	0.23	0.7	<0.01	620	4.2	0
ALSP 7	<0.05	0.16	0.3	0.33	<10	6.0	6
$\overline{X}$	-	0.16	0.95	0.12	165.0		4.5
$\sigma_{\overline{X}}$	-	0.03	0.27	0.11	151.8		1.5
Alcoa Surface Soil (control)*							
ALSP 1	<0.05	0.08	0.9	<0.01	<10	5.2	2
ALSP 3	<0.05	<0.05	0.7	0.04	<10	6.8	22
ALSP 6	<0.05	0.19	1.3	0.03	10	6.7	14
ALSP 8	<0.05	<0.05	0.6	0.03	<10	6.4	8
$\overline{X}$	<0.05	0.08	0.88	0.03	6.3		11.5
$\sigma_{\overline{X}}$	-	0.04	0.15	0.01	1.3		4.3

* Control samples collected outside of strip-mined area

Table 11. Seven-day Leachate Study, Metals

Sample	As ppb	Be ppb	Cd ppb	Cr ppb	Cu ppb	Fe ppm	Hg ppb	Mn ppm	Ni ppb	Pb ppb	Se ppb	Zn ppb
Lignite												
Alcoa 1	5	<0.1	<1.0	<1	3	<0.1	0.7	<0.05	3	<1	8	14
Alcoa 2	5	<0.1	<1.0	<1	3	<0.1	0.8	<0.05	4	<1	33	11
Alcoa 3	11	<0.1	<1.0	<1	2	<0.1	0.2	<0.05	<2	<2	12	8
Big B 1	8	0.3	<1.0	<1	3	<0.1	0.6	<0.05	3	<1	38	20
Big B 2	11	0.1	<1.0	<1	1	<0.1	0.5	0.15	<2	<2	9	4
Big B 3	2	<0.1	1.3	<1	3	<0.1	0.6	<0.05	3	<1	<2	42
Darco 1	8	<0.1	1.0	<1	2	<0.1	0.9	<0.05	<2	<2	3	8
$\overline{X}$	7.1	0.09	0.36	<1	2.4	<0.1	0.61	0.04	2.3	0.7	14.9	15.3
$\sigma_{\overline{X}}$	1.3	0.04	0.21	-	0.8	-	0.09	0.02	0.5	0.1	5.5	4.9
Fly Ash (Big Brown)												
Fine	17	<0.1	<1.0	<1	2	<0.1	5.8	<0.05	4	3	26	32
Total	17	0.2	<1.0	<1	<2	<0.1	0.5	<0.05	3	3	33	2

Table 11. Seven-day Leachate Study, Metals (continued)

Sample	As ppb	Be ppb	Cd ppb	Cr ppb	Cu ppb	Fe ppm	Hg ppb	Mn ppm	Ni ppb	Pb ppb	Se ppb	Zn ppb
Big Brown Spoil												
FDSP-1	<2	<0.1	<1.0	<2	5	<0.1	1.4	<0.05	2	<2	12	6
FDSP-4	5	-	1.1	<2	3	<0.1	1.1	<0.05	<4	4	2	17
FDSP-6	18	<0.1	<1.0	3	8	1.0	0.8	0.28	2	<2	8	35
FDSP-7	150	-	<1.0	36	1	12	1.2	<0.05	5	1	5	8
FDSP-9	5	<0.1	<1.0	<2	1	-	0.6	<0.05	3	<2	25	14
FDSP-11	<2	<0.1	<1.0	<2	<2	<0.1	0.5	<0.05	<2	<2	8	2
FDSP-12	2	<0.1	1.0	25	7	0.2	0.8	0.08	6	9	11	8
FDSP-14	6	-	<1.0	3	2	<0.1	0.8	0.70	4	<1	10	24
FDSP-15	<2	<0.1	<1.0	<2	<2	<0.1	0.5	<0.05	5	<2	5	18
$\overline{X}$	21	<0.1		8	3.2	1.68	0.86	0.13	3.3	2.2	9.6	14.7
$\sigma_{\overline{X}}$	16.2	-		4.4	0.9	1.48	0.11	0.08	0.6	0.9	2.2	3.4
Big Brown Surface Soil (control)*												
FDSP-2	2	<0.1	<1.0	16	2	2.9	1.2	0.28	<2	2	6	16
FDSP-3	11	<0.1	<1.0	<2	1	1.4	0.9	0.78	<2	<2	6	4
FDSP-5	54	-	<1.0	12	4	2.7	0.8	0.17	<4	1	8	18
FDSP-8	23	0.1	<1.0	22	8	0.8	2.1	0.22	4	8	6	12
FDSP-10	94	-	<1.0	23	2	11.0	1.1	0.08	4	<1	30	58
FDSP-13	10	-	<1.0	5	7	0.8	1.0	0.58	<4	1	2	47
FDSP-16	15	<0.1	1.2	4	<2	1.5	0.8	<0.05	2	<2	12	2
$\overline{X}$	29.9			11.9	3.6	3.01	1.13	0.31	2.3	2.1	10.0	22.4
$\sigma_{\overline{X}}$	12.4			3.4	1.1	1.37	0.17	0.10	0.5	1.0	3.5	8.2

Table 11. Seven-day Leachate Study, Metals (continued)

Sample	As ppb	Be ppb	Cd ppb	Cr ppb	Cu ppb	Fe ppm	Hg ppb	Mn ppm	Ni ppb	Pb ppb	Se ppb	Zn ppb
Alcoa Spoil												
ALSP-2	6	<0.1	<1.0	16	1	0.6	0.7	<0.05	4	2	3	18
ALSP-4	<2	<0.1	<1.0	<2	2	0.4	0.6	<0.05	3	<1	<2	6
ALSP-5	37	10.0	3.4	<2	2	0.7	0.5	<0.05	57	3	26	49
ALSP-7	96	<0.1	<1.0	21	3	9.4	0.5	<0.05	3	<2	5	14
$\overline{X}$	35	2.54	1.23	9.8	2.0	2.78	0.42	<0.05	16.8	1.6	8.8	21.8
$\sigma_{\overline{X}}$	21.8	2.49	0.73	5.2	0.4	2.21	0.12	-	13.4	0.6	5.8	9.4
Alcoa Surface Soil (control)*												
ALSP-1	<2	<0.1	<1.0	<2	1	<0.1	0.4	0.22	3	2	<1	13
ALSP-3	26	<0.1	<1.0	2	1	2.2	0.3	<0.05	3	2	5	4
ALSP-6	23	0.2	1.2	<2	8	1.8	0.4	0.18	7	8	8	13
ALSP-8	26	<0.1	<1.0	2	1	4.6	0.6	0.28	2	<2	<4	3
$\overline{X}$	19	0.09	0.68	1.5	2.8	2.16	0.43	0.18	3.8	3.3	3.9	8.3
$\sigma_{\overline{X}}$	6.0	0.04	0.18	0.3	1.8	0.94	0.06	0.05	1.1	1.6	1.7	2.8

* Control samples collected outside of strip-mined area.

The acid extract concentration of trace metals of the spoil at Big Brown tended to be higher than the acid extract trace metals of the control soil samples (As, Be, Cr, Cu, Fe, Hg, Ni, Se, and Zn). The leachate from the spoil at Big Brown was higher than the control soil samples in only two trace metals (Ni and Pb). At Alcoa the Acid extract concentration of the spoil was higher in As, Cu, Fe, Ni, Se and Zn than the control soil samples. The leachate from the spoil at Alcoa was higher in As, Be, Cd, Cr, Cu, Fe, Ni, Se and Zn than the leachate from the surface soil control samples. The major difference might be that the pH of the leachate was higher at Big Brown for the spoil than the control samples, while at Alcoa the pH of the leachate was lower for the spoil than the control samples.

Water Quality Study

Sampling Stations. Water quality sampling stations were established near active strip-mine operations at Fairfield and Rockdale. Stations were sampled monthly for one year and analyzed for both chemical parameters and trace metals. Locations of the stations are shown in Figures 36, 37 and 38.

Eight groundwater stations were located about the strip-mined area near Fairfield, three stream stations along Tehuacana Creek, two stream stations along Cottonwood Creek and one lake station at Fairfield Lake. Fairfield Lake was completed in December 1969 and has a surface area of 2,350 acres and a storage capacity of 50,600 acre-feet. It is the cooling lake for the 1,150 megawatt Big Brown Power Plant. The present

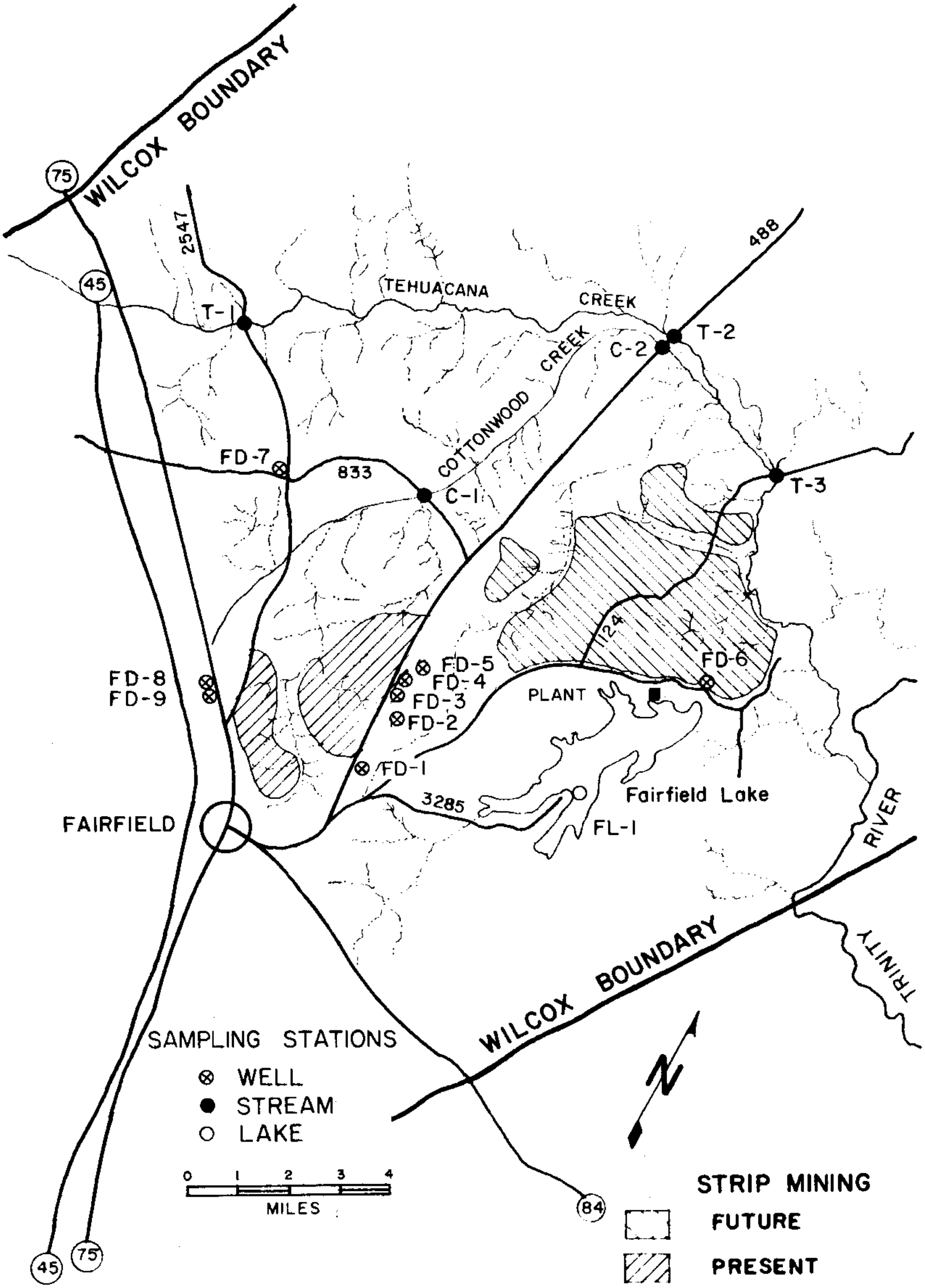


Figure 36. Location of Sampling Stations Near Fairfield

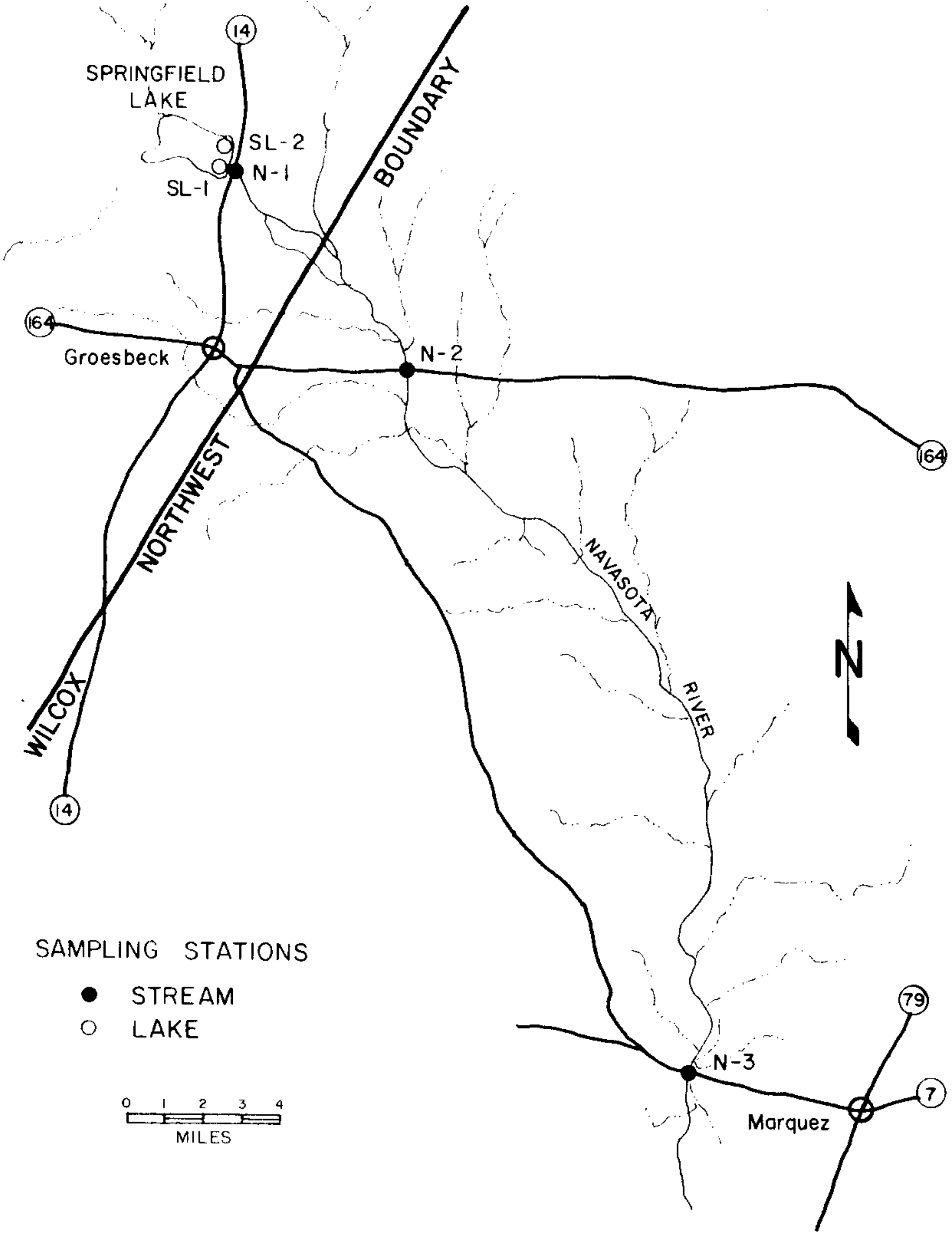


Figure 37. Location of Sampling Stations on the Navasota River

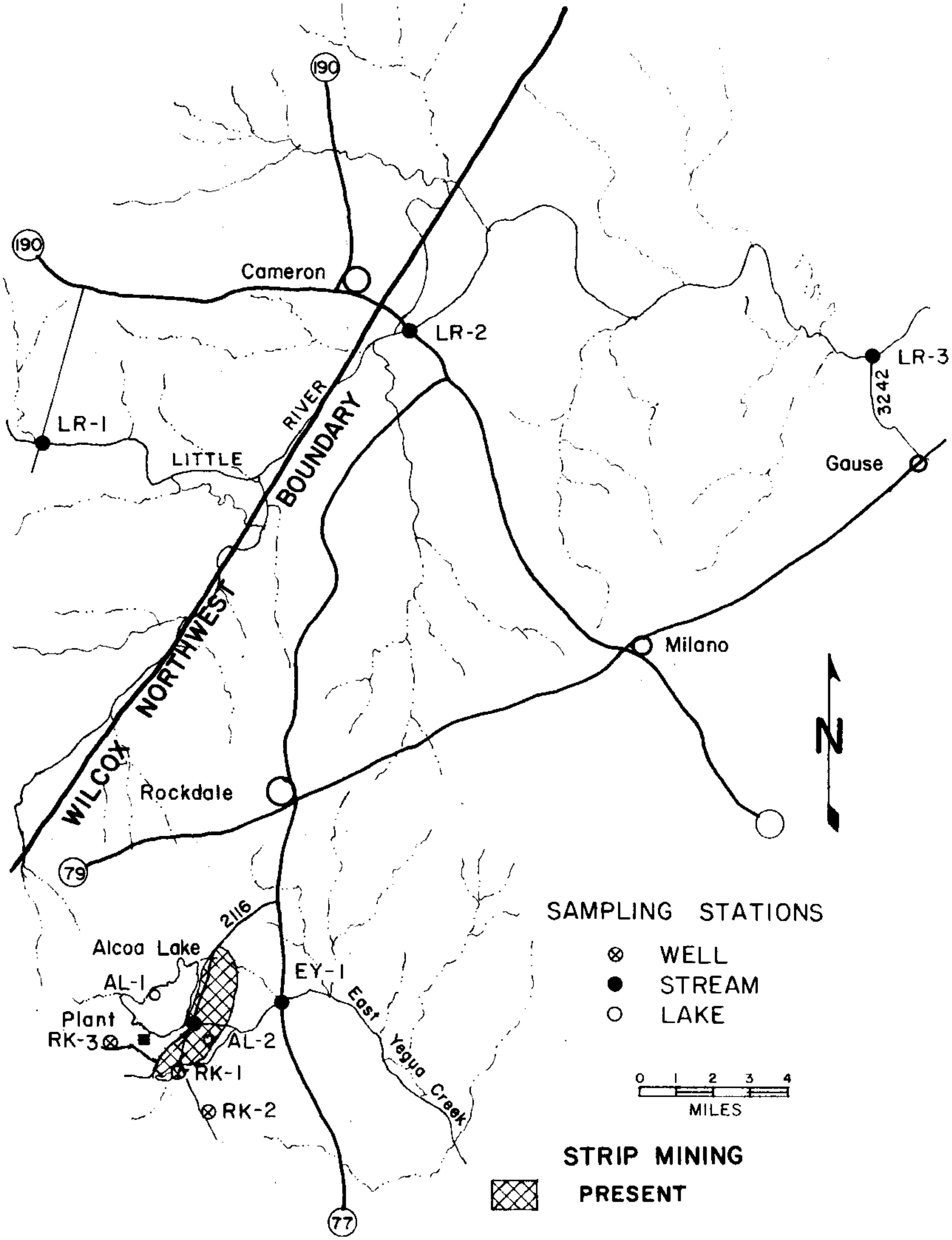


Figure 38. Location of Sampling Stations Near Rockdale

strip-mined area at Fairfield drains into Cottonwood Creek which enters Tehuacana Creek below station T-2. The water quality at stations C-1, C-2 and T-3 might have been affected by the strip mining activity while water quality of stations T-1 and T-2 was not.

Three groundwater stations were located near the strip mining at Alcoa. Alcoa Lake is the cooling lake for the 360-megawatt power plant and was formed by a dam across East Yegua Creek. Two sampling stations were located along East Yegua Creek. EY-2 was located just downstream of the dam while EY-1 was located about three miles downstream. Sampling station AL-1 was located in the 880-acre cooling lake. Alcoa Lake was completed in 1952 and was filled by pumping from Little River. The reservoir has a drainage area of only 6 square miles and up to 18,000 ac-ft of water per year can be pumped from Little River to provide water for the plant. Sampling station AL-2 was in a spoil lake in the strip-mined area.

In addition to the stations established near the strip mining operations, three stations were established along Little River, three stations along the Navasota River and two stations in Springfield Lake. Springfield Lake is primarily a recreational lake associated with Fort Parker State Park. It is located on the Navasota River, has a capacity of 4,200 acre-feet and has a surface area of 750 acres. Samping station N-1 is located just downstream of the Springfield Lake, N-2 is located about eight miles downstream and N-3 is located about 30 miles downstream. Three sampling stations (LR-1, LR-2 and LR-3) were located north of Rockdale about 20 miles apart along Little River.

Wells FD-1, FD-3, FD-5, FD-7 and FD-8 are dug wells 30 to 50 feet deep. FD-4, FD-6 and FD-9 are drilled wells approximately 50 feet deep while FD-2 is also a drilled well but approximately 200 feet deep. In general, the shallow wells yield little water of relatively poor water quality. Water in wells FD-1, FD-3, FD-4 and FD-5 is apparently from above the lignite. Groundwater stations FD-3, FD-4 and FD-5 are located down slope from the strip mining area; however, as groundwater movement is only about 100 feet per year, any effect of strip mining on groundwater quality is not expected to be reflected in the water quality at these stations.

Three well sampling stations were located in Rockdale area. Wells RK-1, RK-2 and RK-3 are deep wells and apparently obtain their water from below the lignite.

Background Water Quality Data. Background information on water quality in the area was obtained from the U.S. Geological Survey Water Quality Data for Texas for the years 1969 to 1974. Location of U.S.G.S. water quality stations are shown in Figure 39. Three stations were selected on the Trinity, three on Navasota and one each on Yegua Creek, Little River and Tehuacana Creek. Dissolved solids, sulfates, pH and iron were plotted as a function of flow rate, Figures 40 through 48. It can be observed that in general the dissolved solids varied between 100 and 1000 mg/ℓ, sulfates varied between 10 and 400 mg/ℓ and pH between 6.5 and 8.5, depending on the flow rate. The iron concentration did not appear to be a function of the flow rate. The dissolved solids and sulfates were higher in the Trinity River than the other streams for the same flow rates. The

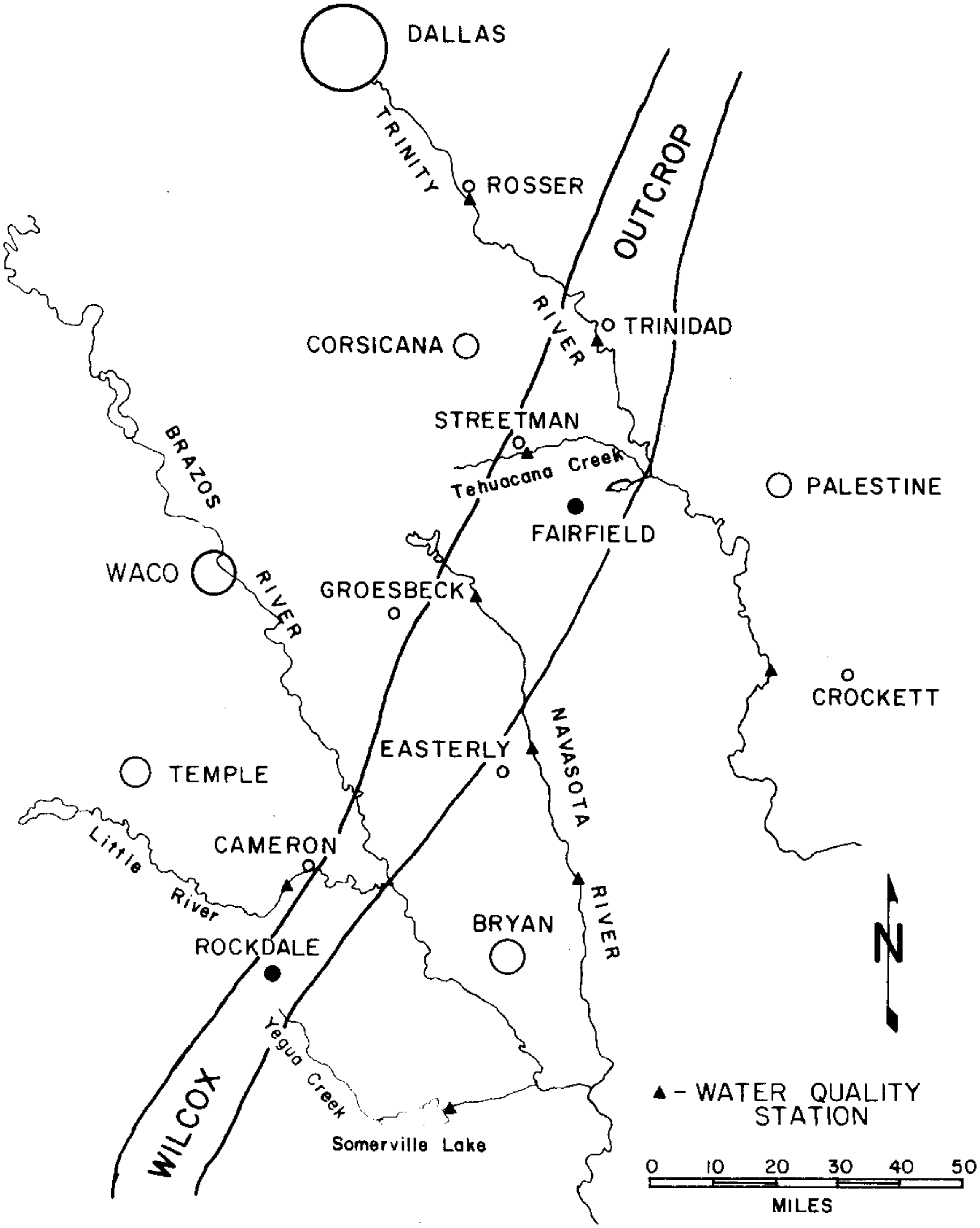


Figure 39. Location of U.S.G.S. Water Quality Stations

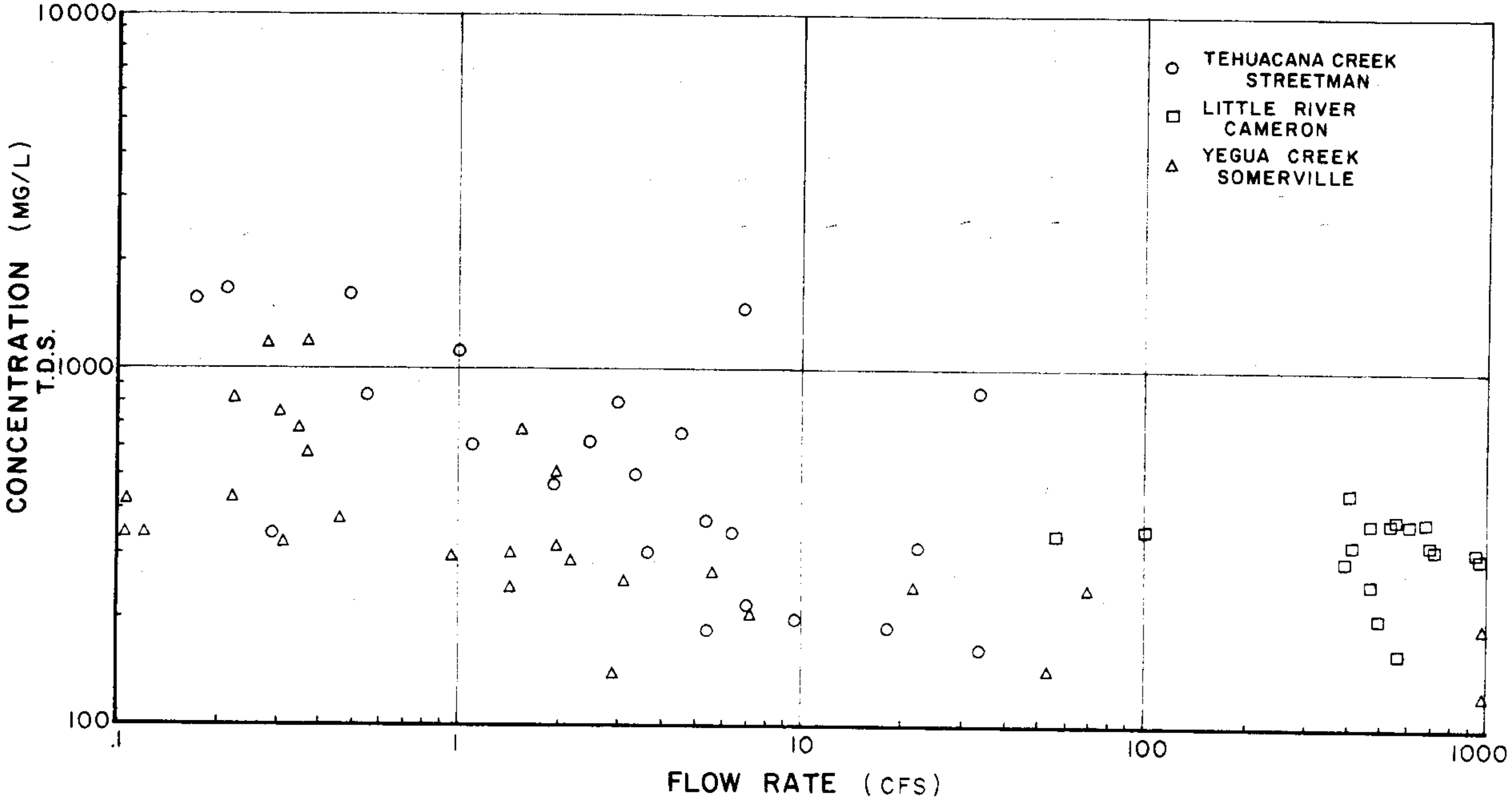


Figure 40. Dissolved Solids - Tehuacana Creek, Little River and Yegua Creek

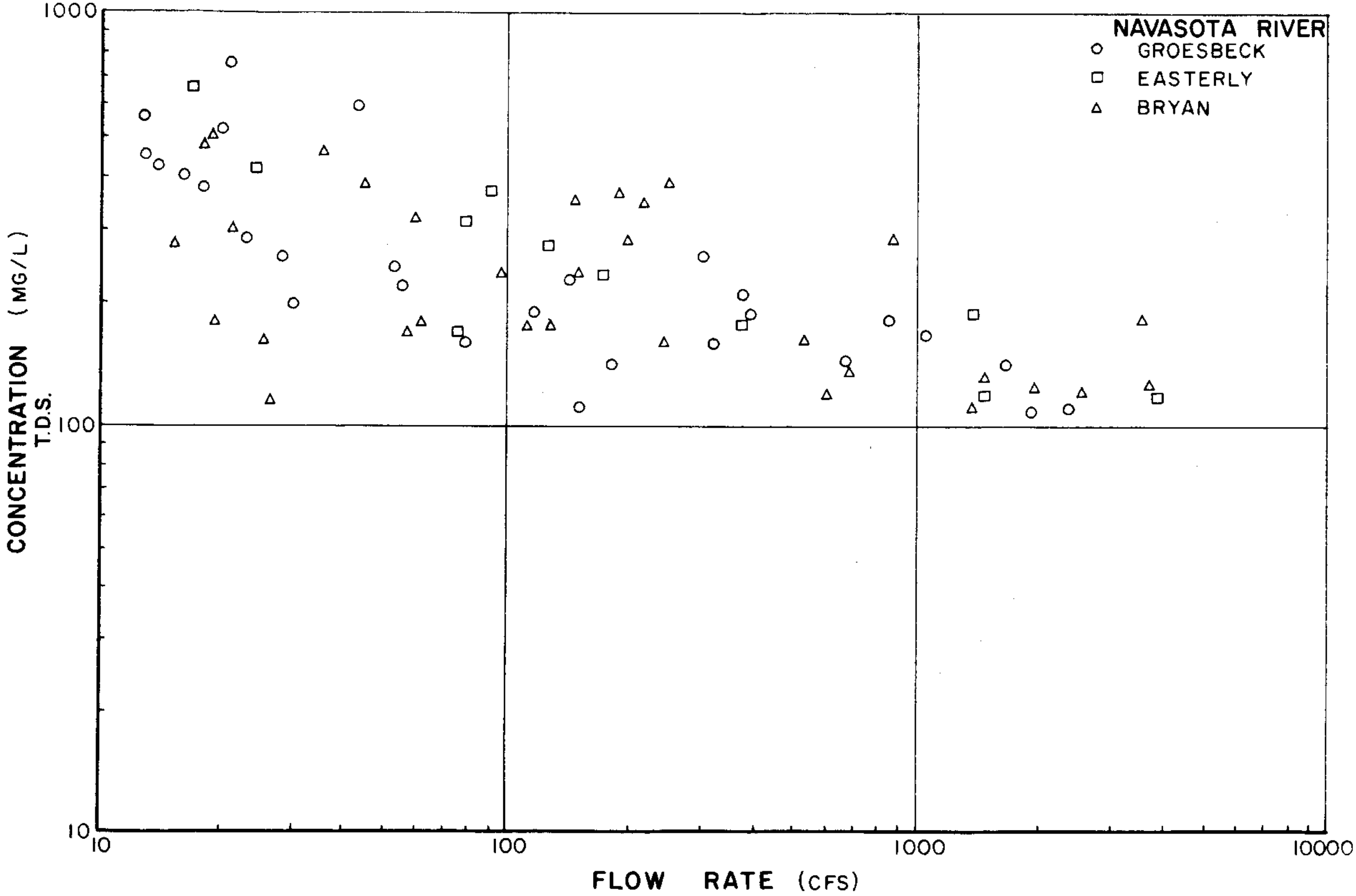


Figure 41. Dissolved Solids - Navasota River

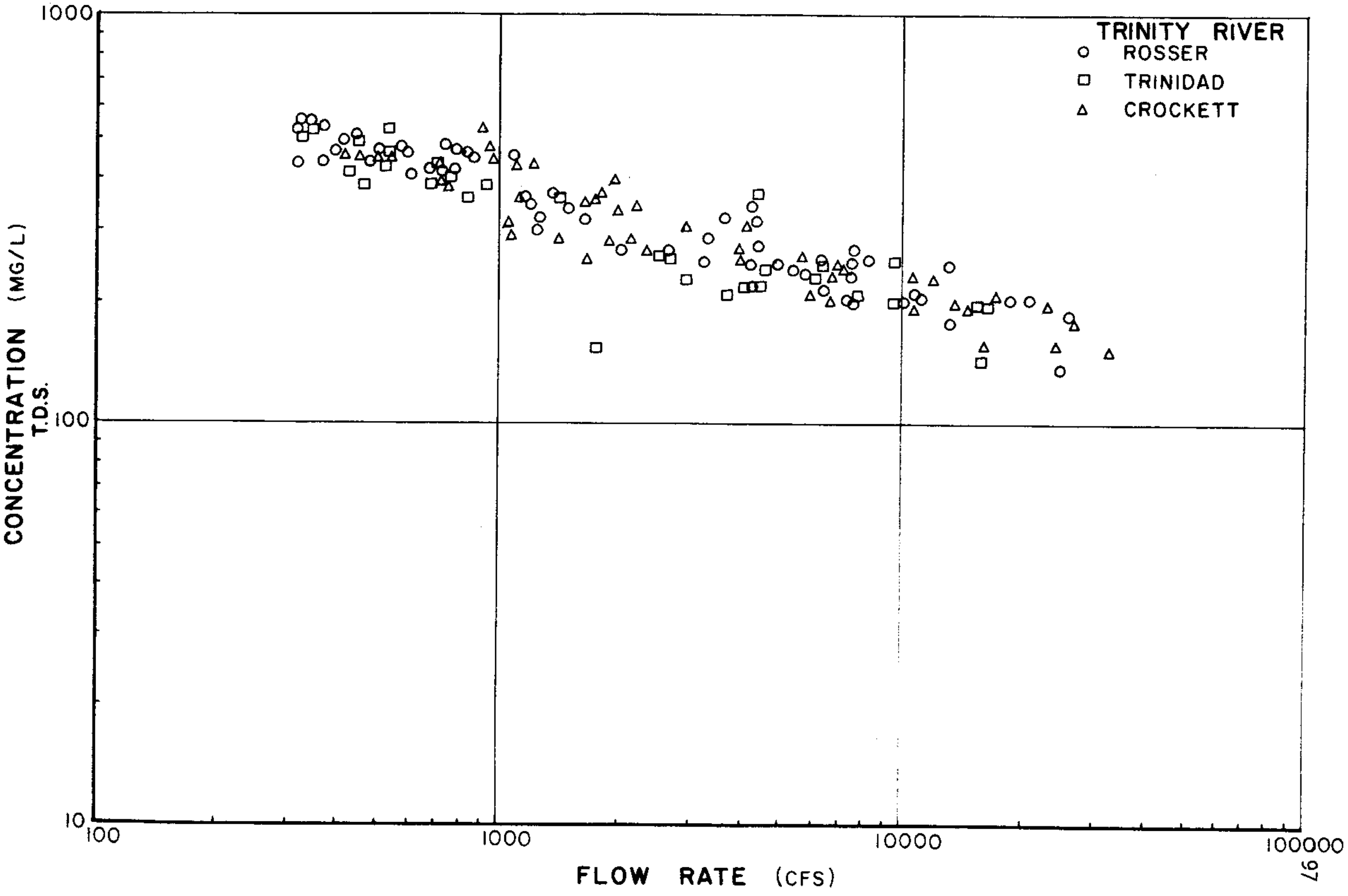


Figure 42. Dissolved Solids - Trinity River

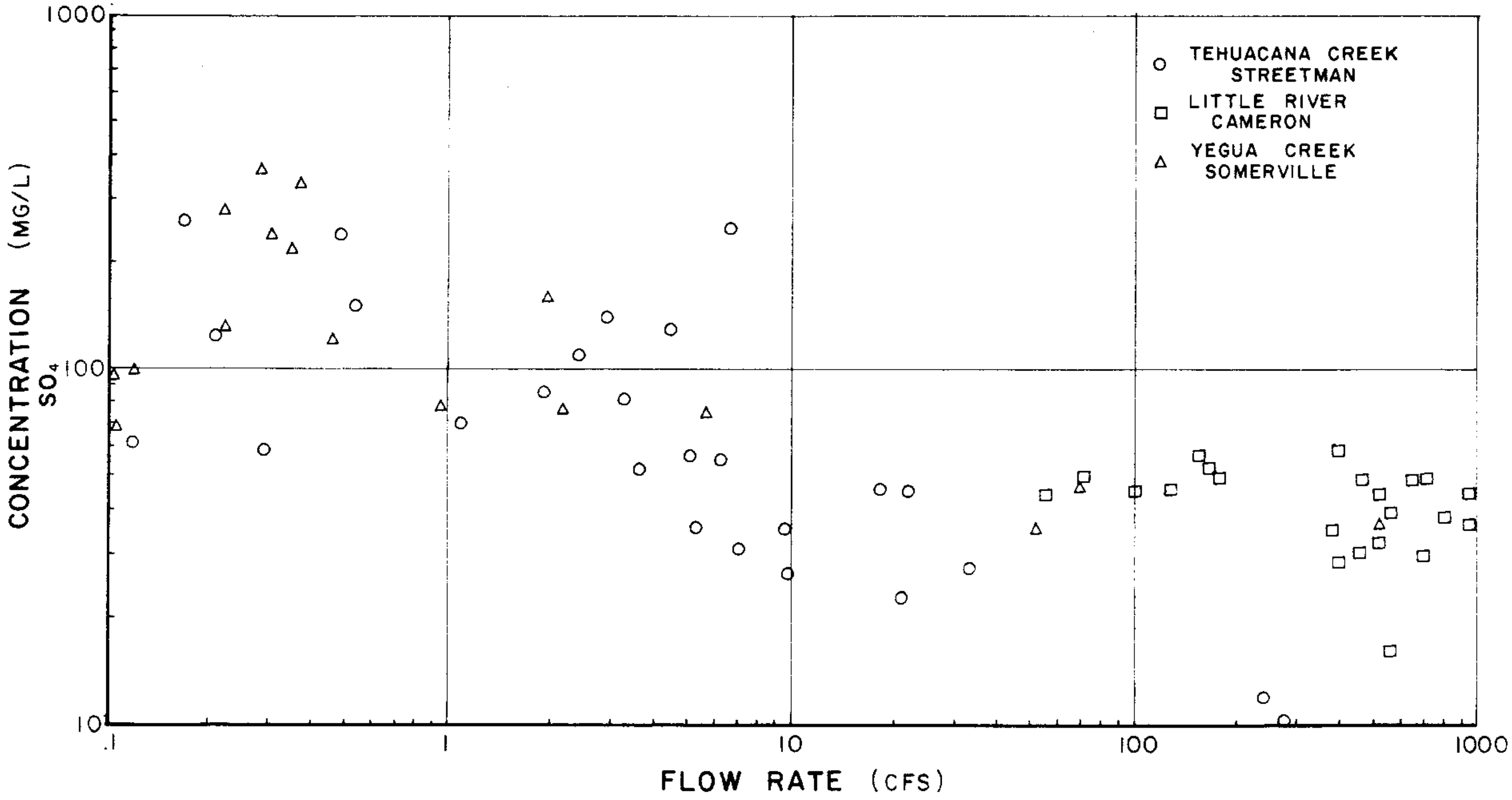


Figure 43. Sulfates - Tehuacana Creek, Little River and Yegua Creek

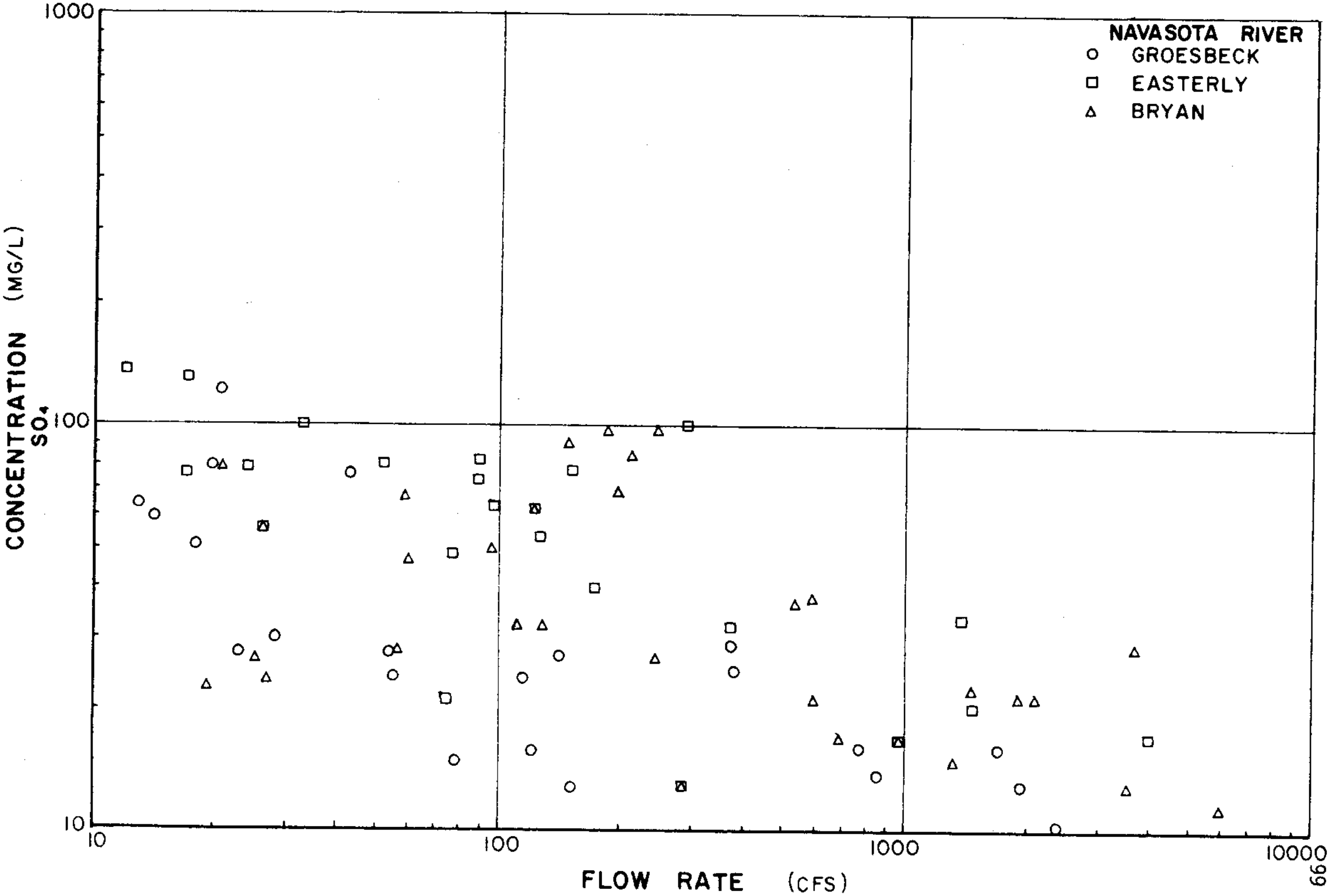


Figure 44. Sulfates - Navasota River

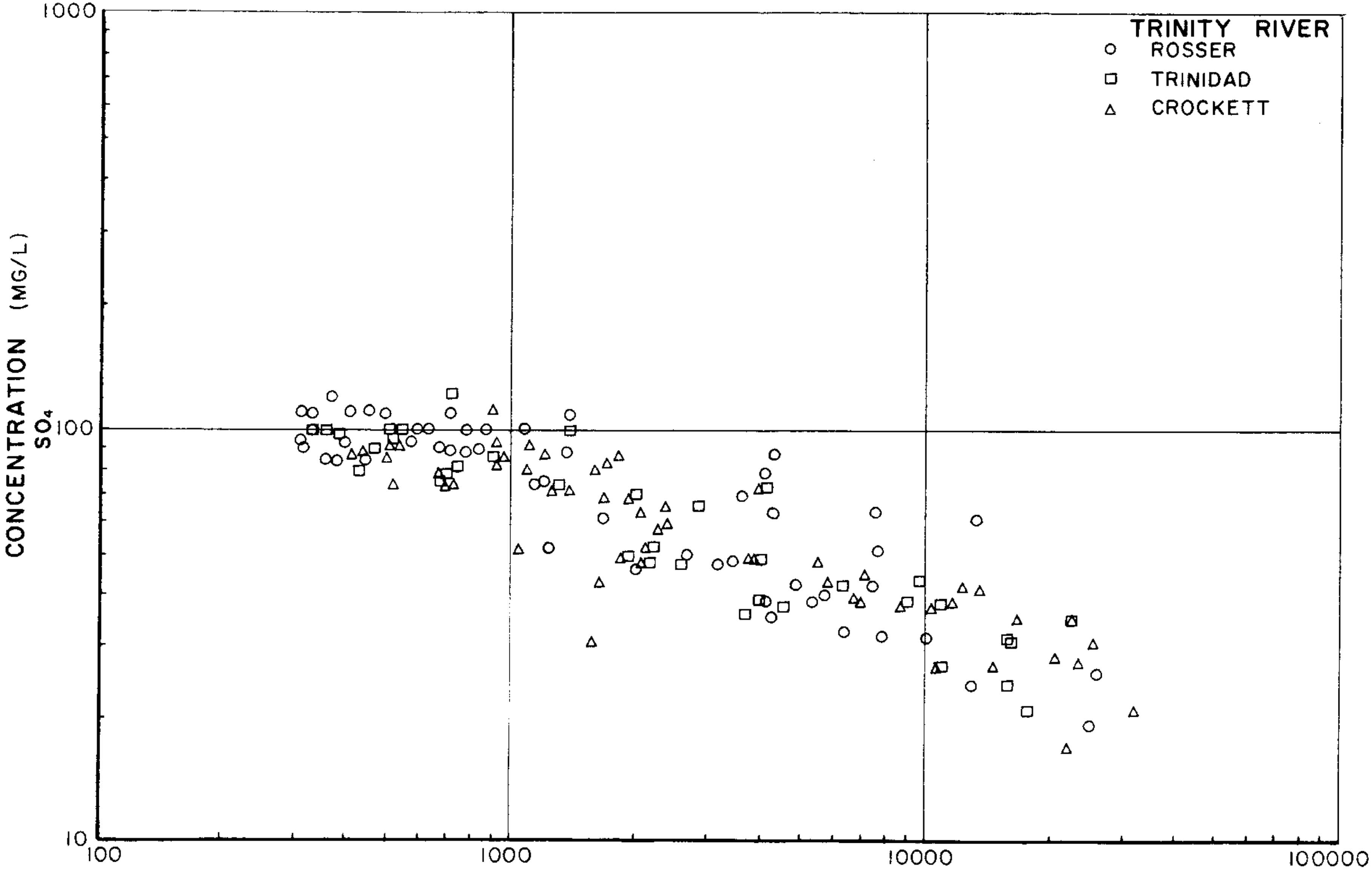


Figure 45. Sulfates - Trinity River

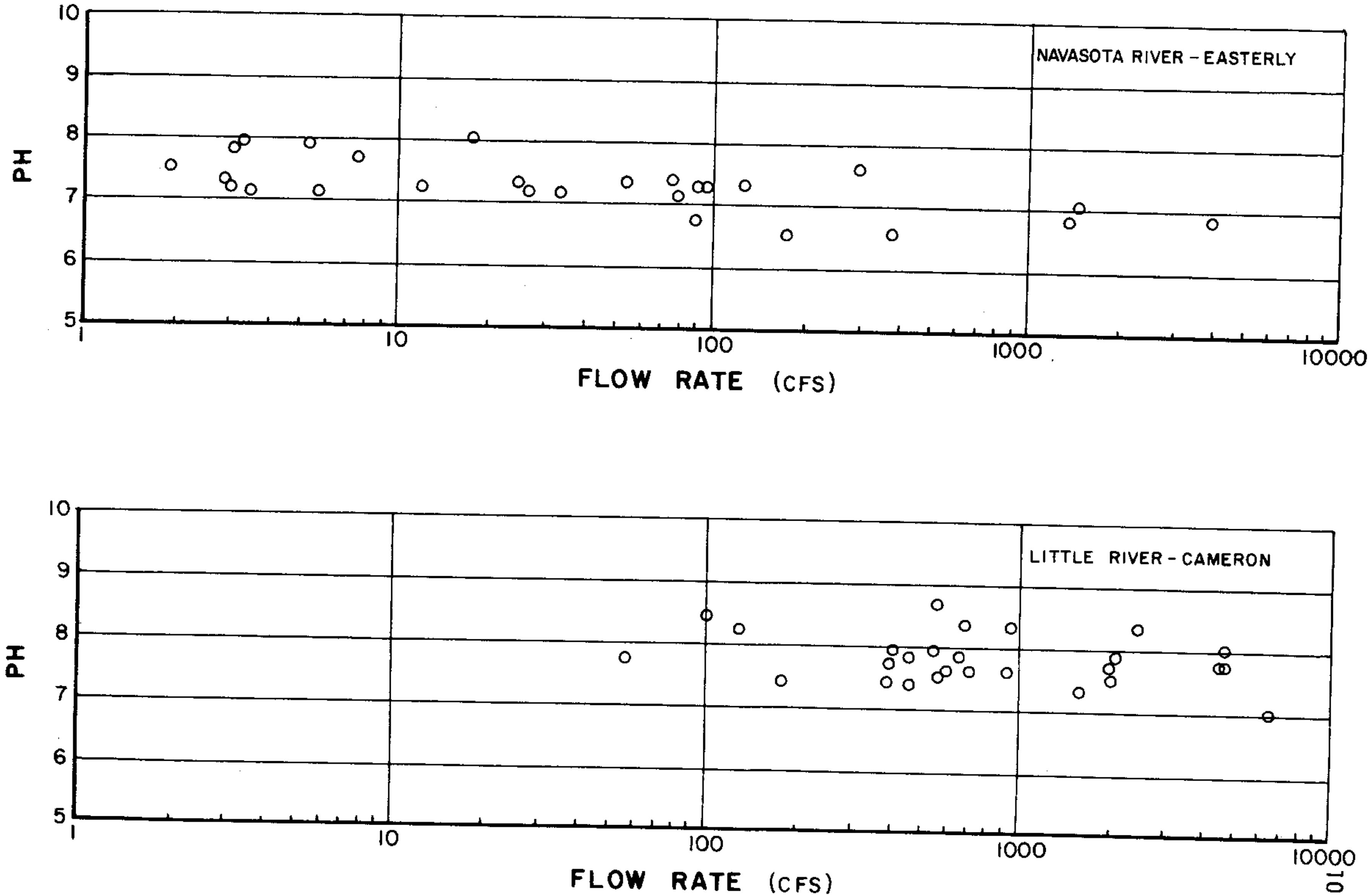


Figure 46. pH - Navasota River at Easterly and Little River at Cameron

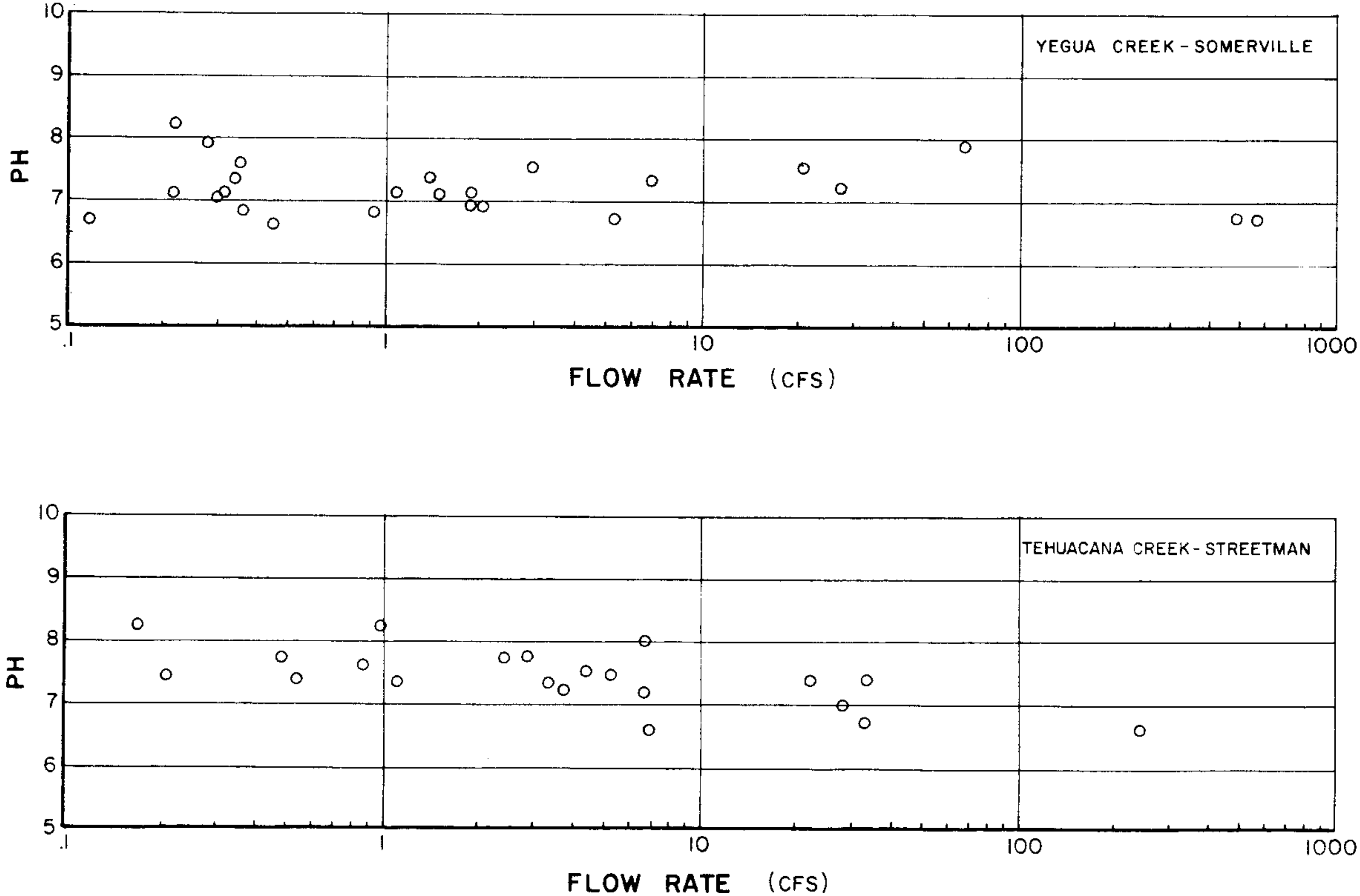


Figure 47. pH - Yegua and Tehuacana Creeks

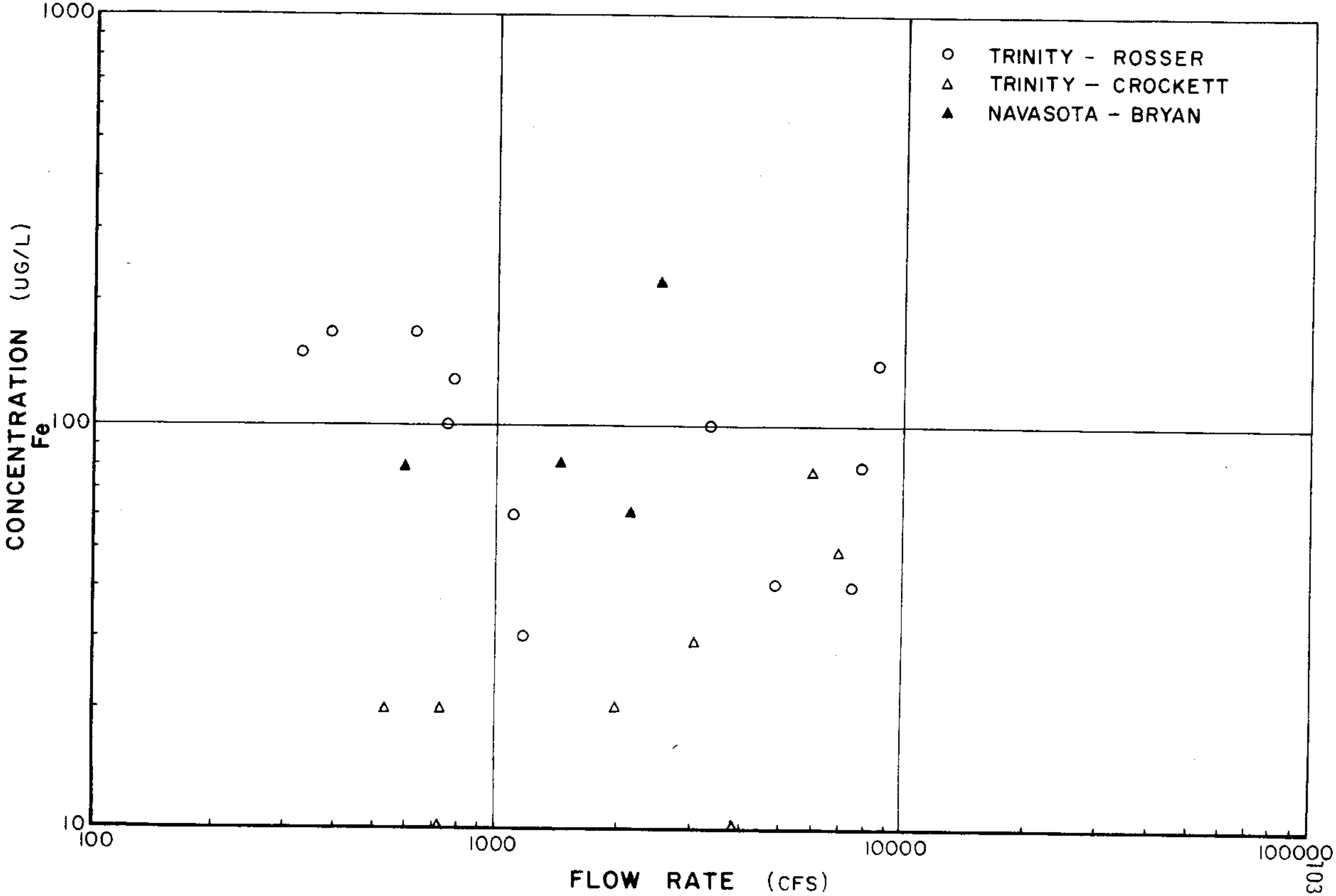


Figure 48. Iron - Trinity and Navasota Rivers

dissolved solids in Tehuacana Creek appeared to be higher than in Yegua Creek. The station on Yegua Creek was located below Somerville Reservoir.

The Texas Water Development Board Groundwater Reports for Anderson, Bastrop, Cadwell, Freestone, Nacogdoches and Wood Counties were reviewed to find pairs of similar wells, one with lignite reported in the screened interval and the other well without lignite reported in the screened interval. The concentrations of sulfate and iron for the pair of wells were obtained from the report and tabulated in Table 12. It can be observed from the table that there was no significant difference in the sulfates and iron in the wells reported with lignite and those not reporting lignite within the screen interval. In general the sulfates tended to be higher in the shallower wells.

Results of Sampling Program. Results of the monthly water quality sampling program are listed in Appendix D. When reviewing the data, the reader should be aware of two factors. First, the July, August and September results are totals while during the remainder of the year the samples were filtered through a 0.45μ filter and the values listed in the tables for the last nine months represent dissolved. The second consideration is that little rain fell until April and the streams were very low until that time.

It can be observed that in general the pH values of the groundwater stations were lower than the pH of the surface water and the pH values of lake waters were higher than the pH of the streams. It appears that the pH of water drained from strip mined areas was not significantly

Table 12. Concentration of Sulfate and Iron in Paired Wells With and Without Lignite

			SULFATE (mg/ℓ)			IRON (mg/ℓ)		
County	Well Number	Depth or Screened Interval (ft)	With Lignite	Without Lignite	Difference	With Lignite	Without Lignite	Difference
Anderson	DJ 38-06-604 DJ 38-08-105	947-970 906-993	0	<4	-<4	0.4	0.16	0.24
Anderson	DJ 38-15-601 DJ 38-15-601	1,134-1,144 1,292-1,331	0	1	-1	0.9	0.9	0
Bastrop	AT 58-54-505 AT 58-54-508	550 550	85	96	-11	0.85	1.31	-0.46
Bastrop	AT 58-54-503 AT 58-54-502	233-340 297-357	73	68	5	-	-	-
Cadwell	BU-67-12-502 BU 67-12-502	225 320	30	43	-13	0.2	1.27	-1.07
Freestone	KA 39-23-303 KA 39-22-901	495-716 455-685	22	9	11	<0.05	<0.02	0.03
Nacogdoches	TX 37-10-403 TX 37-10-403	368-480 995-1,005	1	0	1	0.7	0.7	0
Nacogdoches	TX 37-11-802 TX 37-11-802	1,350-1,370 1,105-1,126	0	0	0	4.0	0.6	3.4
Wood	ZS 34-31-201 ZS 34-31-101	220 222	11	2	9	0.47	-	-
					$\overline{x}$ = $\sigma_{\overline{x}}$ =			$\overline{x}$ = +0.27 $\sigma_{\overline{x}}$ =

Reference: TWDB - Groundwater Reports

different from that of runoff from non-strip mined areas. While the pH in Cottonwood Creek and East Yegua Creek is lower near the strip mined areas and increase downstream, the pH in Tehuacana Creek also increases downstream.

During the sampling period the dissolved solids in Fairfield Lake (cooling lake for Big Brown Plant) was not significantly higher than the dissolved solids in Springfield Lake. The dissolved solids in the cooling lake, spoil lake and Yegua Creek near Alcoa were significantly higher than the dissolved solids in Cottonwood Creek near Big Brown. Dissolved solids observed for this study are within the range of values reported by the U.S.G.S., displayed in Figure 40-42. It can also be observed that there is a wide range in dissolved solids for the groundwater stations. In general, the shallow wells had a higher dissolved solids value than the deeper wells.

The maximum concentration of sulfates in raw water for drinking supplies has not been established but was recommended to be 250 mg/ℓ (U.S. E.P.A., 1973). This limit was usually exceeded at three locations (Alcoa spoil lake (AL-2), East Yegua Creek about three miles downstream of the strip mining area (EY-1) and at the groundwater station near the strip mine area near Fairfield (FD-4)).

High nitrate values were observed at three groundwater stations near Fairfield (FD-1, FD-5 and FD-9). The higher values probably indicated surface contamination and apparently were not associated with either the mining or electric generating activities. Little River stations were high in both nitrate and phosphate values.

High values of phenols did not appear to be associated with lignite activity in these areas but may be associated with natural processes.

The highest values of arsenic were found in Tehuacana Creek (15 ppb at the upstream station, decreasing to 10 ppb downstream), spoil lake at Alcoa (38 ppb) and two groundwater stations near Fairfield (54 and 43 ppb). Except for perhaps the spoil lake, the higher levels of arsenic do not appear to be associated with lignite development. EPA (1975) recommended maximum concentration for public water supply sources is 50 ppb.

Only at a few stations were the concentrations of cadmium above the detection level of the equipment (2 ppb). The EPA (1975) recommended a maximum concentration for public water supply sources of 10 ppb. The highest consistent values of 4 ppb were observed at the Alcoa spoil lake (AL-2).

The analysis for chromium was discontinued in January as this trace element did not appear at significant levels in any samples. Highest observed values of copper were at the groundwater stations and were about one tenth the U.S. EPA (1973) recommended maximum for drinking water.

The highest mercury concentrations were observed in Fairfield Lake (8 ppb) in the first three months of the study when the water samples were not filtered. Beginning in October samples were filtered with a 0.45μ filter and the mercury levels in the filtered samples were at or near the detection level.

Highest observed values of manganese were in the spoil lake at Alcoa (AL-2) which had an average of 5,000 ppb. The 1973 U.S. EPA Water Quality Criteria recommends a maximum of 50 ppb for drinking water. Concentrations at nearly all stations exceeded this recommended maximum. Concentrations in the cooling lakes (FL-1 and AL-1) were relatively low while concentrations in Yegua, Cottonwood and Tehuacana Creek were relatively high. Groundwater stations in the Rockdale area generally had higher concentrations of manganese than those in the Fairfield area.

Lead concentrations in the surface waters generally ranged from 1 to 4 ppb while the values in groundwater ranged from 2 to 12 ppb. Higher values were not in any particular location nor did they appear to be associated with power generation. U.S. EPA (1975) maximum concentration for drinking water is 50 ppb.

The highest average concentration of nickel (91 ppb) was observed in the spoil lake at Alcoa (AL-2). In general the higher values in surface waters were observed at those stations that include runoff from strip mined areas (C-1, C-2, T-3, EY-1, and EY-2). Wells just east of the strip mined area at Fairfield generally had the higher concentrations of nickel than those on the west side of the strip mined area.

High selenium concentrations were observed in the surface waters near Fairfield (10 to 21 ppb), surface waters near Rockdale (16 to 51 ppb) and groundwater stations ($<$ 79 ppb). The 1975 EPA maximum allowed concentration is 10 ppb for public water supply sources. Average concentrations at all stations on Cottonwood, Tehuacana and Yegua Creeks exceeded the recommended maximum concentration while average concentrations at all stations on Navasota and Little Rivers were under the recommended maximum value. Since the concentration of selenium was the highest in Tehuacana Creek above the strip-mined area, it appears that the lignite mining activity is not the primary source in the Fairfield area. However, the spoil lake at Alcoa (AL-2) had the highest concentration (51 ppb) of selenium in the Rockdale area.

Concentration of zinc in samples from Cottonwood Creek were generally higher than those in Tehuacana Creek indicating runoff from the strip-mined area at Fairfield could be a major source of zinc. The highest average concentration of zinc (339 ppb) at a surface water station was in the spoil lake at Alcoa (AL-2). No samples exceeded the EPA 1973 recommended maximum concentration of 5,000 ppb for public water supply. Only one groundwater station at Rockdale (RK-3) exceeded 1,000 ppb. The high zinc values in the wells, FD-2, FD-9, RK-1, RK-2 and RK-3 may have been caused by galvanized plumbing.

In Tehuacana Creek and Cottonwood Creek near Fairfield, the highest values of selenium, manganese and sulfate occurred during low flow conditions. This would tend to indicate that the high values are not associated with surface runoff or fallout from the power plant.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This study was conducted for the Office of Water Resources Research, U.S. Department of the Interior by the Texas Engineering Experiment Station. The study was concerned with the affect of lignite strip mining and lignite utilization on the hydrology and water quality of the area. Both field and desk studies were conducted to evaluate the impact of lignite development on the Water Resources of the area. The following conclusions and recommendations were developed by the project.

1. Lignite development will consume a significant quantity of water.

Most lignite-fired electric generating plants will probably utilize cooling lakes to dissipate waste heat. A 1,000-megawatt plant will consume approximately 8,000 acre-feet of water per year (not including blowdown or flushing water). When all the lignite plants that are presently in the planning stage (12,000 megawatts) are in operation, approximately 100,000 acre-feet per year of water will be consumed by these plants. This is equivalent to the water requirement for a city of about 600,000 people. Lignite-fired power plants, because of their lower efficiency, require slightly more water (about 10 percent) for heat dissipation than oil- or gas-fired plants. Nuclear plants require considerably more water (about 30 percent) for heat dissipation than lignite-fired plants.

While there are no modern-design, commercial-scale coal gasification or liquefaction in the United States to accurately estimate water consumption, it appears that the water consumption will be about the same for these processes as converting lignite to electricity. If the output from a gasification or liquefaction plant is used as fuel for electric power generation, the water requirements for the two processes are additive and the consumptive use of water would be approximately doubled.

2. <u>Full development of the near-surface lignite reserves in east and east central Texas could have a significant impact on the groundwater resources of the region</u>.

Eighty percent of the near-surface lignite reserves in Texas are located in the outcrop area of the Wilcox aquifer. The Wilcox is a major aquifer in east and east central Texas and provides the water supply for many of the cities in this region. Lignite reserves as defined by Kaiser (1975) cover about 41 percent of the outcrop area. A study utilizing the U.S. Soil Conservation Service soil maps of the Wilcox outcrop area revealed that some areas are relatively pervious and contribute significant recharge to the aquifer while other less pervious areas contribute little recharge to the aquifer. If all the potential near-surface lignite reserves are developed, approximately 40 percent of the pervious soils in the recharge area would be affected.

<u>It is recommended that changes in the recharge rate of the Wilcox aquifer be considered when identifying new lignite deposits for development</u>.

3. Strip mining can change the hydrologic characteristics of the mined areas.

The soils over much of the Wilcox lignite area have a sandy surface and a clayey subsoil. The sandy surface soil permits relatively rapid infiltration of precipitation and provides storage capacity for the gravity water while it slowly percolates through the clayey subsoil. While the lignite is often associated with clay deposits, the overburden which is disturbed in the mining operation usually contains layers which are capable of transmitting groundwater along the formation.

The material over much of the lignite was generally deposited as alternating layers of sand and clay. The sandy material is capable of transmitting water along the slope of the formation while the clayey material transmits little water. In the mining process, the overburden is removed and the layers mixed together. In the process, the overburden expands about 15 percent and the pore space is temporarily increased. After the spoil has been reclaimed, the surface soil is generally clayey. When the top soil is not replaced on the leveled spoil material, the infiltration capacity of the reclaimed area will generally be reduced.

Before mining, the factor limiting recharge for most of the Wilcox area is the transmissibility of the aquifer. When the top soil is not replaced after the spoil has been reclaimed, surface entry will probably limit recharge. Vegetation and time should improve the infiltration capacity of the reclaimed area. However, after many years when the overburden has reconsolidated to its original density, the permeability of the overburden will probably be reduced from its original value.

It is recommended that several small watersheds both in the reclaimed strip-mined area and similar, natural watersheds for control be instrumented and monitored for several years to evaluate the change in the hydrologic characteristics of the area.

4. Lignite-fired power plants cause environmental modifications of considerable magnitude.

Based on average characteristics of the Wilcox lignite, a 1,000-megawatt power plant requires that approximately 600 acres per year of lignite be strip mined to provide fuel to keep the plant in operation at an 80 percent load factor. During the 35-year expected life of a lignite-fired power plant, about 21,000 acres of land would be strip mined. Existing and presently planned lignite-fired power plants in Texas have a combined capacity of 12,000 megawatts and would require about 240,000 acres of land for strip mining during the 35-year life of these plants.

It is recommended that hydrologic characteristics be considered in developing reclamation plans for the spoil area.

5. Development of deep-basin lignite deposits appears inevitable.

Approximately 2.5 billion tons of lignite or about 25 percent of the identified near-surface lignite deposits are committed to existing and presently planned lignite-fired power plants in Texas. Deep-basin lignite occurs downdip from the near-surface lignite, between 200 and 5,000 feet below the surface, and was estimated by Kaiser (1975) to be more than 100 billion tons. Underground gasification of lignite is technically feasible but poses environmental hazards as well as environmental advantages over strip mining.

It is recommended that the groundwater quality be carefully monitored around all underground gasification projects.

6. Lignite-fired electric generating plants tend to concentrate certain elements.

Lignites can contain high amounts of certain trace elements depending upon the local chemical environment associated with the decay of plant material during the formation of the lignite.

The utilization of lignite for electric power generating requires that large amounts of lignite be moved, hauled to the plant and burned. For example, a 1,000-megawatt plant requires approximately 6 million tons of lignite per year. Texas lignite analyzed in the study indicated higher than average concentrations of manganese, mercury and selenium.

After the lignite is fired at the plant some of the trace elements are concentrated in the fly ash (arsenic, iron, manganese, and lead). While others are discharged primarily as a vapor from the stack (mercury and selenium). If the concentration of selenium in the lignite was 7 ppm, a 1,000-megawatt plant would release approximately 40 tons of selenium per year primarily as a vapor from the stack and with the fly ash.

It is recommended that the levels of certain trace elements concentrations be considered when identifying lignite deposits for utilization by electric generating plants.

7. Lignite-fired power plants can increase the concentration of trace elements in the precipitation.

Precipitation samples were collected under the airborne waste plume from the Big Brown power plant near Fairfield and compared to precipitation samples collected away from the influence of the plant. Concentrations of chromium, iron, manganese, selenium and phosphate were significantly higher at a 90 percent confidence level in precipitation samples collected under the plume from the plant when compared to the concentration in samples collected away from the influence of the plant. However, limited trace element enrichment study of the soils surrounding the Big Brown plant near Fairfield did not reveal any significant increases in concentration that could be attributed to the plant operations.

It is recommended that a more extensive sampling program be established about the Big Brown plant and a trace element enrichment study of the soils be repeated at five-year intervals to accurately monitor the increase in concentrations of those elements that could have adverse affects on plant and animal life in the area.

8. Improper handling and disposal of fly ash could result in the pollution of water supplies.

A 1,000-megawatt power plant utilizing lignite with an ash content between 10 to 20 percent would generate between 300,000 and 600,000 tons per year of fly ash. Acid extract of the fly ash revealed elevated levels of arsenic, copper, chromium, iron, manganese, lead, and selenium as compared to the lignite and soil samples. Seven-day leachate test on the fly ash indicated high values of pH, alkalinity, arsenic and selenium.

9. Lime or limestone scrubbers for sulfur oxide stack gas control generate large amounts of sludge and could create water pollution problems.

The sulfur content for central and east Texas lignite is relatively low. However, if lime or limestone scrubbers are required for sulfur control in the stack gas, they would generate large amounts of sludge. A typical 1,000 megawatt plant utilizing lignite with a 1.0 percent sulfur concentration would generate about 200,000 dry tons of sludge and would require about 200 acre-feet of storage space each year. Supernatant waters from scrubber sludge de-watering typically have high concentrations of sodium, potassium, and magnesium sulfate and sulfite as well as certain trace metals and could pose a potential water pollution problem by leaching or overflow.

10. Water quality in the cooling lakes at the Alcoa plant near Rockdale and the Big Brown near Fairfield was generally good.

The water quality parameters monitored in the cooling lakes were not significantly different from those of other surface waters. Alcoa Lake at Rockdale had slightly elevated levels of dissolved solids (750 ppm), apparently due to the cooling process by evaporation.

11. Small surface streams near Rockdale and Fairfield had elevated levels of zinc, selenium, manganese and sulfate as compared to other surface waters observed in the study.

High values of zinc, selenium, manganese, and sulfate were observed in East Yegua Creek near the Alcoa plant and Tehuacana Creek and Cottonwood Creek near the Big Brown Plant. Observed values of selenium exceeded the 1975 EPA maximum values for drinking water. Not all stations included runoff from strip-mined areas. At the Big Brown Plant near Fairfield, the highest observed values of selenium and sulfates were in Tehuacana Creek above the strip-mined area. Strip mining and power generation may not be the primary source of the elevated levels of these parameters.

It is recommended that a water quality study be initiated to accurately identify the source of these elevated parameters.

12. Spoil lakes in the strip-mined area at Alcoa could cause groundwater contamination of the shallow aquifer.

Highest observed values of many surface water quality parameters were in the spoil lake in the strip-mined area at Alcoa. Average observed values for these parameters in the lake were: dissolved solids, 2400 ppm; sulfates, 1100 ppm; arsenic, 38 ppb; cadmium, 4 ppb; manganese, 5050 ppb; nickel, 90 ppb; selenium, 50 ppb; and zinc, 340 ppb. Sulfates, manganese and selenium exceeded both the EPA 1973 recommended drinking water criteria and the observed values for water wells in the area. Since there appears to be a direct hydraulic connection between water in the spoil lakes and the shallow groundwater aquifer in the area, poor water quality in the spoil lakes could adversely affect the groundwater.

It is recommended that several groundwater wells be established about the area and developed in the aquifer above the lignite seam to determine permeability of the aquifer, compute the velocity and direction of movement of the groundwater and monitor groundwater quality.

13. Groundwater quality in the shallow aquifer at Fairfield was generally poor; however, it did not appear that the poor quality was associated with strip-mining or power generation.

Analyses of water samples from the shallow wells developed above the lignite at Fairfield indicated a poor water quality. Most of the shallow wells are not being utilized for domestic supplies since rural water systems were installed in the late 1960's. Three shallow groundwater wells sampled in the study are located several hundred feet downdip of the strip-mined area. Groundwater movement is estimated to be about 100 feet per year. The effect of the mining operation on the water quality and recharge rate should be observable at these wells within several years.

It is recommended that the existing shallow wells near the strip-mined area at Fairfield be monitored for several years to evaluate the effect of the mining on groundwater quality and recharge rates.

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APPENDICES

APPENDIX A

CONSUMPTIVE USE OF WATER FROM COOLING LAKES

The heat budget for a cooling lake can be expressed as:

$$\Delta H = H_{sw} + H_{lw} - (H_b + H_c + H_e)$$

where

ΔH = net heat transferred through the air--water interface in BTU/(hr-ft^2)

H_{sw} = net short-wave solar atmospheric radiation in BTU/(hr-ft^2)

H_{lw} = net long-wave atmospheric radiation in BTU/(hr-ft^2)

H_b = outgoing long-wave back radiation

$= B_w \sigma (T_s + 460)^4$ in BTU/(hr-ft^2)

H_c = Convective energy flux in BTU/(hr-ft^2)

$= \gamma_w H_l (a + bW)\, 0.01\, (T_s - T_a)\, Pa/29.92$

H_e = Energy lost by evaporation in BTU/(hr-ft^2)

$= \gamma_w H_l (a + bW) (E_s - E_a)$

T_a = Air temperature in ^oF

T_s = Surface water temperature in ^oF

σ = Stefan-Boltzman Constant

$= 1.73 \times 10^{-9}$ BTU/(hr-ft^2 $^oR^4$)

B_w = Emissivity of water (0.97)

γ_w = Unit weight of water (62.4 lbs/ft^3)

H_l = Average latent heat of evaporation (1054 BTU/lb)

$a = 6.8 \times 10^{-4}$ ft/(hr-in. Hg)

$b = 2.7 \times 10^{-4}$ ft/(hr-in. Hg-mph)

W = Wind speed 6 ft above water surface in mph

E_a = Water vapor pressure 6 ft above water surface in in. Hg

$= E_{wb} - 0.000367\, P_a (T_a - T_s) (1.0 + (T_{wb} - 32)/1571)$

E_{wb} = Saturation vapor pressure at wet bulb temperature in in. Hg

T_{wb} = Wet bulb temperature °F

E_s = Saturation vapor pressure of the air at the temperature of the water surface in in. Hg.

P_a = Barometric pressure in in. Hg.

Using the following average conditions for winter and summer:

Table A-1. Average Meteorological Conditions.

	Winter	Summer
Air Temperature	53°F	85°F
Water Temperature	60°F	80°F
Wind Velocity	14mph	10mph
Relative Humidity	68%	60%

results in the following table assuming H_{sw} and H_{lw} remain constant

Table A-2. Increase in Heat Dissipation Rates Caused by Cooling Lake Temperature Rise.

ΔT °F	ΔH_b BTU/(hr-ft^2)	ΔH_c BTU/(hr-ft^2)	ΔH_e BTU/(hr-ft^2)	Total Change BTU/(hr-ft^2)
Winter				
1	0.9	2.8	2.6	6.3
5	4.8	14.2	12.8	31.8
10	9.7	28.4	30.4	68.5
15	14.8	42.7	53.3	110.8
20	20.0	57.0	82.6	159.6
Summer				
1	1.0	2.2	5.3	8.5
5	5.3	10.9	26.7	52.9
10	10.8	21.8	59.5	92.1
15	16.8	32.8	98.9	148.5
20	22.3	43.7	145.9	211.9

Table A-2 shows to raise the temperature of a lake one degree in the winter would require adding 6.3 BTU/(hr-ft^2) of heat while in the summer 8.5 BTU/(hr-ft^2) of heat is required.

A 1000-megawatt plant operating at full capacity would require 5.5×10^9 BTU/hour of heat be dissipated in the cooling lake. The heat loss rates and lake temperature rise are listed in Table A-3.

Table A-3. Cooling Lake Temperature Rise for a 1000-Megawatt Plant.

Cooling Lake Size Acres	Heat Loss Rate BTU/(hr-ft^2)	Temperature Rise Summer °F	Temperature Rise Winter °F
1000	126.4	13.1	16.7
2000	63.2	7.0	9.3
5000	25.3	3.0	4.0
10000	12.6	1.5	2.0
15000	6.3	0.8	1.0

APPENDIX B

PROCEDURES FOR DETERMINING WATER AND SEDIMENT QUALITY

Water Quality

Water quality work included the following parameters: suspended solids dissolved solids, dissolved oxygen, pH, NO_2-N, NO_3-N, Kjeldahl Nitrogen, PO_4-P, SO_4, Phenols, and selected trace element concentrations. The trace elements investigated include: As, Be, Cd, Cr, Fe, Hg, Mn, Ni, Pb, Se and Zn.

Suspended solids were determined gravimetrically as presented in Standard Methods for the Examination of Water and Wastewater Treatment, thirteenth edition, 1971, p. 537. Dissolved solids determination was conducted in accordance with procedures published in Standard Methods for the Examination of Water and Wastewater Treatment, thirteenth edition, 1971, p. 535.

Dissolved oxygen was measured with a Y.S.I. model 51A oxygen meter on site and cross-checked with a Winkler alkaline azide method presented in APHA Standards Methods for the Examination of Water and Wastewater Treatment, thirteenth edition, 1971, pg. 477.

pH was measured on-site with a Brinkman model E488 Metrohm pH meter. A neutral standard was used after each reading to insure calibration.

NO_2-N was analyzed colorimetrically on an auto Analyzer II system utilizing the diazotization-couping reaction on pages 135-194 of Methods for Chemical Analysis of Water and Wastes, U.S. Environmental Protection Agency, 1971. After every eighth sample, a standard was run to insure calibration. Nutrient samples were collected in the field and frozen until they were analyzed in the laboratory. NO_3-N was determined colorimetrically on an auto Analyzer II System through reduction with hydrazine sulfate to form nitrite. Once nitrite is formed, the standard diazotization coupling reaction is used. The procedure is contained in Methods for Chemical Analysis of Water and Wastes, U.S. Environmental Protection Agency, 1971, pp. 185-194.

Kjeldahl nitrogen was measured colormetrically using a Bauch and Lomb spectronic 20 after preliminary distillation and Nesselerization as per Methods for Chemical Analysis of Water and Wastes, U.S. Environmental Protection Agency, 1971, pp. 157-163. PO_4-P determination used the molybdate-potassium antimonyl tartarate reaction procedure contained in Methods for Chemical Analysis of Water and Wastes, U.S. Environmental Protection Agency, 1971, pp. 241-258.

SO_4 concentrations were determined utilizing the automated cholranilate method with an auto Analyzer II System as per Methods for Chemical Analysis of Water and Wastes, U.S. Environmental Protection Agency, 1971, pp. 283-291. The sulfate ion is converted to a suspension of barium sulfate. Since the suspension alters the turbidity of the solution, a colorimeter measures the turbidity and the resulting values are compared to a graph of standard sulfate solutions. A blank is used after eight samples to insure a lack of interference.

Phenols were analyzed using Hach Chemicals for the 4-aminoantipyrine method with chloroform extraction which is contained in Standard Methods for the Examination of Water and Wastewater, thirteenth edition, 1971. Once extraction has occurred, a Bauch and Lomb Spectronic 20 is used as the colorimeter. The initial reaction occurs when the phenols react with 4-aminoantipyrine at a pH of 10 in the presence of potassium ferricyanide to form a colored antipyrine complex. The colored complex is extracted using chloroform and the absorbance of the mixture is measured at 460 nm.

Trace element concentrations were run on water samples taken. From July 1975 through October 1975, the data reflected total metal concentration. After October, the samples were filtered and the soluble trace element concentrations were determined. The trace elements vary in physical and chemical characteristics and necessitated four different procedures for analysis.

Cd, Cu, Ni, and Zn utilized procedures for filtering and methyl isobutyl ketone (MIBK) extraction, as per Methods for Chemical Analysis of Water and Wastes, U.S. Environmental Protection Agency, 1971. Once prepared using these techniques, the samples were analyzed using a Perkin-Elmer Model 403 Atomic Absorption Spectrophotometer according to manufacturer's recommended procedures.

Mn and Fe were measured directly using a Perkin-Elmer Model 403 Atomic Absorption Spectrophotometer in accordance with the procedures recommended by the manufacturer.

As, Cr, Pb, and Se required a HGA-2100 heated graphite furnace on a Perkin-Elmer Model 403 Atomic Absorption Spectrophotometer in accordance with procedures established by the manufacturer. Hg analysis utilized flameless atomic absorption spectrophotometer method developed by Hach and Ott which is a slight variation requiring a single pass of the vapor with respect to the procedure contained in Methods for Chemical Analysis of Water and Wastes, U.S. Environmental Protection Agency, 1971.

Sediment Quality

The acid extractable metals in the sediment, lignite and soil samples were determined as described below.

Mercury was analyzed utilizing the Flameless Atomic Absorption Procedure or Cold Vapor Technique. For all other metals, sediments were digested with 30% hydrogen peroxide and nitric acid to dryness twice. The acid extract was then taken up in 10% (volume-volume) hydrochloric acid and analyzed utilizing atomic absorption spectroscopy techniques.

APPENDIX C

TEXAS WATER QUALITY BOARD

STANDARD LEACHATE TEST

TWQB Standard Leachate Test

In an attempt to be able to correlate all data submitted for evaluation, the TWQB has determined that the following procedure should be followed to obtain a "leachate" solution to analyze to determine the Hazardous Index of a solid waste. It should be noted that the procedure outlined is a modification of the Pennsylvania Standard Leachate Test.

The leachate procedure is as follows:

1. Triplicate 250 gram representative samples of the "dry" material should be taken according to AOAC or ASTM Standard methods, and placed in 1500 ML Erylenmeyer flasks*.
2. One liter of distilled or de-ionized water should be added to the flasks and the material stirred mechanically at a low speed, or slowly by hand for five (5) minutes.
3. Stopper the flasks and allow to stand for seven (7) days.
4. Filter the supernatent solution through a 0.45μ M (45 micron) glass filter.

When the "leachate solution" is collected it should be subjected to the same procedure outlined in Step 1 for a liquid, slurry, or sludge material.

* Since 1500 ML Erylenmeyer flasks were not available 2000 ML Erylenmeyer flasks were used for the lignite study.

APPENDIX D

WATER QUALITY SAMPLING RESULTS

Table D-1. Date/Hour of Water Quality Sampling (1975-76)

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr*	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	27/10	9/13	21/11	26/11	-	30/8	25/18	29/8	21/10	25/8	14/9	-	-	-
C-1	27/13	9/15	21/15	18/15	15/12	30/12	25/17	29/11	21/15	25/10*	14/13	11/13	-	-
C-2	27/12	9/15	21/17	18/15	15/10	30/12	25/16	29/10	21/14	25/10*	14/11	7/13	-	-
T-1	27/14	9/15	21/15	18/16	15/12	30/12	25/17	29/11	21/15	25/11*	14/14	11/14	-	-
T-2	27/13	9/15	21/17	18/15	15/10	30/12	25/16	29/11	21/14	25/11*	14/11	7/13	-	-
T-3	27/12	9/14	21/12	18/14	15/11	30/10	30/9	-	21/14	25/10*	14/10	7/13	-	-
SL-1	27/16	10/10	21/10	26/10	-	30/14	24/16	28/16	20/14	24/15	-	-	-	-
SL-2	27/16	10/10	21/10	26/10	-	30/14	24/16	28/16	20/13	24/14	-	11/15	-	-
N-1	27/16	10/10	21/9	26/9	-	30/14	24/15	28/16	20/13	24/14*	-	-	-	-
N-2	27/17	10/10	21/9	26/9	-	30/15	24/16	28/16	20/12	24/14*	-	-	-	-
N-3	27/17	10/9	21/8	26/8	-	30/16	24/17	28/15	20/12	24/12*	-	-	-	-
Lakes, Streams and Rivers in the Rockdale Area														
AL-1	-	-	-	26/10	-	-	-	28/9	-	-	14/15	-	-	-
AL-2	-	-	-	26/11	-	-	-	28/9	-	-	14/15	-	-	-
EY-1	27/20	10/14	19/15	24/15	-	29/11	24/8	28/10	20/8	24/9	14/15	-	-	-
EY-2	-	10/13	19/16	24/16	-	29/12	24/11	28/10	20/9	24/10	14/15	-	-	-
LR-1	27/20	10/12	19/18	24/18	-	29/14	24/10	28/11	20/10	24/11	31/10	-	-	-
LR-2	27/19	10/12	19/17	24/19	-	29/15	24/10	28/12	20/10	24/11	31/10	-	-	-
LR-3	27/18	10/14	19/19	24/20	-	29/15	24/13	28/13	20/11	24/12	31/11	-	-	-

Table D-1. Date/Hour of Water Quality Sampling (1975-76) (Continued)

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Groundwater Stations near Fairfield														
FD-1	-	9/10	21/14	18/10	-	30/11	25/14	29/9	21/11	25/8	-	7/15	-	-
FD-2	-	9/10	21/14	18/11	-	-	25/14	-	-	-	-	-	-	-
FD-3	-	9/11	21/15	18/11	-	30/11	25/15	29/9	21/11	25/9	-	7/15	-	-
FD-4	-	9/11	21/16	18/12	-	30/11	-	-	21/12	25/10	-	7/16	-	-
FD-5	-	9/12	21/16	-	-	-	-	29/10	21/12	25/10	-	7/16	-	-
FD-6	-	9/14	21/11	18/14	-	30/9	-	-	21/13	25/11	-	-	-	-
FD-7	-	-	-	26/16	-	30/13	30/10	29/11	21/15	25/13	-	11/14	-	-
FD-8	-	-	-	26/18	-	-	30/10	29/11	21/15	25/14	-	11/14	-	-
FD-9	-	-	-	-	-	-	-	29/12	21/16	25/14	-	11/14	-	-
Groundwater Stations near Rockdale														
RK-1	-	10/13	19/16	24/16	-	29/12	24/11	28/10	20/9	24/10	31/9	-	-	-
RK-2	-	10/13	19/16	24/17	-	29/12	24/12	28/10	20/9	24/10	31/9	-	-	-
RK-3	-	-	19/16	24/17	-	29/12	24/12	28/11	20/10	24/10	31/10	-	-	-

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* Cottonwood, Tehuacana and Navasota at flood stage.

Table D-2. Water Quality Sampling Results (1975-76), pH

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Lakes, Streams and Rivers in the Fairfield Area												
FL-1	8.6	8.2	8.2	8.4	-	8.3	8.4	6.8	8.3	8.4	7.4	-
C-1	7.4	7.2	7.4	7.2	6.8	7.2	7.3	6.8	7.5	7.1	6.5	6.9
C-2	7.7	7.9	7.7	7.6	7.1	7.1	7.5	7.1	7.9	6.9	6.5	-
T-1	7.3	7.2	7.7	7.4	6.9	7.3	7.2	6.5	7.4	6.9	6.4	7.0
T-2	7.5	7.6	7.9	7.9	7.3	7.1	8.0	7.0	8.3	7.1	5.8	-
T-3	7.9	8.2	7.8	6.8	7.0	7.8	7.2	-	8.3	7.1	6.8	-
SL-1	8.8	7.4	6.6	7.6	-	8.4	8.9	7.2	9.0	7.4	-	-
SL-2	9.2	8.1	7.5	8.2	-	8.2	9.0	7.7	8.9	7.5	-	-
N-1	8.0	7.4	7.2	7.6	-	7.6	7.9	7.0	9.0	7.4	-	-
N-2	8.1	7.7	7.6	7.6	-	7.6	7.9	7.0	8.3	7.2	-	-
N-3	7.7	7.5	7.0	6.8	-	7.2	6.9	7.1	8.0	7.2	-	-
Streams and Rivers in the Rockdale Area												
EY-1	6.9	7.1	7.2	7.3	-	6.8	7.2	6.5	6.9	7.3	7.1	7.2
EY-2	-	7.3	6.8	7.9	-	6.7	8.5	8.2	7.3	7.2	7.3	6.8
LR-1	7.9	7.5	7.0	7.6	-	7.2	8.6	6.7	7.9	7.8	-	6.9
LR-2	8.3	7.7	7.0	7.2	-	7.8	8.6	6.7	8.0	7.8	-	6.5
LR-3	8.3	7.6	7.0	7.4	-	7.8	8.3	6.7	8.0	7.8	-	-

Table D-2. Water Quality Sampling Results (1975-76), pH (Continued)

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Groundwater Stations near Fairfield												
FD-1	-	6.5	6.0	6.6	-	6.4	6.4	6.6	6.7	6.7	-	-
FD-2	-	5.2	6.8	7.4	-	-	6.2	-	-	-	-	-
FD-3	-	6.8	6.7	6.4	-	7.1	6.0	7.0	6.3	7.1	-	-
FD-4	-	5.8	6.4	6.6	-	-	-	-	6.3	6.4	-	-
FD-5	-	6.8	6.2	-	-	6.0	-	6.8	6.4	6.5	-	-
FD-6	-	7.0	7.0	6.7	-	7.2	-	-	7.5	-	-	-
FD-7	-	-	-	7.2	-	7.0	7.0	7.1	7.5	6.9	-	6.8
FD-8	-	-	-	6.5	-	-	8.8	8.4	8.9	8.9	-	-
FD-9	-	-	-	-	-	-	-	6.9	-	7.8	-	-
Groundwater Stations near Rockdale												
RK-1	-	6.3	6.3	6.3	-	6.7	6.3	6.2	6.7	6.9	-	6.6
RK-2	-	6.6	6.5	6.7	-	6.6	6.7	6.4	6.9	6.8	-	6.6
RK-3	-	-	6.2	6.6	-	5.9	6.2	6.4	-	5.9	-	-

Table D-3. Water Quality Sampling Results (1975-76), Dissolved Oxygen in ppm

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	*** Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	6.2	6.4	7.3	8.7	-	10.8	9.8	-	-	-	-	-	8.20	0.77
C-1	7.7	7.5	5.0	5.8	6.8	11.2	7.6	-	-	-	-	-	7.37	0.75
C-2	7.9	10.0	5.7	9.0	10.2	10.9	8.8	-	-	-	-	-	8.93	0.66
T-1	7.4	10.6	8.1	7.6	9.5	10.9	8.3	-	-	-	-	-	8.91	0.54
T-2	6.4	7.4	7.1	11.4	9.4	11.2	8.4	-	-	-	-	-	8.76	0.75
T-3	7.0	8.4	7.2	9.0	10.1	11.1	-	-	-	-	-	-	8.80	0.66
SL-1	11.9	7.2	4.1	7.8	-	11.6	8.0	-	-	-	-	-	8.43	1.20
SL-2	13.1	5.4	6.6	8.4	-	11.6	12.2	-	-	-	-	-	9.55	1.31
N-1	10.4	10.4	6.2	7.4	-	10.1	12.8	-	-	-	-	-	9.55	0.97
N-2	8.8	6.8	7.8	7.5	-	10.2	12.1	-	-	-	-	-	8.87	0.81
N-3	8.6	6.8	6.7	7.2	-	11.0	7.0	-	-	-	-	-	7.88	0.69
Streams and Rivers in the Rockdale Area														
EY-1	7.4	8.2	7.4	7.4	-	10.4	8.8	-	-	-	-	-	8.27	0.49
EY-2	-	11.2	10.5	12.4	-	9.8	14.8	-	-	-	-	-	11.74	0.88
LR-1	8.5	7.3	7.4	8.4	-	10.6	9.9	-	-	-	-	-	8.68	0.54
LR-2	9.0	7.5	7.2	6.2	-	11.6	9.8	-	-	-	-	-	8.55	0.81
LR-3	12.8	7.8	6.8	6.4	-	11.3	12.2	-	-	-	-	-	9.55	1.17

Table D-3. Water Quality Sampling Results (1975-76), Dissolved Oxygen in ppm (Continued)

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb***	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Groundwater Stations near Fairfield														
FD-1	-	1.2	1.6	1.9	-	4.1	4.0	-	-	-	-	-	2.55	0.62
FD-2	-	6.4	3.8	4.6	-	-	4.8	-	-	-	-	-	4.90	0.55
FD-3	-	2.4	1.5	2.8	-	3.1	5.6	-	-	-	-	-	3.08	0.68
FD-4	-	3.2	2.5	3.4	-	3.8	-	-	-	-	-	-	3.23	0.27
FD-5	-	1.4	1.7	-	-	-	-	-	-	-	-	-	1.55	0.15
FD-6	-	3.3	2.4	3.0	-	2.6	-	-	-	-	-	-	2.83	0.20
FD-7	-	-	-	1.2	-	3.9	-	-	-	-	-	-	2.55	1.35
FD-8	-	-	-	2.4	-	-	-	-	-	-	-	-	2.40	-
FD-9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Groundwater Stations near Rockdale														
RK-1	-	3.8	2.6	3.7	-	2.6	1.3	-	-	-	-	-	2.80	0.46
RK-2	-	4.2	4.8	2.8	-	2.8	2.4	-	-	-	-	-	3.40	0.47
RK-3	-	-	2.4	1.8	-	1.8	2.2	-	-	-	-	-	2.05	0.15

*** This parameter did not appear to be significant and was discontinued in February.

Table D-4. Water Quality Sampling Results (1975-76), Suspended Solids in mg/l

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{x}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	22	6	50	12	-	-	16	1	8	22	2	-	15.4	5.0
C-1	-	10	50	32	31	-	200	68	62	312	800	-	173.9	84.8
C-2	30	38	50	46	27	-	140	68	82	210	216	66	88.5	20.8
T-1	14	8	20	8	82	-	-	68	62	464	194	-	102.2	49.3
T-2	73	18	180	24	76	-	110	152	48	562	40	78	123.7	46.4
T-3	33	156	30	6	119	-	94	-	44	242	262	1340	232.7	126.2
SL-1	31	4	80	54	-	-	36	20	22	178	-	-	53.1	19.6
SL-2	76	80	90	46	-	-	26	6	8	98	-	-	53.8	13.1
N-1	13	24	40	2	-	-	2	1	10	198	-	-	36.3	23.6
N-2	29	32	20	134	-	-	134	50	54	326	-	-	97.4	36.3
N-3	28	92	25	232	-	-	50	86	24	144	-	-	85.1	25.7
Lakes, Streams and Rivers in the Rockdale Area														
AL-1	-	-	-	-	-	-	-	-	-	-	-	-		
AL-2	-	-	-	-	-	-	-	-	-	-	-	-		
EY-1	86	18	40	30	-	-	34	6	14	102	84	-	41.0	13.0
EY-2	-	-	40	92	-	-	56	26	13	22	8	-	42.9	12.2
LR-1	31	226	270	44	-	-	2	4	70	198	-	-	105.6	38.2
LR-2	51	582	630	1640	-	-	8	42	102	880	-	-	491.9	201.7
LR-3	15	597	220	740	-	-	22	21	96	644	-	-	294.4	110.6

Table D-4. Water Quality Sampling Results (1975-76), Suspended Solids in mg/l (Continued)

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Groundwater Stations near Fairfield														
FD-1	-	3	50	36	-	-	1	4	23	16	-	12	18.1	6.2
FD-2	-	6	30	<1	-	-	-	-	-	-	-	-	12.0	9.2
FD-3	-	75	40	140	-	-	1	2	4	98	-	8	46.0	18.7
FD-4	-	1150	130	184	-	-	-	-	15	38	-	138	275.8	176.8
FD-5	-	59	10	-	-	-	-	4	20	106	-	18	36.2	16.0
FD-6	-	438	190	106	-	-	-	-	114	140	-	-	197.6	61.8
FD-7	-	-	-	6	-	-	14	1	59	6	-	-	17.2	10.6
FD-8	-	-	-	8	-	-	5	1	2	5	-	-	4.2	1.3
FD-9	-	-	-	-	-	-	-	<1	1	4	-	-	2.0	1.0
Groundwater Stations near Rockdale														
RK-1	-	54	50	36	-	-	17	18	42	40	-	-	36.7	5.5
RK-2	-	81	30	2	-	-	12	<1	96	52	-	-	39.1	14.5
RK-3	-	-	30	20	-	-	2	1	40	33	-	-	21.0	6.7

Table D-5. Water Quality Sampling Results (1975-76), Dissolved Solids*in mg/l

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{x}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	290	190	240	320	-	-	260	410	370	380	330	-	310	23.9
C-1	620	460	530	650	60	-	600	600	460	200	180	-	436	67.2
C-2	730	370	650	680	80	-	60	650	530	180	190	430	449	74.7
T-1	1530	1760	1870	850	220	-	-	60	490	150	-	-	866	266.2
T-2	1300	1410	938	2190	190	-	310	540	460	140	-	420	790	209.4
T-3	1170	950	1050	1720	290	-	520	-	500	180	180	1180	774	182.7
SL-1	130	180	150	230	-	-	300	480	470	110	-	-	256	52.2
SL-2	120	120	110	230	-	-	370	630	490	130	-	-	275	70.6
N-1	-	250	370	330	-	-	80	370	440	110	-	-	279	52.1
N-2	930	800	660	580	-	-	710	770	590	170	-	-	651	79.9
N-3	510	960	250	100	-	-	30	490	530	180	-	-	381	10.7
Lakes, Streams and Rivers in the Rockdale Area														
AL-1	-	-	-	-	-	-	-	790	-	-	720	-	754	-
AL-2	-	-	-	-	-	-	-	2440	-	-	2390	-	2415	-
EY-1	-	820	850	850	-	-	1150	1300	1160	900	640	-	959	78.1
EY-2	1030	700	840	860	-	-	730	1400	670	780	700	-	857	77.4
LR-1	420	290	-	370	-	-	420	470	380	270	-	-	374	27.3
LR-2	440	290	-	940	-	-	340	470	370	240	-	-	441	88.4
LR-3	400	360	-	80	-	-	530	480	400	270	-	-	360	56.3

Table D-5. Water Quality Sampling Results (1975-76), Dissolved Solids in mg/l (Continued)

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{x}}$
Groundwater Stations near Fairfield														
FD-1	-	3170	3580	3890	-	-	4000	4750	5300	4230	-	3960	4110	234.8
FD-2	-	270	260	310	-	-	-	-	-	-	-	-	280	15.3
FD-3	-	520	370	480	-	-	240	430	370	370	-	530	414	34.1
FD-4	-	2580	3310	3400	-	-	-	-	3950	1550	-	3500	3048	383.3
FD-5	-	1720	1110	-	-	-	-	1750	1580	2180	-	1720	1677	140.6
FD-6	-	330	380	560	-	-	-	-	430	780	-	-	496	80.7
FD-7	-	-	-	3040	-	-	2900	2680	2500	1330	-	-	2490	304.3
FD-8	-	-	-	400	-	-	470	440	370	450	-	-	430	20.8
FD-9	-	-	-	-	-	-	-	300	260	290	-	-	283	12.1
Groundwater Stations near Rockdale														
RK-1	-	250	190	230	-	-	320	260	180	290	-	-	246	19.1
RK-2	-	1610	1550	1390	-	-	1610	1840	1730	1710	-	-	1634	54.6
RK-3	-	-	-	180	-	-	430	280	200	250	-	-	268	44.2

Table D-6. Water Quality Sampling Results (1975-76), NO_3-N* in ppm

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr**	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	<0.05	<0.10	0.14	<0.05	-	0.12	0.36	0.19	0.30	-	-	-	0.15	0.05
C-1	<0.05	<0.05	0.08	<0.05	-	<0.05	<0.05	<0.05	<0.05	-	-	-	0.03	0.01
C-2	<0.05	<0.05	0.12	<0.05	-	0.06	<0.05	<0.05	<0.05	-	-	-	0.04	0.01
T-1	<0.05	<0.05	<0.05	<0.05	-	0.14	-	<0.05	<0.05	-	-	-	0.04	0.02
T-2	<0.05	<0.05	<0.05	<0.05	-	0.05	<0.05	0.18	<0.05	-	-	-	0.04	0.02
T-3	<0.05	<0.05	<0.05	<0.05	-	<0.05	<0.05	-	<0.05	-	-	-	0.03	0.00
SL-1	0.98	<0.05	0.07	<0.05	-	<0.05	<0.05	<0.05	<0.05	-	-	-	0.15	0.12
SL-2	0.72	<0.05	0.07	<0.05	-	<0.05	<0.05	<0.05	<0.05	-	-	-	0.12	0.08
N-1	0.11	<0.05	0.15	<0.05	-	0.30	0.06	<0.05	<0.05	-	-	-	0.09	0.04
N-2	<0.05	0.08	0.64	0.36	-	0.94	0.35	0.69	<0.05	-	-	-	0.39	0.12
N-3	0.05	0.10	0.41	0.08	-	0.61	<0.05	0.12	<0.03	-	-	-	0.18	0.08
Lakes, Streams and Rivers in the Rockdale Area														
AL-1	-	-	-	<0.05	-	-	-	<0.05	-	-	-	-	0.03	0.00
AL-2	-	-	-	0.27	-	-	-	0.23	-	-	-	-	0.25	0.02
EY-1	0.69	<0.05	0.05	<0.05	-	<0.05	<0.05	<0.05	<0.05	-	-	-	0.11	0.08
EY-2	-	<0.05	0.06	<0.05	-	0.33	0.18	0.17	<0.05	-	-	-	0.12	0.05
LR-1	4.8	0.07	0.47	1.7	-	1.8	2.9	3.1	2.5	-	-	-	2.17	0.54
LR-2	3.4	0.30	1.3	1.3	-	2.8	2.4	1.8	1.9	-	-	-	1.90	0.34
LR-3	3.0	0.38	1.0	1.1	-	2.8	2.4	2.6	2.5	-	-	-	1.91	0.38

Table D-6. Water Quality Sampling Results (1975-76), NO_3-N* in ppm (Continued)

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr**	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Groundwater Stations near Fairfield														
FD-1	-	1.0	0.05	7.2	-	9.2	9.2	13.4	10.2	-	-	-	7.18	1.86
FD-2	-	<0.05	0.18	0.08	-	-	-	-	-	-	-	-	0.09	0.05
FD-3	-	<0.05	0.33	<0.05	-	0.25	0.31	0.32	0.31	-	-	-	0.22	0.05
FD-4	-	<0.05	0.20	0.09	-	0.22	0.10	-	0.44	-	-	-	0.18	0.06
FD-5	-	0.70	-	-	-	-	-	15.6	13.4	-	-	-	9.90	4.64
FD-6	-	<0.05	0.15	<0.05	-	<0.05	-	-	2.70	-	-	-	0.58	0.53
FD-7	-	-	-	0.50	-	0.45	<0.05	0.35	0.15	-	-	-	0.29	0.09
FD-8	-	-	-	0.55	-	-	0.56	<0.05	<0.05	-	-	-	0.29	0.15
FD-9	-	-	-	-	-	-	-	5.19	4.35	-	-	-	4.77	0.42
Groundwater Stations near Rockdale														
RK-1	-	0.06	0.05	<0.05	-	<0.05	<0.05	<0.05	<0.05	-	-	-	0.03	0.00
RK-2	-	<0.05	0.18	<0.05	-	0.11	<0.05	0.20	0.09	-	-	-	0.09	0.03
RK-3	-	-	<0.05	<0.05	-	<0.05	0.06	<0.05	<0.05	-	-	-	0.03	0.00

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* 10 ppm permissible level for public water supply (EPA, 1975).

** Since NO_3-N did not appear significant analysis was discontinued in April.

Table D-7. Water Quality Sampling Results (1975-76), K_j-N in ppm

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	*Apr	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	1.7	-	9.1	-	-	0.8	1.4	0.7	1.4	-	-	-	2.52	1.33
C-1	0.6	-	0.6	-	-	0.8	1.5	0.6	0.8	-	-	-	0.82	0.14
C-2	0.7	-	1.9	-	-	0.6	1.1	0.8	1.0	-	-	-	1.02	0.19
T-1	1.3	-	0.6	-	-	1.2	-	0.4	<0.1	-	-	-	0.71	0.24
T-2	0.7	-	1.9	-	-	0.7	0.9	0.8	1.0	-	-	-	1.00	0.19
T-3	1.3	-	2.6	-	-	0.7	0.7	-	2.1	-	-	-	1.48	0.38
SL-1	2.2	-	2.6	-	-	2.4	2.7	2.2	1.8	-	-	-	2.32	0.13
SL-2	2.2	-	3.3	-	-	1.9	2.6	-	1.5	-	-	-	2.30	0.31
N-1	1.0	-	-	-	-	0.6	1.2	0.8	2.1	-	-	-	1.14	0.26
N-2	1.4	-	5.9	-	-	2.7	-	0.8	1.7	-	-	-	2.50	0.90
N-3	0.9	-	3.3	-	-	1.1	1.2	1.0	0.8	-	-	-	1.38	0.39
Lakes, Streams and Rivers in the Rockdale Area														
AL-1	-	-	-	-	-	-	-	0.3	-	-	-	-	0.30	-
AL-2	-	-	-	-	-	-	-	0.3	-	-	-	-	0.30	-
EY-1	0.6	-	1.9	-	-	0.5	0.8	0.1	0.3	-	-	-	0.70	0.26
EY-2	-	1.4	3.3	-	-	1.3	1.7	0.7	0.7	-	-	-	1.52	0.39
LR-1	0.9	-	1.9	-	-	1.3	1.4	0.8	1.4	-	-	-	1.28	0.16
LR-2	1.0	-	2.6	-	-	1.1	0.9	1.1	1.0	-	-	-	1.28	0.27
LR-3	1.1	-	3.3	-	-	1.3	0.9	0.4	1.3	-	-	-	1.38	0.41

Table D-7. Water Quality Sampling Results (1975-76), K_j-N in ppm (Continued)

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr*	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Groundwater Stations near Fairfield														
FD-1	-	0.8	1.3	-	-	0.7	0.5	0.4	0.3	-	-	-	0.67	0.15
FD-2	-	0.7	3.3	-	-	-	-	-	-	-	-	-	2.00	1.30
FD-3	-	1.9	0.6	-	-	0.4	0.3	<0.1	0.3	-	-	-	0.59	0.27
FD-4	-	4.4	3.9	-	-	0.8	1.1	-	0.7	-	-	-	2.18	0.81
FD-5	-	3.4	4.6	-	-	-	-	1.5	1.5	-	-	-	2.75	0.76
FD-6	-	1.8	4.6	-	-	2.0	-	-	2.1	-	-	-	2.63	0.66
FD-7	-	-	-	-	-	0.4	0.2	<0.1	0.6	-	-	-	0.31	0.12
FD-8	-	-	-	-	-	-	0.5	0.3	0.7	-	-	-	0.50	0.12
FD-9	-	-	-	-	-	-	-	0.3	0.8	-	-	-	0.55	0.25
Groundwater Stations near Rockdale														
RK-1	-	0.6	1.9	-	-	0.1	0.2	0.3	0.4	-	-	-	0.58	0.27
RK-2	-	0.7	1.9	-	-	0.6	0.3	<0.1	0.3	-	-	-	0.64	0.27
RK-3	-	-	1.9	-	-	<0.1	<0.1	0.7	0.1	-	-	-	0.56	0.36

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* Since Kj-N did not appear to be significant, analysis was discontinued in April.

Table D-8. Water Quality Sampling Results (1975-76), PO_4-P* in ppm

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	** Apr	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	0.05	0.02	0.14	0.12	-	0.14	0.16	0.13	0.11	-	-	-	0.11	0.02
C-1	0.03	0.07	0.05	0.02	-	0.57	0.10	0.15	0.11	-	-	-	0.14	0.06
C-2	0.06	0.07	0.06	0.02	-	0.11	0.08	0.16	0.11	-	-	-	0.08	0.01
T-1	0.04	0.07	0.07	0.10	-	0.03	-	0.15	0.10	-	-	-	0.08	0.02
T-2	0.10	0.04	0.08	0.01	-	0.04	0.09	0.24	0.08	-	-	-	0.08	0.02
T-3	0.04	0.13	0.09	<0.01	-	0.07	0.10	-	0.23	-	-	-	0.09	0.03
SL-1	0.16	0.21	0.18	0.06	-	0.10	0.16	0.18	0.16	-	-	-	0.15	0.02
SL-2	0.28	0.06	0.10	0.03	-	0.10	0.15	0.16	0.13	-	-	-	0.13	0.03
N-1	0.06	0.07	0.01	0.05	-	<0.01	0.07	0.07	0.25	-	-	-	0.07	0.03
N-2	0.08	0.13	0.05	2.40	-	0.95	0.75	1.26	0.27	-	-	-	0.74	0.29
N-3	0.05	0.08	0.18	0.18	-	0.70	0.08	0.30	0.18	-	-	-	0.22	0.07
Lakes, Streams and Rivers in the Rockdale Area														
AL-1	-	-	-	-	-	-	-	0.03	-	-	-	-	0.03	-
AL-2	-	-	-	-	-	-	-	0.03	-	-	-	0.03	0.03	-
EY-1	0.06	0.10	0.03	0.01	-	<0.01	0.02	0.03	0.03	-	-	-	0.04	0.01
EY-2	-	0.04	0.11	0.01	-	<0.01	0.03	0.04	0.03	-	-	-	0.04	0.01
LR-1	0.21	0.10	0.15	1.15	-	0.25	1.02	1.28	0.75	-	-	-	0.61	0.17
LR-2	0.13	0.23	0.38	0.30	-	0.62	0.44	0.63	0.40	-	-	-	0.39	0.06
LR-3	0.06	0.28	0.26	0.17	-	0.57	0.40	0.66	0.54	-	-	-	0.37	0.07

Table D-8. Water Quality Sampling Results (1975-76), PO_4-P* in ppm (Continued)

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	**Apr	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Groundwater Stations near Fairfield														
FD-1	-	0.32	0.63	0.50	-	0.42	0.41	0.40	0.40	-	-	-	0.44	0.04
FD-2	-	0.40	0.03	0.01	-	-	-	-	-	-	-	-	0.15	0.13
FD-3	-	0.36	0.42	0.40	-	0.09	0.10	0.11	0.11	-	-	-	0.23	0.06
FD-4	-	0.55	0.01	0.04	-	0.04	0.04	-	0.08	-	-	-	0.13	0.09
FD-5	-	0.51	0.43	-	-	-	-	0.40	0.24	-	-	-	0.39	0.06
FD-6	-	0.23	0.02	0.02	-	0.04	-	-	0.08	-	-	-	0.08	0.04
FD-7	-	-	-	1.30	-	<0.01	0.17	0.09	0.09	-	-	-	0.33	0.24
FD-8	-	-	-	0.16	-	-	0.12	0.12	0.10	-	-	-	0.12	0.02
FD-9	-	-	-	-	-	-	-	0.08	0.17	-	-	-	0.12	0.04
Groundwater Stations near Rockdale														
RK-1	-	<0.01	<0.01	<0.01	-	0.01	0.10	0.04	0.13	-	-	-	0.04	0.02
RK-2	-	0.04	<0.01	0.01	-	0.03	0.04	0.07	0.06	-	-	-	0.04	0.01
RK-3	-	-	<0.01	0.06	-	<0.01	0.01	<0.01	0.01	-	-	-	0.16	0.01

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* Total phosphates

** Since PO_4-P did not appear to be significant, analysis was discontinued in April.

Table D-9. Water Quality Sampling Results (1975-76), SO_4* in ppm

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	39	46	39	39	-	44	68	62	65	44	71	96	55.7	5.5
C-1	136	135	170	170	-	144	70	86	81	41	31	80	104.0	14.8
C-2	150	121	214	110	-	162	130	95	78	34	24	60	107.9	17.2
T-1	208	390	310	310	-	77	-	61	74	<10	<10	130	157.0	43.9
T-2	198	450	176	180	-	170	84	74	75	10	22	68	136.5	37.2
T-3	160	250	154	150	-	170	73	-	77	10	51	74	116.4	22.9
SL-1	<10	27	<10	<10	-	<10	14	<10	23	<10	-	33	12.7	3.5
SL-2	<10	14	<10	<10	-	<10	40	<10	18	<10	-	22	12.4	3.7
N-1	<10	<10	17	17	-	11	15	<10	17	34	-		14.0	2.9
N-2	99	106	64	64	-	40	126	52	35	32	-	73	69.1	10.1
N-3	66	76	41	43	-	38	86	61	46	<10	-	86	54.8	8.0
Lakes, Streams and Rivers in the Rockdale Area														
AL-1	-	-	-	-	-	-	-	153	-	-	224	100	159.0	36.1
AL-2	-	-	-	1210	-	-	-	1000	-	-	1433	890	1133.3	120.0
EY-1	260	330	214	110	-	260	400	160	370	265	195	672	294.2	46.0
EY-2	-	300	105	105	-	200	300	105	224	172	180	390	208.10	30.6
LR-1	27	31	21	21	-	29	56	43	49	<10	180	-	46.2	15.6
LR-2	25	24	26	26	-	44	60	53	58	<10	26	-	34.7	5.7
LR-3	34	35	35	35	-	46	67	58	64	<10	-	35	41.4	5.8

Table D-9. Water Quality Sampling Results (1975-76), SO_4* in ppm (Continued)

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Groundwater Stations near Fairfield														
FD-1	-	100	93	93	-	120	165	72	105	128	-	55	103.4	10.7
FD-2	-	51	41	41	-	-	-	-	-	-	-	-	44.3	3.3
FD-3	-	38	30	25	-	12	28	<10	23	38	-	42	26.8	4.1
FD-4	-	690	138	140	-	870	340	-	740	320	-	-	462.6	113.3
FD-5	-	210	154	-	-	-	-	105	135	240	-	390	205.7	42.0
FD-6	-	63	44	440	-	<10	-	-	29	90	625	-	185.1	92.5
FD-7	-	-	-	376	-	24	110	364	330	112	-	120	205.1	55.1
FD-8	-	-	-	30	-	-	<10	<10	17	16	-	<10	13.0	4.1
FD-9	-	-	-	-	-	-	-	44	53	41	-	44	45.5	2.6
Groundwater Stations near Rockdale														
RK-1	-	25	21	21	-	<10	13	<10	<10	66	-	24	20.6	6.3
RK-2	-	125	112	110	-	94	147	102	18	71	-	126	100.6	12.6
RK-3	-	-	<10	-	-	<10	14	<10	<10	43	-	-	12.8	6.2

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* Recommended maximum level for public water supply is 250 ppm (EPA, 1973).

Table D-10. Water Quality Sampling Results (1975-76), Phenols* in ppm.

Station	Sept	Feb	June
Lakes, Streams and Rivers in the Fairfield Area			
FL-1	0.05	0.03	0.08
C-1	-	0.03	0.04
C-2	0.08	0.07	0.04
T-1	-	<0.01	0.03
T-2	0.05	0.08	0.03
T-3	-	-	0.11
SL-1	-	0.06	0.05
SL-2	-	0.10	0.04
N-1	-	0.06	0.04
N-2	-	0.05	<0.01
N-3	-	0.10	0.03
Streams and Rivers in the Rockdale Area			
EY-1	-	0.03	0.11
EY-2	-	0.04	0.04
LR-1	-	0.01	0.01
LR-2	-	<0.01	0.02
LR-3	-	-	<0.01
Groundwater Stations Near Fairfield			
FD-1	-	0.08	0.04
FD-3	-	0.04	0.02
FD-4	-	0.06	0.04
FD-5	0.14	-	0.03
FD-6	-	0.04	0.06
FD-7	-	<0.01	0.03
FD-8	-	0.01	<0.01
FD-9	-	-	0.09
Groundwater Stations Near Rockdale			
RK-1	-	0.05	0.06
RK-2	-	0.02	0.02
RK-3	-	0.06	-

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* 1973 EPA Water Quality Criteria recommends a maximum concentration of 0.001 ppm. The 1975 interim Drinking Water Standards did not list phenols.

Table D-11. Water Quality Sampling Results (1975-76), As* in ppb**

Station	*** July	*** Aug	*** Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{x}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	8	<2	3	<2	-	3	<2	-	12	<5	8	4	4.35	1.18
C-1	4	<2	4	5	<2	3	2	3	12	6	4	13	4.83	1.12
C-2	5	3	6	9	2	3	2	5	12	<5	-	5	4.95	0.94
T-1	26	24	45	31	23	3	5	5	12	5	3	5	15.58	4.00
T-2	21	17	25	26	22	12	6	14	14	<5	2	7	14.04	2.43
T-3	9	12	18	21	14	8	3	-	8	5	13	2	10.27	1.81
SL-1	3	4	2	<2	-	2	3	9	8	6	-	5	4.30	0.84
SL-2	3	3	2	<2	-	3	3	-	<2	<5	-	3	2.39	0.29
N-1	2	<2	<2	<2	-	<2	<2	<2	14	13	-	7	4.20	1.66
N-2	10	7	10	7	-	7	5	10	14	11	-	10	9.10	0.82
N-3	6	3	<2	<2	-	2	2	4	6	8	-	13	4.60	1.20
Lakes, Streams and Rivers in the Rockdale Area														
AL-1	-	-	-	6	-	-	-	6	-	-	14	5	7.75	2.10
AL-2	-	-	-	56	-	-	-	-	-	-	35	24	38.33	9.39
EY-1	9	3	4	<1	-	4	3	9	17	13	12	9	7.59	1.54
EY-2	-	<2	6	<2	-	5	3	12	16	17	3	7	7.10	1.87
LR-1	2	2	3	3	-	2	<2	3	16	11	-	2	4.50	1.56
LR-2	2	3	4	4	-	3	<2	2	17	11	-	5	5.20	1.57
LR-3	2	3	4	3	-	2	6	3	13	21	-	10	6.70	1.97

Table D-11. Water Quality Sampling Results (1975-76), As* in ppb** (Continued)

Station	*** July	*** Aug	*** Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Groundwater Stations near Fairfield														
FD-1	-	68	49	61	-	32	40	44	50	121	-	26	54.56	9.38
FD-2	-	<2	<2	<2	-	-	2	-	-	-	-	-	1.25	0.25
FD-3	-	2	4	17	-	3	-	2	8	16	-	3	6.88	2.21
FD-4	-	24	61	21	-	43	48	-	59	32	-	56	43.0	5.58
FD-5	-	12	20	-	-	-	-	<2	28	38	-	22	20.17	5.22
FD-6	-	3	4	3	-	3	-	-	6	18	-	3	5.71	2.09
FD-7	-	-	-	31	-	22	34	3	30	30	-	13	23.29	4.32
FD-8	-	-	-	6	-	-	2	6	10	8	-	4	6.00	1.16
FD-9	-	-	-	-	-	-	-	4	6	<5	-	4	4.13	0.72
Groundwater Stations near Rockdale														
RK-1	-	<2	3	2	-	2	5	<2	10	<5	-	<2	3.06	0.97
RK-2	-	12	13	7	-	2	3	27	31	29	-	22	16.22	3.77
RK-3	-	-	2	<2	-	<2	<2	<2	6	6	-	-	2.57	0.90

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* 1975 EPA interim Drinking Water Standards listed maximum concentration of 50 ppb

** Accuracy & Precision. EPA std. no. 3, lot 575 conc.= 27.8 ppb, $\overline{x}$ = 26.7 ppb, d.f. = 15, σ = 2.02 ppm.

*** July, August and September samples were not filtered while October through June were filtered through a 0.45μ filter.

Table D-12. Water Quality Sampling Results (1975-76), Cd* in ppb**

Station	*** July	*** Aug	*** Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	-	<1	<1	1	-	<1	<1	-	<1	1	<2	<2	0.72	0.09
C-1	-	<1	<1	<1	1	<1	<1	6	3	3	<2	<2	1.59	0.52
C-2	-	<1	<1	<1	1	<1	2	1	4	2	<2	<2	1.41	0.31
T-1	-	<1	<1	<1	<1	<1	<1	4	3	2	<2	<2	1.27	0.36
T-2	-	<1	<1	<1	1	<1	<1	<1	<1	<1	<2	<2	0.64	0.07
T-3	-	<1	<1	<1	1	<1	1	-	2	2	<2	<2	1.00	0.18
SL-1	-	<1	<1	1	-	<1	2	3	1	2	-	<2	1.28	0.29
SL-2	-	<1	<1	<1	-	<1	2	-	<1	<1	-	<2	0.75	0.19
N-1	-	<1	<1	<1	-	<1	2	1	3	<1	-	<2	1.06	0.29
N-2	-	<1	<1	<1	-	<1	3	3	<1	<1	-	<2	1.11	0.36
N-3	-	<1	<1	2	-	<1	4	5	<1	2	-	<2	1.89	0.58
Lakes, Streams and Rivers in the Rockdale Area														
AL-1	-	-	-	1	-	-	-	3	-	-	3	<2	2.00	0.58
AL-2	-	-	-	2	-	-	-	6	-	-	4	5	4.25	0.86
EY-1	-	<1	1	<1	-	<1	<1	3	<1	<1	<2	<2	0.90	0.24
EY-2	-	<1	<1	<1	-	<1	2	3	<1	<1	<2	<2	1.00	0.27
LR-1	-	<1	<1	1	-	<1	3	1	<1	11	-	<2	2.11	1.14
LR-2	-	<1	<1	<1	-	<1	<1	1	<1	3	-	<2	0.89	0.27
LR-3	-	<1	<1	<1	-	<1	<1	2	4	<1	-	<2	1.11	0.40

Table D-12. Water Quality Sampling Results (1975-76), Cd* in ppb** (Continued)

Station	*** July	*** Aug	*** Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{x}}$
Groundwater Stations near Fairfield														
FD-1	-	2	1	1	-	<1	3	3	3	1	-	<2	1.72	0.34
FD-2	-	3	<1	<1	-	-	-	-	-	-	-	<2	1.25	0.60
FD-3	-	1	<1	1	-	<1	3	2	1	<1	-	<2	1.17	0.28
FD-4	-	1	<1	1	-	<1	4	-	1	2	-	<2	1.38	0.41
FD-5	-	2	1	-	-	<1	-	2	1	1	-	<2	1.21	0.22
FD-6	-	<1	<1	<1	-	<1	-	-	<1	<1	-	<2	0.57	0.07
FD-7	-	-	-	<1	-	<1	2	3	<1	<1	-	<2	1.14	0.37
FD-8	-	-	-	<1	-	<1	1	3	<1	1	-	<2	1.07	0.34
FD-9	-	-	-	-	-	-	-	<1	<1	<1	-	<2	0.63	0.13
Groundwater Stations near Rockdale														
RK-1	-	<1	<1	<1	-	<1	<1	2	<1	1	-	<2	0.78	0.17
RK-2	-	<1	<1	<1	-	<1	<1	1	1	<1	-	<2	0.67	0.08
RK-3	-	-	<1	1	-	<1	<1	1	1	<1	-	<2	0.75	0.10

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* 1975 EPA interim Drinking Water Standards listed a maximum concentration of 10 ppb.

** Accuracy and precision. EPA std. no. 2, lot 575 conc.= 2.3 ppb, $\overline{x}$ = 2.6 ppb, d.f.= 8, σ = 0.4 ppb.

*** July, August and September samples were not filtered while October through June samples were filtered through a 0.45μ filter.

Table D-13. Water Quality Sampling Results (1975-76), Cr* in ppb**

Station	*** July	*** Aug	*** Sept	Oct	Nov	Dec	**** Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{x}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	<1	<1	<2	<1	-	<1							0.60	0.10
C-1	<1	<1	2	<1	<1	<1							0.75	0.25
C-2	<1	<1	3	<1	<1	<1							0.92	0.42
T-1	<1	<1	<2	<1	<1	<1							0.58	0.08
T-2	<1	<1	3	<1	<1	<1							0.92	0.42
T-3	<1	11	3	<1	<1	<1							2.66	1.71
SL-1	<1	<1	<2	<1	-	<1							0.60	0.10
SL-2	<1	3	<2	<1	-	<1							1.10	0.48
N-1	<1	<1	<2	<1	-	<1							0.60	0.10
N-2	<1	<1	<2	<1	-	<1							0.60	0.10
N-3	<1	3	3	<1	-	<1							1.50	0.61
Lakes, Streams and Rivers in the Rockdale Area														
AL-1	-	-	-	<1	-	-							0.50	-
AL-2	-	-	-	<1	-	-							0.50	-
EY-1	<1	6	3	<1	-	<1							2.10	1.09
EY-2		<1	<2	<1	-	<1							0.63	0.12
LR-1	<1	4	7	<1	-	<1							2.50	1.31
LR-2	<1	9	10	<1	-	<1							4.10	2.21
LR-3	<1	11	4	<1	-	<1							3.30	2.04

Table D-13. Water Quality Sampling Results (1975-76), Cr* in ppb** (Continued)

Station	July***	Aug***	Sept***	Oct	Nov	Dec	Jan****	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{x}}$
Groundwater Stations near Fairfield														
FD-1	-	<1	<2	<1	-	<1							0.63	0.13
FD-2	-	<1	<2	<1	-	-							0.67	0.15
FD-3	-	<1	<2	<1	-	<1							0.63	0.13
FD-4	-	13	<2	<1	-	<1							3.75	0.09
FD-5	-	<1	<2	-	-	-							0.75	0.25
FD-6	-	3	<2	<1	-	<1							1.25	0.60
FD-7	-	-	-	<1	-	<1							0.50	0.00
FD-8	-	-	-	<1	-	-							0.50	-
FD-9	-	-	-	-	-	-							-	-
Groundwater Stations near Rockdale														
RK-1	-	<1	<2	<1	-	<1							0.63	0.13
RK-2	-	<1	<2	<1	-	<1							0.63	0.13
RK-3	-	-	<2	<1	-	<1							0.67	0.17

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* 1975 EPA interim Drinking Water Standards maximum concentration for Cr is 50 ppb.

** Precision and accuracy. EPA std. No. 2, lot 575 conc.= 16 ppb, $\overline{x}$ = 17.5 ppb, d.f.= 3, σ = 3.0 ppb.

*** July, August and September samples were not filtered while October, November and December samples were filtered through a 0.45μ filter.

**** Since Cr did not appear to be significant it was dropped from analysis after December.

Table D-14. Water Quality Sampling Results (1975-76), Cu* in ppb**

Station	July	*** Aug	*** Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	-	17	1	7	-	4	2	-	11	4	3	2	5.7	1.7
C-1	-	3	3	13	9	3	2	21	18	16	13	<2	9.3	2.2
C-2	-	3	7	11	8	2	7	14	21	7	13	3	8.7	1.7
T-1	-	1	<1	7	6	2	3	10	21	10	15	2	7.1	2.0
T-2	-	5	<1	6	9	3	5	2	9	12	15	6	6.6	1.3
T-3	-	5	2	3	8	2	8	-	10	10	13	12	7.3	1.3
SL-1	-	<1	<1	20	-	5	6	12	12	10	-	<1	5.9	2.2
SL-2	-	<1	<1	9	-	4	5		9	3		5	7.5	2.2
N-1	-	2	<1	8	-	1	4	9	10	7	-	2	4.8	1.2
N-2	-	<1	<1	15	-	3	6	11	15	7	-	2	6.7	1.9
N-3	-	2	2	17	-	5	6	12	5	13	-	4	7.3	1.8
Lakes, Streams and Rivers in the Rockdale Area														
AL-1	-	-	-	12	-	-	-	4	-	-	7	6	7.2	1.7
AL-2	-	-	-	7	-	-	-	21	-	-	6	7	10.2	3.6
EY-1	-	3	6	5	-	<1	5	12	2	-	9	<2	4.8	1.3
EY-2	-	5	5	7	-	27	10	17	30	7	11	2	12.1	3.0
LR-1	-	7	5	11	-	3	5	11	11	-	-	2	6.9	1.3
LR-2	-	10	8	17	-	<1	1	12	21	7	-	2	8.7	2.4
LR-3	-	23	<1	22	-	2	1	19	5	6	-	1	8.8	3.2

Table D-14. Water Quality Sampling Results (1975-76), Cu* in ppb** (Continued)

Station	July	*** Aug	*** Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{x}}$
Groundwater Stations near Fairfield														
FD-1	-	54	48	53	-	8	10	28	42	14	-	17	30.4	6.3
FD-2	-	6	15	<2	-	-	-	-	-	-	-	-	7.3	3.5
FD-3	-	8	3	11	-	<1	3	3	15	2	-	4	5.5	1.6
FD-4	-	56	12	9	-	<1	2	-	56	3	-	6	18.1	8.4
FD-5	-	9	14	-	-	-	-	14	22	3	-	3	10.8	3.0
FD-6	-	32	23	19	-	<1	-	-	11	7	-	6	14.1	4.2
FD-7	-	-	-	3	-	<1	2	2	21	9	-	<4	5.6	2.8
FD-8	-	-	-	27	-	-	4	13	10	9	-	3	11.0	3.5
FD-9	-	-	-	-	-	-	-	111	91	120	-	103	106.2	6.2
Groundwater Stations near Rockdale														
RK-1	-	33	120	1	-	<1	<1	22	9	<1	-	7	22.2	
RK-2	-	280	75	<1	-	<1	160	44	17	2	-	8	65.2	32.0
RK-3	-	-	22	2	-	6	<1	29	31	1	-	-	13.1	5.2

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* 1973 EPA recommended maximum concentration for copper in livestock water supply is 500 ppb.

** Precision and accuracy. EPA std. No. 3, lot 575 conc.= 31.4 ppb, $\overline{x}$ = 35.6 ppb, d.f. = 9, σ = 2.8 ppb.

*** August and September samples were unfiltered while October through June samples were filtered through a 0.45μ filter.

Table D-15. Water Quality Sampling Results (1975-76), Fe* in ppm

Station	Aug**	Sept**	Oct***	Nov***	June***
Lakes, Streams and Rivers in the Fairfield Area					
FL-1	<0.1	<0.1	<0.1	<0.1	<0.3
C-1	1.2	1.5	-	<0.1	<0.3
C-2	1.2	2.3	-	<0.1	<0.3
T-1	0.5	0.8	-	<0.1	<0.3
T-2	1.4	2.7	-	<0.1	<0.3
T-3	1.8	3.4	-	<0.1	<0.3
SL-1	0.9	1.6	<0.1	<0.1	<0.3
SL-2	3.4	1.9	<0.1	<0.1	<0.3
N-1	0.5	0.1	-	<0.1	<0.3
N-2	2.0	1.6	<0.1	<0.1	<0.3
N-3	2.3	6.1	<0.1	<0.1	<0.3
Lakes, Streams and Rivers in the Rockdale Area					
AL-2	-	-	0.5	-	0.6
EY-1	4.2	1.7	-	<0.1	<0.3
EY-2	1.1	1.6	-	0.5	<0.3
LR-1	2.9	1.3	-	<0.1	<0.3
LR-2	5.3	14.0	-	<0.1	<0.3
LR-3	11.0	4.2	-	<0.1	<0.3
Groundwater Stations Near Fairfield					
FD-1	<0.1	<0.1	-	<0.1	<0.3
FD-2	9.1	1.0	-	-	
FD-3	2.3	1.8	-	<0.1	<0.3
FD-4	15.0	3.2	-	<0.1	<0.3
FD-5	0.4	0.4	-	<0.1	<0.3
FD-6	4.6	16.0	-	<0.1	<0.3
FD-7	-	-	1.1	<0.1	<0.3

Table D-15. Water Quality Sampling Results (1975-76), Fe* in ppm (Continued)

Station	Aug**	Sept**	Oct***	Nov***	June***
Groundwater Stations Near Rockdale					
RK-1	24.0	15.0	<0.1	15.	<0.3
RK-2	2.7	1.9	<0.1	<0.1	<0.3
RK-3	-	14.0	<0.1	5.8	<0.3

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* 1973 EPA Water Quality Criteria recommends maximum acceptable soluble iron in raw water for drinking of 0.3 ppm.

** Total iron.

*** Samples filtered through a 0.45μ filter. Value represents the dissolved Fe.

Table D-16. Water Quality Sampling Results (1975-76), Hg* in ppb**

Station	*** July	*** Aug	*** Sept	Oct	Nov	Dec	Jan	Feb	Mar	**** Apr	**** May	**** June	$\overline{X}$	$\sigma_{\overline{x}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	17	1.7	5.3	<0.2	-	<0.2	0.3	-	0.2	-	-	-	3.53	2.35
C-1	0.7	0.7	2.4	<0.2	<0.02	<0.2	<0.2	<0.2	0.4	-	-	-	0.54	0.25
C-2	1.0	1.1	0.4	<0.2	<0.02	<0.2	<0.2	0.4	0.2	-	-	-	0.38	0.13
T-1	4.2	1.0	4.5	<0.2	<0.02	0.4	<0.2	0.6	<0.2	-	-	-	1.20	0.60
T-2	4.6	0.3	3.6	<0.2	<0.02	<0.2	<0.2	<0.2	<0.2	-	-	-	1.00	0.59
T-3	4.2	0.9	2.8	<0.2	<0.02	<0.2	<0.2	-	0.2	-	-	-	1.05	0.56
SL-1	3.3	0.2	2.3	<0.2	-	<0.2	<0.2	0.3	<0.2	-	-	-	0.80	0.45
SL-2	4.0	0.8	2.8	<0.2	-	<0.2	<0.2	-	<0.2	-	-	-	1.14	0.60
N-1	3.2	0.9	2.4	<0.2	-	<0.2	<0.2	0.45	<0.2	-	-	-	0.92	0.43
N-2	2.7	1.3	0.3	<0.2	-	<0.2	<0.2	<0.2	0.1	-	-	-	0.60	0.33
N-3	2.7	1.3	3.5	0.5	-	<0.2	<0.2	0.7	<0.2	-	-	-	1.12	0.46
Lakes, Streams and Rivers in the Rockdale Area														
AL-1	-	-	-	<0.2	-	-	-	0.4	-	-	-	-	-	-
AL-2	-	-	-	<0.2	-	-	-	0.5	-	-	-	-	0.30	-
EY-1	0.7	<0.2	1.6	<0.2	-	<0.2	<0.2	0.4	<0.2	-	-	-	0.40	0.19
EY-2	-	<0.2	3.3	<0.2	-	<0.2	<0.2	0.4	<0.1	-	-	-	0.59	0.45
LR-1	8.8	0.6	1.4	<0.2	-	<0.02	<0.2	0.6	<0.1	-	-	-	1.47	1.06
LR-2	2.2	1.2	4.6	0.5	-	<0.2	0.5	<0.2	0.2	-	-	-	1.17	0.55
LR-3	2.2	0.8	1.6	0.5	-	<0.2	<0.2	1.1	<0.2	-	-	-	0.81	0.28

Table D-16. Water Quality Sampling Results (1975-76), Hg* in ppb** (Continued)

Station	*** July	*** Aug	*** Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Groundwater Stations near Fairfield														
FD-1	-	0.7	3.2	0.2	-	0.2	<0.2	0.4	0.2	-	-	-	0.71	0.42
FD-2	-	<0.2	1.2	<0.2	-	-	-	-	-	-	-	-	0.47	0.36
FD-3	-	0.8	0.8	0.3		<0.2	0.2	0.8	0.1	-	-	-	0.44	0.13
FD-4	-	0.9	1.6	0.2		<0.2	<0.2	-	0.2	-	-	-	0.62	0.25
FD-5	-	2.6	0.9					0.7	0.1	-	-	-	1.07	0.48
FD-6	-	1.0	3.9	0.4	-	<0.2	-	-	0.2	-	-	-	1.12	0.71
FD-7	-	-	-	0.3	-	<0.2	<0.2	0.2	0.3	-	-	-	0.20	0.04
FD-8	-	-	-	0.5	-	-	<0.2	2.3	0.2	-	-	-	0.76	0.52
FD-9	-	-	-	-	-	-	-	0.6	0.1				0.35	0.25
Groundwater Stations near Rockdale														
RK-1	-	0.3	0.9	<0.2	-	<0.2	<0.2	0.7	<0.2	-	-	-	0.33	0.13
RK-2	-	<0.2	3.0	<0.2	-	<0.2	<0.2	0.6	<0.2	-	-	-	0.60	0.40
RK-3	-	-	0.9	<0.2	-	<0.2	0.2	0.7	<0.1	-	-	-	0.32	0.15

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* 1973 EPA Water Quality Criteria recommended maximum concentration is 0.2 ppb for freshwater aquatic life. 1975 EPA Drinking Water maximum concentration is 2 ppb.

** Precision and accuracy. EPA std. no. 2 (lot 575) conc.= 4.5 ppb, $\overline{x}$ = 4.42 ppb, d.f.= 8, σ = 0.85 ppb.

*** July, August and September samples were not filtered while the October through March samples were filtered with a 0.45μ filter.

**** The dissolved mercury analysis in water samples was discontinued in April.

Table D-17. Water Quality Sampling Results (1975-76), Mn* in ppb**

Station	*** July	*** Aug	*** Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	50	100	60	<100	-	<10	30	-	20	<100	<50	<50	40.0	8.8
C-1	350	900	1400	<100	320	110	490	470	480	400	40	630	470.0	110.4
C-2	1300	2000	2600	<100	1000	190	2100	960	870	<100	<40	100	936.7	262.0
T-1	1400	2500	1100	<100	1100	80	250	560	360	<100	<50	260	644.6	217.2
T-2	720	1400	720	<100	190	230	230	100	160	<100	<50	<50	325.0	120.4
T-3	160	1200	360	<100	160	70	120	-	<20	<100	<50	<50	187.9	100.6
SL-1	140	400	450	<100	-	<10	90	<10	<20	<100	-	<50	122.5	52.3
SL-2	230	400	510	<100	-	30	<10	-	30	<100	-	<50	147.8	59.6
N-1	60	400	<30	<100	-	30	130	20	30	<100	-	<50	81.0	37.0
N-2	130	500	360	<100	-	70	120	270	40	<100	-	<50	161.5	51.1
N-3	120	400	330	<100	-	60	80	110	120	<100	-	60	138.0	39.1
Lakes, Streams and Rivers in the Rockdale Area														
AL-1	-	-	-	<100	-	-	-	<110	-	-	<50	<50	37.5	7.2
AL-2	-	-	-	3900	-	-	-	5300	-	-	5400	5600	5050.0	388.4
EY-1	1800	1200	750	250	-	430	1000	1800	2300	1800	540	1500	1215.5	203.4
EY-2	-	400	660	<100	-	60	40	410	<20	<100	170	60	191.0	70.0
LR-1	30	400	240	<100	-	<10	80	<10	<20	<100	-	<50	89.5	40.9
LR-2	40	400	510	<100	-	<10	60	50	<20	<100	-	<50	120.0	56.7
LR-3	30	500	230	<100	-	<10	30	20	<20	<100	-	<50	95.0	49.5

Table D-17. Water Quality Sampling Results (1975-76), Mn* in ppb** (Continued)

Station	***July	***Aug	***Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Groundwater Stations near Fairfield														
FD-1	-	600	270	150	-	80	50	70	<20	<100	-	<50	145.0	62.7
FD-2	-	200	180	<100	-	-	-	-	-	-	-	-	143.3	47.1
FD-3	-	200	300	<100	-	20	50	40	<20	<100	-	<50	82.8	33.0
FD-4	-	1500	390	<100	-	80	110	-	90	<100	-	90	295.0	176.6
FD-5	-	600	480	-	-	-	-	70	40	200	-	200	265.0	92.3
FD-6	-	500	540	150	-	730	-	-	220	300	-	<50	352.1	93.6
FD-7	-	-	-	450	-	60	340	100	<20	<100	-	110	160.0	63.1
FD-8	-	-	-	<100	-	-	<10	<10	<20	<100	-	<50	24.2	8.7
FD-9	-							20	40	100	-	<50	46.3	18.4
Groundwater Stations near Rockdale														
RK-1	-	400	210	250	-	220	150	220	190	300	-	290	247.8	24.6
RK-2	-	1900	1500	900	-	1100	-	340	1000	1000	-	1400	1142.5	164.4
RK-3	-	-	120	<100	-	1350	1910	1910	40	6100	-	-	1640.0	809.5

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* EPA 1973, desirable limit for manganese is 50 ppb for public water sources.

** Precision and accuracy. EPA sample concentration = 397 ppb, $\overline{x}$ = 380 ppb, d.f. = 9, σ = 10.5 ppb.

*** July through September samples were not filtered while the October through June samples were filtered with a 0.45μ filter.

Table D-18. Water Quality Sampling Results (1975-76), Ni in ppb

Station	*** July	*** Aug	*** Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{x}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	-	2	6	4	-	<2	7	-	-	3	-	5	4.0	0.82
C-1	-	<2	6	<3	15	4	6	15	8	8	-	17	8.1	1.81
C-2	-	3	6	<3	12	4	1	13	5	<2	-	19	6.5	1.93
T-1	-	2	<2	5	14	2	8	15	<2	4	-	3	5.5	1.64
T-2	-	3	<2	<3	10	2	6	<2	8	10	-	6	4.8	1.14
T-3	-	3	<2	5	17	4	9	-	15	3	-	12	7.7	1.94
SL-1	-	<2	5	<3	-	2	4	8	<1	<2	-	3	2.9	0.81
SL-2	-	<2	<2	3	-	2	4	-	<1	<2	-	2	1.6	0.39
N-1	-	<2	<2	<3	-	2	4	4	<1	<2	-	<2	1.8	0.44
N-2	-	<2	<2	3	-	2	7	17	3	<2	-	4	4.3	1.71
N-3	-	5	3	8	-	6	10	13	5	4	-	3	6.3	1.13
Lakes, Streams and Rivers in the Rockdale Area														
AL-1	-	-	-	10	-	-	-	9	-	-	10	-	9.7	0.33
AL-2	-	-	-	100	-	-	-	83	-	-	91	-	91.3	4.91
EY-1	-	8	5	6	-	2	11	13	8	6	-	7	7.3	1.15
EY-2	-	6	15	7	-	14	9	19	5	6	-	9	10.0	1.62
LR-1	-	<2	8	<3	-	2	9	13	<2	8	-	<2	4.9	1.52
LR-2	-	7	10	<3	-	2	8	9	<2	6	-	<2	5.1	1.23
LR-3	-	11	3	<3	-	3	11	10	8	2	-	<2	5.6	1.43

Table D-18. Water Quality Sampling Results (1975-76), Ni in ppb (Continued)

Station	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Groundwater Stations near Fairfield														
FD-1	-	16	17	4	-	6	13	19	12	10	-	8	11.7	1.71
FD-2	-	<2	6	<3	-	-	-	-	-	-	-	2	2.6	1.15
FD-3	-	2	6	9	-	2	8	8	<2	<2	-	11	5.3	1.29
FD-4	-	22	17	15	-	12	23	-	5	7	-	15	14.5	2.27
FD-5	-	16	33	-	-	-	-	21	7	20	-	23	20.0	3.48
FD-6	-	18	20	13	-	6	-	-	3	14	-	5	11.3	2.52
FD-7	-	-	-	<3	-	2	3	9	<2	2	-	3	3.1	1.02
FD-8	-	-	-	<3	-	-	<2	7	<2	<2	-	5	2.7	1.06
FD-9	-	-	-	-	-	-	-	6	<3	<2	-	3	2.9	1.13
Groundwater Stations near Rockdale														
RK-1	-	2	3	7	-	2	4	11	<1	<2	-	1	3.5	1.15
RK-2	-	<2	<2	<2	-	2	6	6	5	<2	-	4	3.0	0.75
RK-3	-	-	12	10	-	4	13	14	5	9	-	-	9.6	1.46

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* Recommended maximum concentration for public water sources were not included in the 1973 EPA Water Quality Criteria.

** Precision and accuracy. EPA std. no. 2, lot 575 conc.= 4.5 ppb, $\overline{x}$ = 6.78 ppb, d.f. = 3, σ = 1.39 ppb.

*** August and September samples were not filtered while October through June samples were filtered with a 0.45μ filter.

Table D-19. Water Quality Sampling Results (1975-76), Pb* in ppb**

Station	*** July	*** Aug	*** Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{x}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	<1	<1	<2	<2	-	<5	8	-	<5	6	-	3	2.78	0.87
C-1	1	1	<2	4	1	<5	<5	1	<5	17	-	2	3.23	1.41
C-2	1	<1	<2	<2	1	<5	12	4	9	<5	-	3	3.41	1.12
T-1	3	4	<2	<2	2	<5	<5	<1	<5	<5	<5	<2	2.08	0.29
T-2	1	2	<2	<2	4	<5	<5	1	<2	<5	<5	2	1.92	0.15
T-3	3	2	<2	<2	2	<5	<5	-	<2	<5	<5	14	3.09	1.11
SL-1	4	2	<2	<2	-	<5	<5	1	2	12	-	<2	2.90	1.06
SL-2	<1	2	<2	<2	-	<5	<5	-	<2	<5	-	<2	1.56	0.27
N-1	<1	<1	<2	<2	-	<5	10	<1	<1	<5	-	<2	2.00	0.92
N-2	<1	2	<2	8	-	<5	8	1	<5	<5	-	<2	2.90	0.88
N-3	<1	2	2	<2	-	<5	6	1	<2	7	-	<2	2.40	0.71
Lakes, Streams and Rivers in the Rockdale Area														
AL-1	-	-	-	<2	-	-	-	<1	-	-	<5	<2	1.25	0.43
AL-2	-	-	-	<2	-	-	-	4	-	-	<5	<2	2.13	0.72
EY-1	.2	4	<2	<2	-	<5	<5	2	<5	-	-	5	2.50	0.43
EY-2	-	2	<2	<2	-	<5	<5	8	<5	-	-	6	3.19	0.88
LR-1	<1	2	<2	<2	-	<5	10	4	<5	9	-	5	3.75	1.06
LR-2	<1	4	4	<2	-	<5	<5	<1	<5	9	-	<2	2.75	0.81
LR-3	<1	6	2	<2	-	<5	8	<1	<2	5	-	<2	2.75	0.84

Table D-19. Water Quality Sampling Results (1975-76), Pb* in ppb** (Continued)

Station	*** July	*** Aug	*** Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{x}}$
Groundwater Stations near Fairfield														
FD-1	-	9	<2	<2	-	<5	6	23	5	-	-	3	6.31	7.27
FD-2	-	7	<2	8	-	-	-	-	-	-	-	-	5.33	3.79
FD-3	-	15	<2	<2	-	<5	<5	<1	5	<5	-	<2	3.44	4.54
FD-4	-	35	9	<2	-	<5	16	-	9	<5	-	16	11.38	11.20
FD-5	-	4	<2	-	-	-	-	3	<5	8	-	12	5.08	4.13
FD-6	-	15	14	<2	-	<5	-	-	11	<5	-	2	6.86	6.20
FD-7	-	-	-	<2	-	<5	5	13	<5	-	-	4	4.67	4.31
FD-8	-	-	-	<2	-	-	10	<1	<5	-	-	<2	3.00	3.98
FD-9	-	-	-	-	-	-	-	11	<2	<5	-	<2	3.88	4.80
Groundwater Stations near Rockdale														
RK-1	-	2	<2	<2	-	<5	<5	4	<2	<5	-	<2	1.94	1.04
RK-2	-	10	<2	8	-	<5	<1	4	<5	<5	-	3	3.78	3.17
RK-3	-	-	<2	<2	-	<5	<5	1	<5	<5	-	<2	1.75	0.80

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* 1975 EPA Interim Drinking Water Standards maximum concentration is 50 ppb and the 1973 EPA Water Quality Criteria recommended maximum concentration is 30 ppb for freshwater aquatic life.

** Precision and accuracy. EPA std. No. 2, lot 575 conc.= 29.8 ppb, $\overline{x}$ = 27.4 ppb, d.f.= 8, σ = 1.9 ppb.

*** July, August and September samples were not filtered while the October through June samples were filtered with a 0.45µ filter.

Table D-20. Water Quality Sampling Results (1975-76), Se* in ppb**

Station	*** July	*** Aug	*** Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{X}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	<5	15	<5	8	-	17	<5	-	4	7	5	<2	6.45	1.74
C-1	20	11	8	12	6	11	13	18	9	9	5	10	11.00	1.27
C-2	33	11	12	15	7	13	13	9	8	2	<2	6	10.83	2.37
T-1	12	54	40	58	43	16	<5	13	8	<2	<2	6	21.21	6.16
T-2	15	34	22	58	37	6	6	-	4	<2	<2	5	17.18	5.61
T-3	10	22	16	54	28	17	8	-	4	<2	5	<2	15.09	4.70
SL-1	<5	7	<5	8	-	<5	<5	5	4	<2	-	<2	3.60	0.76
SL-2	<5	9	8	8	-	6	<5	-	-	<2	-	<2	4.75	1.19
N-1	<5	<5	<5	<5	-	6	<5	<5	3	<2	-	4	2.90	0.41
N-2	5	17	12	14	-	7	8	9	6	<2	-	5	8.40	1.51
N-3	10	19	12	6	-	6	6	7	7	<2	-	6	8.00	0.48
Lakes, Streams and Rivers in the Rockdale Area														
AL-1	-	-	-	19	-	-	-	14	-	-	17	14	16.00	1.22
AL-2	-	-	-	58	-	-	-	44	-	-	57	47	51.50	3.53
EY-1	23	23	20	24	-	19	29	25	29	26	13	17	22.54	1.49
EY-2	-	15	14	24	-	17	13	26	11	21	17	6	16.40	1.91
LR-1	<5	10	<5	<5	-	11	<5	14	10	5	-	10	7.00	1.40
LR-2	<5	21	8	<5	-	6	<5	10	5	5	-	3	6.55	1.79
LR-3	<5	24	6	<5	-	10	10	16	-	3	-	6	8.89	2.40

Table D-20. Water Quality Sampling Results (1975-76), Se* in ppb** (Continued)

Station	July***	Aug***	Sept***	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{x}}$
Groundwater Stations near Fairfield														
FD-1	-	59	76	45	-	74	228	109	23	58	-	39	79.0	20.37
FD-2	-	<5	<5	<5	-	-	-	-	-	-	-	-	2.50	0.00
FD-3	-	11	<5	24	-	6	<5	6	5	8	-	5	7.78	2.21
FD-4	-	79	72	45	-	83	198	-	50	47	-	48	77.75	18.02
FD-5	-	53	60	-	-	-	-	59	39	45	-	46	50.33	3.42
FD-6	-	9	<5	27	-	<5	-	-	6	20	-	3	10.00	3.68
FD-7	-	-	-	64	-	42	253	120	15	13	-	17	74.86	33.00
FD-8	-	-	-	9	-	-	<5	<5	<2	10	-	<2	4.33	1.66
FD-9	-	-	-	-	-	-	-							
Groundwater Stations near Rockdale														
RK-1	-	6	<5	<5	-	6	<5	5	4	<2	-	<2	3.39	0.65
RK-2	-	32	18	21	-	33	19	39	13	4	-	33	23.56	3.80
RK-3	-	-	<5	<5	-	<5	<5	5	4	26	-	-	6.43	3.28

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* 1975 EPA Interim Drinking Water Standards maximum concentration of 10 ppb.

** Precision and accuracy. EPA std. No. 2, lot 575 conc.= 26 ppb, $\overline{x}$ = 26.55 ppb, d.f.= 9, σ = 1.59 ppb.

*** July, August and September samples were not filtered while the October through June samples were filtered with a 0.45μ filter.

Table D-21. Water Quality Sampling Results (1975-76), Zn* in ppb**

Station	*** July	*** Aug	*** Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{x}}$
Lakes, Streams and Rivers in the Fairfield Area														
FL-1	-	1	4	<1	-	14	1	-	33	7	5	11	8.5	3.4
C-1	-	1	9	<1	14	2	4	63	21	29	12	4	14.5	5.6
C-2	-	1	9	<1	10	2	41	40	20	27	12	8	15.5	4.4
T-1	-	2	6	9	6	1	5	33	17	12	17	3	10.1	2.8
T-2	-	3	6	8	4	<1	9	<1	9	11	13	5	6.3	1.2
T-3	-	3	9	2	3	11	21	-	12	12	17	19	10.9	2.2
SL-1	-	2	9	9	-	11	5	7	4	21	-	2	9.0	2.0
SL-2	-	3	12	5	-	4	3	-	8	< 1	-	4	7.5	2.2
N-1	-	3	4	4	-	<1	7	4	5	13	-	2	4.7	1.2
N-2	-	<1	3	4	-	<1	10	37	23	9	-	<1	9.7	5.2
N-3	-	<1	11	5	-	<1	10	29	18	15	-	<1	9.9	3.2
Lakes, Streams and Rivers in the Rockdale Area														
AL-1	-	-	-	19	-	-	-	41	-	-	9	7	19.0	7.8
AL-2	-	-	-	220	-	-	-	320	-	-	437	380	339.2	46.4
EY-1	-	2	6	7	-	<1	13	49	2	8	12	4	10.3	4.5
EY-2	-	5	15	18	-	58	22	154	27	15	14	12	34.0	14.1
LR-1	-	3	6	7	-	4	10	14	5	38	-	2	9.9	3.7
LR-2	-	4	20	8	-	1	3	7	17	21	-	<1	9.1	2.7
LR-3	-	7	7	<1	-	5	9	12	21	5	-	2	7.6	2.0

Table D-21. Water Quality Sampling Results (1975-76), Zn* in ppb** (Continued)

Station	*** July	*** Aug	*** Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	$\overline{X}$	$\sigma_{\overline{x}}$
Groundwater Stations near Fairfield														
FD-1	-	29	33	67	-	61	58	74	39	49	-	53	51.4	5.1
FD-2	-	39	710	280	-	-	-	-	-	-	-	-	343.0	196.3
FD-3	-	30	29	40	-	<1	28	35	32	45	-	15	28.3	4.5
FD-4	-	37	23	40	-	70	70	-	28	42	-	65	46.9	6.7
FD-5	-	103	116	-	-	-	-	115	48	54	-	110	91.0	12.8
FD-6	-	62	34	6	-	<1	-	-	30	30	-	22	26.4	7.7
FD-7	-	-	-	13	-	18	13	31	24	29	-	26	22.0	2.8
FD-8	-	-	-	<1	-	-	70	15	7	30	-	1	20.6	10.9
FD-9	-	-	-	-	-	-	-	243	63	70	-	200	144.0	45.6
Groundwater Stations near Rockdale														
RK-1	-	278	1760	13	-	2	18	67	78	34	-	66	257.3	189.9
RK-2	-	272	145	170	-	35	52	41	54	61	-	420	138.9	43.9
RK-3	-	-	1600	2880	-	1310	42	1870	62	64	-	-	1118.3	417.6

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* EPA 1973 Water Quality Criteria recommended maximum concentration is 5000 ppb for public water supply sources.

** Precision and accuracy. EPA std. No. 3, lot 575 conc. = 36.7 ppb, $\overline{x}$ = 35.8 ppb, d.f. = 6, σ = 2.4 ppb.

*** August and September samples were not filtered while October through June samples were filtered with a 0.45μ filter.