

**BRINE CONTAMINATION OF GROUND WATER AND
STREAMS IN THE BAXTERVILLE OIL FIELD AREA,
LAMAR AND MARION COUNTIES, MISSISSIPPI**

By Stephen J. Kalkhoff

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**CONVERSION FACTORS, VERTICAL DATUM,
AND ABBREVIATIONS**

<u>Multiply</u>	<u>By</u>	<u>To obtain</u>
inch (in.)	25.4	millimeter
barrel	0.1590	cubic meter
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
mile (mi)	1.609	kilometer
square mile (mi ²)	2.590	square kilometer
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second
cubic foot per day per square foot times foot of aquifer thickness [(ft ³ /d)/ft ²]ft	0.09290	cubic meter per day per square meter times meter of aquifer thickness
gallon per day (gal/d)	0.003785	cubic meter per day
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units used in report:

mg/L	milligram per liter
µg/L	microgram per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius

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ABSTRACT

A hydrologic investigation to define the extent of brine contamination in ground water and streams in the Baxterville oil field area was conducted from October 1984 through November 1985. The 260-square-mile study area includes the Baxterville oil field (approximately 12.5 square miles) in southwestern Lamar and southeastern Marion Counties, Mississippi. Since 1944, disposal of more than 1 billion barrels of brine pumped from the oil-producing zones has contaminated (increased chloride to greater than background concentrations) parts of the Citronelle and shallow Miocene aquifers and some streams that drain the oil field. Many domestic wells have been abandoned because of the presence of substantial quantities of brine in the ground water. Brine has moved laterally through the shallowest aquifers and discharged into Clear Creek and its tributaries. Although the presence of brine in surface water was greatest during periods of low flow when streamflow originated primarily from ground-water inflow, brine was also detected during high-flow periods when streamflow consisted largely of precipitation runoff.

INTRODUCTION

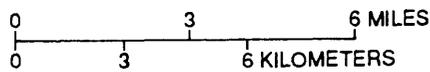
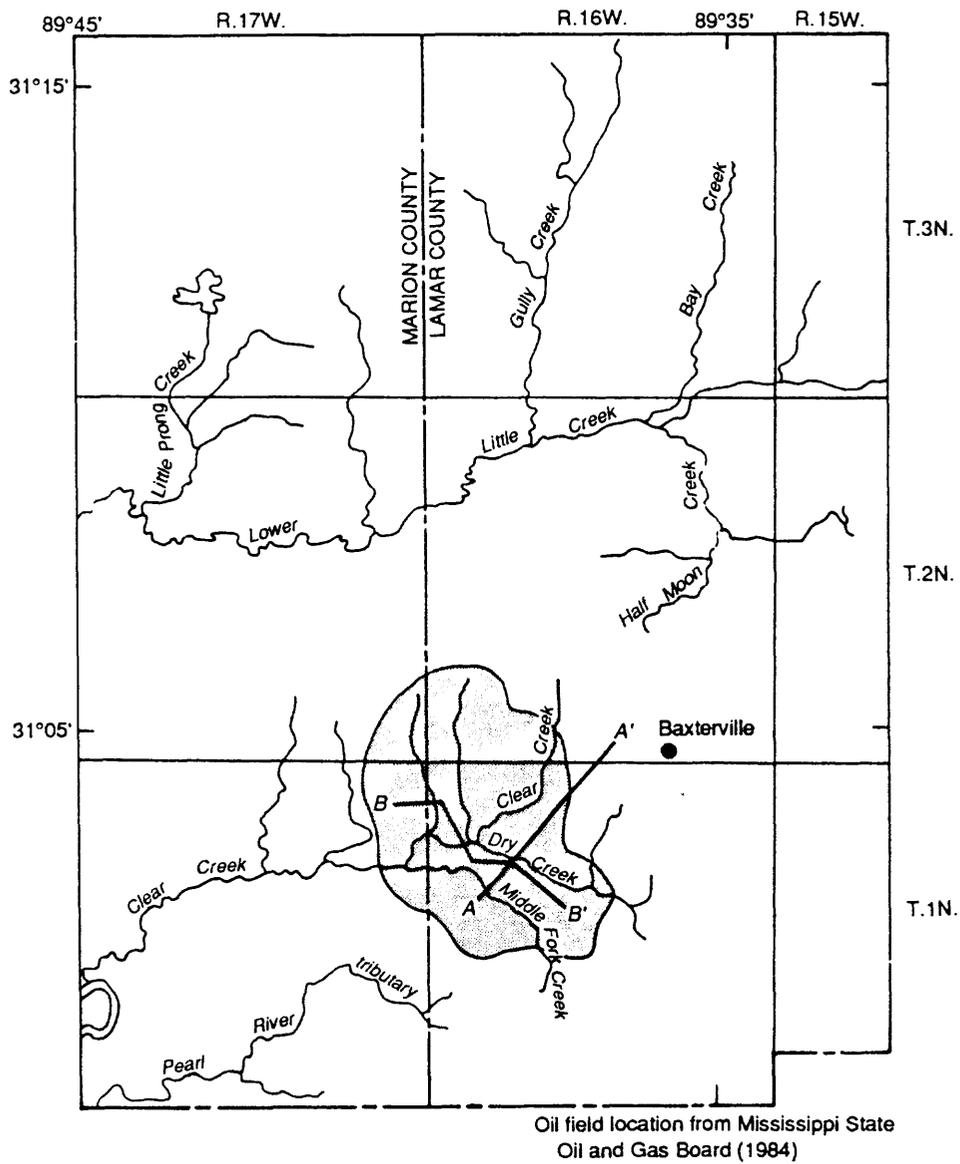
Large quantities of brine, water with a dissolved-solids concentration greater than 35,000 mg/L, are produced in conjunction with petroleum. In Mississippi, where petroleum production began in 1939, disposal of brine has resulted in contamination of streams and aquifers. In the early years of oil production in the State, brine was pumped into nearby streams. In an attempt to avoid surface-water contamination, producers later pumped brine into evaporation ponds or pits. This practice led to the contamination of shallow ground water, and this disposal method was prohibited in 1978 (Mississippi State Oil and Gas Board, 1985, p. 91). Most of the brine produced in the Baxterville oil field is injected (1986) into the saline Cook Mountain Formation, which ranges in depth from 2,340 to 2,700 ft below land surface (Bicker, 1972).

Information about the extent of brine contamination and about the movement and ultimate fate of the brine and the constituents that it contains is useful to local water planners and managers. To determine the extent of brine contamination, a study to collect water-quality data in oil-producing areas of Mississippi was begun in 1981 by the U.S. Geological Survey in cooperation with the Mississippi Department of Environmental Quality, Office of Pollution Control.

Background

The Baxterville oil field (fig. 1), located in southwestern Lamar and southeastern Marion Counties, is (1986) the most productive oil field in Mississippi. Oil production in the Baxterville oil field began on November 19, 1944. Production figures for the first few years of operation are not available, but more than 7.5 million barrels of oil were produced in 1948 (fig. 2). Production decreased and ranged from about 5 to 6 million barrels per year until 1970. Production increased in 1970 and reached a maximum of almost 8.9 million barrels in 1972. Since then, yearly oil production gradually decreased to approximately 4.4 million barrels in 1985 (Mississippi State Oil and Gas Board, 1984, 1985).

During initial development of oil reservoirs, relatively little brine in proportion to petroleum is brought to the surface. As petroleum is removed, however, formation water (brine) fills the pore spaces vacated by the oil, and subsequent pumping produces brine with the oil. The yearly brine production in Baxterville oil field gradually increased from about 1.7 million barrels in 1948 to about 20 million barrels in 1970. This increase continued through the 1970's and early 1980's, and brine production reached a



EXPLANATION



BAXTERVILLE OIL FIELD

A-A' TRACE OF GEOLOGIC SECTION

Figure 1.--Location of the study area, the Baxterville oil field, and trace of geologic sections.

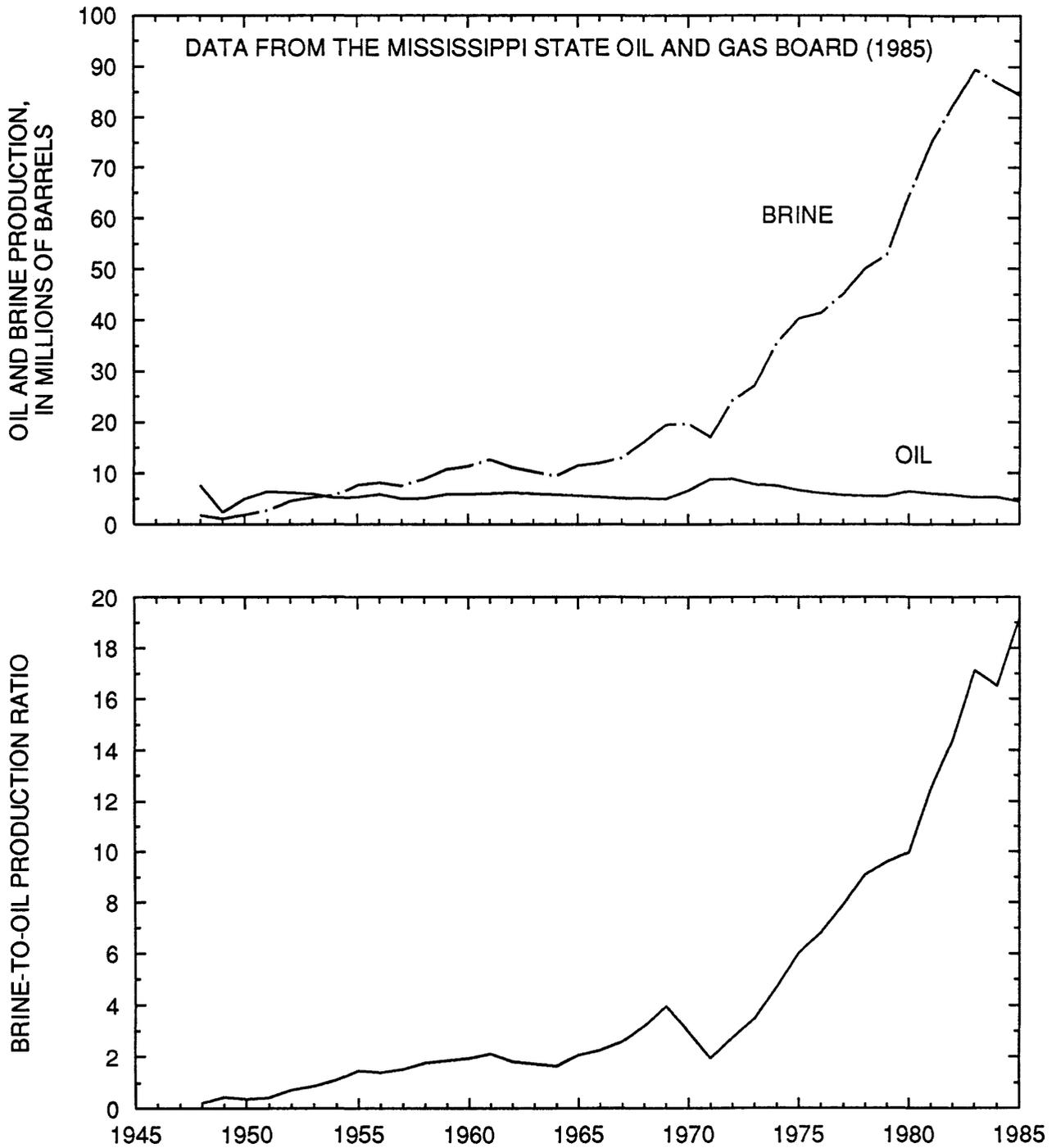


Figure 2.--Oil and brine production and the brine-to-oil production ratio in the Baxterville oil field.

maximum of 89.5 million barrels in 1983 (fig. 2). More than 1 billion barrels of brine with chloride concentrations greater than 100,000 mg/L was produced from 1948 to 1985. A combination of decreasing oil production and increasing brine production caused a large increase in the brine-to-oil ratio in the 1970's and 1980's (Mississippi State Oil and Gas Board, 1984, 1985).

Purpose and Scope

This report defines the extent of oil-field-brine contamination in ground water and streams in the Baxterville oil field area. This report is based largely on data collected during the period October 1984 through November 1985. Water samples were collected from streams and wells in the study area. Data from a previous study conducted in the vicinity of the nearby Tatum Salt Dome were used for background water-quality information. Natural surface-water quality was determined by sampling streamflow from a nearby basin having no oil field activities and from samples collected in an adjacent basin during a previous study.

Acknowledgments

Appreciation is extended to Mr. Fred Hille with the Mississippi Department of Environmental Quality, Office of Pollution Control, who arranged for the drilling and collection and analysis of water samples from five test wells in the study area, and to personnel with the Mississippi Department of Environmental Quality, Office of Geology, who ran electrical resistivity and gamma ray logs in the test wells.

Location and Topography

The 260-mi² study area is located in southwestern Lamar and southeastern Marion Counties, Mississippi. The Baxterville oil field (approximately 12.5 mi²) lies entirely within the study area. The study area is in the Pine Hills physiographic district, which is characterized as having a high and rolling land surface with moderately high ridges forming divides between streams (Cross and Wales, 1974, p. 7). Land in the study area is heavily forested, but a few flat areas have been cleared for agricultural purposes. In the oil field, much of the land is used for roads, well sites, storage tanks, pipelines, and other facilities related to oil production.

Geology

The geologic units that crop out or are present in the shallow subsurface in the study area are unconsolidated sedimentary deposits of Tertiary and

Quaternary age. The deposits of Tertiary age include the undifferentiated Hattiesburg and Pascagoula Formations of the Miocene Series. The deposits of Quaternary age consist of the Citronelle Formation of the Pliocene Series.

Sediments of the undifferentiated Hattiesburg and Pascagoula Formations make up the upper part of the Miocene aquifer system described by Newcome (1975) and are the oldest and deepest units investigated in this study. Deposited in a nonmarine, near-shore environment (Bicker, 1969, p. 29), these units consist mainly of silty clays with minor amounts of sand. However, some prominent sand units exist in these sediments (Brown, 1944, p. 32). Stephenson and others (1928) assigned the exposed Miocene strata in the study area to the Pascagoula Formation; but in this report, the undifferentiated Hattiesburg and Pascagoula Formations are considered as one unit and are referred to as the Miocene Series. The undifferentiated strata consist of several distinct sand layers separated by clay and silt. Taylor (1971), in a report on the nearby Tatum Salt Dome, considered several of the sand layers to be separate aquifers. The two deepest sand layers (sand layer 1 and the local sand) may be equivalent to aquifer 1 and the local aquifer, respectively, in the Tatum Salt Dome area described by Taylor (1971).

Sand layer 1 and the local sand are the two principal sand units in the study area. Thicknesses of these sand units are shown in geologic sections in figures 3 and 4. In section A-A' (fig. 3), sand layer 1 ranges in thickness from about 130 ft in the northeastern part of the section near Baxterville to about 80 ft in thickness near Middle Fork Creek, several miles to the southwest. The local sand layer ranges in thickness from less than 40 ft in the northeastern part to about 120 ft in the southwestern part of the section. Additional unnamed sand layers are present in the Miocene strata above the local sand layer in some areas. These sand layers appear to be discontinuous in the study area, and range from approximately 10 to more than 100 ft in thickness (fig. 4).

Overlying the Miocene strata in the eastern part of the study area is the Citronelle Formation, which is composed of discontinuous sand and gravel units separated by sandy clay lenses. The Citronelle Formation is more than 200 ft thick near the northeastern part of section A-A' (fig. 3) and thins to the southwest. The Citronelle Formation is absent from many stream valleys and areas of lower elevation (fig. 4).

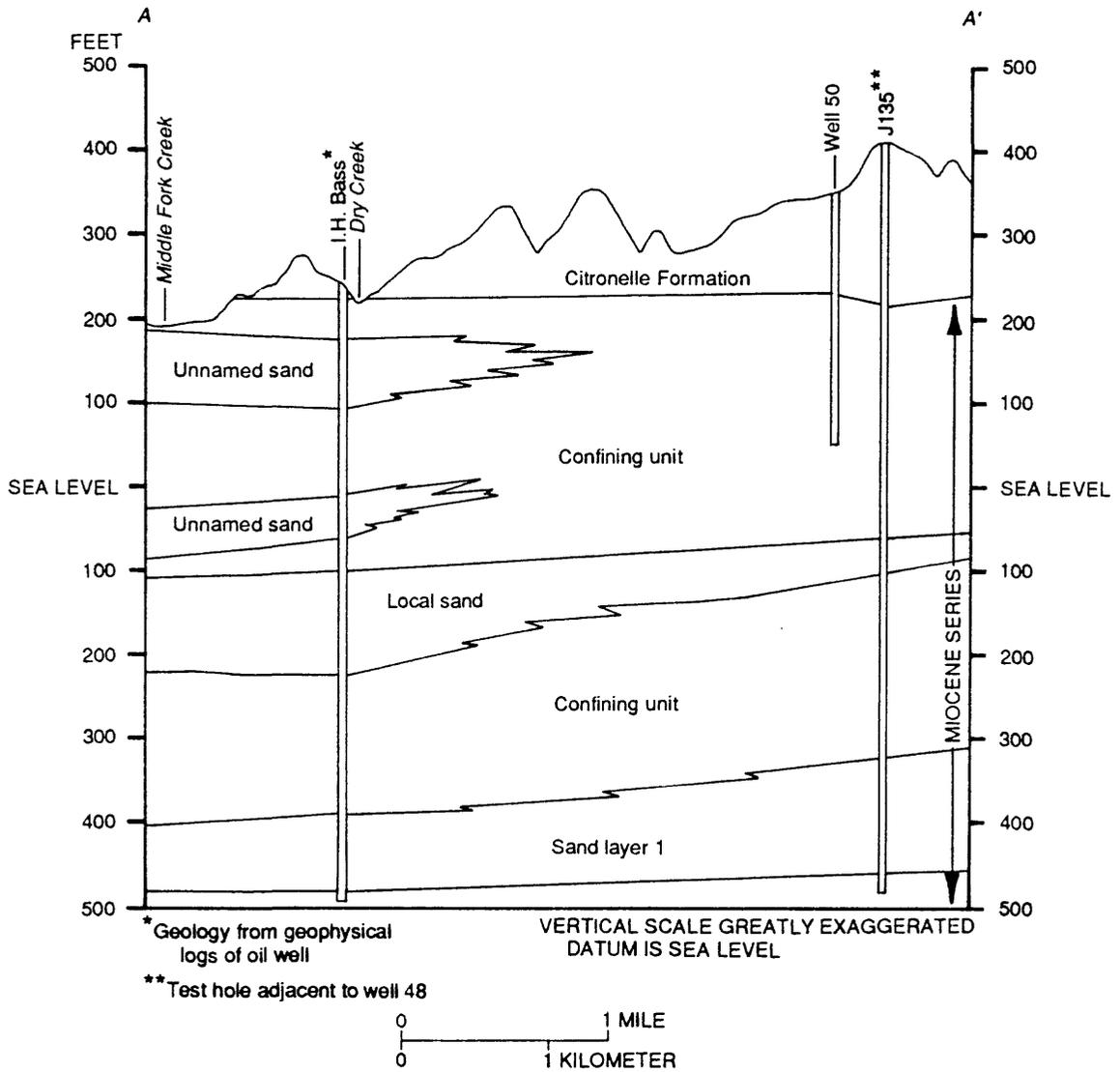


Figure 3.--Generalized geologic section A-A' in the Baxterville oil field.

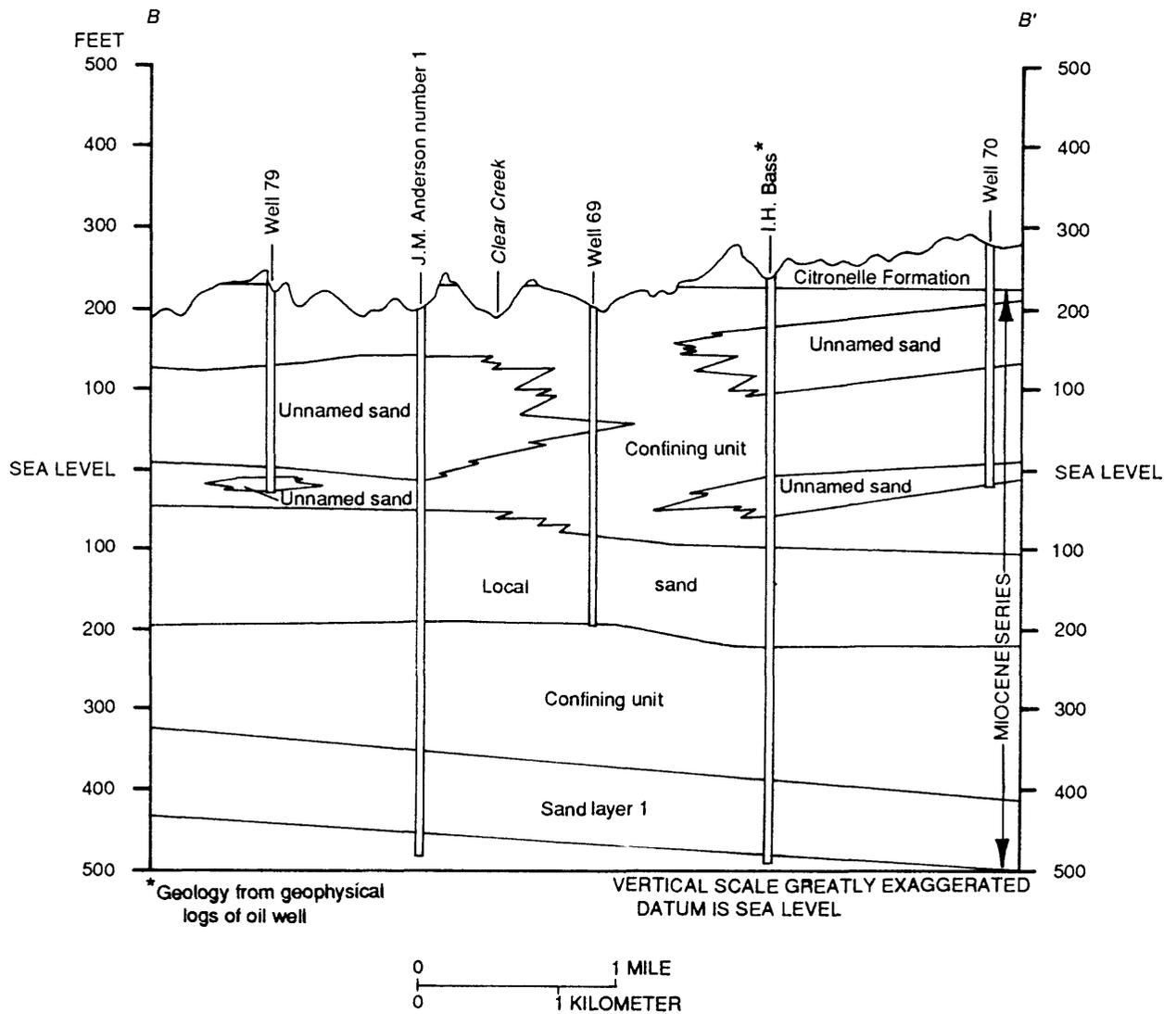


Figure 4.--Generalized geologic section B-B' in the Baxterville oil field.

Hydrology

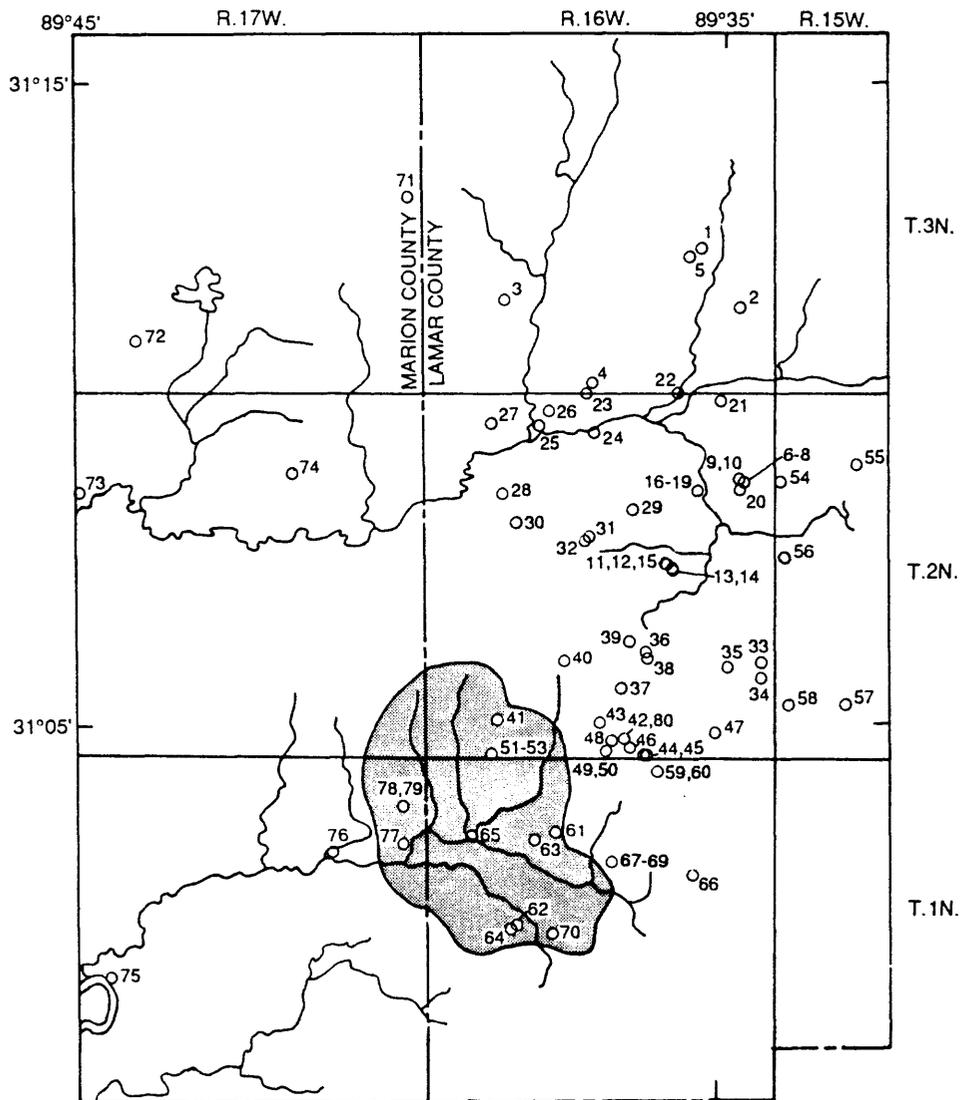
The geologic units of the Citronelle Formation and the Miocene Series that contain sufficient saturated permeable material to yield significant quantities of water serve as aquifers in the study area. These units are identified in this report as the Citronelle aquifer (Boswell, 1979) and the Miocene aquifer system (Newcome, 1975). The locations of wells for which hydraulic or water-quality data are used in this study are listed in table 1 and are shown in figure 5.

Citronelle Aquifer

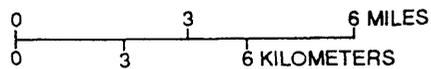
Water in the Citronelle aquifer originates from precipitation that percolates through the soil and unsaturated zones to the water table. From there, water moves downgradient and discharges into Clear Creek and its tributaries or downward into underlying hydraulically connected Miocene sands. The direction and rate of water movement are dependent on lithologic and hydrologic characteristics of the aquifer. Data on the hydraulic characteristics of the Citronelle aquifer are scarce, but the results of an aquifer test on a shallow well at Baxterville indicate that the aquifer has a transmissivity of about 13,000 [(ft³/d)/ft²]ft. [The term [(ft³/d)/ft²]ft is hereafter reduced to ft²/d, or feet squared per day.] The specific capacity of the aquifer at that site is 6.2 (gal/min)/ft and the hydraulic conductivity is 120 ft/d (Newcome, 1971, p. 30). Caution should be exercised in using these values, however, because the sands penetrated in this test may have included some sands not in the Citronelle Formation (Taylor and others, 1968, p. 66).

Water levels in the Citronelle aquifer change in response to precipitation and withdrawals. Water-level fluctuations in well 80 during the period 1961-65 are shown in figure 6. The water level in this well declined from March 1962 to March 1964 during a period of below normal rainfall, but began to recover in March 1964 in a delayed response to increased rainfall (Taylor, 1971, p. 15). Water-level data were not collected during the 1984-85 study; however, on the basis of data previously collected in the area, water levels would be expected to rise during the wet spring months and to decline during the drier summer and fall months.

Few domestic wells are screened in the Citronelle aquifer in the study area, but two public-supply wells at Baxterville tap the Citronelle aquifer. Withdrawal of approximately 183,000 gal/d (J.A. Callahan, U.S. Geological Survey, oral commun., 1987) causes a cone of depression in the Citronelle water table at Baxterville. Ground-water movement in the Citronelle aquifer near Baxterville probably is toward this depression. In other parts of the study



Oil field location from Mississippi State Oil and Gas Board (1984)



- EXPLANATION
- BAXTERVILLE OIL FIELD
 - 70 SAMPLING SITE AND NUMBER

Figure 5.--Location of wells for which hydraulic or water-quality data are used in this study.

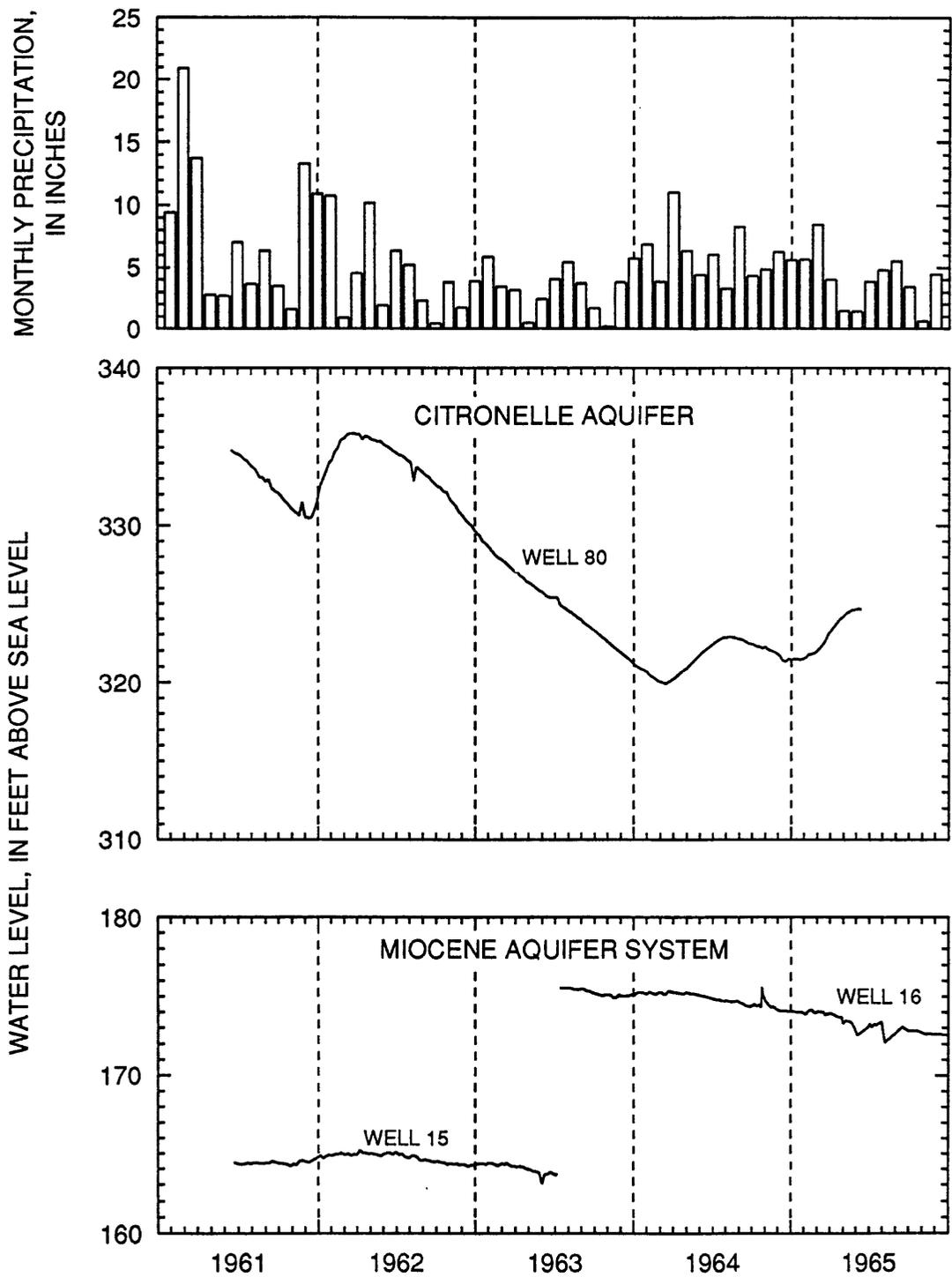


Figure 6.--Monthly precipitation at Columbia, Mississippi, and water levels in the Citronelle aquifer and Miocene aquifer system in the study area.

area, ground-water movement is from topographic highs toward the streams and pumping wells. Generally, ground water moves from the ridges along the northern, eastern, and southern parts of the oil field toward Clear Creek.

Miocene Aquifer System

Water in the shallowest parts of the Miocene aquifer system in the study area originates as infiltration from the overlying Citronelle aquifer, as infiltration from terrace and alluvial deposits in the valleys, and as direct infiltration from rainfall where Miocene strata are exposed. Ground-water flow generally is down the dip to the south and southwest. Some water may be discharged into streams that incise the aquifer system.

The hydraulic conductivity and transmissivity of the Miocene aquifer system in the study area probably are similar to the average values of 95 ft/d and 13,000 ft²/d, respectively, reported by Newcome (1975) for the Miocene aquifer system in southern Mississippi.

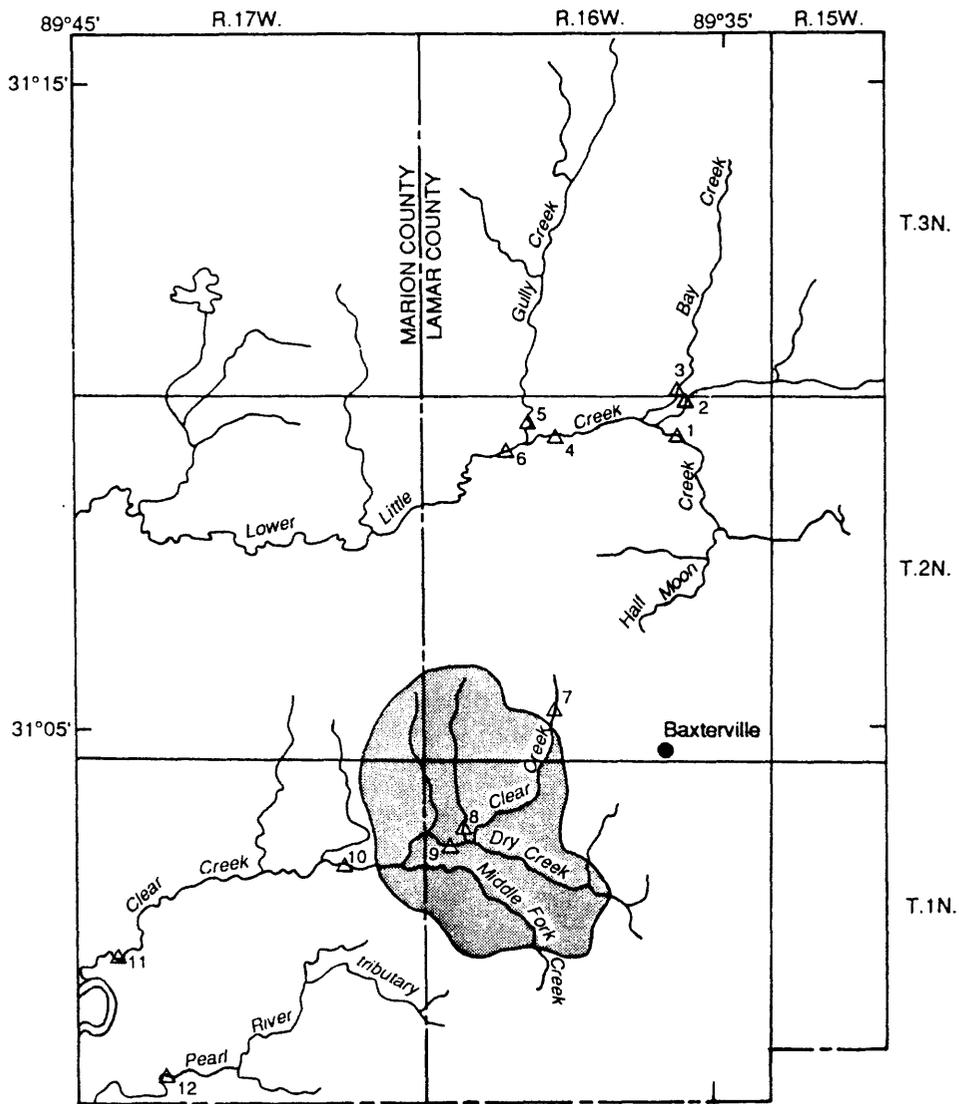
Water levels in wells in the Miocene aquifer system rise and fall in response to general long-term trends in precipitation and changes in ground-water withdrawals, but seasonal and short-term variations in water levels generally are smaller in these aquifers than in the Citronelle aquifer (fig. 6).

Clear Creek and Tributaries

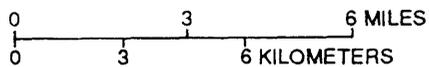
Baxterville oil field, in the southern one-half of the study area, is entirely within the Clear Creek drainage basin (fig. 1). Clear Creek originates north of the oil field and flows westward into the Pearl River. Dry and Middle Fork Creeks, the major tributaries to Clear Creek, drain the southern part of the oil field and two unnamed tributaries drain the northern part. Most of the northern half of the study area is drained by Lower Little Creek and its tributaries. Locations of surface-water sites for which water-quality data are used in this report are listed in table 2 and are shown in figure 7.

During the study, daily mean discharges for Clear Creek downstream of the study area (site 11) ranged from about 11 ft³/s on Sept. 20-22, 1985, to 835 ft³/s on Oct. 30, 1985 (fig. 8). The largest daily mean discharge occurred as a result of rainfall associated with Hurricane Juan.

During the wettest months of the study period (November 1984 through March 1985) the discharge of Clear Creek characteristically peaked soon after a rain and then decreased rapidly (fig. 8). If a substantial quantity of rain did not fall within 4 or 5 days, the daily mean discharge of Clear Creek normally



Oil field location from Mississippi State Oil and Gas Board (1984)



EXPLANATION

-  BAXTERVILLE OIL FIELD
-  SAMPLING SITE AND NUMBER

Figure 7.--Location of surface-water sampling sites.

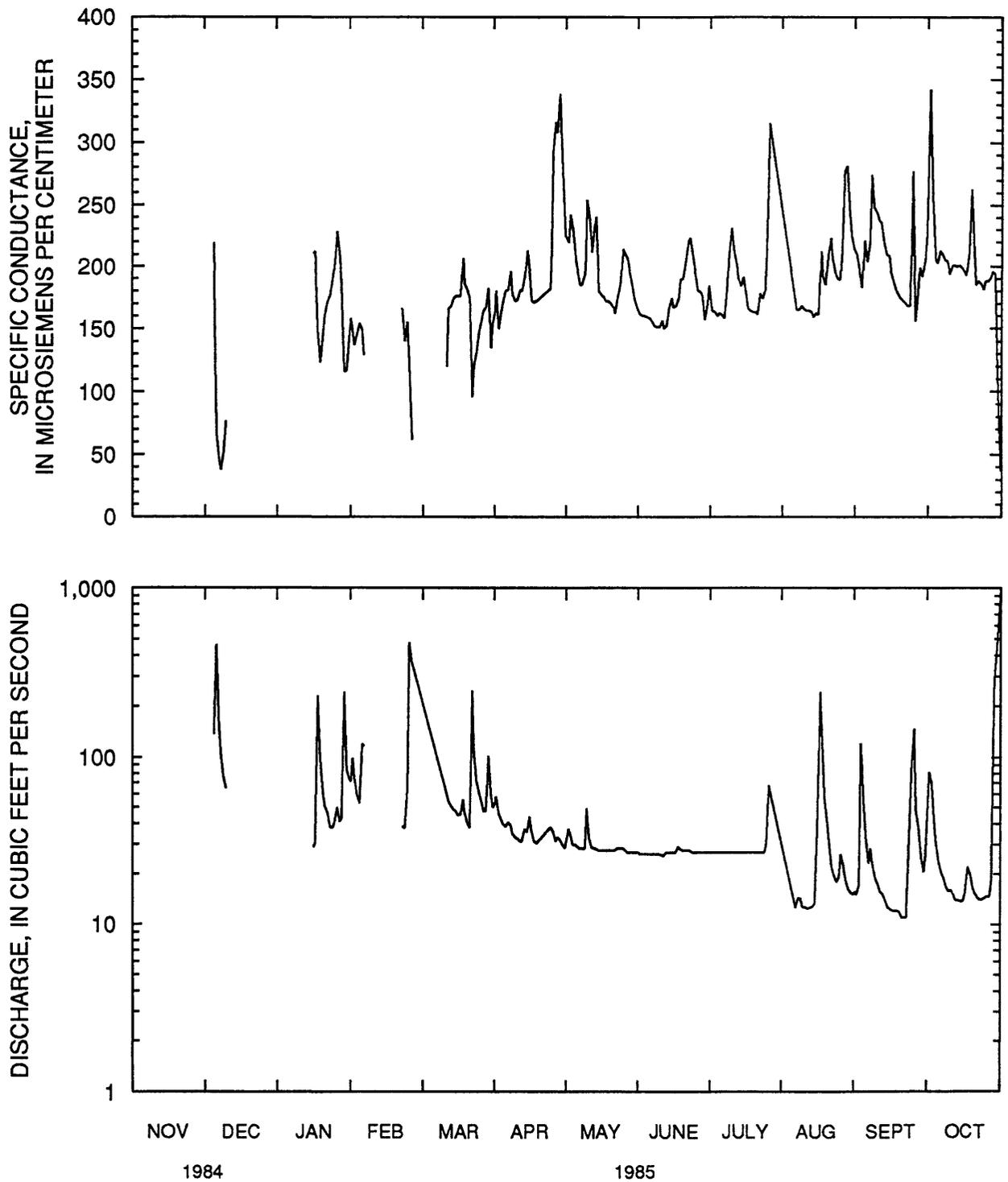


Figure 8.--Daily mean specific conductance and discharge at site 11 on Clear Creek.

decreased to less than 40 ft³/s. During low-flow periods when streamflow originated primarily from ground-water discharge, streamflow at site 11 generally was less than 40 ft³/s.

Dry and Middle Fork Creeks (fig. 1) were dry during extended periods of no precipitation, whereas the unnamed tributaries flowed even during the driest period of August through mid October 1985. The difference in the base flows in these streams may reflect differences in the geologic makeup of the drainage basins.

Methods

Water samples were collected and analyzed to identify the presence of oil-field brine in ground water and streams in the Baxterville oil field area. The results were compared to water-quality data (collected during the study and from previous investigations) from nearby wells and streams outside the oil field area.

Ground-water samples were collected from 2 wells tapping the Citronelle aquifer, 12 wells tapping the Miocene aquifer system, and 5 test wells drilled during this study. Results of analyses of those samples were compared to water-quality data from 23 wells tapping the Citronelle aquifer and 26 wells tapping the Miocene aquifer system outside the oil field and unaffected by oil-field brines.

Surface-water samples were collected and analyzed from five sites in the Clear Creek Basin and from seven sites in nearby basins (fig. 7 and table 2). Six of the sites outside the oil-field area are in the Lower Little Creek Basin north of the oil field, and one site was on a Pearl River tributary south of the oil field. Surface-water-quality data generally were collected during periods of low flow, but at two sites (site 11 on Clear Creek and site 12 on a tributary to the Pearl River), samples were collected during both high- and low-flow periods. Water samples were analyzed to determine concentrations of major ions and of bromide, barium, and strontium, which are commonly present in relatively large concentrations in oil-field brines. At site 11 on Clear Creek, water temperature, specific conductance, and stage were monitored continuously throughout the study.

GROUND-WATER CONTAMINATION

Injection of brines into formations containing water with dissolved-solids concentrations greater than 10,000 mg/L is environmentally more acceptable than surface disposal, but this practice also can affect shallow ground-water

quality. Improperly constructed and maintained or deteriorated injection wells may leak brine directly into shallow aquifers or allow brine to move upward through the annular space outside the well casing. Also, increased pressure in the injection zone may cause formation water to migrate up nearby abandoned production wells. If the casing of an abandoned well has deteriorated, the water may leak into freshwater aquifers.

Analyses of brines in earlier studies from two oil-producing formations (the Eutaw and the lower Tuscaloosa Formations of Cretaceous age) in the Baxterville oil field are summarized in table 3. Sodium and chloride are the predominant constituents in water from both of these formations. Sodium concentrations exceed 50,000 mg/L and chloride concentrations are 100,000 mg/L or greater in brines from both of the oil-producing formations in the Baxterville oil field. The mean dissolved-solids concentration of brine from the shallower Eutaw Formation is about 170,000 mg/L. The sodium to chloride ratio in this brine is about 0.54. The Eutaw Formation brine contains relatively large concentrations of bromide (mean of 500 mg/L) and barium plus strontium (mean of 63 mg/L) that normally occur in very small concentrations in shallow ground water and streams. The brine from the deeper lower Tuscaloosa Formation is more mineralized than brine from the Eutaw Formation and has larger concentrations of calcium, magnesium, sulfate, and chloride. The sodium to chloride ratio in brine from the lower Tuscaloosa Formation is about 0.45.

Water-quality data for wells that tap the Citronelle aquifer and the Miocene aquifer system in southwestern Lamar and southeastern Marion Counties are given in table 4. Comparisons of these data are discussed for each aquifer in the following sections.

Citronelle Aquifer

Uncontaminated water in the Citronelle aquifer in the study area is typically a calcium sodium bicarbonate water. Dissolved-solids concentrations (median concentration, 30 mg/L) are small, and pH values (median 5.7) are low (table 5). Concentrations of major constituents generally are less than 10 mg/L, but some sodium, chloride, and bicarbonate concentrations exceed that value. Consequently, a chloride concentration of 10 mg/L or less, is considered background level for water from the Citronelle aquifer for purposes of this study. Median concentrations of bromide (less than 0.01 mg/L), barium (48 µg/L), and strontium (12 µg/L) are small. The median sodium to chloride ratio for the uncontaminated water is about 0.79.

Although the specific conductance of ground water in the Citronelle aquifer is relatively small, it varies seasonally in response to variations in rainfall. In water from well 46, the specific conductance ranged from 18 to 36 $\mu\text{S}/\text{cm}$ during a 3-year period (1963-66). Conductance values generally were largest during periods of little rainfall and smallest during or shortly after periods of large quantities of rainfall.

Few shallow wells were available for collecting water-quality samples in the Baxterville oil field because many domestic wells were abandoned or destroyed because of the presence of substantial quantities of brine in the ground water. In order to collect water-quality samples from the shallow Citronelle aquifer, a well (well 51, table 1) was drilled in the northern part of the oil field. The chloride concentration in water from this well was relatively small (28 mg/L), but was substantially larger than background concentrations. Chloride concentrations were less than 10 mg/L in water from other shallow Citronelle wells near and upgradient (northeast) of the oil field.

Miocene Aquifer System

Uncontaminated water in the Miocene aquifer system in the study area is typically a sodium bicarbonate water. The median dissolved-solids concentration is 160 mg/L, the median pH is 6.8 (table 6). Concentrations of the major constituents, except for sodium and bicarbonate, generally are less than 20 mg/L. Sodium to chloride ratios typically range (for the interquartile range or middle 50 percent of the data) from 1.5 to 5.9.

The quality of uncontaminated water in the Miocene aquifer system has minor seasonal variations in response to variations in recharge, but the seasonal variations generally are much smaller than those in water in the Citronelle aquifer. The specific conductance of water from Miocene aquifer system well 41, just northeast of the oil field, ranged from 225 to 235 $\mu\text{S}/\text{cm}$ during the period 1963-66.

In the Baxterville oil field, areal variations in the quality of water in the Miocene aquifer system were large. A chloride concentration of 10 mg/L or less is considered background level for water from the Miocene aquifer system for purposes of this study. The maximum chloride concentration was 1,120 mg/L (table 4). Dissolved-solids concentrations ranged from less than 50 to 2,600 mg/L and strontium concentrations ranged from less than 20 to 2,000 $\mu\text{g}/\text{L}$.

Data collected from wells 78 and 79 (completed in the same test hole) indicate that a 20-ft layer of freshwater overlies approximately 70 ft of highly contaminated water in the shallow Miocene aquifer system at the site. The chloride concentration was 12 mg/L in water from well 78 screened at a depth from 126 to 147 ft in the upper part of the aquifer system, whereas the chloride concentration was 1,120 mg/L in well 79 screened at a depth from 210 to 231 ft near the base of the sand layer. Barium and strontium concentrations were less than 5 and 120 $\mu\text{g/L}$, respectively, in water from the shallower well but were 4,100 and 2,000 $\mu\text{g/L}$, respectively, in water from the deeper well.

Ground-water contamination was also detected at wells 67, 68, and 69 completed in another test hole. The chloride concentration was 163 mg/L in water from well 67 (depth 252 ft) screened in the shallowest sand layer; however, chloride concentrations were less than 5 mg/L in water from well 68 (depth 357 ft) screened in the middle of the underlying aquifer and well 69 (depth 410 ft) screened near the base of the local sand (fig. 4). Concentrations of barium and strontium each were less than 100 $\mu\text{g/L}$ for the deeper wells (well 68 and well 69) but were 170 and 150 $\mu\text{g/L}$, respectively, for shallow well 67.

Chloride concentrations for well 52 and well 53, completed in another test hole, were relatively small but did increase somewhat with depth. For well 52, which was screened at a depth of about 220 ft, the chloride concentration was 5.1 mg/L. For well 53, screened at a depth of about 300 ft, the chloride concentration was 18 mg/L, substantially larger than the background chloride concentration.

Chloride concentrations in water from some Miocene aquifer system wells in the Baxterville oil field not only were larger than the concentrations considered typical of uncontaminated ground water but also were increasing with time. Water-quality data for water from the Miocene aquifer system wells in the study area are scarce, but available data indicate that between 1982 and 1985, the specific conductance of water from well 65 increased from 100 to 160 $\mu\text{S/cm}$, and chloride concentrations increased from 24 to 44 mg/L. Although the chloride concentrations in most of the wells sampled during this study were less than the recommended limit of 250 mg/L for drinking water (U.S. Environmental Protection Agency, 1986), chloride concentrations and trends indicate that oil-field brines are present and are moving within the shallow Miocene aquifer system in the Baxterville oil field area.

SURFACE-WATER CONTAMINATION

The extent of brine contamination in streams in the Baxterville oil field area was determined during this study by comparing the quality of water in Clear Creek, which drains the oil field, with that of streams outside the oil field. Water-quality data collected in the 1960's in the Lower Little Creek Basin north of the oil field indicate that streams unaffected by brines have a specific conductance of less than 50 $\mu\text{S}/\text{cm}$ and a chloride concentration of less than 5 mg/L (sites 1 to 6, fig. 7 and table 7). During this study (1984-85), water-quality data were collected at two sites unaffected by oil-field brines -- on Clear Creek upstream of the oil field (site 7) and on a Pearl River tributary southwest of the oil field (site 12, fig. 7 and table 7). The quality of water at these sites (site 7 and site 12) was similar to that in Lower Little Creek in the 1960's (the specific conductance was less than 50 $\mu\text{S}/\text{cm}$ and chloride concentration was less than 5 mg/L).

Brine has moved laterally through the shallowest aquifers and discharged into Clear Creek and its tributaries. Although the presence of brine in surface water was greatest during periods of low flow when streamflow originated primarily from ground-water inflow, brine was also detected during high-flow periods when streamflow consisted largely of precipitation runoff.

Water quality at site 12 on the Pearl River tributary (southwest of the oil field and unaffected by oil-field brines) varied with discharge (table 8). For the two samples, concentrations of dissolved solids and most major constituents were smaller during a high-flow period (March 1985) than during a low-flow period (October 1984). During high flow, the dissolved-solids concentration at site 12 was 29 mg/L (compared to 40 mg/L during low flow), and concentrations of most constituents were less than 5 mg/L. Concentrations of sulfate and chloride were slightly larger in samples collected during high flow than during low flow but were less than 5 mg/L.

The quality of water from site 11 on Clear Creek downstream of the oil field differs in many aspects from the quality of water from site 12 on the Pearl River tributary (table 8). Specific conductance and concentrations of dissolved solids and most constituents at site 11 were much smaller during high flow (March 1985) than during low flow (October 1984). During a low-flow period in October 1984, the dissolved-solids concentration at site 11 was 110 mg/L, almost three times the dissolved-solids concentration at site 12. The low-flow chloride concentration was 48 mg/L at site 11 but was only 3.8 mg/L at site 12. The low-flow sodium to chloride ratio for water at site 11 was much smaller than for water at site 12 (0.44 and 0.74, respectively, table 8) and was similar to the ratio for oil-field brine in the area (0.45 to 0.54, table 3).

During both high- and low-flow periods, concentrations of sodium, bromide, barium, and strontium, which are often associated with brines, were also substantially larger in Clear Creek than in the Pearl River tributary. Magnesium, potassium, bicarbonate, and sulfate concentrations were similar at both sites.

Although the concentrations of sodium, chloride, and other constituents at site 8 and site 9 on tributaries to Clear Creek (in the Baxterville oil field) and site 10 on Clear Creek (just downstream from the oil field) generally do not exceed the recommended limits for drinking water, they are substantially larger than concentrations in streams unaffected by oil-field brine and indicate the presence of brine in Clear Creek. Concentrations of sodium and chloride at these sites, similar to those at site 11 on Clear Creek, generally are largest during low-flow periods when streamflow consists largely of groundwater discharge. This relation indicates that shallow ground water in the drainage basin is affected by brine.

The specific conductance of water in Clear Creek was monitored at hourly intervals at site 11 throughout the study. Specific-conductance values at this site most frequently (about 75 percent of the samples) were from 160 to 240 $\mu\text{S}/\text{cm}$ (fig. 9) and typically varied inversely with discharge (fig. 8). In several instances, however, the specific conductance increased abruptly, indicating likely contamination of Clear Creek by oil-field brines from surface runoff or by the release of brines directly into the stream. During Oct. 18-19, 1985, the specific conductance increased from 230 to about 300 $\mu\text{S}/\text{cm}$ and then decreased to about 175 $\mu\text{S}/\text{cm}$ after a relatively small increase in discharge. On Oct. 28, 1985, the specific conductance increased from about 200 to about 300 $\mu\text{S}/\text{cm}$ for a few hours before decreasing quickly as the stream discharge increased from about 30 to about 600 ft^3/s (fig. 10). On Sept. 30, 1985, the specific conductance increased abruptly from 200 to more than 1,000 $\mu\text{S}/\text{cm}$ and remained higher than 1,000 $\mu\text{S}/\text{cm}$ for most of the day (fig. 10). It is likely that the maximum specific conductance value on this day was substantially greater than 1,000 $\mu\text{S}/\text{cm}$, but this value was the maximum that equipment at the site could measure. The conductance decreased to less than 500 $\mu\text{S}/\text{cm}$ by October 1 and to less than 250 $\mu\text{S}/\text{cm}$ by October 3.

Sodium and chloride concentrations in Clear Creek were not determined during the period of apparent brine contamination on Sept. 30, 1985. However, the water-quality data collected at site 11 indicate the concentrations of these constituents were linearly related to specific conductance at

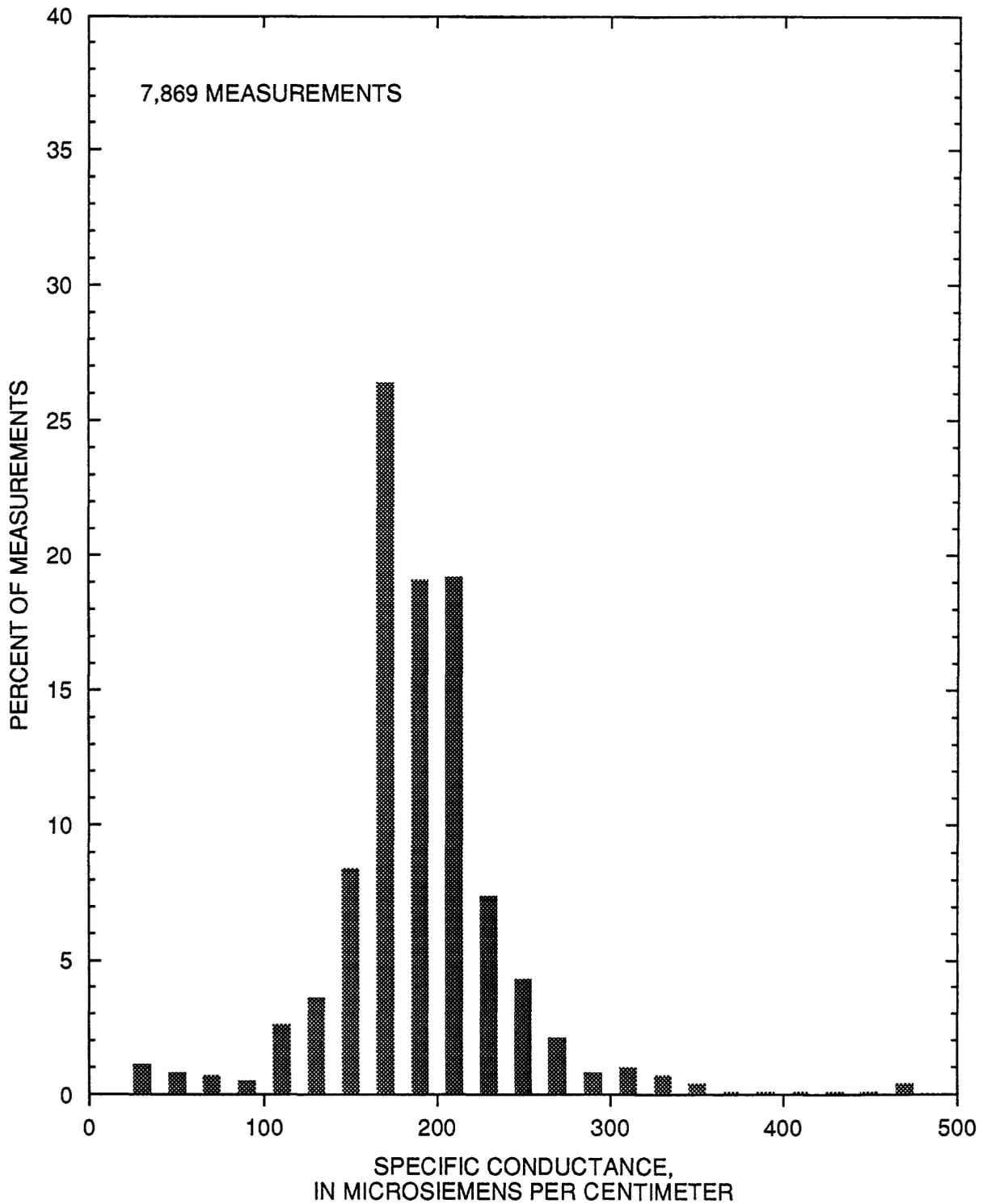


Figure 9.--Frequency distribution of specific conductance at site 11 on Clear Creek.

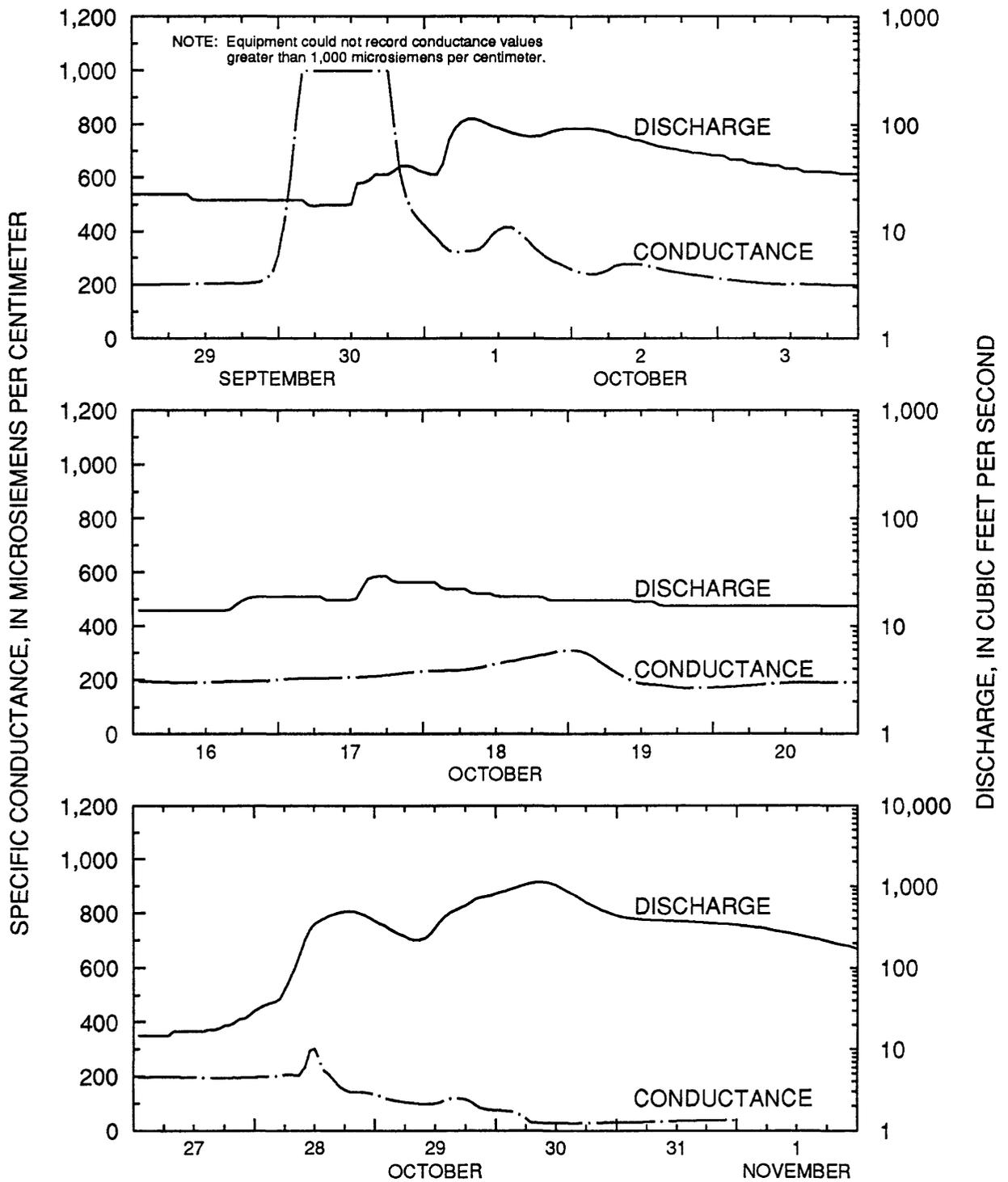


Figure 10.--Specific conductance and stream discharge during selected periods in 1985 at site 11.

conductance values as large as 375 $\mu\text{S}/\text{cm}$ (fig. 11). If these relations are valid at larger specific conductance values, the sodium concentrations exceeded 110 mg/L and the chloride concentrations exceeded 270 mg/L on Sept. 30, 1985. During the period of contamination, the chloride concentration probably exceeded the recommended limit for public water supplies.

When streamflow is low, as on Oct. 4, 1984, a major source of contamination in Clear Creek is from ground-water inflow. Water entering the oil field at site 7 had sodium and chloride concentrations of 1.6 and 3.4 mg/L, respectively (table 7). Sodium and chloride concentrations had increased to 36 and 83 mg/L, respectively, in water flowing from the oil field at site 10. The following equation can be used to calculate the mean chloride concentration of water entering Clear Creek between sampling sites.

$$(C_f) (D_f) = (C_{S_1}) (D_{S_1}) + \dots (C_{S_n}) (D_{S_n}) ,$$

where

- C is the concentration, in milligrams per liter;
- D is the discharge, in cubic feet per second;
- f is the final water mix;
- S_1 is site 1; and
- S_n is site n, any "contributing" site with known discharge but unknown chloride concentration.

Discharge between sites 7 and 9 increased 6.16 ft^3/s . Approximately 0.54 ft^3/s of the increased streamflow originated from an unnamed tributary upstream of site 8. The remaining 5.62 ft^3/s originated from Dry Creek and direct ground-water inflow. The mean chloride concentration is calculated using the equation above. Substituting the known concentration and discharge values for site 7 and site 8, using the concentration and discharge from site 9 as the final water mix, and knowing that an additional 5.62 ft^3/s enters Clear Creek upstream of site 9, the only unknown left in the equation is the concentration of the additional water (C_a) which is calculated from:

$$(64) (7.63) = (3.4) (1.47) + (350) (0.54) + (C_a) (5.59) .$$

The mean chloride concentration of the additional 5.62 ft^3/s ground-water inflow is 52 mg/L. This calculated chloride concentration is substantially greater than the 3.4 mg/L at site 7 and 3.8 mg/L at site 12 and is evidence of additional sources of contamination other than from the unnamed tributaries sampled.

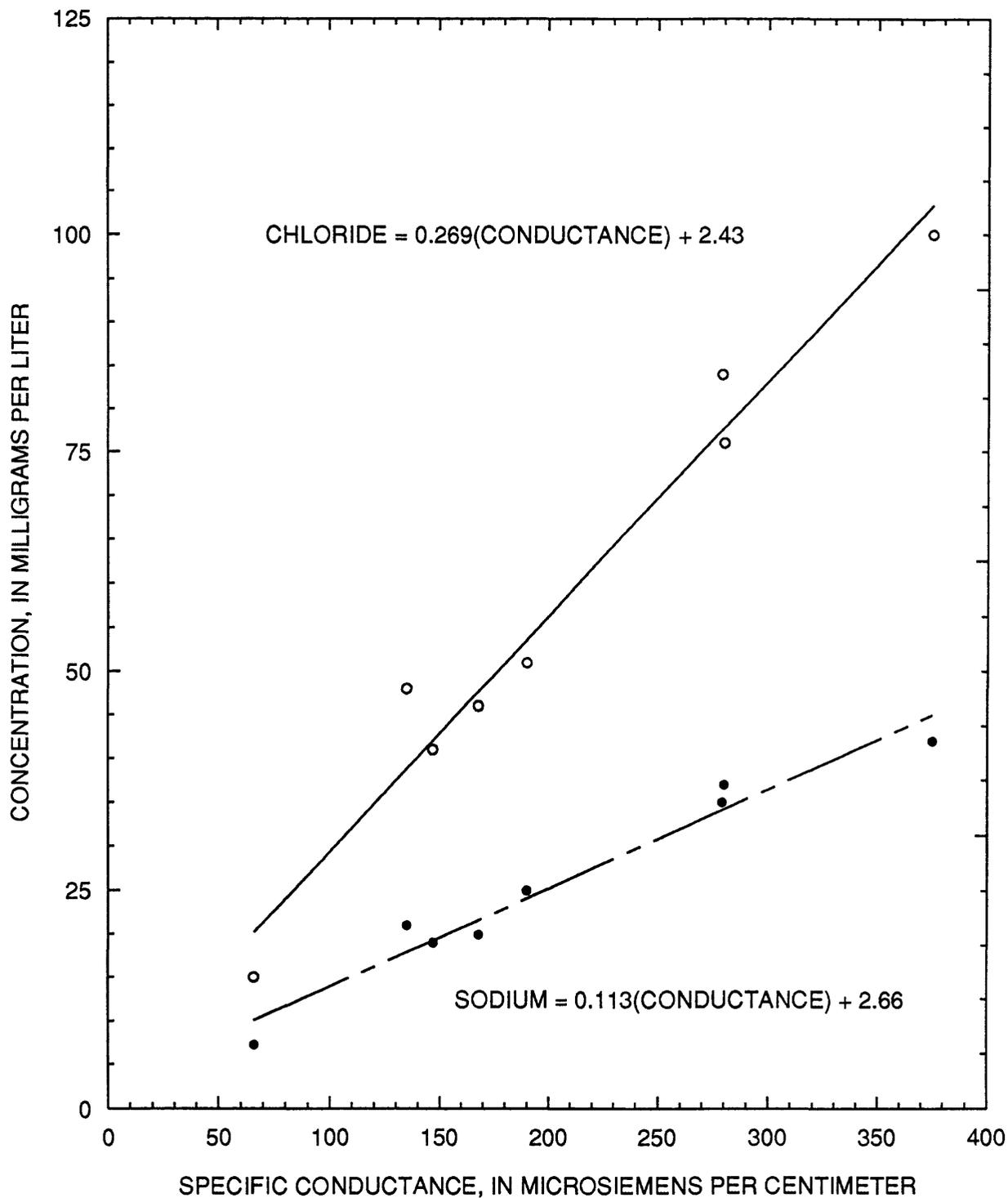


Figure 11.--Relation between specific conductance and sodium and chloride concentrations at site 11 on Clear Creek, October 1984 to October 1985.

Also on Oct. 4, 1984, between sites 9 and 10, the discharge increased from 7.63 to 9.44 ft³/s and chloride concentration increased from 64 to 83 mg/L. The combined inflow from Middle Fork Creek, the smaller tributaries, and direct ground-water inflow, represented by this increase in discharge, had an estimated chloride concentration of 163 mg/L.

The chloride concentration in surface water in the Baxterville oil field often exceeded 50 mg/L and was substantially larger than the concentration in nearby streams that do not drain the oil field. Streams in the oil-field area may also be subject to occasional contamination from surface runoff and other sources of brines that cause chloride concentrations to exceed the recommended limit of 250 mg/L for drinking water.

SUMMARY

A hydrologic investigation to define the extent of brine contamination in ground water and streams in the 260-mi² Baxterville oil field area was conducted from October 1984 through November 1985. The Baxterville oil field includes approximately 12.5 mi² in southwestern Lamar and southeastern Marion Counties, Mississippi. More than 1 billion barrels of brine with chloride concentrations greater than 100,000 mg/L have been produced in the Baxterville oil field since production began in 1944. Prior to the regulation of brine disposal (1978), brine was discharged to streams or pumped into evaporation ponds or pits where it could migrate into shallow freshwater aquifers.

Brine disposal in the Baxterville oil field has contaminated some ground water in the Citronelle aquifer. Few shallow wells were available for collecting water-quality samples in the oil field area because many domestic wells were abandoned and destroyed because of the presence of substantial quantities of brine in the ground water. The chloride concentration in water from a well drilled during this study and completed in the shallow Citronelle aquifer in the northern part of the oil field was relatively small (28 mg/L), but was substantially larger than background concentrations (less than 10 mg/L). Chloride concentrations were less than 10 mg/L in water from other shallow Citronelle wells near and upgradient (northeast) of the oil field.

In the Baxterville oil field, areal variations in the quality of water in the Miocene aquifer system were large--chloride concentrations ranged from less than 5 mg/L to 1,120 mg/L. A chloride concentration of 10 mg/L or less is considered background level for water from the Miocene aquifer system. At one site a 20-ft layer of relatively fresh water (chloride concentration 12 mg/L) overlies approximately 70 ft of brine (chloride concentration 1,120 mg/L) in

the shallow Miocene aquifer system. At another site, moderately contaminated water (chloride concentration 163 mg/L) in the shallowest sand layer overlies freshwater (chloride concentrations less than 5 mg/L) in the middle of the underlying aquifer and near the base of the local sand. At a third site, chloride concentrations were relatively small but increased somewhat with depth (5.1 mg/L at about 220 ft to 18 mg/L at about 300 ft).

Although the chloride concentrations in most of the wells sampled during this study are less than the recommended limit of 250 mg/L for drinking water, chloride concentrations and trends indicate that oil-field brines are present and are moving within the shallow Miocene aquifer system in the Baxterville oil field area.

Brine has moved laterally through the shallowest aquifers and discharged into Clear Creek and its tributaries. Although the presence of brine in surface water was greatest during periods of low flow when streamflow originated primarily from ground-water inflow, brine was also detected during high-flow periods when streamflow consisted largely of precipitation runoff.

During both high- and low-flow periods, concentrations of sodium, chloride, bromide, barium, and strontium, which are commonly associated with brines, were substantially larger in Clear Creek downstream of the oil field than in the Pearl River tributary (southwest of the oil field and unaffected by oil-field brines). However, concentrations of these constituents in Clear Creek and its tributaries generally do not exceed the recommended limits for drinking water. In a low-flow period during this study, the chloride concentration in water from Clear Creek ranged from less than 5 mg/L (background level for streams in the study area) upstream of the oil field to 83 mg/L downstream of the oil field.

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Table 1.--Records of selected wells for which hydraulic or water-quality data are used in this study

[CRNL, Citronelle Formation; MOCN, Miocene Series]

Map number (fig.5)	Local well number	Station identification number	Location			Altitude (feet above sea level)	Well depth (feet below land surface)	Water-bearing unit
			Sec.	T.	R.			
Lamar County								
1	F014	311220089340701	NWSW24	03N	16W	315	112	CRNL
2	F015	311125089334301	SESW25	03N	16W	325	80	CRNL
3	F019	311139089374101	SESW29	03N	16W	360	279	MOCN
4	F032	311024089361401	SESE33	03N	16W	200	230	MOCN
5	FS01	311214089341965	SESE23	03N	16W	280	--	CRNL
6	J001	310856089333401	NWSE12	02N	16W	306	782	MOCN
7	J002	310856089333402	NWSE12	02N	16W	306	1,130	MOCN
8	J003	310856089333403	NWSE12	02N	16W	306	1,310	MOCN
9	J006	310858089333801	NESW12	02N	16W	283	1,096	MOCN
10	J007	310859089334001	SENW12	02N	16W	272	887	MOCN
11	J008	310749089345801	SWSW14	02N	16W	295	820	MOCN
12	J010	310749089345803	SWSW14	02N	16W	295	1,400	MOCN
13	J013	310746089345401	SWSW14	02N	16W	292	986	MOCN
14	J014	310745089345201	SESW14	02N	16W	290	986	MOCN
15	J015	310749089345601	SWSW14	02N	16W	294	366	MOCN
16	J017	310849089342202	NENE14	02N	16W	266	474	MOCN
17	J018	310849089342203	SENE14	02N	16W	264	667	MOCN
18	J019	310849089342204	NENE14	02N	16W	266	762	MOCN
19	J020	310849089342205	SENE14	02N	16W	265	860	MOCN
20	J041	310850089333901	NWSE12	02N	16W	330	62	CRNL
21	J048	311002089340201	SENW01	02N	16W	285	29	CRNL
22	J050	311014089343601	SWSE35	03N	16W	250	367	MOCN
23	J053	311015089362101	SWSE33	03N	16W	250	212	MOCN
24	J056	310942089362401	NESE04	02N	16W	210	21	CRNL
25	J059	310948089370701	NWSW04	02N	16W	230	196	MOCN
26	J060	311001089365801	SWNW04	02N	16W	235	19	CRNL
27	J066	310946089380301	NESW05	02N	16W	220	225	MOCN
28	J074	310845089375301	SESW08	02N	16W	250	280	MOCN
29	J079	310833089352601	NENE10	02N	16W	325	43	CRNL
30	J082	310821089374001	SESW16	02N	16W	390	60	CRNL
31	J083	310813089361401	SENE16	02N	16W	365	70	CRNL
32	J084	310809089361901	SENE16	02N	16W	360	66	CRNL
33	J104	310625089331601	NESE25	02N	16W	340	61	CRNL
34	J105	310611089331701	SENE25	02N	16W	365	71	CRNL
35	J106	310620089335801	SWNE25	02N	16W	340	60	CRNL
36	J109	310633089352001	NENE27	02N	16W	325	38	CRNL
37	J110	310602089354401	SESW27	02N	16W	390	95	CRNL
38	J111	310628089351901	SENE27	02N	16W	335	36	CRNL
39	J113	310643089353501	NWNE27	02N	16W	335	65	CRNL
40	J114	310626089364101	SWSE28	02N	16W	400	110	CRNL

Table 1.--Records of selected wells for which hydraulic or water-quality data are used in this study--Continued

Map number (fig.5)	Local well number	Station identification number	Location			Altitude (feet above sea level)	Well depth (feet below land surface)	Water-bearing unit
			Sec.	T.	R.			
41	J117	310542089375301	NENW32	02N	16W	373	454	MOCN
42	J120	310519089354201	NWSE34	02N	16W	400	132	CRNL
43	J122	310533089360601	SWNW34	02N	16W	390	138	CRNL
44	J123	310504089352101	SESE34	02N	16W	400	175	CRNL
45	J124	310505089352301	SWSE24	02N	16W	412	125	CRNL
46	J125	310510089353601	SWSE34	02N	16W	395	100	CRNL
47	J133	310525089335901	SWNE25	02N	16W	340	61	CRNL
48	J136	310517089355501	SWNE34	02N	16W	416	200	CRNL
49	J287	310508089360001	SWSW34	02N	16W	354	147	CRNL
50	J288	310508089360002	SWSW34	02N	16W	354	231	MOCN
51	J289	310512089380001	SWSW32	02N	16W	330	74	CRNL
52	J290	310512089380002	SWSW32	02N	16W	330	231	MOCN
53	J291	310512089380003	SWSW32	02N	16W	330	315	MOCN
54	K004	310857089330001	SWNW07	02N	15W	360	90	CRNL
55	K007	310917089314301	NENW08	02N	15W	360	130	CRNL
56	K013	310758089325601	NWSW18	02N	15W	330	62	CRNL
57	K032	310546089320201	SWNE32	02N	15W	365	85	CRNL
58	K042	310547089325901	NWNW31	02N	15W	380	70	CRNL
59	M006	310450089351001	SWNW02	01N	16W	410	170	CRNL
60	M007	310450089351002	SENW02	01N	16W	412	173	CRNL
61	M012	310352089365401	NWSE09	01N	16W	300	510	MOCN
62	M021	310227089374201	SESW17	01N	16W	270	185	CRNL
63	M022	310346089371501	SENE08	01N	16W	275	425	MOCN
64	M085	310224089374701	SESW17	01N	16W	270	--	MOCN
65	M086	310402089382201	NESE07	01N	16W	240	235	MOCN
66	M098	310320089343601	SWSE11	01N	16W	367	100	CRNL
67	M101	310331089382801	NWSE07	01N	16W	210	252	MOCN
68	M102	310331089382802	NWSE07	01N	16W	210	357	MOCN
69	M103	310331089382803	NWSE07	01N	16W	210	410	MOCN
70	M104	310256089364601	SENW16	01N	16W	283	143	MOCN
Marion County								
71	M004	311310089392901	NESE13	03N	17W	390	327	MOCN
72	M055	311105089440001	NWNE32	03N	17W	220	250	MOCN
73	P023	310852089450001	NESW07	02N	17W	150	1,028	MOCN
74	P060	310906089412401	SENE10	02N	17W	247	281	MOCN
75	R002	310141089443501	SWSE19	01N	17W	100	850	MOCN
76	R028	310342089405401	NESW11	01N	17W	165	130	MOCN
77	R029	310339089393801	NWSE12	01N	17W	200	148	MOCN
78	R034	310412089393801	SWSE01	01N	17W	230	147	MOCN
79	R035	310412089393802	SWSE01	01N	17W	230	231	MOCN
[Water-level data only] Lamar County								
80	J138	310518089354101	SWSE34	02N	16W	400	94	CRNL

Table 2.--Location and drainage area of selected surface-water sampling sites in the study area

Site number (fig. 7)	Station identification number	Station name	Drainage area (square miles)
Lamar County			
1	02489225	Halfmoon Creek near Baxterville	23.30
2	02489230	Hurricane Creek near Baxterville	16.40
3	02489235	Bay Creek near Baxterville	11.20
4	02489237	Lower Little Creek near Baxterville	56.60
5	02489239	Gully Creek near Baxterville	23.20
6	02489240	Lower Little Creek near Baxterville	81.50
7	024892685	Clear Creek near Baxterville	2.99
8	02489269	Unnamed Creek near Baxterville	2.50
Marion County			
9	024892693	Clear Creek southwest of Baxterville	12.61
10	024892695	Clear Creek near Pinebur	27.02
11	02489270	Clear Creek near Sandy Hook	40.80
12	02489273	Pearl River tributary near Sandy Hook	13.66

Table 3.--Summary of analyses of brine samples from the Baxterville oil field

[From Hawkins and others, 1963; Collins and others, 1966. Mean concentrations in milligrams per liter except as noted]

Formation	Eutaw	Lower Tuscaloosa
Depth (range, in feet)	7,614-8,010	8,734-8,901
Number of analyses	2	4
Dissolved solids, sum	170,000	200,000
Calcium	7,800	18,000
Magnesium	1,200	2,000
Sodium	56,000	56,000
Bicarbonate	85	42
Sulfate	53	210
Chloride	100,000	120,000
Bromide	500	880
Barium and strontium	63	10
Sodium to chloride ratio	0.54	0.45

Table 4.--Selected ground-water quality data for the study area

[Dissolved constituents in milligrams per liter, except as indicated; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 °C; °C, degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; --, data not collected; <, less than.
Mean values if a well has multiple samples]

Map number (fig. 5)	Specific conductance ($\mu\text{S}/\text{cm}$)	pH	Dissolved solids, residue at 180 °C	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulfate	Chloride	Bromide	Barium ($\mu\text{g}/\text{L}$)	Strontium ($\mu\text{g}/\text{L}$)
Lamar County													
1	120	6.4	--	12	1.7	7.8	3.0	62	1.0	4.7	--	--	--
2	35	5.2	27	.8	.3	2.1	.6	4	.7	2.7	0.01	23	8
3	180	6.5	140	17	2.6	14	2.6	91	.2	8.8	--	--	--
4	240	7.3	200	20	4.1	27	2.7	140	<.2	8.7	--	--	--
5	19	5.1	12	.4	.6	1.7	.4	5	.8	2.9	<.01	31	8
6	260	8.2	210	5.2	.3	58	1.8	150	7.4	4.5	--	--	--
7	170	7.3	150	5.7	.7	33	2.3	93	8.5	4.3	--	--	--
8	680	7.4	420	14	1.7	130	3.9	230	99	21	--	--	--
9	210	6.8	140	9.4	5.3	29	4.4	86	31	6.4	--	--	--
10	77	6.3	--	3.1	1.0	12	2.4	27	11	4.3	--	--	--
11	160	6.7	160	7.5	.1	25	3.1	85	<.2	4.6	--	--	--
12	2,400	8.0	1,400	4.7	.8	540	10	590	1.2	500	--	--	--
13	75	6.2	90	4.4	.5	10	2.4	26	11	4.2	--	--	--
14	77	6.3	90	6.1	.2	6.0	2.9	26	5.4	4.2	--	--	--
15	220	7.0	170	7.2	.5	43	1.8	130	1.2	5.2	--	--	--
16	420	6.3	330	29	8.2	23	4.7	15	7.4	90	--	--	--
17	150	5.8	120	3.7	2.3	16	3.3	12	7.2	24	--	--	--
18	740	6.8	510	50	6.1	100	2.9	130	160	60	--	--	--
19	3,900	6.2	2,400	140	54	580	4.2	44	360	990	--	--	--
20	130	6.8	76	12	3.4	8.5	1.8	56	6.8	8.0	--	--	--
21	34	5.7	30	1.3	.7	2.8	.6	6	.6	3.5	--	--	--
22	210	7.2	160	13	2.3	32	2.6	130	3.2	3.2	--	--	--
23	250	7.7	190	23	2.3	26	2.7	140	1.6	8.1	--	--	--
24	34	6.1	--	1.1	.3	3.0	1.2	7	<.2	3.8	--	--	--
25	280	7.2	220	28	7.8	19	2.4	160	.2	8.8	--	--	--
26	90	5.8	100	1.1	1.3	17	2.0	16	<.2	23	--	--	--
27	220	6.6	--	20	3.2	20	2.3	120	.6	7.5	--	--	--
28	260	7.1	190	22	6.1	25	2.2	150	<.2	9.2	--	--	--
29	19	6.0	22	.9	.2	2.1	.7	7	.6	3.3	--	--	--
30	500	4.9	--	35	52	24	2.1	1	.4	24	--	--	--
31	38	5.9	--	.8	.7	4.4	.8	14	<.2	2.5	--	--	--
32	100	6.7	80	16	.5	3.2	.6	46	<.2	4.1	--	--	--
33	85	6.6	78	11	.6	3.4	1.4	39	.4	3.9	--	--	--
34	21	6.0	26	4.7	1.5	2.5	.6	20	.4	4.2	--	--	--
35	27	5.4	26	1.4	.4	2.5	.7	7	<.2	3.6	--	--	--
36	28	--	--	--	--	--	--	--	--	--	--	--	--
37	18	--	--	--	--	--	--	--	--	2.6	--	--	--
38	58	--	--	--	--	--	--	--	--	4.0	--	--	--
39	15	--	--	--	--	--	--	--	--	--	--	--	--
40	57	6.2	--	1.5	1.0	5.3	.8	20	1.4	2.0	--	--	--

**Table 4.--Selected ground-water quality data for the study area--
Continued**

Map number (fig. 5)	Spec- ific con- duct- ance (μ S/cm)	pH	Dissolved solids, residue at 180 °C	Cal- cium	Mag- nesi- um	Sodium	Potas- sium	Bi- carbon- ate	Sul- fate	Chlor- ide	Bromide	Barium (μ g/L)	Stron- tium (μ g/L)
41	230	7.0	180	17	3.8	28	2.5	130	<.2	7.2	--	--	--
42	25	6.4	--	.8	.9	1.2	.4	8	.2	2.2	--	--	--
43	36	--	--	--	--	--	--	--	--	--	--	--	--
44	41	--	--	--	--	--	--	--	--	3.0	--	--	--
45	18	--	--	--	--	--	--	--	--	4.0	--	--	--
46	24	--	--	--	--	--	--	--	--	--	--	--	--
47	22	5.4	26	1.4	.4	2.5	.7	7	<.2	4.1	--	--	--
48	87	6.2	82	5.0	1.5	8.8	2.6	37	3.2	4.6	.03	27	12
49	32	--	48	2.4	--	--	--	<1	--	9.9	--	60	30
50	46	--	--	4.0	--	--	--	5	--	9.4	--	<5	10
51	118	--	78	28	--	--	--	11	--	28	--	50	60
52	33	--	--	2.0	--	--	--	10	--	5.1	--	30	80
53	74	--	67	2.0	--	--	--	5	--	18	--	30	40
54	32	5.6	28	.9	.7	3.0	.7	6	.4	3.6	0.01	48	12
55	56	5.2	40	4.8	1.2	4.1	.5	4	.2	6.2	.02	68	19
56	21	6.4	19	1.0	.1	1.2	.7	5	.4	2.0	--	--	--
57	25	5.5	--	1.4	.1	1.8	.4	6	<.2	2.2	--	--	--
58	40	5.9	37	1.5	.8	4.6	.3	17	<.2	2.5	--	--	--
59	31	--	--	--	--	--	--	--	--	2.4	--	--	--
60	34	6.7	26	3.3	1.4	1.5	.4	18	.8	2.0	--	--	--
61	250	7.3	190	9.1	.8	47	1.6	140	6.8	6.5	--	--	--
62	26	6.0	35	1.6	.5	1.8	.5	6	.2	3.0	--	--	--
63	52	6.0	40	1.5	1.3	4.8	1.1	20	.6	2.9	--	--	--
64	1,400	4.2	--	49	21	170	--	--	--	430	3.0	--	610
65	120	5.4	130	4.8	3.6	11	1.9	5	.8	34	.32	210	56
66	--	5.5	32	1.3	.7	2.4	1.2	10	1.6	3.0	<.01	58	20
67	650	--	410	--	--	--	--	<5	--	163	--	170	150
68	50	--	33	--	--	--	--	22	--	3.8	--	70	50
69	46	--	49	--	--	--	--	34	--	2.8	--	70	50
70	--	--	120	4.0	--	--	--	4	--	41	--	210	70
Marion County													
71	130	6.4	110	11	2.6	9.4	1.8	60	<.2	8.0	--	--	--
72	180	6.5	150	17	3.3	14	3.0	81	8.5	9.2	--	--	--
73	240	7.7	150	1.0	.1	55	1.1	140	6.6	1.7	--	--	--
74	170	6.5	140	17	3.0	15	2.4	89	2.3	10	<.2	--	240
75	110	6.5	120	2.0	.5	18	1.7	44	7.6	2.9	--	--	--
76	57	--	--	--	--	--	--	--	--	11	--	--	--
77	54	5.4	39	1.8	.9	2.9	1.6	13	.3	2.8	.01	55	15
78	44	--	83	7.3	--	--	--	11	--	12	--	<5	120
79	3,400	--	2,600	140	--	--	--	7	--	1,120	--	4,100	2,000

Table 5.--Statistical summary of water-quality data for uncontaminated ground water in the Citronelle aquifer in the study area

[Dissolved constituents in milligrams per liter, except as indicated; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 °C; °C, degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; ROE, residue at 180 °C]

Parameter	Number of samples	Median	Interquartile range	Minimum	Maximum
Depth (feet)	20	64	60 - 71	19	112
Specific conductance ($\mu\text{S}/\text{cm}$)	23	34	22 - 85	17	500
pH	23	5.7	5.4 - 6.1	4.9	6.8
Dissolved solids, ROE	19	30	26 - 76	12	133
Calcium	23	1.4	.9 - 4.8	.4	35
Magnesium	23	.6	.3 - 1.2	.1	52
Sodium	23	3.0	2.2 - 4.4	1.2	24
Potassium	23	.7	.6 - 1.3	.3	3.0
Bicarbonate	23	7.0	5.0 - 17	1.0	62
Sulfate	23	.4	<.2 - .6	<.2	6.8
Chloride	23	3.6	2.7 - 4.2	2.0	24
Bromide	5	<.01	<.01 - <.01	<.01	.01
Silica	20	6.7	5.1 - 8.0	4.4	38
Barium ($\mu\text{g}/\text{L}$)	5	48	27 - 63	23	68
Iron ($\mu\text{g}/\text{L}$)	5	17	13 - 18	3	69
Strontium ($\mu\text{g}/\text{L}$)	5	12	8.0 - 20	8.0	20
Sodium to chloride ratio	23	0.79	0.64 - 1.02	0.35	1.8

Table 6.--Statistical summary of water-quality data for uncontaminated ground water in the Miocene aquifer in the study area

[Dissolved constituents in milligrams per liter, except as indicated; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 °C; °C, degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; ROE, residue at 180 °C]

Parameter	Number of samples	Median	Interquartile range	Minimum	Maximum
Depth (feet)	26	710	280 - 990	196	1,400
Specific conductance ($\mu\text{S}/\text{cm}$)	26	220	159 - 260	75	3,900
pH	26	6.8	6.3 - 7.3	5.8	8.2
Dissolved solids, ROE	26	160	130 - 210	85	2,400
Calcium	26	11	5.1 - 20	1.0	140
Magnesium	26	2.3	.5 - 4.4	.1	54
Sodium	26	25	15 - 46	6.0	580
Potassium	26	2.6	2.3 - 3.2	1.1	10
Bicarbonate	26	92	40 - 140	12	590
Sulfate	26	6.9	1.0 - 10	<.2	360
Chloride	26	7.8	4.3 - 13	1.7	990
Silica	26	34	16 - 43	9.2	63
Sodium to chloride ratio	26	2.5	1.5 - 5.9	0.26	32

Table 7.--Water-quality data for selected streams in the study area

[Dissolved constituents in milligrams per liter, except as indicated; ft³/s, cubic feet per second; μ S/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius; μ g/L, micrograms per liter; --, data not collected; <, less than]

Map number (fig. 5)	Date	Dis-charge (ft ³ /s)	Spec-ific con-duct-ance (μ S/cm)	pH	Dissolved solids, residue at 180 °C	Cal-cium	Mag-nesi-um	Sodium	Potas-sium	Bi-carbon-ate	Sul-fate	Chlor-ide	Bromide	Barium (μ g/L)	Stron-tium (μ g/L)
Lower Little Creek and tributaries															
1	10/31/61	--	23	6.4	18	1.0	0.9	2.0	0.7	8	<0.2	3.0	--	--	--
1	11/08/62	18.7	--	6.4	23	--	--	--	--	--	--	3.1	--	--	--
1	11/20/62	--	18	6.7	16	--	.7	2.3	.8	7	<.2	2.1	--	--	--
1	01/15/63	23.8	<50	5.8	--	1.0	--	--	--	3	--	3.2	--	--	--
1	02/10/63	22.1	<50	5.2	--	1.4	--	--	--	2	--	2.8	--	--	--
1	03/12/63	29.0	<50	4.9	--	.6	.6	--	--	2	--	3.2	--	--	--
1	07/17/63	15.3	24	6.3	22	1.0	.6	2.5	.7	6	<.2	4.6	--	--	--
1	10/23/64	15.0	26	5.8	17	.5	.2	2.1	.5	3	<.2	3.0	0.63	--	--
2	11/08/62	12.4	16	--	--	--	--	--	--	--	--	2.9	--	--	--
2	11/20/62	--	17	6.8	19	.9	.4	2.3	.8	6	<.2	3.6	--	--	--
2	12/05/62	13.4	<50	5.9	--	.4	.7	--	--	4	--	2.0	--	--	--
2	01/05/63	--	<50	6.1	--	1.2	--	--	--	3	--	2.8	--	--	--
2	02/10/63	17.0	<50	4.8	--	1.4	.4	--	--	2	--	2.8	--	--	--
2	03/12/63	19.5	<50	4.8	--	1.4	.1	--	--	2	--	2.8	--	--	--
2	07/17/63	10.0	18	6.3	17	1.0	1.1	.2	.3	4	<.2	3.2	--	--	--
3	11/08/62	4.17	17	--	--	--	--	--	--	--	--	3.5	--	--	--
3	11/20/62	--	20	6.5	20	.7	.5	2.5	.5	7	<.2	3.5	--	--	--
3	12/05/62	5.54	<50	5.5	--	1.2	.5	--	--	3	--	3.8	--	--	--
3	01/15/63	8.03	<50	5.7	--	1.6	--	--	--	4	--	4.2	--	--	--
3	02/10/63	6.46	<50	5.1	--	1.0	.4	--	--	2	--	3.0	--	--	--
3	03/13/63	--	<50	5.4	--	1.4	.6	--	--	2	--	3.0	--	--	--
3	07/17/63	2.61	21	6.4	20	.9	.7	2.9	.5	6	<.2	4.7	--	--	--
4	11/20/62	--	19	6.8	17	.7	.3	2.5	.8	--	<.2	2.8	--	--	--
4	07/17/63	--	20	6.4	19	1.0	.4	2.3	.5	--	<.2	3.7	--	--	--
5	11/08/62	10.5	16	--	--	--	--	--	--	--	--	2.4	--	--	--
5	11/20/62	--	20	7.0	18	.8	.5	2.3	.9	7	<.2	3.0	--	--	--
5	12/05/62	11.6	<50	5.8	--	1.4	.1	--	--	5	--	2.4	--	--	--
5	01/15/63	15.1	<50	5.9	--	1.4	.1	--	--	3	--	3.2	--	--	--
5	02/10/63	16.0	<50	5.1	--	2.6	--	--	--	2	--	3.6	--	--	--
5	03/12/63	21.3	<50	5.0	--	.8	.5	--	--	2	--	3.4	--	--	--
5	07/17/63	7.06	18	6.6	17	.6	.6	2.8	.4	5	.8	3.8	--	--	--
6	10/31/61	72.4	18	6.5	16	1.0	.9	1.6	.6	8	<.2	3.0	--	--	--
6	11/08/62	47.0	16	--	--	--	--	--	--	--	--	2.9	--	--	--
6	11/20/62	73.3	19	6.8	17	.7	.3	2.5	.8	7	--	2.8	--	--	--
6	12/05/62	54.6	<50	7.2	--	1.0	.1	--	--	28	--	3.0	--	--	--
6	12/06/62	57.0	<50	5.5	--	1.4	.1	--	--	4	--	2.4	--	--	--
6	01/15/63	70.6	<50	5.8	--	1.4	--	--	--	2	--	3.6	--	--	--
6	02/10/63	65.8	<50	4.9	--	1.0	.4	--	--	1	--	3.8	--	--	--
6	03/12/63	85.9	<50	5.2	--	.6	.6	--	--	4	--	2.6	--	--	--
6	07/17/63	36.2	20	6.4	19	1.0	.4	2.3	.5	5	--	3.7	--	--	--
6	04/11/69	285	24	5.8	37	1.7	.9	2.0	.7	--	.4	3.5	--	--	--
6	12/17/69	55.0	23	6.0	30	1.3	.2	2.5	.8	--	.2	3.3	--	--	--
6	05/24/70	--	20	6.1	28	.6	.1	3.0	.6	--	<.2	3.5	--	--	--

Table 7.--Surface-water quality in the study area--Continued

Map number (fig. 5)	Date	Dis-charge (ft ³ /s)	Spec-ific con-duct- ance (µS/cm)	pH	Dissolved solids, residue at 180 °C	Cal- cium	Mag- nesi- um	Sodium	Potas- sium	Bi- carbon- ate	Sul- fate	Chlor- ide	Bromide	Barium (µg/L)	Stron- tium (µg/L)
Clear Creek and tributaries															
7	08/18/82	--	--	4.8	--	.7	.4	1.8	--	--	2.0	3.2	.07	--	8
7	10/04/84	1.47	19	5.6	--	--	--	1.6	--	--	--	3.4	--	--	--
8	09/01/82	0.57	1,070	5.7	--	40	5.9	150	--	--	2.0	320	2.9	--	1,500
8	10/04/84	.54	810	5.3	--	--	--	100	--	--	--	350	--	--	--
9	10/04/84	7.63	210	6.1	--	--	--	37	--	--	--	64	--	--	--
10	08/18/82	15.0	534	5.1	--	23	3.5	59	--	--	3.0	150	1.8	--	750
10	10/04/84	9.44	279	6.0	--	--	--	36	--	--	--	83	--	--	--
11	10/03/84	14.5	135	6.5	112	7.2	1.6	21	1.1	7.0	.8	48	.31	110	210
11	10/23/84	116	147	5.8	112	--	--	19	--	--	--	41	--	--	--
11	11/28/84	39.6	279	6.2	178	--	--	35	--	--	--	84	--	--	--
11	03/21/85	601	66	5.9	46	3.1	.8	7.3	.9	5.0	3.2	15	.10	65	67
11	05/13/85	21.1	190	6.2	--	--	--	25	--	--	--	51	--	--	--
11	07/25/85	49.5	375	5.5	--	--	--	42	--	--	--	100	--	--	--
11	08/06/85	13.2	168	6.5	--	--	--	20	--	--	--	46	--	--	--
11	08/27/85	17.7	280	6.2	192	--	--	37	--	--	--	76	--	--	--
Pearl River tributary															
12	10/03/84	4.78	36	6.2	40	2.4	.9	2.8	1.3	15	1.5	3.8	.01	48	20
12	03/21/85	104	32	6.1	29	1.9	.7	2.4	.8	6.0	4.3	4.2	.03	43	16
12	03/22/85	41.1	32	6.2	--	--	--	2.2	--	--	--	3.4	--	--	--
12	04/24/85	20.8	40	6.3	21	--	--	2.6	--	--	--	3.0	--	--	--
12	08/07/85	5.79	42	6.4	--	--	--	2.8	--	--	--	3.1	--	--	--

Table 8.--Water-quality data for Clear Creek and the Pearl River tributary during low-flow and high-flow periods

[Dissolved constituents in milligrams per liter, except as indicated; ft³/s, cubic feet per second; μ S/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius; μ g/L, micrograms per liter; ROE, residue at 180 °C]

Constituent	Clear Creek Site 11		Pearl River tributary Site 12	
	Low flow	High flow	Low flow	High flow
Date	10/03/84	03/21/85	10/03/84	03/21/85
Discharge(ft ³ /s)	14.5	569	4.78	104
Specific conductance (μ S/cm)	135	66	36	32
pH	6.5	5.9	6.2	6.1
Dissolved solids, ROE	110	46	40	29
Calcium	7.2	3.1	2.4	1.9
Magnesium	1.6	.8	.9	.7
Sodium	21	7.3	2.8	2.4
Potassium	1.1	.9	1.3	.8
Bicarbonate	7.0	5.0	15	6.0
Sulfate	.8	3.2	1.5	4.3
Chloride	48	12	3.8	4.2
Bromide	.31	.10	.01	.03
Barium (μ g/L)	110	65	48	43
Strontium (μ g/L)	210	67	20	16
Sodium to chloride ratio	.44	.49	.74	.57