BRINE CONTAMINATION OF SHALLOW GROUND WATER AND STREAMS IN THE BROOKHAVEN OIL FIELD, LINCOLN COUNTY, MISSISSIPPI

by Stephen J. Kalkhoff

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FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM (SI) UNITS

Factors for converting inch-pound units to metric units are shown below to four significant figures. In the text, metric equivalents are shown only to the number of significant figures consistent with the accuracy of analytical determinations or measurements.

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot per mile (ft/mi)	18.9	centimeter per kilometer (cm/km)
square foot per day (ft^2/d)	0.09290	square meter per day (m^2/d)
gallons per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]
micromho per centimeter at 25° Celsius (µmho/cm at 25°C)	1.000	microSiemens per centimeter at 25° Celsius (µS/cm at 25°C)

Throughout this report water temperatures are reported in degrees Celsius (°C). Temperatures may be converted to degrees Fahrenheit (°F) equivalent with the following formula:

$$°F = 1.8°C+32$$

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ABSTRACT

A hydrologic investigation to define areas of brine contamination in shallow freshwater aquifers commonly used for domestic water supplies and to define contamination of streams that drain the Brookhaven Oil Field was conducted from October 1983 to September 1984. The Brookhaven Oil Field covers approximately 15 square miles in northwestern Lincoln County, Mississippi. Since 1943, disposal of approximately 54.2 million barrels of brine pumped from the oil producing zone (lower part of the Tuscaloosa Formation) has contaminated the Citronelle aquifer, the Hattiesburg aquifers and streams that drain the oil field. Approximately 5 square miles of the shallow Citronelle aquifer contain water with chloride concentrations higher than normal for this area (greater than 20 milligrams per liter). Brine contamination has moved from the source laterally through the Citronelle aquifer to discharge into nearby streams and vertically into the underlying Hattiesburg aquifers. Contamination is most noticeable in

Shaws Creek when streamflow originates primarily from ground-water inflow (approximately 87 percent of the time during the study).

Additional study is required to define contaminant plumes, rates of ground-water movement and geohydrochemical reactions between the contaminant and aquifer materials. These data would allow accurate predictions of location, extent and degree of contamination in the study area.

INTRODUCTION

The Brookhaven Oil Field, located in northwestern Lincoln County west of Brookhaven, Miss., (fig. 1) was one of the first fields discovered in Mississippi. Oil production commenced with the completion of the No. 1, G. T. Smith well, on March 10, 1943. Following the discovery of oil, yearly production increased significantly, first exceeding 1 million barrels in 1946 (fig. 2). The following year production almost quadrupled with the completion of 75 new oil wells. Yearly oil production peaked in 1949 when over 5.25 million barrels were produced. Since then production has gradually decreased, dropping below 1 million barrels in 1973 and then to less than 200,000 barrels from 20 active wells in 1984 (Mississippi State Oil and Gas Board, 1984a, p. 122).

Water high in dissolved solids (brine) is produced along with the oil. Brines from the major oil producing formation (lower part of the Cretaceous Tuscaloosa Formation) are characterized as having dissolved solids that range from 157,000 to 163,000 milligrams per liter (mg/L) (table 1). Sodium and chloride are the predominant ions and are present in a sodium/chloride ratio of 0.49. The brines also contain relatively large concentrations of the minor ions bromide (mean of 610 mg/L) and strontium plus barium (mean of 1,220 mg/L) that occurs in very small concentrations in shallow freshwaters and streams.

Table 1.--Results of chemical analyses of three brine samples from the lower part of the Tuscaloosa Formation in the Brookhaven Oil Field

[From Hawkins and others, 1963, p. 13]

[Dissolved constituents given in milligrams per liter]

Reference number	152	153	154
Depth (Ft)	10443-10512	10416-10452	10340-10364
Calcium (Ca)	12,100	12,900	12,900
Magnesium (Mg)	1,100	780	1,090
Sodium (Na)	48,700	48,700	46,700
Barium,Strontium (Ba,Sr)	1,565	2,073	34
Bicarbonate (HCO3)	0	0	77
Sulfate (SO4)	133	160	0
Chloride (Cl)	99,600	100,100	95,900
Bromide (Br)*	579	660	590
Dissolved Solids	162,000	163,000	157,000
Na/Cl Ratio	0.49	0.49	0.49

* From Collins and others, 1966, p. 22

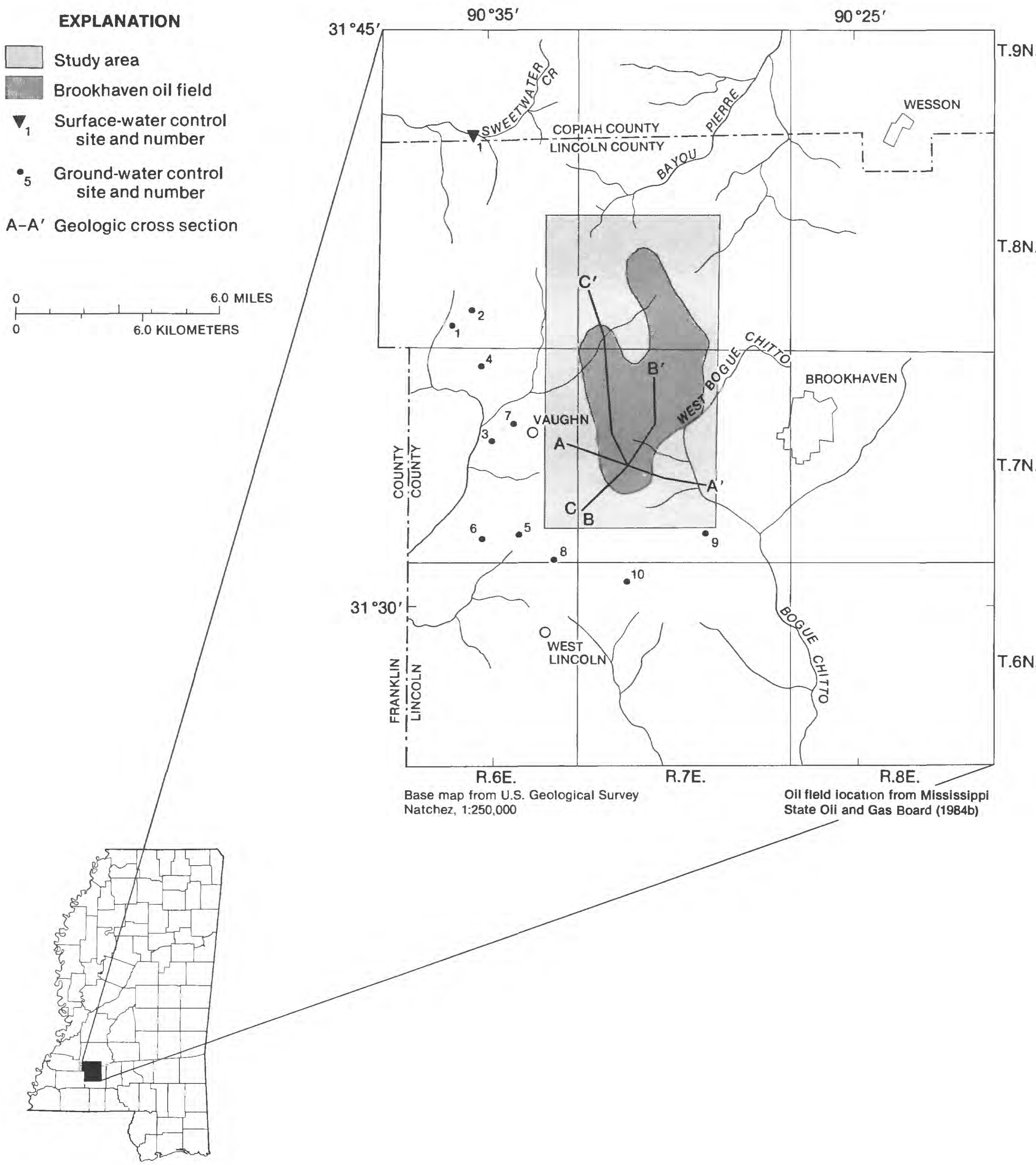

Figure 1.--Location of study area, control sampling sites, and geologic sections.

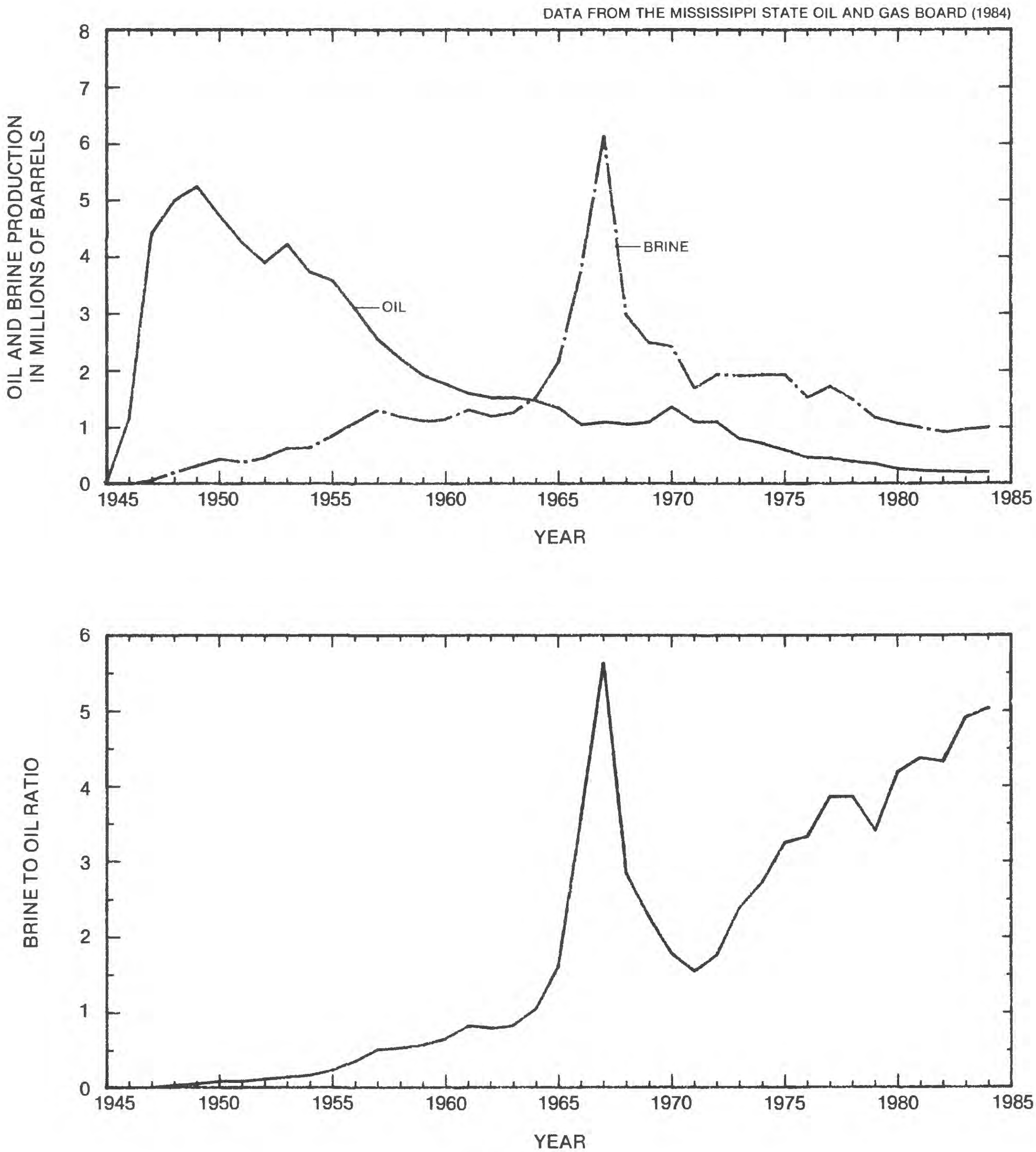

Figure 2.--Oil and brine production and brine to oil ratio in the Brookhaven oil field.

During initial development, very little brine in proportion to oil is pumped to the surface. As more petroleum is removed from the formation, increasing quantities of brine are produced. This is reflected in the yearly brine production figures which gradually increased from 1945 to 1967 (fig. 2). After brine production peaked in 1967 (over 6 million barrels were produced) yearly production significantly decreased. Approximately 54.2 million barrels (Mississippi Oil and Gas Board, written commun., 1984) have been pumped to the surface from the Brookhaven Oil Field since 1943. During the years of peak brine production, 1964-67, the ratio of brine to oil increased from about 1.0 to 5.6 and then decreased to 1.5 in 1971 (fig. 2). Since 1971 the brine to oil ratio generally has risen again as oil production decreased.

The earliest disposal method was to dump the brine on the ground or into a nearby stream. In a later method, brine was pumped into evaporation ponds or pits; however, this disposal method was prohibited in 1978 (Mississippi State Oil and Gas Board, p. 91). Presently, in the Brookhaven Oil Field brine is injected into the lower Tertiary Wilcox Formation at depths ranging from 3,984 to 6,758 feet and into the Tuscaloosa Formation at unknown depths (Bicker, 1972, p. 62). All three disposal methods in some degree pose a threat to the water quality of freshwater aquifers and streams.

The practice of uncontrolled surface dumping of brine in past years poses a direct threat to the water quality in streams. Leakage of brines from evaporation ponds directly affects shallow ground-water quality and indirectly threatens the water quality of streams if the contaminant migrates through shallow aquifers and discharges into nearby streams. Injection of brines into formations containing water with high dissolved-solids concentration may threaten shallow ground-water quality in two ways. First, improperly constructed and maintained or deteriorated injection wells may leak brine directly into shallow aquifers. Second, increased pressure in the injection zone may cause formation water to migrate up nearby improperly plugged and abandoned production wells. If the casing of the old production well has deteriorated the formation water will leak into freshwater aquifers.

Shallow freshwater aquifers serve as the primary source of domestic water supplies in the southern half of the study area. The population dependent on these aquifers for water supplies is increasing in the area. In order to protect water supplies for the growing population in the study area, there is a need to define the extent and impact of brine disposal of the shallow aquifers and streams in the vicinity of the Brookhaven Oil Field.

Purpose and Scope

The primary objectives of this report are to (1) define areas of brine contamination in shallow freshwater aquifers commonly used for domestic water supplies and (2) define the extent of brine contamination of streams that drain the oil field.

To identify brine contamination in the study area, water quality within the oil field was compared to water quality at control sites located outside the study area. Water samples were analyzed for major ions as well as minor ions (bromide and strontium) found in relatively large amounts in oil-field brines. Ground-water samples were collected from shallow domestic wells, generally less than 300 feet deep, completed in the Citronelle and Hattiesburg aquifers and stream samples were collected during periods of low and high streamflow. Specific conductance and gage height were continuously monitored at sites on two streams that drain the oil field to detect changes in water quality over the period of study. The study was conducted from October 1983 to September 1984.

Acknowledgments

Nancy Derryberry and Martha Barker, students of Millsaps College, assisted in collecting stream samples and in measuring stream-discharge. David Ruhl, who in addition to collecting water samples, inventoried and measured water levels of many wells in the study area. In addition to the Millsaps students, two people contributed help and advice to successfully complete the project. Daphne Darden of the U.S. Geological Survey assisted in the ground-water sampling, and Mr. Fred Grenn, a water-well driller in the Brookhaven area, provided well record information and descriptive drillers logs for numerous wells in the study area.

Previous Investigations

Newcome and Thomson (1970) listed six analyses from municipal water-supply wells completed in the Citronelle aquifer in Brookhaven. The general geology of Lincoln County was also described by Newcome and Thomson. A description of the geology and hydrologic characteristics of the Citronelle Formation by Boswell (1979) included Lincoln County. Water quality samples were collected from 10 wells in the Brookhaven Oil Field (Kalkhoff, 1985) in 1981 and 1982 as part of a reconnaissance water-quality study in major oil producing areas of Mississippi.

Location and Topography

The 45-mi^2 study area is located just west of Brookhaven in northwestern Lincoln County, Miss. (fig. 1). Brookhaven Oil Field (approximately 15 mi^2) lies entirely within the study area.

The study area is in the Pine Hills physiographic district which is characterized by Cross and Wales (1974, p. 7) as high and rolling with moderately high ridges forming divides between streams. This description accurately describes the topography of the eastern half of the area. In the western and northern parts of the study area, however, streams have eroded the land surface into narrow steep-sloped ridges.

The study area lies within three major drainage basins. The western and central parts lie within the Homochitto River drainage basin. Water in this area drains to the southwest through Shaws Creek and several of its unnamed tributaries. The southeastern part of the study area is in the Bogue Chitto drainage basin and drainage is to the south through West Bogue Chitto and its tributaries. One tributary, Doolittle Creek, drains the southernmost part of the study area. The northern two tiers of sections in T. 8 N., R. 7 E., and T. 8 N., R. 6 E., are in the Bayou Pierre drainage basin. Water drains to the north through Bayou Pierre and one unnamed tributary of Bayou Pierre.

Land in the study area is used primarily for agricultural purposes (crops and pastures) or is wooded (U.S. Geological Survey, 1979). Agricultural land covers approximately 40 percent of the study area and is located primarily in areas of moderate topographic relief, ridge tops, and wide valleys. Forests cover approximately 60 percent of the study area and are located in areas of steep relief, ridge flanks and narrow valleys. A small part of the land is used for oil production, well sites, storage tanks, and pipeline. Both forest and agricultural land are being converted to residential home sites in the southern half of the study area. Most homes lie within the boundaries of a Brookhaven-Zetus-Red Star triangle.

Geology

The shallow geologic units in the Brookhaven Oil Field are unconsolidated sedimentary deposits of Tertiary and Quaternary age. The oldest and deepest unit of interest in the study area, the Miocene Hattiesburg Formation, was deposited in a nonmarine near shore environment (Bicker, 1969, p. 29). Bicker notes that the exposed part of the Hattiesburg Formation consists mainly of silty clays with minor amounts of sand. Downdip, Brown (1944, p.32) described two prominent sand units in the Hattiesburg Formation in the subsurface of Forrest and Perry Counties. The Pliocene Citronelle Formation, which overlies the Hattiesburg Formation, was deposited in a high energy fluvial environment (Matson and Berry, 1916; Brown, 1967). Two Quaternary units, consisting of loess and alluvium, overlie the Citronelle deposits. Fine wind-blown alluvial material (loess) was deposited in a shallow layer over the older sediments. Since the deposition of the loess, Citronelle and loess material have been eroded and redeposited as alluvium in the stream valleys. Three cross sections (figs. 3 and 4) showing hydrogeologic units in the Brookhaven Oil Field were prepared from drillers logs supplied by water-well drillers and from electric logs made in oil test holes. Bicker (1969, p. 29) states that unweathered material from the Hattiesburg Formation contains clays that are gray, grayish brown, and blue. These weather rapidly to a greenish-gray color. On the basis of this description all sands deeper than the first reported blue or gray clay shown on drillers logs were assumed to be sands of the Hattiesburg Formation.

The Hattiesburg Formation in the study area consists of discontinuous sands separated by confining layers. The sands are fine to coarse grained and the confining layers are made up of silt and clay. Three sands are identified as separate units (layers A, B, and C) in this report because the layers appear to be three discreet mapable units in the study area. They range in thickness from less than 10 to more than 90 feet and generally dip to the south at approximately 20-30 ft/mi. A westward dipping component to the sand layers is apparent as the corresponding sands in section B-B' are approximately 10 feet higher in altitude than in section C-C'.

The Hattiesburg Formation, layer A, ranges from 0 to approximately 70 feet thick. The updip limit of layer A extends across the southern part of the study area and appears to be separated from the overlying Citronelle Formation by a thin (20 feet) layer of silt and clay. In some areas the sand layer may subcrop beneath the Citronelle Formation. Geologic section A-A' (fig. 3A) shows that layer A of the Hattiesburg Formation extends laterally east and west across the southern third of the study area, and is generally thicker to the east. Sand thickness ranges from 20 feet at the west edge of the study area to approximately 70 feet at the east edge.

Hattiesburg Formation, layer B, is thinner, approximately 20 feet thick (fig. 3B). In some areas the sand is replaced by silt and clay, resulting in a discontinuous layer. Westward, the sand thickens and merges with the deeper Hattiesburg Formation layer C (fig. 4).

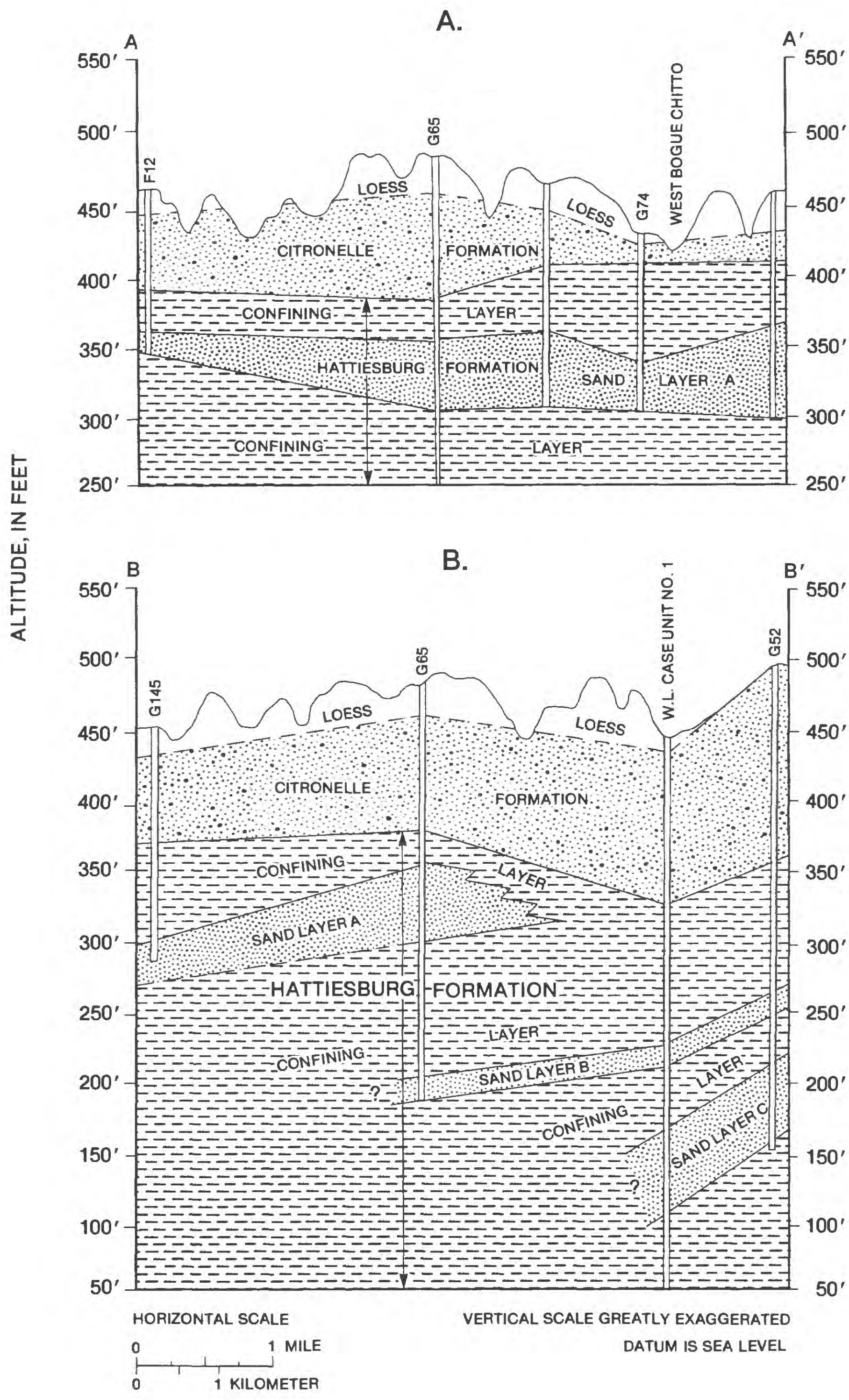

Figure 3.--Geologic sections A-A' and B-B' showing hydrogeologic units in the Brookhaven oil field (Refer to figure 1 for location).

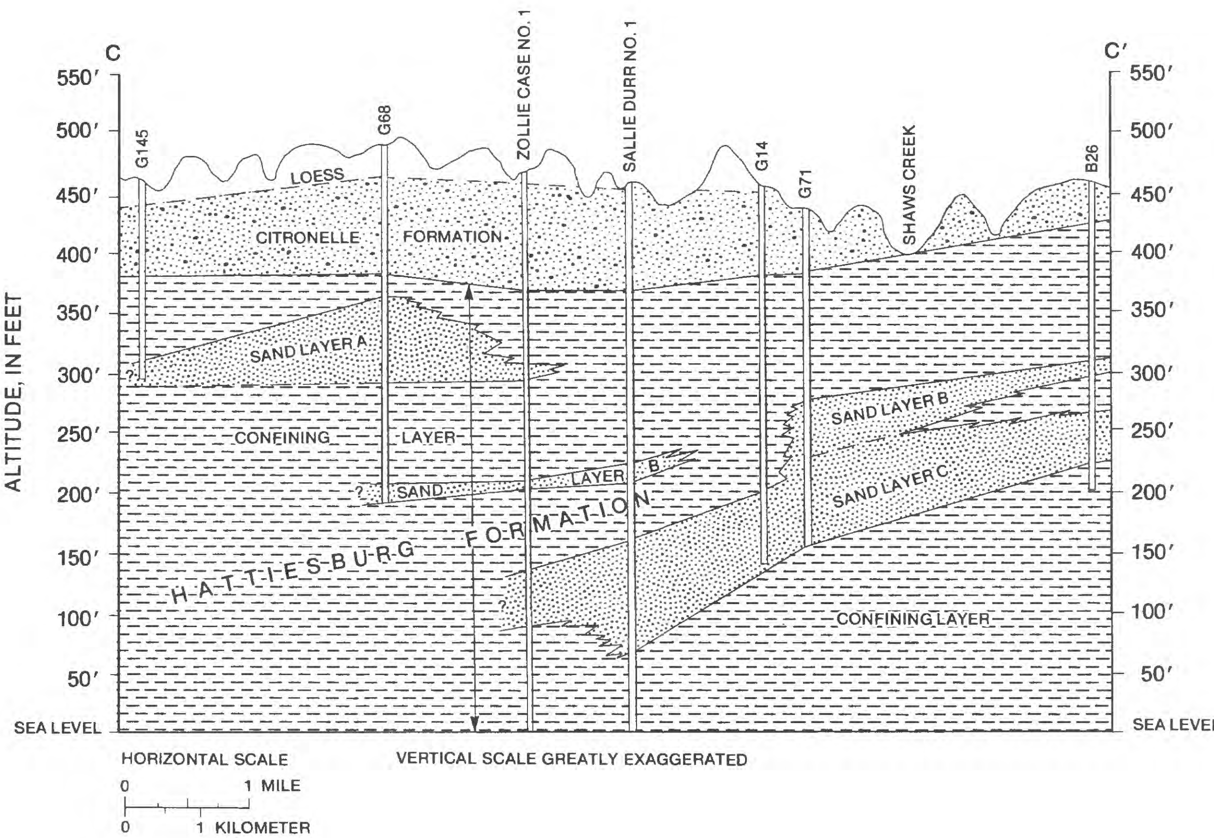

Figure 4.--Geologic section C-C′ showing hydrogeologic units in the Brookhaven oil field (Refer to figure 1 for location).

The Hattiesburg Formation, layer C, is the deepest sand of interest in the study area. The sand is variable in thickness, ranging from approximately 50 feet updip in the northern part of the study area to approximately 90 feet near the central part of the study area.

Overlying the Hattiesburg Formation and exposed at places on the surface is the Citronelle Formation. The Citronelle Formation consists of discontinuous sand and gravel units separated by sandy clay lenses. Generally the thickest gravel layers are present in the basal part of the formation and the upper part is made up of sandy clay.

The base of the Citronelle ranges from an altitude of 440 feet above sea level at the northern limit of the study area to an altitude of 370 feet at the southern boundary. Through the study area, the base of the Citronelle dips at a rate of approximately 9.5 ft/mi, slightly greater than the average regional dip of the formation reported by Boswell (1979). In the study area the Citronelle gradually thickens southward, ranging in thickness from approximately 40 feet in the north to over 100 feet in the central part of the oil field. Near the West Bogue Chitto the formation thins to approximately 20 feet (fig. 3A).

Hydrology

The Citronelle Formation and the three layers in the Hattiesburg Formation contain sufficient saturated permeable material to yield significant quantities of water to wells and thus serve as aquifers in the study area. These formations will be identified as aquifers in this report.

Hattiesburg aquifer A

During the current study, data needed to define aquifer characteristics (transmissivity and specific capacity) were not collected. Analysis of drillers' logs and electric logs indicate that well G19, located about 0.5 mi east of the study area, was screened in a sand below the Citronelle Formation. The sand is at a corresponding altitude of the Hattiesburg aquifer A and is interpretated to be an eastward extension of this aquifer. The results of an aquifer test in the vicinity of well G19 near Brookhaven indicate the transmissivity was 4,000 ft^2/d and the hydrologic conductivity was 200 ft/d (Newcome, 1971, p. 33).

Generalized potentiometric-surface contours were drawn using water-level measurements made in May 1984 at nine wells screened in the Hattiesburg aquifer A. The potentiometric surface slopes southward at approximately 10 ft/mi and ranges from about 430 to 400 feet above sea level (fig. 5). Potentiometric contours bulge southward near West Bogue Chitto.

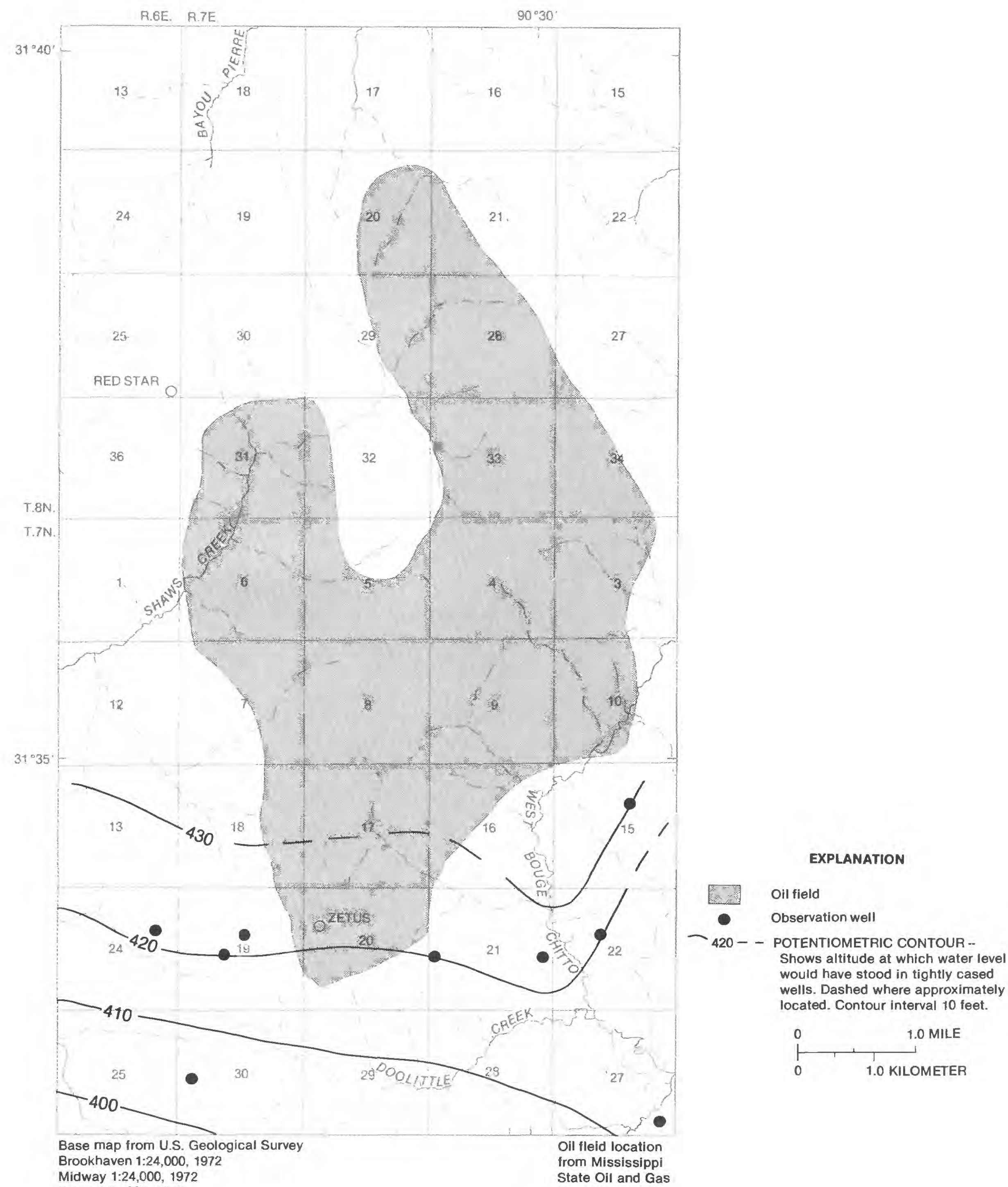

Figure 5.--Potentiometric surface map of the Hattiesburg Formation sand layer A in the Brookhaven oil field, May 1984.

Ground-water movement in the Hattiesburg aquifer A is to the south. Bulging contour lines near West Bogue Chitto show that water movement is away from the stream, possibly indicating recharge from the overlying Citronelle aquifer. At the northern limit of the Hattiesburg aquifer A, the potentiometric surface and the water-table surface of the Citronelle aquifer are at the same altitude. This may indicate that the two aquifers are hydraulically connected in this area. Southward, the potentiometric surface of the Hattiesburg aquifer A is lower than the water-table surface of the Citronelle aquifer, indicating hydraulic separation of the two aquifers.

Citronelle aquifer

Few aquifer tests have been completed on wells screened in the Citronelle aquifer. Therefore, data on the hydrologic characteristics of the Citronelle aquifer are scarce. Results of a test completed on well J136 in Baxterville in Lamar County may be useful, however, in estimating the hydrologic characteristics of the Citronelle aquifer in the Brookhaven Oil Field. Newcome (1971, p. 30) reported a transmissivity of 13,000 ft^2/d, a specific capacity of 62 gal/min/ft and a hydrologic conductivity of 120 ft/d of the Citronelle aquifer in Baxterville.

Ground-water movement in the Citronelle aquifer can be determined from a map of the water table (fig. 6). Movement is perpendicular to the contour lines and down the hydraulic gradient. Contours from water-level measurements at observation wells indicate that the water-table surface of the Citronelle aquifer slopes generally to the south and southwest. Highest water-table altitudes are along the ridges forming the drainage divides between West Bogue Chitto, Shaws Creek, and Bayou Pierre. A water-table high ranging from approximately 0.5 to 2 miles wide extends along a divide from the northwest corner of the study area eastward and then south through the east-central part of the area. Altitudes of the high gradually decreased from over 450 feet in the north to 430 feet in the central and southern parts of the study area. The slope along the ridge ranges from 10 to 20 ft/mi.

The water-table slopes from 20 to 40 ft/mi towards Shaws Creek and West Bogue Chitto. The steepest gradients are located in T. 8 N., R. 7 E., sec. 31, and T. 7 N., R. 7 E., sec. 6, along Shaws Creek and its tributaries. Alluvial material has been deposited along Shaws Creek and West Bogue Chitto; therefore, water-table contours may represent the water level in alluvial material rather than in the Citronelle aquifer near these two streams.

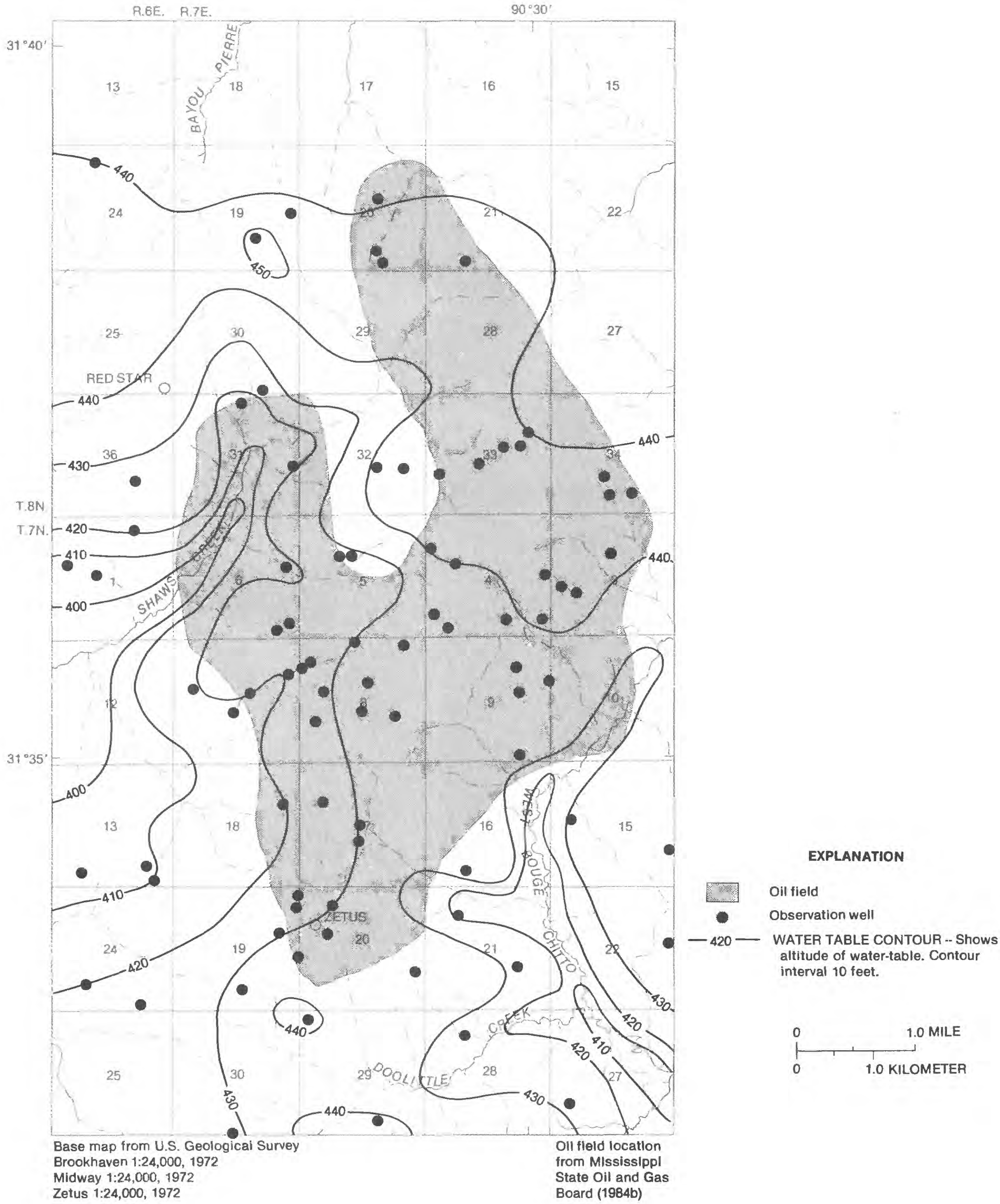

Figure 6.--Water-table map of the Citronelle aquifer in the Brookhaven oil field, May 1984.

West Bogue Chitto

West Bogue Chitto originates north of Brookhaven and then arcs southward, flowing through the southeastern part of the study area. West Bogue Chitto and its tributaries drain approximately 16 mi^2 of the study area. Several unnamed tributaries originate in the Brookhaven Oil Field. Water flows in these tributaries only after rains. Doolittle Creek, a perennial stream, drains approximately 5 mi^2 (most within the study area) just south of the oil field.

The gage height was recorded at 15-minute intervals at site 4 on West Bogue Chitto. The discharge was calculated from the gage height by using a stage-discharge relationship described by Rantz and others (1982, p. 287-294).

Figure 7 shows mean-daily discharge at site 4 on West Bogue Chitto. The lowest mean-daily discharge occurred during the months of June and July. Mean-daily discharge averaged about 1.0 ft^3/s or less through June and half of July and generally averaged less than 3.0 ft^3/s from June to October. During the wettest months (November to April), the mean-daily discharge peaks soon after a rain and then drops rapidly. If significant rain doesn't fall within 4 or 5 days the mean-daily discharge drops below 5.0 ft^3/s. Therefore, low flow--periods between rains when streamflow originates primarily from ground water inflow--varies from less than 5.0 ft^3/s during the wet winter and spring months to less than 3.0 ft^3/s during drier summer and fall months. High flow--when most streamflow originates as runoff from precipitation--is at discharge normally greater than 10 ft^3/s. At discharges from low flow (3.0 to 5.0 ft^3/s) to 10 ft^3/s, streamflow originates from ground-water inflow and surface runoff in more equal parts.

Figure 8 summarizes discharge at site 4 on West Bogue Chitto during the study period. Low flow (less than 5 ft^3/s) occurred 70 percent of the time.

Shaws Creek

Shaws Creek originates in the north-central part of the study area and flows southwest out of the study area. Shaws Creek and its tributaries drain 13.8 mi^2 in the north-central and western parts of the area. Several small unnamed perennial tributaries originate in the Brookhaven Oil Field.

The stage-discharge relation to a stage of 4.0 ft was prepared from discharge measurements made during the study. As discharge measurements greater than 4.0 ft were una-

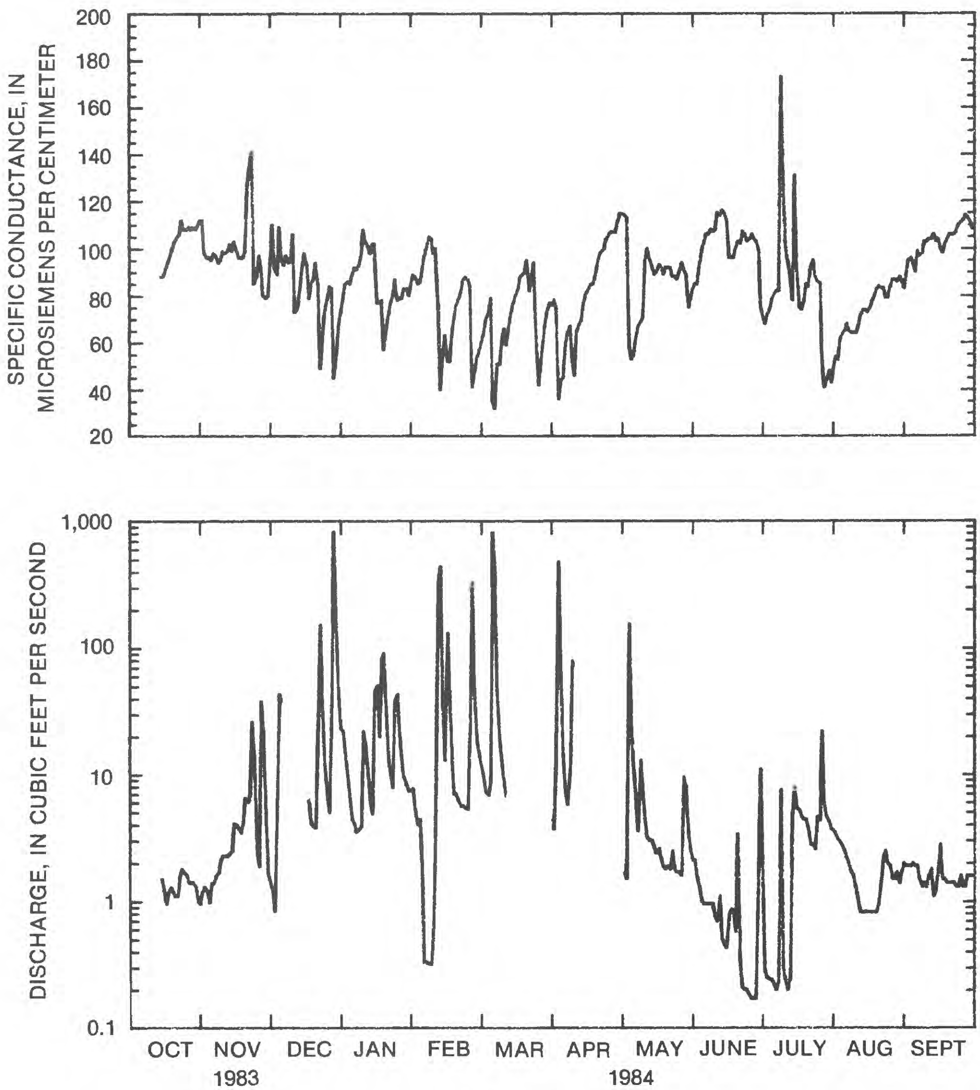

Figure 7.--Mean daily specific conductance and discharge at site 4 on West Bogue Chitto near Zetus, Mississippi.

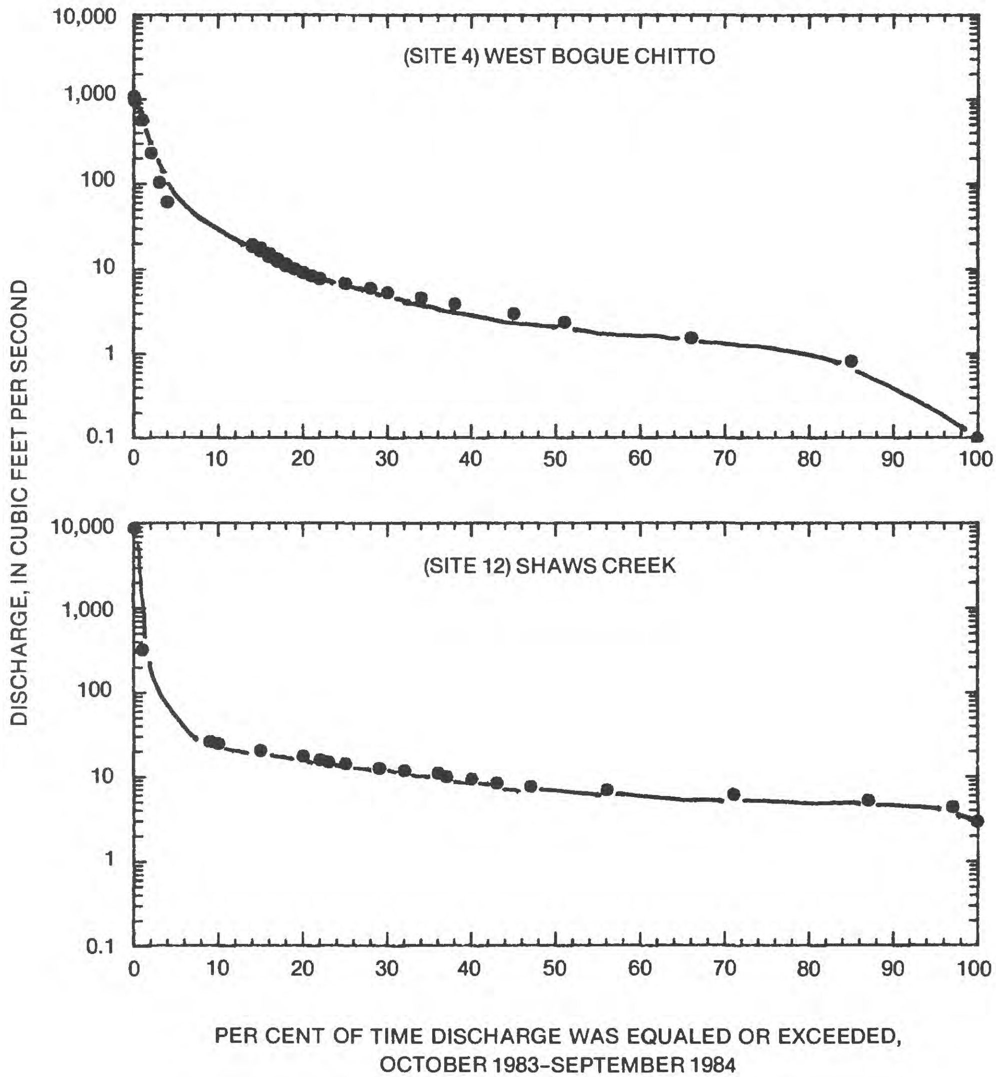

Figure 8.--Flow duration at site 4 on West Bogue Chitto and at site 12 on Shaws Creek

vailable, the relation was extrapolated above 4.0 ft using conveyance-slope methods described by Rantz and others (1982, p. 334-337).

Mean-daily discharge at site 12 on Shaws Creek is shown in figure 9. Lowest mean-daily discharge occurred from June to November. During this period, discharge ranged from approximately 4.0 to 8.0 ft^3/s and occasionally peaked at over 10 ft^3/s after rainfalls. The discharge peaks soon after a rain during the wettest months (November through April). The maximum discharge occurred on March 5 when mean-daily discharge exceeded 1,000 ft^3/s. Low-flow gradually increased from approximately 7.0 ft^3/s in October to 10 or 11 ft^3/s in February and March and then gradually decreased through April and May to 5.0 or 6.0 ft^3/s in the summer (June to August). Low flow decreased to less than 5.0 ft^3/s in September.

A summary (as flow duration) of discharge at site 12 on Shaws Creek is shown in figure 8. Low-flow discharge of less than 11 ft^3/s occurred during approximately 87 percent of the study period.

Methods

The first step in defining areas of contamination was to establish criteria to indicate brine contamination. As water-quality data are limited for the study area, background information on the quality of water in the Citronelle aquifer and in streams that drain the Citronelle outcrop areas was established by analysis of samples from control sites (fig. 1). Water from these sites was not free from all human influences, but the quality is unaffected by oil-field activities. Ten wells located west and south of the study area were sampled at control sites for the Citronelle aquifer. A control site on Sweetwater Creek, whose drainage area contains land-use activities and geologic outcrops similar to streams that drain the study area, was sampled over a range of stream discharge.

Ground-water samples were collected from 91 domestic wells screened in the Citronelle aquifer and 20 domestic wells screened in Hattiesburg aquifers in the study area. Domestic wells are bored and cased with 6-or 8-inch cement tile or constructed using a rotary drill and cased with 4-inch PVC (polyvinyl chloride). The location of sampling points varied according to the type of pump installation and kind of domestic-well distribution system; however, samples were generally collected within 20 feet of the well head.

Location and other information for wells in the study area and control wells in northwestern Lincoln County are given in tables 2 and 3 in the hydrologic data section in the back of the report.

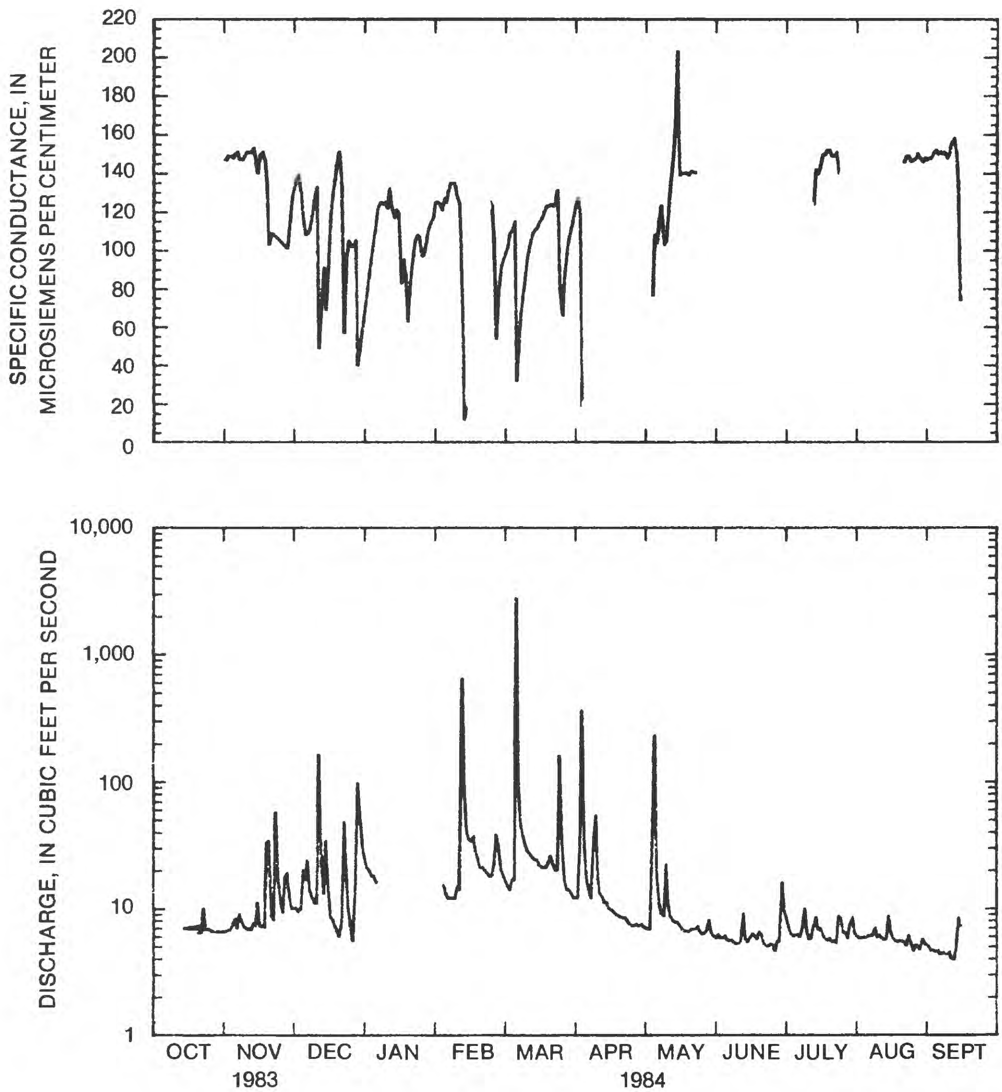

Figure 9.--Mean daily specific conductance and discharge at site 12 on Shaws Creek near Red Star, Mississippi.

To obtain a representative water sample from the aquifer, the well was pumped until both temperature and specific conductance of the water stabilized. Water temperature and specific conductance measurements were made at 5-minute intervals. When two consecutive measurements were the same, a water sample was collected and the pH and temperature were immediately determined. Water to be analyzed for dissolved ions was filtered through a 0.45 μm membrane filter into polyethylene bottles. The filtrate was then acidified with nitric acid to a pH less than 2.0 for analysis of cationic constituents. Analysis of alkalinity as $CaCO_3$, was performed on an unfiltered and untreated sample of water. Alkalinity as $CaCO_3$ concentrations in this report may be converted to bicarbonate concentrations by multiplying by a factor of 1.22.

Areal stream water-quality data were collected under two separate flow conditions. Field parameters and sodium and chloride concentrations were determined at 12 sites during periods of low and high streamflow. Low flow was during periods of little or no rain when streamflow originated from ground-water discharge. High-flow periods were after heavy rains when most streamflow originated from surface runoff. In addition to field parameters and sodium and chloride concentrations, other major ions, and bromide and strontium concentrations were determined at site 4 on West Bogue Chitto and site 12 on Shaws Creek. A discription of sampling site locations and drainage areas of sampling sites on streams in the study area and on the control stream are listed in table 4 in the hydrologic data section of the report.

Background surface water-quality data were collected at control site 1 on Sweetwater Creek near Midway over a range of streamflows. This stream drains an area with similar geology and land-use activities as the streams which drain the study area; however, there is no oil field activity in the drainage basin.

Sample bottles were placed in ice chests and shipped to the U.S. Geological Survey National Water-Quality Laboratory in Atlanta, Ga. Dissolved ions were analyzed by standard atomic absorption and ion chromatogaphy methods described by Skougstad and others (1979). The results of chemical analyses along with field measurements are permanently stored in the U.S. Geological Survey WATSTORE water-quality file and are published in the U.S. Geological Survey "Water Resources Data-Mississippi, Water Year 1983" (1985).

The results of analyses of surface- and ground-water samples along with site identification and location information are given in tables 5-8 in the hydrologic data section of the report.

Continuous water-quality and gage-height data were recorded at site 4 on West Bogue Chitto near Zetus and site 12 on Shaws Creek near Red Star. Maximum-, minimum-, and mean-water temperature and specific conductance values are stored in the WATSTORE daily values file and will be published in the U.S. Geological Survey "Water Resources Data-Mississippi, Water Year 1984."

Before field parameters were measured or a water sample collected, streamflow was gaged using techniques described by Buchanan and Sommers (1969, p. 37-40). In addition to specific conductance, unstable parameters--water temperature, dissolved oxygen, and pH--were measured directly in the stream or immediately after the sample was collected. To obtain a representative sample, each grab sample was taken from a well-mixed part of the stream, below riffles and in the main flow. In deeper and wider streams such as Shaws Creek, specific conductance was first measured at several points to determine whether significant differences in dissolved solids occurred horizontally in the stream cross section. Water samples were filtered and treated as described for ground-water samples.

GROUND-WATER CONTAMINATION

Descriptive statistical summaries of water quality of the Citronelle aquifer in the Brookhaven Oil Field and in northwestern Lincoln County outside the oil field are listed in tables 9 and 10. All samples were selected at random from 10 wells outside the oil field and a statistical summary of all parameters was made. Samples were randomly collected in the oil field; however, only conductance, pH, and sodium and chloride concentrations were measured for all samples. Analyses of other major ions and selected minor ions (bromide, strontium, and barium) were made only in selected samples; therefore, a meaningful statistical summary could only be prepared for those parameters measured at all sites.

One of the basic assumptions in determining measures of central tendency (mean) and dispersion (standard deviation) of samples from a population is that the data are normally distributed. Using the "univariate" procedure with the "normal" option (Ray, 1982, p. 575-583) of the SAS[1] computer software system, only well depth, specific conductance, pH, and chloride values at control sites were found to be normally distributed ($p<0.05$). Thus the mean and standard deviation of the remaining data may be skewed and not truly describe the water quality of the aquifer. An alternative nonparametric procedure (based on rank) which does not rely on the presence of normally distributed data was used to prepare a descriptive statistical summary and to test data from the control sites against data from the study area to

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[1]Use of trade or product names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Table 9.--Statistical summary of uncontaminated water-quality data for the Citronelle aquifer in northwestern Lincoln County

[Dissolved constituents in milligrams per liter, except as indictated]

Parameter	Number of samples	Median	Interquartile range	Minimum	Maximum
Depth (ft)	10	80	66-102	40	120
Conductance (uS/cm)	10	44	31-64	25	86
pH (units)	10	5.2	5.1-5.4	4.9	5.4
Calcium (Ca)	10	1.4	.87-1.7	.83	2.5
Magnesium (Mg)	10	.56	.51-.77	.50	1.1
Sodium (Na)	10	4.5	3.4-9.0	2.7	14
Potassium (K)	10	.50	.4-.7	.2	1.0
Alkalinity as CaCO3	10	7.5	7.0-8.8	6.0	11
Sulfate (SO4)	10	<.20	<.2-.3	<.20	.60
Chloride (Cl)	10	5.9	4.2 -14.2	3.4	21
Dissolved Solids	10	40	33-53	28	66
Bromide (Br)	10	.04	0.02-0.06	.02	.17
Strontium (Sr)(ug/L)	10	10	8.0-16	6.0	20
Barium (Ba)(ug/L)	10	31	24-41	20	50
Na/Cl ratio	10	.80	.69-.85	.57	1.03

Table 10.--Statistical summary of water-quality data for the Citronelle aquifer in the Brookhaven Oil Field

[Dissolved constituents in milligrams per liter, except as indictated]

Parameter	Number	Median	Interquartile range	Minimum	Maximum
Depth	95	75	58-90	28	150
Conductance(uS/cm)	103	149	56-325	23	2570
pH (units)	83	5.1	4.9-5.4	4.4	10.3
Sodium (Na)	94	16	6.7-36	2.6	330
Chloride (Cl)	104	34	9.2-87	.2	830
Na/Cl ratio	94	.54	.45-.76	.32	1.2

determine if significant differences exist. The nonparametric equivalent of the mean is the median, and the nonparametric equivalent of the standard deviation is the interquartile range. A procedure for comparing the median of two populations, the Wilcoxon-Mann-Whitney rank sum test (Wilcoxon, 1945, and Mann and Whitney, 1947) was used to test for differences in the Citronelle aquifer between normal water and water from the oil field.

Citronelle Aquifer

Normal or uncontaminated water of the Citronelle aquifer (table 9) was found to be low in dissolved solids concentrations (generally less than 60 mg/L) and to have a low pH (median of 5.2 units). The median specific conductance (an indicator of the dissolved solids concentration) was 44 µS/cm. The median dissolved-solids concentration was 40 mg/L. Concentrations of each major ion was generally less than 10 mg/L. Occasionally sodium and chloride concentrations reach 20 mg/L. Sodium, chloride, and bicarbonate were the predominant ions in solution. Median concentrations of bromide (0.04 mg/L), strontium (10 µg/L), and barium (31 µg/L) were low. The median sodium to chloride ratio for the uncontaminated water was 0.80.

Differences between typical water quality of the Citronelle aquifer and water quality of the Citronelle aquifer within the study area are readily apparent. Median specific conductance (149 µS/cm), sodium (16 mg/L), and chloride concentrations (34 mg/L) were significantly greater ($p<0.05$) than in the control samples. Although minimum concentrations of all major ions were within the same range with those typically found in the Citronelle aquifer, maximum concentrations (except alkalinity) were more than 10 times the maximum concentrations found in water typical of the Citronelle aquifer. A similar pattern was found in the concentrations of the minor ions, bromide and strontium. The median sodium/chloride ratio calculated for water in the Citronelle aquifer in the study area was 0.54.

The sodium/chloride ratio in the Citronelle aquifer in Brookhaven ranged from greater than 1.0 (similar to that in control samples) to approximately 0.40 (similar to that of a brine in the oil producing formation). Ratios were scattered but they are generally greater than 0.60 in samples with chloride concentrations less than 20 mg/L (fig. 10). Ratios were more tightly clustered and were less than 0.60 when chloride concentrations exceeded 60 mg/L.

Normal variation in sodium and chloride in dilute waters would account for scattered ratios at low (less than 20 mg/L) concentrations. As chloride concentration increases, a larger proportion of the sodium and chloride in solution

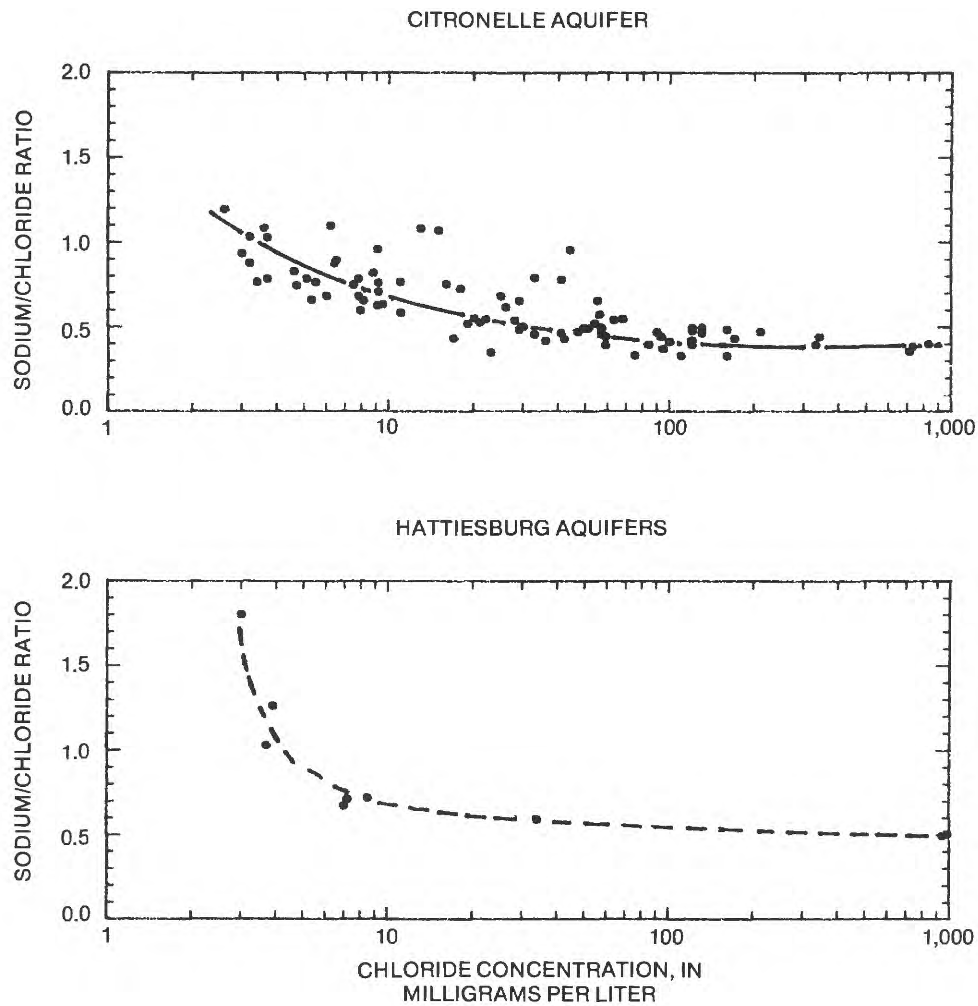

Figure 10.--Sodium/chloride ratio versus chloride concentration in the Citronelle aquifer and Hattiesburg aquifers in the Brookhaven oil field.

originates from the brine. For example, in a sample having a chloride concentration of 60 mg/L and using the median chloride concentration of normal water in the Citronelle aquifer (table 9), 90 percent (by weight) of the chloride originated from brine. The sodium/chloride ratio for a receiving water will become lower to reflect the ratio of the brine it mixes with. In the transition zone (chloride 10-60 mg/L), sodium and chloride originates from both uncontaminated Citronelle water and brine in variable proportions in the Citronelle aquifer. Thus, the sodium/chloride ratio in the resulting mix will vary to the degree of con tamination.

Based on the results of the analysis of control samples, the primary indicator of brine contamination in the Citronelle aquifer are: (1) significant increase in chloride concentration, waters with chloride concentrations exceeding 20 mg/L are probably contaminated; and (2) sodium/chloride ratio less than 0.60. Supplementary indicators of brine contamination are concentrations of minor ions (barium, bromide, and strontium) exceeding maximum concentrations found in the water at control sites. Concentrations of bromide greater than 0.20 mg/L, strontium greater than 20 µg/L, and barium greater than 50 µg/L are indicators of probable contamination by brines.

The chloride concentration in water from the Citronelle aquifer exceeds 20 mg/L in several areas in the Brookhaven Oil Field. The largest area of increased chloride concentrations is located in the central part of the oil field in T. 7 N., R. 7 E., sections 5-8, 18, and in T. 7 N., R. 6 E., in sections 1 and 12 (fig. 11). Within an area of about 2.5 mi^2 are two distinct subareas where chloride concentrations in the Citronelle aquifer exceed 100 mg/L. These two subareas of higher chloride concentration indicate that a source (or sources) of contamination is present in the northern part of section 7 or the northwest corner of section 8 in addition to a contaminant source in the northeastern part of section 18. The maximum chloride concentrations were 210 mg/L in well G114 in section 7 and 730 mg/L in well G107 in section 18.

Smaller areas of the Citronelle aquifer where chloride concentrations exceed 20 mg/L are present in sections 3-5, and 17-20 in T. 7 N., R. 7 E., and in sections 28 and 33 in T. 8 N., R. 7 E. Water from wells in a total of seven areas ranging in size from 0.20 to 2.5 mi^2 had chloride concentrations exceeding 20 mg/L.

In the Brookhaven Oil Field, chloride concentrations increased in 7 of 10 wells sampled between 1981 and 1982 (Kalkhoff, 1985). Two wells sampled in the previous investigation in 1982 were resampled during this study.

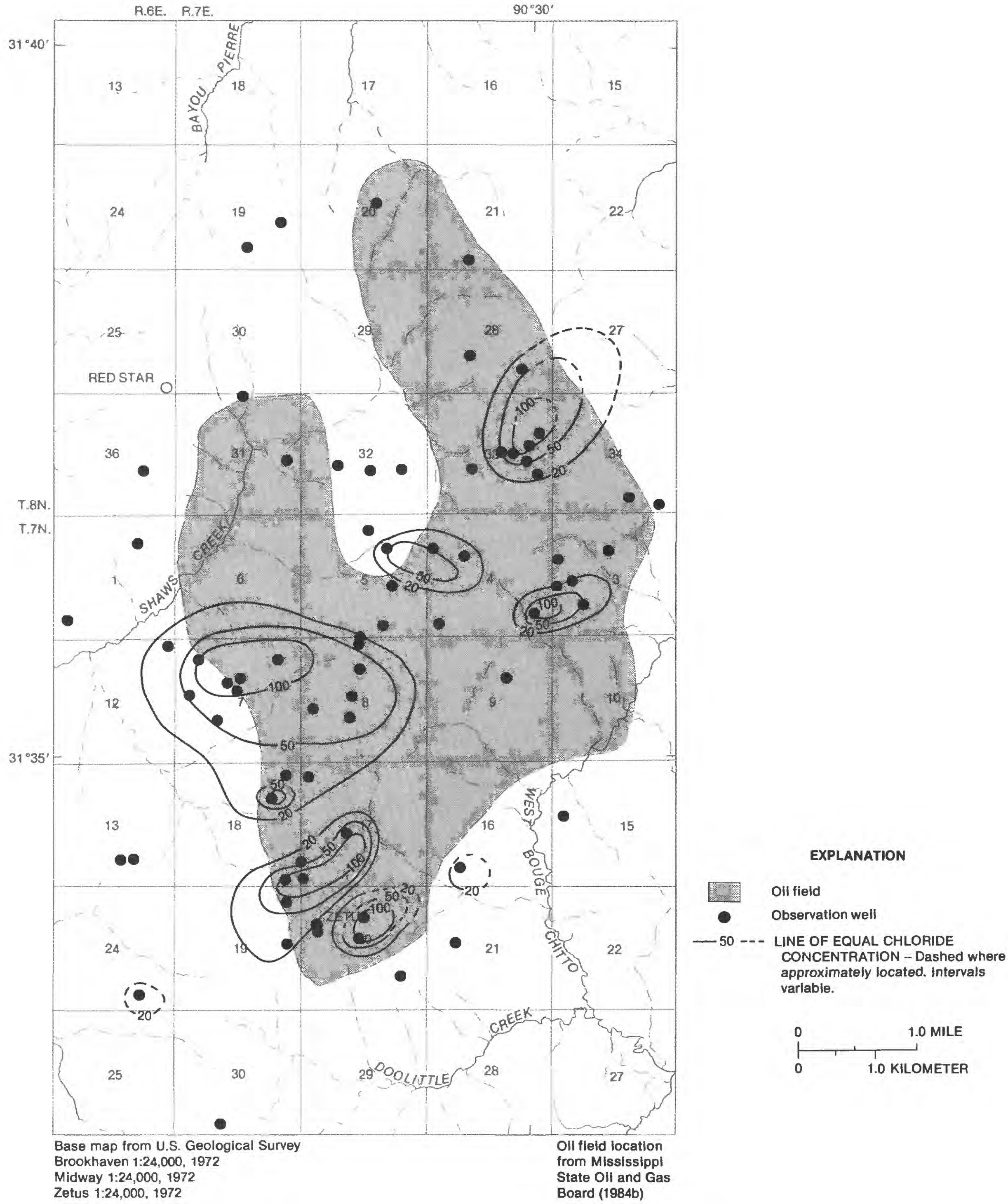

Figure 11.--Chloride concentrations in the Citronelle aquifer in the Brookhaven oil field, 1984.

Chloride concentrations increased in well G56 from 260 to 330 mg/L and in well G99 from 56 to 110 mg/L (table 7). During this study a slightly elevated chloride concentration was evident in water samples collected from well G107 in August 1983 (710 mg/L) and in November 1983 (730 mg/L). Increased chloride concentrations in water from well G107 were accompanied by slightly increased concentrations of other major ions and two minor ions, strontium, and bromide (table 5). In August 1983, the barium concentration was 2.5 mg/L or 2-1/2 times the recommended drinking-water standard (U. S. Environmental Protection Agency, 1976, p. 19).

Hattiesburg Aquifers

On the basis of samples from a few wells that are completed in the upper Hattiesburg aquifers, it appears that normally there is very little water-quality variation between individual aquifers (table 6). Total dissolved-solids concentrations are generally less than 50 mg/L. Major ion concentrations, with the exception of bicarbonate, are less than 10 mg/L. Bromide (0.03 to 0.12 mg/L) and strontium (13 to 48 µg/L) concentrations are variable but low.

Since the water quality is similar in the Hattiesburg and Citronelle aquifers in the study area, indicators of brine contamination are the same as those in the Citronelle aquifer. The primary indicator is chloride concentrations greater than 20 mg/L with sodium/chloride ratios less than 0.60 mg/L.

Although only a few samples are available from the Hattiesburg aquifers, the sodium/chloride ratios lie close to the line shown in figure 10. Sodium/chloride ratios for water having chloride concentrations less than 20 mg/L were greater than 0.60 and in water with greater than 20 mg/L chloride the ratios were generally less than 0.60.

Dissolved-solids concentrations were significantly higher than normal, chloride concentrations were 20 mg/L or greater, and sodium/chloride ratios were 0.60 or less in several wells. All of these factors indicate brine contamination in parts of the Hattiesburg aquifers.

In section 20, T.7 N., R.7 W., water from two wells completed in Hattiesburg aquifer A had chloride concentrations exceeding 20 mg/L with low sodium/chloride ratios similar to that in the brine of the Tuscaloosa aquifer. The deeper well (G65) screened at 182 feet, had a chloride concentration of 980 mg/L in June 1982 and 940 mg/L in November 1983. A shallower (147 feet) domestic well (G180), located approximately 300 feet northwest of well G65, had a chloride concentration of 75 mg/L. A sample from well G182, located approximately 900 feet north of well G180, had a normal chloride concentration (3.2 mg/L).

Areal differences in chloride concentrations indicate the presence of a relatively small contaminant plume. One well that produces uncontaminated water is separated by a only a few hundred feet from wells that produce contaminated water; however, the unknown part of the contaminant plume could be much larger. Samples could not be collected downdip in aquifer A to determine the extent and lateral movement of the plume.

Since wells G180 and G65 are screened in different vertical parts of the aquifer there appears to be vertical differences within the contaminant plume. The contaminant, being denser, is concentrated in the base of the aquifer.

Also in section 20, T. 7 N., R. 7 E., the deeper aquifer B of the Hattiesburg Formation is being contaminated. A sample from well G68 contained a chloride concentration of 20 mg/L in June 1982. In approximately 18 months, the chloride concentration increased to 30 mg/L and the sodium to chloride ratio decreased from 0.65 to 0.43.

Contamination may be from two sources. Brines moving upward through abandoned production wells (which may have deteriorated casings) and then laterally into the freshwater sand may be one source. Downward migration of water from overlying contaminated sands may be a second source.

Water-level measurements show that the potentiometric surface of the Hattiesburg aquifer A is 70 feet higher than the potentiometric surface in aquifer B. If there is a pathway between sand layers, contaminated water will migrate from aquifer A to aquifer B. Possible pathways include the annular space between the well casing and borehole wall, if not properly sealed, and through openings in the well casing at any level where the head is lower.

Samples collected from a well (G1) in section 8 indicate that the water in Hattiesburg aquifer B was contaminated in the early years of production in the Brookhaven Oil Field. The chloride concentration increased from 13 mg/L in 1949 to 21 mg/L in 1955 and then to 34 mg/L in 1968. During the study, field personnel were unable to resample this well or to locate other nearby wells completed at this depth; therefore, changes in water quality since 1968 are undetermined.

SURFACE-WATER CONTAMINATION

Normal water quality (quality of water unaffected by brines) of streams draining outcrops of the Citronelle and Hattiesburg aquifers can be characterized from the water quality of the control stream--Sweetwater Creek (table 11). During low flow in August, water in Sweetwater Creek was low in dissolved-solids concentrations (46 mg/L) and was

Table 11.--Water-quality data for two streams that drain the Brookhaven Oil Field and for a control stream during low-flow and high-flow periods

[Dissolved constituents in milligrams per liter, except as indicated]

	Sweetwater Creek Site 1 (Control)		West Bogue Chitto Site 4		Shaws Creek Site 12	
	Low flow	High flow	Low flow	High flow	Low flow	High flow
Date	9/12/84	3/07/84	9/12/84	3/08/84	9/13/84	3/07/84
Discharge(ft^3/s)	0.17	20	0.11	16	4.3	32
Conductance(uS/cm)	55	33	106	57	142	63
pH (units)	6.0	6.0	6.4	5.9	6.4	6.1
Calcium (Ca)	3.0	1.7	6.1	2.6	4.8	2.5
Magnesium (Mg)	1.3	.9	1.9	1.1	2.2	1.2
Sodium (Na)	5.0	2.3	8.8	6.0	18	6.8
Potasium (K)	1.1	1.2	2.6	1.3	1.2	1.1
Alkalinity as CaCO3	16	7	29	7	7	7
Sulfate (SO4)	.5	4.9	1.1	6.2	.6	4.0
Chloride (Cl)	6.0	2.8	14	11	39	13
Dissolved Solids	46	50	72	53	99	37
Bromide (Br)	.05	.01	.09	.07	.22	.07
Strontium(Sr)(ug/L)	32	19	70	33	51	30
Barium(Ba)(ug/L)	60	47	91	54	86	52
Na/Cl ratio	.83	.82	.63	.54	.46	.52

slightly acidic (pH of 6.0 units). The major ions in solution are sodium and bicarbonate. The sodium/chloride ratio is 0.83. Concentrations of barium (60 µg/L), bromide (0.05 mg/L), and strontium (32 µg/L) are low.

All major ion concentrations, with the exception of sulfate, were present in the stream in about the same concentrations during high flow in March (table 11). The major ions in solution are sodium, bicarbonate, and sulfate. Sulfate concentrations increased from 0.5 mg/L at low flow to 4.9 mg/L at high flow. Concentrations of barium, bromide, and strontium in the stream are slightly lower at high flow than low flow and sodium/chloride ratios exceeded 0.60 during low and high flow.

West Bogue Chitto

Dissolved-solids concentrations were higher in West Bogue Chitto than in the control streams during low-flow periods. Sodium, chloride, and bicarbonate were the predominant ions in solution. The sodium/chloride ratio (0.63) was significantly less than for water in Sweetwater Creek. Bromide concentrations (0.09 mg/L) were slightly higher and strontium (70 µg/L) and barium (91 µg/L) were present in significantly greater concentrations than in the control stream.

The water quality in West Bogue Chitto was very similar to that in Sweetwater Creek during high flow. Concentrations of calcium, magnesium, and potassium were slightly higher and alkalinity was the same. Sodium and chloride concentrations were over double of those in the control stream with a sodium/chloride ratio of 0.54.

Sodium and chloride are two major ions whose concentrations vary with stream discharge in West Bogue Chitto. Figure 12 illustrates sodium and chloride concentrations versus discharge. At low-flow discharges, chloride concentrations are constant at 14.0 to 16.0 mg/L. At higher discharges chloride concentrations decrease slightly.

Total dissolved solids (as indicated by specific conductance) varied inversely with stream discharge (fig. 7). The specific conductance decreased with increasing discharge and increased with decreasing discharge. Even though there is a general inverse relationship between conductance and discharge, there is poor direct correlation (R = -0.41) between mean-daily conductance and discharge.

The reason for the poor direct correlation can best be seen in plots of specific conductance versus discharge during storm events (fig. 13C). Typically with the initial rise in discharge, there is a decrease in specific conduc-

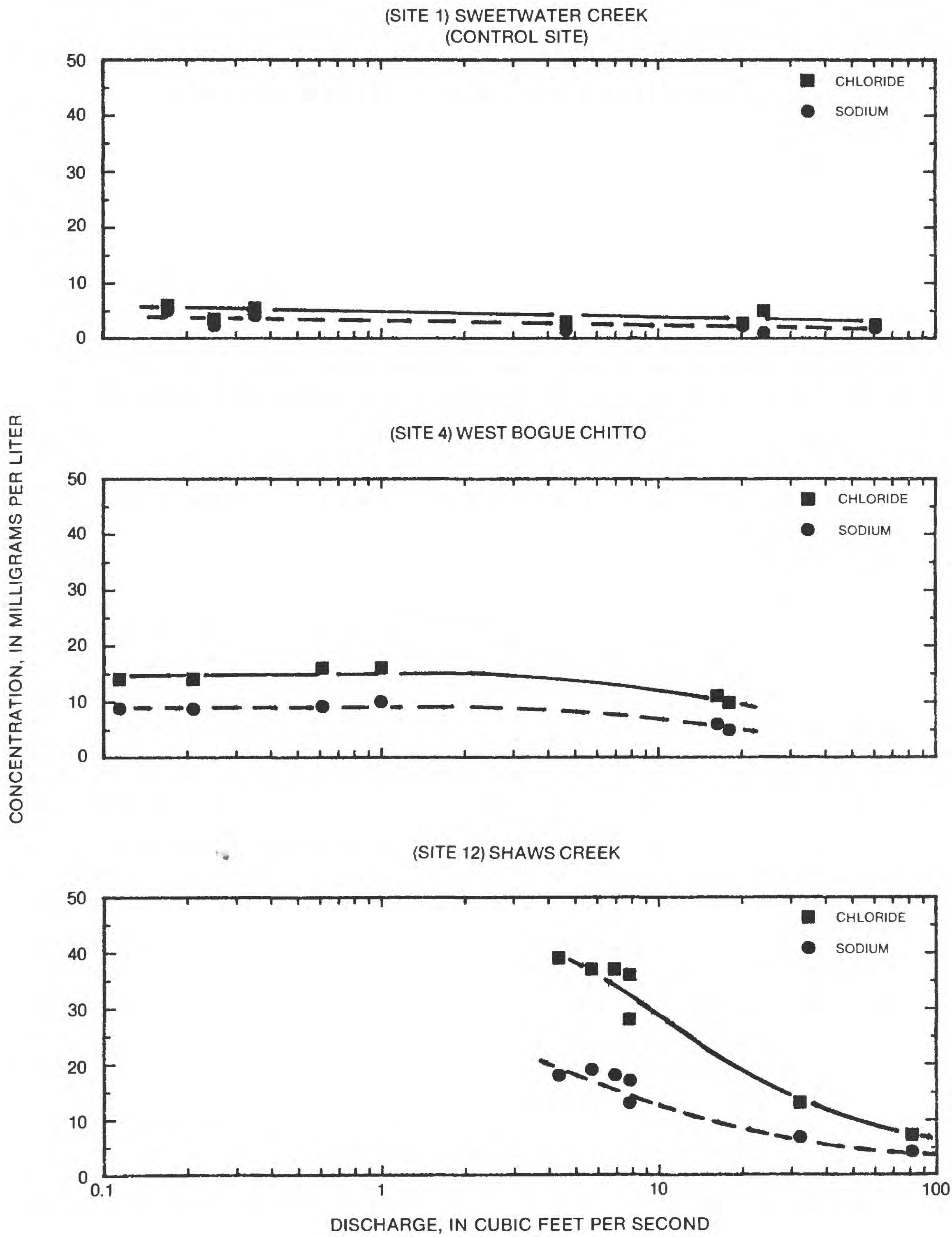

Figure 12.--Sodium and chloride concentrations versus discharge at sites on two streams draining the Brookhaven oil field and at a control site on a stream draining an area of no oil production.

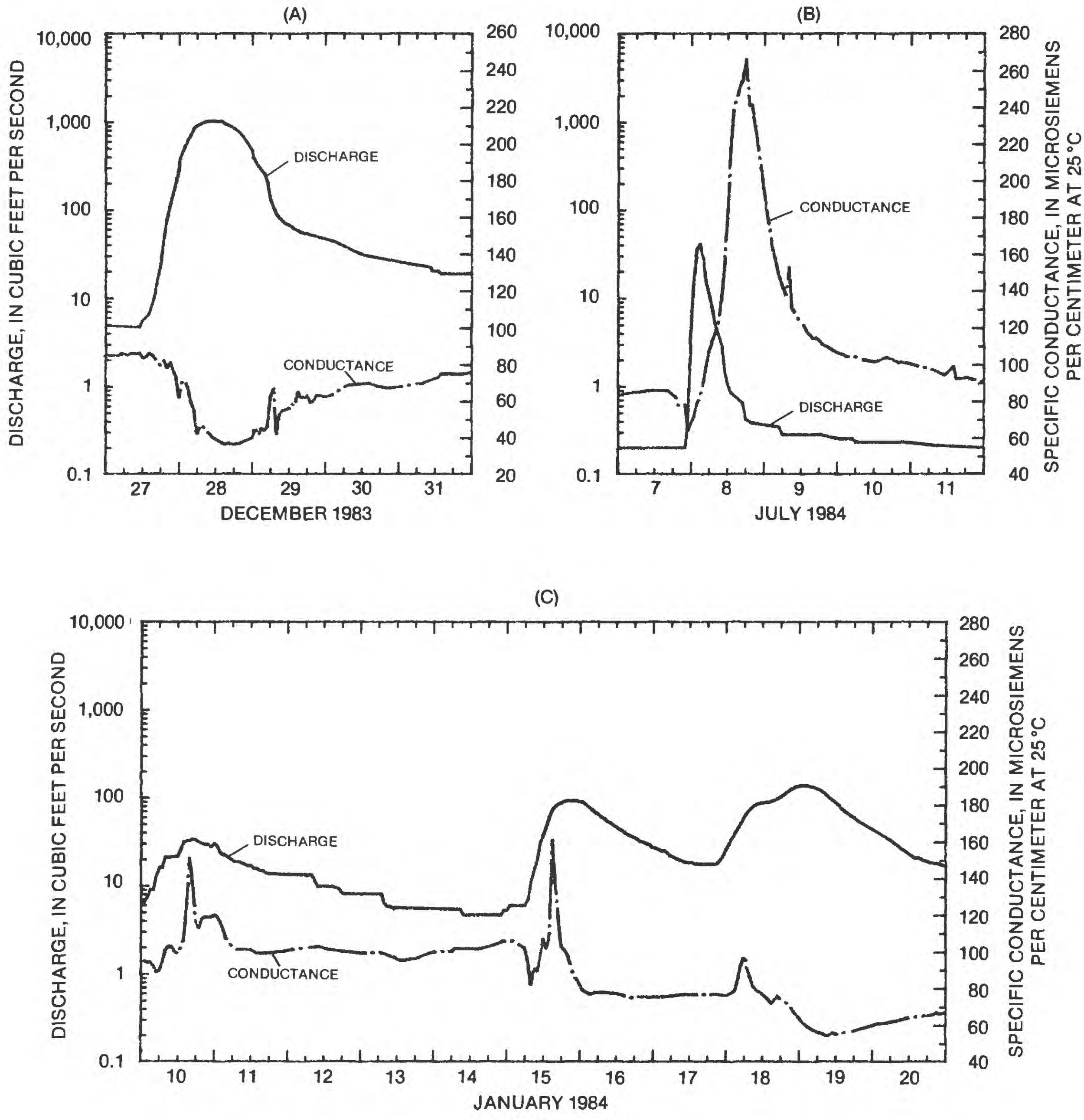

Figure 13.--Specific conductance and discharge during selected storms at site 4 on West Bogue Chitto near Zetus, Mississippi.

tance. As discharge continues to increase, the specific conductance peaks and then falls. Peak conductance values are recorded before stream discharge peaks. Then as discharge falls, conductance values stabilize and may slowly rise again. One possible explanation of increasing conductance with rising discharge is a contaminant in surface runoff entering the stream upstream of site 4. Dissolved-solids concentrations in the stream initially decrease due to dilute runoff and rainfall entering the stream. Concentrations then increase as the contaminant moves downstream past site 4. Further runoff dilutes the contaminant causing the specific conductance to decrease as discharge peaks. The contaminants appear to be transported into the stream during periods of surface runoff since large fluctuations in specific conductance are not observed during low-flow periods.

Exceptions to this general conductance-discharge pattern are evident after heavy precipitation which causes a large and lengthy increase in discharge (fig. 13A) and after light precipitation in summer which causes a small and shorter increase in discharge (fig. 13B). The first exception occurred during the period, December 27-31, 1983, when over 2.5 inches of rain fell on the study area (National Oceanic and Atmospheric Administration, 1983). The discharge increased from approximately 5.0 to over 1,000 ft^3/s and then gradually decreased to less than 20 ft^3/s and specific conductance decreased from 85 µS/cm to a minimum of 36 µS/cm just after peak discharge on December 28. Conductance was then variable, but generally rose as discharge decreased. Any contamination then entering the stream was diluted to low levels by the large volume of streamflow.

The second exception occurred during the period from July 7 to July 11, 1984, after 0.23 inches of rain had fallen (NOAA, 1984b). With the initial rise in discharge, the specific conductance decreased from 86 to 64 µS/cm. As discharge peaked and began to fall, the conductance continued to rise and reached a maximum of 266 µS/cm. The conductance then decreased as streamflow fell below 1.0 ft^3/s. Runoff from the small rainfall on July 7 carried contamination into West Bogue Chitto but the volume of runoff was insufficient to dilute the contaminant to a large degree nor to rapidly flush it through the stream.

Shaws Creek

Dissolved-solids concentrations (99 mg/L) were higher in Shaws Creek than in the control stream during a low-flow period in September (table 11). Sodium and chloride were the predominant ions in solution. The sodium/chloride ratio (0.46) was similar to that in brines produced in the oil field. Bromide (0.22 mg/L), barium (86 µg/L), and strontium

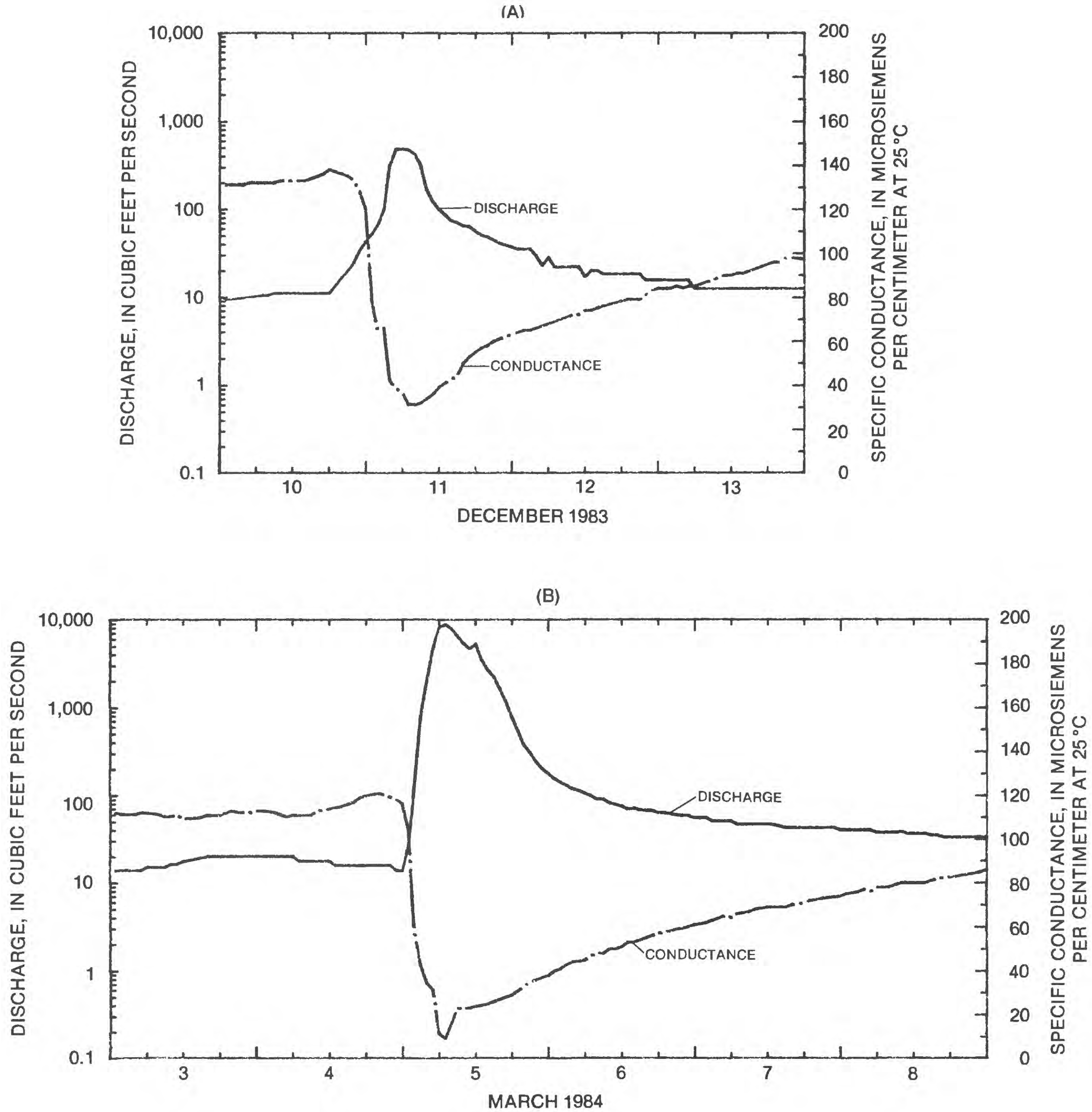

Figure 14.--Specific conductance and discharge during selected storms at site 12 on Shaws Creek near Red Star, Mississippi.

(51 μg/L) concentrations were significantly greater than in Sweetwater Creek.

Although water quality in Shaws Creek is more like that in Sweetwater Creek during high flow than low flow, there were several differences (table 11). Sodium and chloride concentrations were greater than in the control stream. The sodium/chloride ratio (0.52) was significantly lower and was similar to that in brines. Thus it appears that the brine contaminant is affecting the water quality in the stream even during periods of higher flows. At a discharge near 70 ft^3/s, sodium and chloride concentrations approach those in the control stream (fig. 12).

The pattern of dissolved solids versus discharge in Shaws Creek was similar to that in West Bogue Chitto. Dissolved-solids concentrations generally varied inversely with stream discharge (fig. 9). The lowest dissolved-solids concentration (as indicated by specific conductance) were recorded in February and April during peak discharges. Mean-daily specific conductance values of less than 20 μS/cm on February 13 and April 3 are similar to those found in precipitation (U.S. Geological Survey, 1985, p. 354). Highest specific conductance values were generally recorded in October, July, and September during periods of low flow. Figure 9 shows a general relationship between specific conductance and discharge; however, there is a poor direct relationship between mean-daily specific conductance and mean-daily discharge ($R = -0.36$).

Plots of specific conductance versus discharge during two storm events show the typical relationship between the two parameters over a range of discharge (fig. 14). Specific conductance values ranged from 131 to 138 μS/cm during low flow through most of December 10 in which 1.53 inches (National Oceanic and Atmospheric Administration, 1983) fell on the study area. The specific conductance of water in Shaws Creek then decreased with increasing discharge. Minimum specific conductance value (31 μS/cm) occurred a few hours after discharge peaked and then began to fall. Specific conductance values then rose gradually as discharge dropped below 400 ft^3/s. Two days after the storm, the discharge had dropped to 12 ft^3/s and specific conductance had risen to 95 μS/cm.

The same pattern is evident during the heaviest rainfall during the study in which a total of 5.16 inches (National Oceanic and Atmospheric Administration, 1984a) fell from March 3 to March 6, 1984. As discharge rapidly increased, specific conductance rapidly decreased. Discharge reached a peak (over 1,000 ft^3/s) and specific conductance dropped to a minimum (9 μS/cm) at 7:00 a.m. on March 5, 1984. Specific conductance values then rose as discharge decreased. Three days following the heaviest rain during the study on March 5, the discharge was 33 ft^3/s and the conductance was 87 µS/cm.

Water-quality data collected during low flow and continuous specific conductance records indicate that Shaws Creek is being contaminated with brine. Higher than normal dissolved solids concentrations with sodium and chloride ions present in ratios similar to those in brine, and increased concentrations of minor ions, are indicative of brine contamination. Specific conductance values that during low flow are constantly higher than in the control stream indicate a fairly constant source of contamination. One such source is contaminated ground-water inflow from the Citronelle aquifer.

Water from three known brine contaminated areas of the Citronelle aquifer flows towards Shaws Creek and its tributaries (fig. 6 and 11). Higher than normal chloride concentrations were found in three tributaries (fig. 15) that drain the Brookhaven Oil Field.

Field personnel were unable to gain access to several other small tributaries of Shaws Creek that may contribute additional brine contamination upstream of site 10. Only 0.38 ft^3/s (from sites 8 and 9) of the total discharge (1.77 ft^3/s) at site 10 was measured. An additional 1.39 ft^3/s was entering Shaws Creek from the headwaters to site 10. The following equation is used to calculate the mean chloride concentration of the additional water entering Shaws Creek.

$$(C_f)(D_f) = (C_{s_1})(D_{s_2}) + \ldots(C_{s_n})(D_{s_n})$$

C = concentration, in milligrams per liter
D = discharge, in cubic feet per second
f = final water mix,
s_1, s_2 = site 1, site 2
s_n = site n

Entering into the above equation, the known concentration and discharge values for sites 8 and 9 and the concentration and discharge from site 10 as the final water, and knowing that an additional 1.39 ft^3/s enters Shaws Creek upstream of site 10, the only unknown left is the concentration of the additional water (as shown below).

$$(46)(1.77) = (0.18)(96) + (0.20)(32) + (1.39)(C_A)$$

Entering the value of 1.39 ft^3/s for additional discharge and calculating the concentration of additional water indicates that the mean chloride concentration of the additional 1.39 ft^3/s is 42 mg/L. This calculated chloride

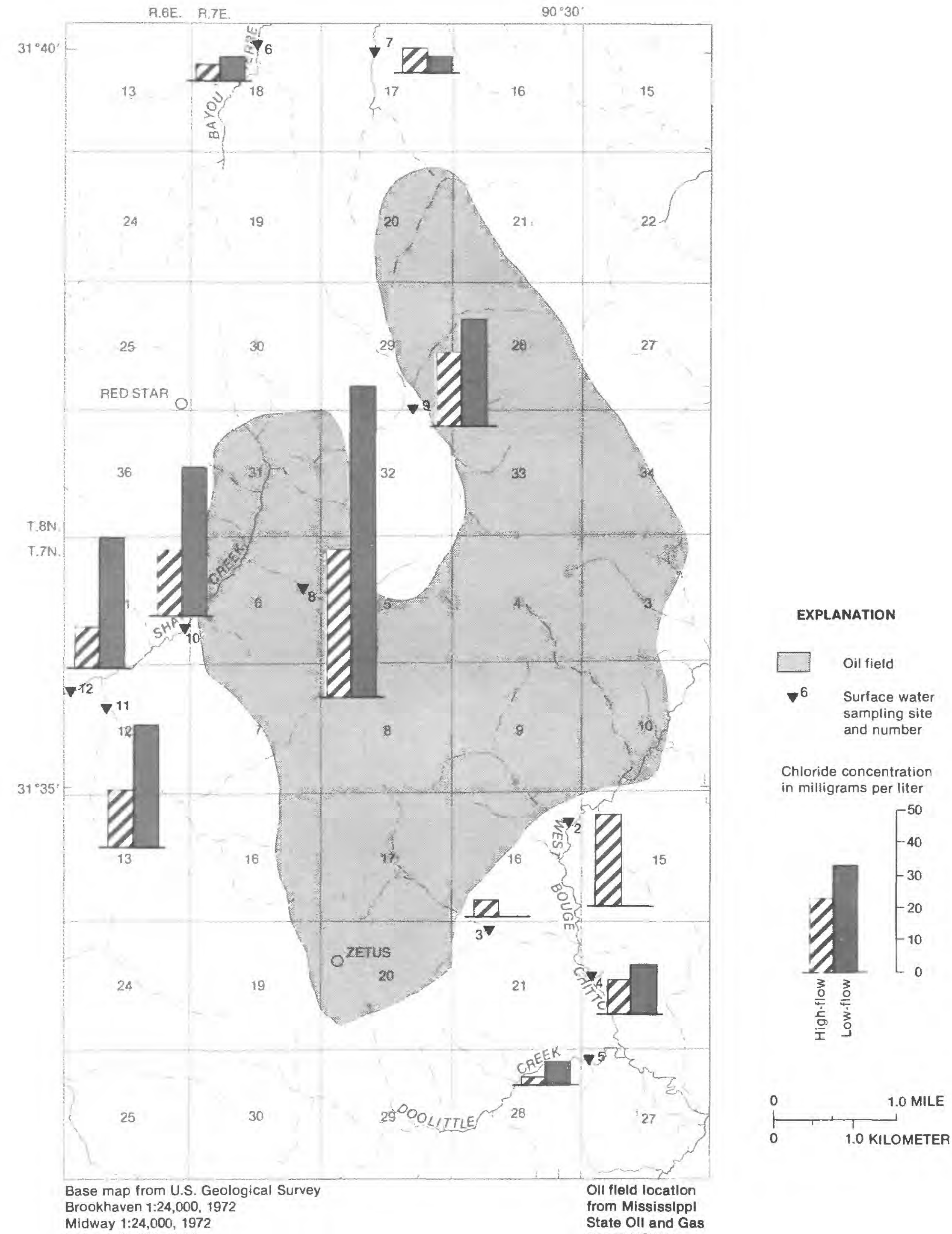

Figure 15.--Dissolved chloride concentrations during a high-flow period in March, 1984 and a low-flow period in September, 1984 in streams draining the Brookhaven oil field.

concentration is significantly greater than in the control stream and is evidence of source(s) of contamination upstream of site 10 other than that entering from the two tributaries sampled.

Discharge increases from 1.77 ft^3/s at site 10 to 4.34 ft^3/s at site 12. Tributary number 3 (site 11) contributes 2.33 ft^3/s to the total at site 12. The remaining 0.24 ft^3/s enters Shaws Creek directly from ground-water inflow. Again, using the equation above, it is found that the mean chloride concentration of the 0.24 ft^3/s is 6.8 mg/L. Within the margin of error, 6.8 mg/L is the background concentration (table 3) of typical water from the Citronelle aquifer; therefore, only the contaminated water entering Shaws Creek between sites 10 and 12 is from tributary 3.

SUMMARY AND CONCLUSIONS

The Brookhaven Oil Field covers approximately 15 mi^2 in northwestern Lincoln County, Miss. Disposal of approximately 54.2 million barrels of brine, pumped from the oil producing formation (lower part of the Cretaceous Tuscaloosa Formation) since oil production began in 1943, poses a threat of brine contamination to shallow freshwater aquifers and streams in and near the oil field. A hydrologic investigation was conducted from October 1983 to September 1984 to define (1) areas of brine contamination in shallow freshwater aquifers commonly used for domestic water supplies, and (2) contamination of streams draining the Brookhaven Oil Field.

The Citronelle Formation and three layers (A, B, and C) in the Hattiesburg Formation contain sufficient saturated permeable material and serve as aquifers in the study area. Water in the Citronelle aquifer is generally moving from ridges to nearby streams and may be recharging underlying Hattiesburg aquifers while water in Hattiesburg aquifer A is generally moving toward the south. Streams into which water from the Citronelle aquifer is moving are West Bogue Chitto, Shaws Creek and their tributaries. Flow in West Bogue Chitto and Shaws Creek is maintained during periods of no rain (low flow) by inflow from the Citronelle aquifer. During the study low flow occurred approximately 70 and 87 percent of the time in West Bogue Chitto and Shaws Creek, respectively.

Generally, ground water from the Citronelle aquifer in the study area contained more dissolved solids than the Citronelle aquifer outside the oil field. The median specific conductance--an indicator of dissolved solids concentration--was 149 µS/cm in the study area compared to 44 µS/cm outside the study area. In the study area sodium and chloride concentrations were significantly greater and the median sodium/chloride ratio (0.54) was close to that of the brine contaminant (0.49).

Several distinct areas of the Citronelle aquifer in the Brookhaven Oil Field have chloride concentrations greater than 20 mg/L and are considered contaminated. Seven contaminated areas with a total area of 5 mi^2 that range in size from 0.20 to 2.5 mi^2 are scattered throughout the oil field. Chloride concentrations in the contaminated areas range from 20 to 730 mg/L.

Brine contamination was also found in the deeper Hattiesburg aquifers. Water from wells G65 and G181 completed in the Hattiesburg aquifer had chloride concentrations of 980 and 120 mg/L, respectively. The calculated sodium/chloride ratios were similar to that of brine in the Tuscaloosa Formation brine. Analysis of water from well G1 indicate increasing levels of contamination as indicated by an increasing chloride concentration from 1949 to 1968.

Differences between water quality in streams draining the Brookhaven Oil Field (Shaws Creek and West Bogue Chitto) and the control stream are apparent during low streamflow periods. Concentrations of ions generally associated with oil field brines (calcium, sodium, chloride, bromide, and strontium) were significantly greater in West Bogue Chitto and Shaws Creek than at the control site on Sweetwater Creek. During low-flow periods, water in Shaws Creek had chloride concentrations in excess of 20 mg/L. Although higher than in Sweetwater Creek, chloride concentrations in West Bogue Chitto remained less than 20 mg/L during low flow. After a rain, specific conductance rose then decreased as discharge increased, indicating a contaminant was being transported overland into West Bogue Chitto.

In conclusion, shallow freshwater aquifers, less than 300 feet deep in the Brookhaven Oil Field, have been contaminated by the introduction of brine (produced as byproducts of oil production) from the Tuscaloosa Formation. Approximately 5 mi^2 of the shallow Citronelle aquifer contains water with chloride concentrations higher than normal for this area (greater than 20 mg/L).

Brine contamination has moved from its source laterally through the Citronelle aquifer to discharge into nearby streams and has moved vertically into underlying Hattiesburg aquifers.

Ground water which discharges into Shaws Creek contaminates the stream more noticeably at streamflows less than 10 ft^3/s. Chloride concentrations in West Bogue Chitto at streamflow less than 10 ft^3/s were higher than in the control stream. An increase in specific conductance after a small rise in discharge indicates a possible surface source of contamination in West Bogue Chitto.

Movement of brines into the deeper Hattiesburg aquifers has contaminated these aquifers in several areas in the oil field.

The results of this study has served to delineate specific areas of brine contamination and will be useful in siting sources of future domestic ground-water supplies. Additional data are needed to further define contaminant plumes, rate of contaminant movement, and geochemical reactions between the contaminant and aquifer materials. These data would allow hydrologists to more accurately predict the location, extent, and degree of contamination in the Brookhaven Oil Field.

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HYDROLOGIC DATA

Table 2.--Records of wells in the Brookhaven Oil Field

Well Number	Station Identification Number	Owner	Location Sec.	T.	R.	Altitude (ft)	Well depth (ft)	Water-bearing unit
B038	313705090330801	Albert Eutrekin	NESE36	08N	06E	500	100	121CRNL
CS01	313714090322101	Lamar Case Jr. (Spring)	SENW31	08N	07E	480	--	121CRNL
C016	313707090302901	Wayne Smith	SENW33	08N	07E	460	56	121CRNL
C017	313653090290201	C L Dunn	SESE34	08N	07E	495	50	121CRNL
C018	313652090291201	Vicki Kinsey	SWSE34	08N	07E	500	65	121CRNL
C019	313722090295801	T Smith	SENE33	08N	07E	492	63	121CRNL
C020	313754090303301	Odee Smith	NESW28	08N	07E	492	--	
C021	313856090311501	Zannie Hunt	SWNE20	08N	07E	470	40	121CRNL
C022	313854090312501	J W Hunter	NESW20	08N	07E	475	200	122MOCN (C)
C023	313808090311601	James Britt	SWNE29	08N	07E	485	300	122MOCN (C)
C024	313826090303401	James E Smith	SESW21	08N	07E	483	49	121CRNL
C025	313747090300501	Claude Britt	SESE28	08N	07E	492	60	121CRNL
C026	313853090315701	Robert Adams Jr.	SENE19	08N	07E	475	45	121CRNL
C027	313838090321601	Maxie Mathis	SWSE19	08N	07E	480	40	121CRNL
C028	313823090324401	Elmer Cockeram	NWNW30	08N	07E	465	200	122MOCN (C)
C029	313707090300001	Neil Lewis	NESE33	08N	07E	490	80	121CRNL
C030	313718090300601	J B Smith	SENE33	08N	07E	495	--	
C031	313616090301001	Herman Smith	SWNE33	08N	07E	495	60	121CRNL
C032	313706090312201	Kirby Humphries	NWSE32	08N	07E	478	100	121CRNL
C033	313706090315701	Lamar Case	NESE31	08N	07E	455	55	121CRNL
C034	313709090313701	Evonne Maxwell	NESW32	08N	07E	485	--	
C035	313714090301501	Jerry Bullock	SWNE33	08N	07E	490	70	121CRNL
C036	313700090304401	Ed B Smith	NWSW33	08N	07E	460	30	121CRNL
C037	313709090300801	Ricky Smith	NWSE33	08N	07E	478	75	121CRNL
C039	313704090310001	Alan Dale Smith	NESE32	08N	07E	495	90	121CRNL
C045	313733090322001	Clarence Allen	NWNE31	08N	07E	430	28	121CRNL
C080	313552090292801	Vivian Smith				472	118	121CRNL
F020	313550090334201	Jack B Smith	SWSW01	07N	06E	415	85	121CRNL
F021	313319090331201	Johnnie Watts	SWSE24	07N	06E	482	80	121CRNL
F022	313349090331001	Frank Jacobs Jr.	SWNE24	07N	06E	470	180	122MOCN (A)
F024	313627090331101	R.H. Williams	NENE01	07N	06E	440	87	121CRNL
F027	313418090331401	Percy Wilson	NWSE13	07N	06E	480	98	121CRNL
F028	313417090331801	Wessie Wiltcher	SWSE13	07N	06E	470	60	121CRNL
F041	313504090344301	Paul B. Smith	SWSW11	07N	06E	450	80	121CRNL
G001	313523090311001	California Co.	SWNE08	07N	07E	--	200	122MOCN (B)
G025	313600090295801	Bryant Johnston	SENE04	07N	07E	492	150	122MOCN (B)
G056	313344090312401	U L Day	SENW20	07N	07E	500	81	121CRNL
G057	313350090314201	S McFadden	SWNW20	07N	07E	495	100	121CRNL

Table 2.--Records of wells in the Brookhaven Oil Field--Continued

Well Number	Station Identification Number	Owner	Location Sec.	T.	R.	Altitude (ft)	Well depth (ft)	Water-bearing unit
G058	313512090314701	H Case	NWSW08	07N	07E	492	80	121CRNL
G059	313523090311601	Elvin Smith	NWSE08	07N	07E	495	80	121CRNL
G060	313540090320401	C Case	NENE07	07N	07E	450	100	121CRNL
G061	313542090315301	J Case Jr.	NWNW08	07N	07E	456	85	121CRNL
G062	313541090315301	J Case Jr.	NWNW08	07N	07E	458	45	121CRNL
G063	313433090312801	C A Watts	SENW17	07N	07E	480	65	121CRNL
G065	313347090312101	Aaron Acord	SWNE20	07N	07E	492	182	122MOCN (A)
G066	313618090321101	J McCurley	SWNE06	07N	07E	460	50	121CRNL
G067	313433090315701	H R Owens	SENE18	07N	07E	475	150	122MOCN (A)
G068	313347090312102	Aaron Accord	SWNE20	07N	07E	492	308	122MOCN (B)
G069	313512090315201	D Ballard	SWSW08	07N	07E	485	85	121CRNL
G071	313622090321201	Rayburn Bowman	SWNE06	07N	07E	440	256	122MOCN (C)
G072	313630090292201	Dale Smith	SWNW03	07N	07E	485	80	121CRNL
G073	313622090294601	Art Ostman	SWNW03	07N	07E	500	120	121CRNL
G074	313335090295601	Jack Hostetler	NESE21	07N	07E	432	120	122MOCN (A)
G075	313339090395501	Gene Simmons	NESE21	07N	07E	433	100	122MOCN (A)
G076	313616090294401	G Adkins	NWSW03	07N	07E	495	--	
G077	313616090293801	Gary Norton	NWSW03	07N	07E	492	--	
G081	313602090295701	B Jones	SESE04	07N	07E	483	80	121CRNL
G082	313605090293201	Clyde Norton	NESW03	07N	07E	487	45	121CRNL
G083	313552090292401	Jimmy Dale Smith	SESW03	07N	07E	470	50	121CRNL
G084	313628090303301	J P Drummand	SENW04	07N	07E	495	--	
G085	313628090310101	T J Smith	SENE05	07N	07E	485	100	121CRNL
G086	313626090311001	M R Smith	SWNE05	07N	07E	485	65	121CRNL
G087	313612090311001	Jinnie Reeves	NWSE05	07N	07E	425	60	121CRNL
G088	313559090311501	Willis Smith	SWSE05	07N	07E	500	80	121CRNL
G089	313629090304001	Charles E Maxwell	SWNW04	07N	07E	493	70	121CRNL
G090	313632090305101	Dewey Smith	NWNW04	07N	07E	498	50	121CRNL
G091	313227090322801	Robert Watts	SESW30	07N	07E	493	65	121CRNL
G095	313341090303201	Glen Thompson	SENW21	07N	07E	460	30	121CRNL
G097	313345090322201	Versie King	SWNE19	07N	07E	500	175	122MOCN (A)
G098	313411090322301	John C Thomas	SWSW17	07N	07E	490	95	121CRNL
G099	313429090313001	Doug Warren	NESW17	07N	07E	472	48	121CRNL
G100	313518090314301	Earl Case	MWSW08	07N	07E	493	90	121CRNL
G104	313452090315001	Edgar Lee Smith	NWNW17	07N	07E	482	65	121CRNL

Table 2.--Records of wells in the Brookhaven Oil Field--Continued

Well Number	Station Identification Number	Owner	Location Sec.	T.	R.	Altitude (ft)	Well depth (ft)	Water-bearing unit
G106	313357090315501	Wendell Laird	NENE19	07N	07E	497	100	121CRNL
G107	313443090320001	Billy Reed	NENE18	07N	07E	475	120	121CRNL
G109	313537090312101	Willie C Case	SWNE08	07N	07E	460	79	121CRNL
G110	313558090304501	Charles W Smith	SWSW04	07N	07E	495	100	121CRNL
G111	313627090320501	Jeane Meek	NENE06	07N	07E	450	220	122MOCN (C)
G114	313536090320401	Charles Case	NENE07	07N	07E	450	84	121CRNL
G117	313550090324901	William Buddy Case	SWSW06	07N	07E	431	73	121CRNL
G118	313407090315501	Eugene Case	SESE18	07N	07E	474	69	121CRNL
G119	313545090312701	Hosie Smith	NENW08	07N	07E	475	98	121CRNL
G121	313525090312201	Felton Case	SENW08	07N	07E	502	80	121CRNL
G125	313542090301001	Betty McDonald	NENE09	07N	07E	472	30	121CRNL
G126	313516090312301	Allen Smith	NESW08	07N	07E	505	97	121CRNL
G127	313534090322001	Francis M. Case	SWNE07	07N	07E	430	70	121CRNL
G128	313407090315001	Debra Case	SWSW17	07N	07E	474	100	121CRNL
G130	313550090312501	Jimmie King	NENW08	07N	07E	485	65	121CRNL
G131	313522090301501	John Pounds	NWSE09	07N	07E	425	140	122MOCN (B)
G132	313414090303801	Jane Case	SWSW16	07N	07E	462	34	121CRNL
G133	313444090314601	Rosy Reed	SWNW17	07N	07E	480	120	121CRNL
G134	313452090315601	Danial Brogden	NENE18	07N	07E	462	--	
G135	313500090315301	W C Little	SWSW08	07N	07E	475	140	122MOCN (A)
G136	313522090322901	Nettie Case	SWSW08	07N	07E	468	60	121CRNL
G137	313530090322301	Maurice Lanny Case	SWNE07	07N	07E	480	75	121CRNL
G138	313532090324501	Dallas Anding	SWNW07	07N	07E	490	85	121CRNL
G139	313536090322601	Curtis Nations	SWNW07	07N	07E	495	93	121CRNL
G140	313539090324401	Winnie Smith	NWNW07	07N	07E	485	80	121CRNL
G141	313558090325501	Dykes A. Britt	NENE12	07N	07E	463	70	121CRNL
G142	313440090294201	T. Banks	SWNW15	07N	07E	463	40	121CRNL
G143	313341090312501	Harold Case	SENE19	07N	07E	497	80	121CRNL
G144	313334090305901	Paul M Lewis	NESW20	07N	07E	481	100	121CRNL
G176	313357090310801	A C Lofton	NWNE20	07N	07E	482	55	121CRNL
G177	313401090311501	W K Wilkinson	NWNE20	07N	07E	495	120	121CRNL
G178	313631090312001	Sam C Smith	NWNE05	07N	07E	468	60	121CRNL
G179	313357090312101	John Jordan	NWNE20	07N	07E	492	80	121CRNL
G180	313349090312101	Aaron Acord	SWNE20	07N	07E	490	147	122MOCN (A)
G182	313356090312101	John Jordan	NWNE20	07N	07E	492	140	122MOCN (A)

121CRNL Citronelle Formation
122MOCN (A) Layer A of the Hattiesburg Formation
122MOCN (B) Layer B of the Hattiesburg Formation
122MOCN (C) Layer C of the Hattiesburg Formation

Table 3.--Records of control wells in northwestern Lincoln County

Map number	Well number	Station identification number	Owner	Location Sec.	T.	R.	Altitude (ft)	Well depth (ft)	Water-bearing unit
1	B042	313743090363801	Kent Calcote	SENW33	08N	06E	480	40	121CRNL
2	B043	313736090350801	Donald Durr	SESE28	08N	06E	480	110	121CRNL
3	F036	313430090352401	Mrs. J.W. Watts	NWSE15	07N	06E	460	100	121CRNL
4	F037	313610090354201	Charles Smith	NESW03	07N	06E	460	55	121CRNL
5	F038	313258090343401	Jaudon Smith	SENW26	07N	06E	475	72	121CRNL
6	F039	313206090353901	Ruth Watts	SENW34	07N	06E	485	80	121CRNL
7	F040	313128090333701	Steve Case	SESW36	07N	06E	480	120	121CRNL
8	F041	313504090344301	Paul B. Smith	SWSW11	07N	06E	450	80	121CRNL
9	G175	313218090292401	Stanley Smith	NENW34	07N	07E	450	70	121CRNL
10	L027	313058090314301	Paul Porter	NWSW05	06N	07E	485	80	121CRNL

121CRNL-Citronelle Formation

Table 4.--Location and drainage area of surface-water sampling sites

Site number	Site identification number	Station name	Location Lat.	Long.	Drainage area(mi^2)
		Copiah county			
1	07290935	Sweetwater Creek nr Midway, Ms.	314208	0903631	11.25
		Lincoln county			
2	02490241	West Bogue Chitto Trib. No. 1	313458	0903015	1.47
3	02490245	West Bogue Chitto Trib. No. 2	313402	0903030	1.97
4	02490246	West Bogue Chitto nr Zetus, Ms.	313340	0902943	18.51
5	02490248	Doolittle Creek nr Zetus, Ms.	313308	0903006	4.92
6	07290217	Bayou Pierre nr Old Red Star, Ms.	313907	0903224	4.30
7	07290218	Bayou Pierre Trib. at Old Red Star, Ms.	314010	0903127	2.96
8	07291217	Shaws Creek Trib. nr Red Star, Ms.	313732	0903117	1.68
9	07291223	Shaws Creek Trib. no. 2 nr Red Star, Ms.	313626	0903206	1.26
10	07291225	Shaws Creek nr Vaughn, Ms	313559	0903308	9.01
11	07291229	Shaws Creek Trib. no. 3 nr Red Star, Ms.	313540	0903336	4.18
12	07291230	Shaws Creek nr Red Star, Ms.	313540	0903348	13.83

Table 5.--Water-quality data for the Citronelle aquifer in the Brookhaven Oil Field

[Dissolved constituents given in milligrams per liter, except as indicated]

Well number	Well depth (ft)	Date of collection	Specific conductance (uS/cm)	pH (units)	Temperature (Deg C)	Dissolved solids, residue at 180 Deg C	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Alkalinity as CaCO3	Sulfate (SO4)	Chloride (Cl)	Bromide (Br)	Strontium (Sr) (ug/L)
B038	100	08/04/83	86	5.1	20.0	51	2.1	0.8	13	1.2	10	0.7	18	0.13	10
CS01	--	08/02/83	56	5.2	--	--	--	--	7.7	--	--	--	10	--	--
C016	56	07/27/83	52	5.1	19.5	--	--	--	5.3	--	--	--	8.1	--	--
C017	50	07/26/83	92	5.5	20.0	--	--	--	11	--	--	--	21	--	--
C018	65	07/26/83	170	5.5	20.0	--	--	--	18	--	--	--	42	--	--
C019	63	07/27/83	615	5.5	21.0	422	24	8.9	73	1.2	15	7.4	170	1.70	75
C020	--	08/03/83	34	5.0	21.5	--	--	--	3.5	--	--	--	4.7	--	--
C021	40	08/04/83	56	5.4	19.5	--	--	--	5.6	--	--	--	7.5	--	--
C024	49	08/03/83	80	5.4	21.5	--	--	--	14	--	--	--	13	--	--
C025	60	08/04/83	220	4.8	21.0	--	--	--	28	--	--	--	57	--	--
C026	45	08/04/83	43	5.1	20.0	--	--	--	2.8	--	--	--	3.2	--	--
C027	40	08/04/83	--	5.2	20.5	--	--	--	8.7	--	--	--	9.1	--	--
C029	80	07/26/83	100	5.4	20.5	92	5.9	2.0	8.0	1.2	9	.5	23	.20	48
C030	--	07/28/83	326	5.4	19.5	223	12	4.4	42	.9	10	2.3	90	.74	45
C031	60	07/27/83	345	5.2	22.5	--	--	--	35	--	--	--	95	--	--
C032	100	07/29/83	52	4.9	20.0	--	--	--	6.1	--	--	--	7.8	--	--
C033	55	07/29/83	38	5.2	21.0	--	--	--	3.8	--	--	--	4.6	--	--
C034	--	07/29/83	52	5.0	20.5	--	--	--	7.2	--	--	--	8.8	--	--
C035	70	07/27/83	360	5.4	20.0	303	13	4.7	41	1.9	5	.5	100	.94	60
C036	30	07/27/83	120	4.4	19.5	--	--	--	10	--	--	--	0.2	--	--
C037	75	08/04/83	52	5.2	20.5	70	4.8	1.4	7.3	.9	9	.3	17	.19	20
C039	90	07/28/83	32	5.4	20.0	36	1.5	.6	3.1	.9	7	.2	2.6	.04	9
C045	28	09/05/84	80	5.3	21.5	64	3.5	3.3	4.7	1.4	9	8.6	7.9	.02	53
C080	118	08/03/83	205	5.2	20.5	--	--	--	25	--	--	--	51	--	--
F020	85	07/28/83	27	5.4	19.5	--	--	--	2.6	--	--	--	3.4	--	--
F021	80	08/05/83	99	5.0	21.0	78	3.3	1.4	12	1.1	8	.2	22	.17	24
F024	87	12/02/83	36	5.3	19.5	35	1.5	.5	4.1	.9	11	1.0	6.0	.07	10
F027	98	08/04/83	56	4.8	22.0	--	--	--	6.5	--	--	--	9.2	--	--
F028	60	08/04/83	85	5.3	22.0	--	--	--	12	--	--	--	16	--	--
F041	80	09/05/84	48	5.2	20.5	48	2.5	1.1	3.5	1.0	7	.3	5.3	.02	20
G056	81	05/26/82	860	4.8	20.0	--	30	9.6	120	--	--	4.0	260	--	--

Table 5.--Water-quality data for the Citronelle aquifer in the Brookhaven Oil Field--Continued

Well number	Well depth (ft)	Date of col-lec-tion	Spe-cific con-duct-ance (uS/cm)	pH (units)	Temper-ature (Deg C)	Dissolved solids, residue at 180 Deg C	Cal cium (Ca)	Mag nesi-um (Mg)	Sodium (Na)	Potas-sium (K)	Alka-linity as CaCO3	Sul-fate (SO4)	Chlo-ride (Cl)	Bromide (Br)	Stron-tium (Sr) (ug/L)
G056	81	05/07/84	1080	4.9	21.0	690	38	14	130	1.8	4	5.1	330	2.10	670
G057	100	11/04/81	38	--	--	--	--	--	--	--	--	--	2.5	--	--
G057	100	05/26/82	38	--	20.0	--	1.2	.4	3.9	--	--	1.0	4.4	.10	5
G058	80	11/05/81	160	--	--	--	--	--	--	--	--	--	40	--	--
G058	80	05/26/82	175	4.8	19.5	--	4.8	1.8	18	--	--	2.0	42	--	--
G059	80	11/04/81	330	--	--	--	--	--	--	--	--	--	88	--	--
G059	80	05/26/82	355	4.8	20.0	--	9.3	4.3	55	--	--	1.0	97	--	--
G060	100	11/06/81	430	--	--	--	--	--	--	--	--	--	120	--	--
G060	100	05/25/82	455	5.2	20.5	--	4.9	1.9	64	--	--	4.0	120	--	--
G061	85	11/06/81	133	--	--	--	--	--	--	--	--	--	30	--	--
G061	85	05/25/82	131	5.1	20.0	--	4.8	1.8	14	--	--	1.0	32	.33	27
G062	45	11/06/81	800	--	--	--	--	--	--	--	--	--	260	--	--
G062	45	05/25/82	895	4.6	20.5	--	2.9	3.7	170	--	--	2.0	270	.94	92
G062	45	07/18/85	455	5.2	21.0	239	.9	1.1	77	.9	8	2.1	120	.45	24
G063	65	11/04/81	176	--	--	--	--	--	--	--	--	--	48	--	--
G063	65	05/25/82	170	4.7	19.0	--	3.1	2.5	22	--	--	2.0	42	--	--
G066	50	11/05/81	190	--	--	--	--	--	--	--	--	--	50	--	--
G066	50	06/02/82	238	4.4	21.0	--	5.2	.8	30	--	--	5.0	66	--	--
G069	85	05/26/82	107	--	--	--	--	--	--	--	--	--	21	--	--
G072	80	07/27/83	54	5.0	19.5	--	--	--	5.3	--	--	--	7.8	--	--
G073	120	08/02/83	50	5.3	--	--	--	--	5.8	--	--	--	6.5	--	--
G076	--	08/02/83	51	5.3	20.0	--	--	--	6.8	--	--	--	6.2	--	--
G077	--	08/02/83	187	4.8	20.0	--	--	--	22	--	--	--	47	--	--
G081	80	08/03/83	565	5.1	20.0	362	16	5.8	77	.4	5	3.8	160	1.30	54
G082	45	08/03/83	119	5.4	--	--	--	--	14	--	--	--	29	--	--
G083	50	08/03/83	67	5.1	20.0	--	--	--	8.4	--	--	--	11	--	--
G084	--	07/28/83	123	4.8	20.0	--	--	--	15	--	--	--	30	--	--
G085	100	07/27/83	220	--	--	--	--	--	28	--	--	--	54	--	--
G086	65	07/27/83	270	5.4	21.5	--	--	--	37	--	--	--	68	--	--
G087	60	07/27/83	49	5.2	21.5	--	--	--	5.7	--	--	--	9.1	--	--

Table 5.--Water-quality data for the Citronelle aquifer in the Brookhaven Oil Field--Continued

Well number	Well depth (ft)	Date of collection	Specific conductance (uS/cm)	pH (units)	Temperature (Deg C)	Dissolved solids, residue at 180 Deg C	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Alkalinity as CaCO3	Sulfate (SO4)	Chloride (Cl)	Bromide (Br)	Strontium (Sr) (ug/L)
G088	80	07/27/83	34	5.0	20.5	--	--	--	4.2	--	--	--	5.5	--	--
G089	70	07/28/83	220	4.6	21.5	--	--	--	26	--	--	--	59	--	--
G090	50	07/28/83	180	--	--	--	--	--	26	--	--	--	33	--	--
G091	65	08/05/83	220	5.6	23.0	--	--	--	42	--	--	--	44	--	--
G095	30	08/05/83	48	5.8	21.5	--	--	--	6.0	--	--	--	9.5	--	--
G098	95	08/04/83	193	4.9	--	--	--	--	32	--	--	--	41	--	--
G099	48	11/04/81	209	--	--	--	--	--	--	--	--	--	56	--	--
G099	48	05/25/82	261	4.7	20.0	--	9.8	5.7	27	--	--	2.0	74	--	--
G099	48	08/04/83	408	5.4	--	--	--	--	36	--	--	--	110	--	--
G100	90	08/03/83	183	5.8	22.0	--	--	--	24	--	--	--	49	--	--
G104	65	12/01/83	105	5.4	--	--	--	--	17	--	--	--	25	--	--
G106	100	08/03/83	259	6.3	--	--	--	--	34	--	--	--	63	--	--
G107	120	08/03/83	2180	5.7	21.5	1670	86	42	250	7.7	--	3.7	710	3.13	780
G107	120	11/30/83	2200	5.0	19.5	1380	92	45	280	8.0	13	3.9	730	4.60	890
G109	79	07/29/83	236	6.0	20.0	--	--	--	32	--	--	--	56	--	--
G110	100	07/28/83	75	--	20.5	--	--	--	9.8	--	--	--	19	--	--
G114	84	12/01/83	715	5.1	19.5	395	15	6.4	99	2.9	10	1.7	210	.90	95
G114	84	07/18/85	583	5.1	19.0	333	12	5.0	85	2.8	7	.5	170	.84	73
G117	73	07/27/83	116	--	21.0	--	--	--	15	--	--	--	33	--	--
G117	73	07/25/85	125	5.0	19.0	--	--	--	14	--	--	--	31	--	--
G118	69	07/27/83	420	--	--	--	--	--	59	--	--	--	120	--	--
G118	69	11/30/83	420	5.2	19.5	236	10	3.8	57	.7	11	.8	120	.77	150
G119	98	08/01/83	118	--	21.0	--	--	--	15	--	--	--	28	--	--
G121	80	08/01/83	222	--	--	--	--	--	36	--	--	--	55	--	--
G125	30	07/29/83	115	5.8	20.0	--	--	--	16	--	--	--	15	--	--
G126	97	07/27/83	220	5.1	20.0	--	--	--	26	--	--	--	57	--	--
G127	70	07/27/83	400	5.0	--	--	--	--	64	--	--	--	130	--	--
G127	70	12/01/83	462	5.0	20.0	260	11	4.7	60	1.8	10	12	130	.56	64
G128	100	07/27/83	950	4.5	20.5	711	40	10	150	1.4	3	.6	340	2.30	1000
G130	65	07/29/83	70	5.5	22.5	--	--	--	11	--	--	--	20	--	--

Table 5.--Water-quality data for the Citronelle aquifer in the Brookhaven Oil Field--Continued

Well number	Well depth (ft)	Date of collection	Specific conductance (uS/cm)	pH (units)	Temperature (Deg C)	Dissolved solids, residue at 180 Deg C	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Alkalinity as CaCO3	Sulfate (SO4)	Chloride (Cl)	Bromide (Br)	Strontium (Sr) (ug/L)
G132	34	12/01/83	149	5.1	18.5	--	--	--	19	--	--	--	41	--	--
G133	120	11/30/83	47	5.3	19.5	--	--	--	5.6	--	--	--	6.4	--	--
G134	--	12/01/83	122	--	--	--	--	--	19	--	--	--	29	--	--
G136	60	12/02/83	305	4.9	18.5	171	11	5.2	33	1.9	10	0.4	84	0.42	66
G137	75	12/01/83	325	5.0	19.5	180	9.7	3.9	41	1.4	10	.4	93	.38	50
G138	85	12/02/83	220	5.1	20.0	--	--	--	23	--	--	--	59	--	--
G139	93	12/02/83	535	4.9	20.0	305	22	9.8	52	2.8	9	.4	160	.44	130
G139	93	07/17/85	505	4.8	20.0	282	18	8.6	54	3.0	4	.4	140	.32	110
G140	80	12/02/83	419	4.9	20.0	--	--	--	50	--	--	--	120	--	--
G141	70	12/02/83	134	4.9	19.5	86	4.6	2.5	15	1.2	9	.2	36	.14	33
G141	70	07/25/85	133	5.0	20.0	85	4.2	2.4	15	1.3	5	.2	34	.12	32
G142	40	05/07/84	23	--	--	--	--	--	2.9	--	--	--	3.7	--	--
G143	80	05/07/84	120	5.7	20.5	--	--	--	16	--	--	--	26	--	--
G144	100	05/07/84	58	--	20.0	--	--	--	7.0	--	--	--	9.2	--	--
G176	55	09/05/84	58	4.9	21.0	44	1.7	1.1	6.4	.5	5	.6	11	.05	11
G177	120	09/05/84	29	5.2	20.0	--	--	--	2.8	--	--	--	3.0	--	--
G178	60	09/05/84	33	5.0	20.0	27	.7	.7	4.0	.7	7	.2	5.1	.03	10
G179	80	09/06/84	2570	10.3	19.0	1370	170	15	330	7.0	10	4.0	830	6.60	1900

Table 6.--Water-quality data for the Hattiesburg aquifers in the Brookhaven Oil Field

[Dissolved constituents given in milligrams per liter, except as indicated]

Well number	Date of collection	Specific conductance (uS/cm)	pH (units)	Temperature (Deg C)	Dissolved solids, residue at 180 Deg C	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Alkalinity as CaCO3	Sulfate (SO4)	Chloride (Cl)	Bromide (Br)	Strontium (Sr) (ug/L)
C022	08/04/83	50	5.0	21.0	--	--	--	6.1	--	--	--	8.5	--	--
C023	08/03/83	58	5.4	21.0	65	3.7	1.4	4.9	1.8	18	3.9	3.9	0.03	48
C028	08/04/83	80	5.7	20.5	--	--	--	5.4	--	--	--	3.0	--	--
F022	08/05/83	42	4.9	20.0	--	--	--	4.7	--	--	--	7.0	--	--
F029	08/04/83	52	5.2	20.5	--	--	--	5.1	--	--	--	7.2	--	--
G001	09/15/49	--	5.6	--	--	.8	2.3	--	--	--	2.0	13	--	--
G001	02/17/55	--	5.4	--	--	.8	7.0	--	--	--	12	21	--	--
G001	04/02/68	--	5.7	21.0	95	5.0	1.3	20	.6	--	1.4	34	--	--
G025	08/02/83	60	5.5	20.5	--	--	--	3.8	--	--	--	3.7	--	--
G065	06/01/82	3290	4.3	19.5	--	100	20	490	--	--	7.0	980	5.57	2500
G065	11/30/83	2900	4.7	20.0	1690	97	20	460	5.9	6	.3	940	6.80	2600
G067	11/04/81	85	--	--	--	--	--	--	--	--	--	15	--	--
G067	06/02/82	49	--	20.5	--	2.9	1.2	5.0	--	--	1.0	6.5	--	--
G068	06/01/82	139	5.9	20.0	--	7.4	2.6	13	--	--	3.0	20	--	--
G068	11/30/83	150	6.0	20.0	--	--	--	13	--	--	--	30	--	--
G071	11/05/81	97	--	--	--	--	--	--	--	--	--	2.7	--	--
G074	07/28/83	44	5.2	21.5	--	--	--	3.9	--	--	--	3.6	--	--
G075	07/28/83	42	5.6	20.5	--	--	--	3.8	--	--	--	3.7	--	--
G097	08/04/83	65	5.5	20.0	--	--	--	5.8	--	--	--	8.0	--	--
G111	07/28/83	65	--	21.0	--	--	--	13	--	--	--	3.2	--	--
G131	07/26/83	52	5.5	21.0	38	1.8	.6	5.9	.7	13	.3	8.9	.12	14
G135	12/01/83	43	5.6	19.5	40	2.1	.8	5.4	1.1	17	1.0	5.1	.07	17
G177	09/05/84	29	5.2	20.0	--	--	--	2.8	--	--	--	3.0	--	--
G180	09/06/84	265	5.0	19.5	180	13	5.1	25	1.6	7	.2	75	.50	91
G181	09/06/84	400	5.2	20.0	--	--	--	47	--	--	--	120	--	--
G182	09/05/84	32	5.3	20.0	34	1.5	.6	3.3	.8	10	.5	3.2	.03	13

Table 7.--Water-quality data for the Citronelle aquifer at control wells in northwestern Lincoln County

[Dissolved constituents given in milligrams per liter, except as indicated]

Well number	Date of col-lec-tion	Spe-cific con-duct-ance (uS/cm)	pH (Units)	Temper-ature (Deg C)	Dissolved solids, residue at 180 Deg C	Cal cium (Ca)	Mag nesi-um (Mg)	Sodium (Na)	Potas-sium (K)	Alka-linity as CaCO3	Sul-fate (SO4)	Chlo-ride (Cl)	Bromide (Br)	Stron-tium (Sr) (ug/L)	Ba-rium (Ba) (ug/L)
B042	8/30/84	58	5.4	20.0	52	1.6	0.6	8.0	0.2	8	<0.2	9.4	0.05	8	32
B043	8/30/84	38	5.4	20.0	38	1.3	.6	4.4	.6	8	.4	5.4	.04	16	31
F036	8/30/84	40	5.2	21.5	38	1.0	.6	4.6	.6	7	<.2	6.4	.02	8	29
F037	8/29/84	25	5.4	21.5	30	.9	.5	2.7	.5	7	<.2	3.4	.02	9	24
F038	9/04/84	32	5.3	20.0	34	.8	.5	4.3	.4	7	<.2	5.0	.03	6	20
F039	9/04/84	27	5.1	22.0	28	.9	.5	3.1	.5	8	<.2	3.5	.02	9	23
F040	9/04/84	48	5.3	20.0	42	1.6	.7	6.7	.4	11	<.2	6.5	.06	12	31
F041	9/05/84	48	5.2	20.5	48	2.5	1.1	3.5	1.0	7	.3	5.3	.02	20	50
G175	9/05/84	86	4.9	19.5	56	2.0	1.1	12	.5	6	<.2	21	.17	17	43
L027	9/05/84	84	5.1	19.5	66	1.4	.6	14	1.0	11	.6	19	.12	14	40

Table 8.--Water-quality data for the control stream in Copiah County and for streams that drain the Brookhaven Oil Field in Lincoln County

[Dissolved constituents given in milligrams per liter, except as indicated]

Site number	Date of collection	Time (Hours)	Streamflow (ft^3/s)	Specific conductance (uS/cm)	pH	Temperature (Deg C)	Dissolved solids, residue at 180 Deg C	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Alkalinity as CaCO3	Sulfate (SO4)	Chloride (Cl)	Bromide (Br)	Strontium (Sr) (ug/L)
							Copiah County									
1	11/28/83	1500	4.63	38	6.2	12.5	51	--	--	1.5	--	--	--	3.0	--	--
1	03/06/84	1315	60.5	30	6.1	10.0	--	--	--	1.9	--	--	--	2.5	--	--
1	03/07/84	1140	20.1	33	6.0	8.5	50	1.7	0.9	2.3	1.2	7	4.9	2.8	0.01	19
1	05/17/84	1015	.35	56	5.9	17.5	51	--	--	4.1	--	--	--	5.5	--	--
1	07/12/84	1300	.25	42	6.0	24.0	49	--	--	2.3	--	--	--	3.5	--	--
1	07/13/84	1540	24.0	30	6.0	23.0	--	--	--	1.1	--	--	--	5.0	--	--
1	09/12/84	1415	.17	55	6.0	22.5	46	3.0	1.3	5.0	1.1	16	.5	6.0	.05	32
							Lincoln County									
2	04/04/84	1330	--	125	5.7	16.5	--	--	--	16	--	--	--	31	--	--
3	04/04/84	1225	1.97	44	5.9	16.5	--	--	--	4.1	--	--	--	5.9	--	--
4	09/12/83	1100	.21	105	6.4	23.5	71	--	--	8.7	--	--	--	14	--	--
4	11/21/83	1200	1.00	88	6.2	12.0	67	--	--	10	--	--	--	16	--	--
4	11/28/83	1215	18.0	63	6.1	13.5	58	--	--	4.9	--	--	--	9.8	--	--
4	03/08/84	1005	16.3	57	5.9	10.0	53	2.6	1.1	6.0	1.3	7	6.2	11	.07	33
4	05/16/84	1540	.61	97	6.1	20.0	76	--	--	9.2	--	--	--	16	--	--
4	09/12/84	1730	.11	106	6.4	23.5	72	6.1	1.9	8.8	2.6	29	1.1	14	.09	70
5	04/04/84	1030	10.1	32	5.8	16.0	--	--	--	2.6	--	--	--	3.5	--	--
5	09/12/84	1550	.42	52	5.8	22.0	38	--	--	6.1	--	--	--	8.2	--	--

Table 8.--Water-quality data for the control stream in Copiah County and for streams that drain the Brookhaven Oil Field in Lincoln County--Continued

[Dissolved constituents given in milligrams per liter, except as indicated]

Site number	Date of collection	Time (Hours)	Streamflow (ft^3/s)	Specific conductance (uS/cm)	pH	Temperature (Deg C)	Dissolved solids, residue at 180 Deg C	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Alkalinity as CaCO3	Sulfate (SO4)	Chloride (Cl)	Bromide (Br)	Strontium (Sr) (ug/L)
							Lincoln County (continued)									
6	03/09/84	1445	4.36	31	6.0	13.0	--	--	--	2.8	--	--	--	3.6	--	--
6	09/12/84	1025	.30	45	5.9	22.0	40	--	--	4.4	--	--	--	7.0	--	--
7	05/09/84	1320	4.00	43	5.9	12.0	--	--	--	4.8	--	--	--	7.3	--	--
7	09/12/84	1215	.22	45	6.1	22.0	39	--	--	3.9	--	--	--	5.8	--	--
8	03/09/84	1115	.75	181	5.5	12.5	--	--	--	22	--	--	--	47	--	--
8	09/13/84	0845	.18	340	5.4	19.5	235	--	--	43	--	--	--	96	--	--
9	03/09/84	0940	1.74	92	5.7	12.0	--	--	--	11	--	--	--	23	--	--
9	09/13/84	1015	.20	120	5.5	19.0	89	--	--	16	--	--	--	32	--	--
10	03/08/84	1420	12.6	82	6.2	12.5	--	--	--	9.5	--	--	--	17	--	--
10	09/03/84	1140	1.77	169	6.1	22.0	119	--	--	23	--	--	--	46	--	--
11	03/08/84	1220	7.96	75	6.0	12.0	--	--	--	8.5	--	--	--	18	--	--
11	09/13/84	1515	2.33	140	6.2	21.5	108	--	--	17	--	--	--	37	--	--
12	09/12/84	1400	6.90	179	6.4	23.5	93	--	--	18	--	--	--	37	--	--
12	11/21/83	1445	7.78	119	5.9	15.5	88	--	--	13	--	--	--	28	--	--
12	03/06/84	1040	81.5	46	6.2	11.0	--	--	--	4.2	--	--	--	7.2	--	--
12	03/07/84	1355	32.2	63	6.1	12.0	37	2.5	1.2	6.8	1.1	7	4.0	13	0.07	30
12	05/17/84	0830	7.82	135	6.2	17.5	87	--	--	17	--	--	--	36	--	--
12	07/12/84	1200	5.69	140	6.3	27.5	112	--	--	19	--	--	--	37	--	--
12	09/13/84	1350	4.34	142	6.4	25.0	99	4.8	2.2	18	1.2	7	.6	39	.22	51

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