Water Resources of the Pascagoula Area Mississippi

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WATER RESOURCES OF THE PASCAGOULA AREA, MISSISSIPPI

By Edward J. Harvey, Harold G. Golden, and Horace G. Jeffery

ABSTRACT

The Pascagoula area, as defined for this study, includes all of Jackson and George Counties, Miss., and a contiguous part of Mobile County, Ala. Sufficient water is available in the area to meet requirements for future developments that may utilize large quantities of water. The average streamflow of the Pascagoula River is about 16,000 cfs (cubic feet per second) or 10,000 mgd (million gallons per day). Total withdrawal of surface and ground water was 60 mgd (1958). An additional 80 mgd is withdrawn from a stream in the area for use in Mobile, Ala. The quantity of water now being withdrawn from supply wells and surface sources is small, when compared to the total that may be obtained in the area through proper utilization of these resources.

An additional water supply of 100 mgd or more can be obtained from the Pascagoula or Escatawpa River for use in the Bayou Casotte industrial area. This industrial area is on the coast, where both rivers are penetrated by salt water; therefore, a water supply from either of these rivers must be obtained upstream from the coastal area. Except for brief periods during hurricane tides, it is unlikely that salt water will penetrate more than 20 miles up the Pascagoula River or 18 miles up the Escatawpa River.

Mississippi water law requires that no water be appropriated from a stream for consumptive use when the flow is less than the legally defined average minimum flow. Water withdrawn from the Pascagoula or Escatawpa River and transported to the Bayou Casotte industrial area would be, in effect, a consumptive use. Storage facilities would be required to assure a continuous supply of water during periods when withdrawals cannot be made owing to legal restrictions. The 1962 Mississippi Legislature is considering an amendment to the water law that will modify this restriction.

The smaller streams of the area have high base flows. A few of these streams are capable of supplying 25 mgd or more, and, if the use is nonconsumptive, no storage will be necessary to assure this supply even during an extended drought. Base flows of several streams exceed 0.4 cfs per square mile during severe droughts. These are among the highest yielding streams in the State.

Surface water in the area above the zones of salt-water penetration is low in dissolved solids. The dissolved-solids content is fairly constant except for the main stem Pascagoula River and Red Creek, which are affected at times by the addition of brine from oil fields. Most of the water in the streams has high color, and some has a low pH. Treatment of this water would be required to meet the general requirements for industrial use. The impoundment of surface water in a reservoir normally would have only a minor effect on the quality of the water. However, impoundment of water containing small amounts of oil-field brine may result in the concentration of more mineralized water in the deeper part of a reservoir.

The ground-water supply is contained in rocks of early Miocene to Recent age. Substantial quantities of water remain to be developed from the Graham Ferry Formation of Pliocene age and the Pascagoula Formation of late Miocene age. The chief aquifer developed for public and industrial supplies is in the Graham Ferry Formation, which consists of 50 to 100 feet of fine to coarse sand. The coefficient of transmissibility, which ranges from 14,000 to 54,000 gpd (gallons per day) per foot at three well fields in the area, is indicative of variations in the texture and thickness of the aquifer. In 1958, the average use of water from this aquifer totaled 6.6 mgd. The yield of the aquifer probably can be more than doubled without impairment of the quality of the water by installing additional pumping facilities at some distance from existing well fields.

The Citronelle Formation, a layer of sand and gravel as much as 100 feet thick, blankets the high ridges and contains a large quantity of water that not only supplies the farm needs but, equally important, sustains the base flow of the streams draining the area. Where the Citronelle Formation has been eroded away in the uplands, gray clay and silt of the Pascagoula and the Graham Ferry Formations are exposed in the valleys. Near the coast, the Citronelle Formation is buried beneath 100 feet of fossiliferous clay and sand. In this area, from 75 to 100 feet of coarse sand containing a large quantity of water in storage is virtually unexploited. The chief danger in future development of this sand is the possible encroachment of saline water from the lower Escatawpa and Pascagoula Rivers and the further possibility that more mineralized water may move up the dip from the south. If proper development techniques, including reinjection, are applied, supplies of several million gallons per day can be withdrawn perennially from the sand.

An area of large ground-water reserves is in the terrace lying between the Pascagoula and Escatawpa Rivers, where 1 million acre-feet (300 billion gallons) of water are estimated to be in storage. In this area, from 60 to 100 feet of older alluvial material underlies the surface. A large part of the area lies north of the farthest known penetration of salt water in the Pascagoula River; hence the likelihood for salt-water encroachment is remote. Wells capable of yielding from 200 to 500 gpm each can be drilled in many parts of the area. Artificial recharge by wells, spreading pits, or other means is not practiced in Jackson County. The terrace is well suited to the development of several million gallons of water per day, and this quantity could be substantially increased and maintained, if the aquifer is replenished by artificial recharge.

INTRODUCTION

Fresh water is an abundant and important natural resource in the Pascagoula area. The municipal supplies are obtained from wells, and industrial supplies are obtained from both surface-water and ground-water sources. Industrial use of water has expanded greatly during recent years, and, as population has increased, municipal use of water also has increased.

An engineering survey prepared in 1956 indicated that a comprehensive study of the water resources would be an important aid to industrial growth. The Jackson County Board of Supervisors and Jackson County Port Authority in the spring of 1958 entered into a cooperative agreement with the U.S. Geological Survey to inventory the water resources of the area (fig. 1). In July 1958 a program was

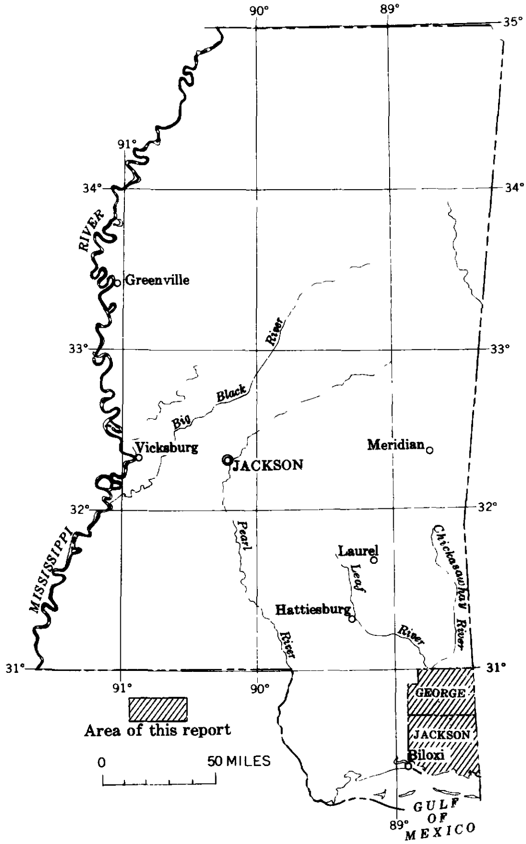

FIGURE 1.—Index map of the Pascagoula area, Mississippi.

organized for the collection and evaluation of basic data on availability and quality of surface and ground waters.

The purpose of this report is to present an evaluation of water-resources data collected in the area. The availability of surface water for future development was determined by statistical study of streamflow data, by analyses of data related to salt-water intrusion in tidal estuaries, and by application of the existing legal restrictions concerning withdrawal of water from streams. The relationship of ground-water development to decline in water levels is given, and an estimate is made of declines to be anticipated as demand increases.

Field data were collected by James W. Hudson, Fayne D. Edwards, and Thad N. Shows. The late Robert K. Butts contributed much to the organization and planning of the quality of water phase of the project and was coauthor of the progress report (Harvey and others, 1959). S. M. Herrick made paleontological examinations of sample cuttings from water wells and oil tests.

The report was prepared under the administrative and technical supervision of J. W. Lang, district geologist, W. H. Robinson, district engineer, and M. E. Schroeder, district chemist.

EARLIER WORK

Hilgard (1860) reported to the Mississippi Legislature on the geology, agriculture, and water resources of the State. In later reports, the availability of ground water was described by Crider and Johnson (1906), Lowe (1925), Stephenson and others (1928), and Brown and others (1944). The reports of 1906, 1925, and 1928 were statewide in scope but Brown's report was of a comprehensive study of six coastal counties only. Brown's report included a detailed geologic map of the area and extensive information on ground-water supplies along the coast. In 1961 probably the main value of the early reports is the historic water-level data given. Thirty-three wells sampled in earlier years were resampled in 1956 by E. H. Boswell. No significant changes in quality had occurred between 1940 and 1956. One observation well near Ocean Springs in Jackson County has been measured periodically since 1956.

Few records of streamflow were collected in the Pascagoula area prior to 1958. Continuous records of daily discharge have been obtained at stream-gaging stations on Pascagoula River at Merrill, Miss., since 1930, and on Escatawpa River near Wilmer, Ala., since 1945. A short continuous streamflow record of Big Creek near Mobile, Ala., was collected prior to the construction of Big Creek Reservoir. A few discharge measurements were also obtained at selected sites on small streams in the area.

The Corps of Engineers has operated a tide gage at the mouth of the Pascagoula River since 1940.

Data concerning the quality of surface water in the Pascagoula area have been collected by other agencies and private organizations for their specific use. Prior to 1958 the U.S. Geological Survey had little information on the quality of surface waters in the area.

WATER LAW

In 1956 the Mississippi Legislature passed an act establishing a Board of Water Commissioners. Powers of the board include: issuance of water permits, commencing January 1, 1957; protection of existing water rights; and control of future use of additional available water for agricultural, industrial, municipal, and recreational purposes. The Mississippi law specified that water in any stream, lake, or other natural water body is public and subject to appropriation in accordance with provisions of the law. The law applies only to surface water and should not be construed or interpreted as affecting ground-water rights or users.

The Board of Water Commissioners has authority to permit appropriation of water of any stream only in excess of the established average minimum flow; however, exceptions may be made for domestic and municipal users, and the board may authorize any appropriator to use the established minimum flow upon written assurance that such water will be returned immediately to the stream in substantially the same amount. Average minimum flow is defined in Mississippi water law as follows: "The average of the minimum daily flow occurring during each of the five (5) lowest years in the period of the preceding twenty (20) consecutive years. Such determinations shall be based upon available stream-flow data, supplemented, when available data is incomplete, by reasonable calculations."

According to the Board of Water Commissioners, water permits have been granted to several industrial firms to appropriate water from the Escatawpa River and Franklin Creek. Specific limits of each permit as to quantity and rate of withdrawal and diversion are shown in the following table.

Appropriator	Stream	Rate of withdrawal (gallons per minute)	Annual use (acre-feet)
Thiokol Chemical Corp	Escatawpa River	1,000	1
Mississippi Menhaden Products, Inc	do	3,200	307
Do	do	700	123
International Paper Co	do	110	175
Do	do	1,500	92
Do	do	8,500	9,541
Do	do	32,000	46,738
Do	Franklin Creek	1,400	2,247

The law states that the Board has authority to enter into compacts and agreements concerning Mississippi's share of water flowing in water courses, where part of such bodies of water are contained within the territorial limits of a neighboring state.

WATER PROBLEMS

The largest potential sources of fresh water for future industrial development are the Pascagoula and Escatawpa Rivers, which contain large quantities of water even during periods of low flow. The lower reaches of these rivers are subject to salt-water penetration that makes the water unsuitable for most industrial uses. To obtain an industrial supply from either of these streams would require that withdrawals be made upstream from the maximum extent of salt-water penetration.

Mississippi water law requires that no water be appropriated from a stream for consumptive use when the flow is less than its average minimum. Therefore, some type of storage facility would be required to assure a continuous supply during periods of low streamflow if the water is withdrawn from a stream and transported outside the drainage basin. Parts of the Escatawpa River system are in Alabama, and appropriations are made from this river in Alabama without regard to Mississippi water law.

Water in the lower reaches of the Escatawpa and Pascagoula Rivers is polluted with industrial and municipal wastes. The municipal wastes of Moss Point and Pascagoula are treated. Most of the industrial wastes are given some type of treatment. Generally the pollution problem is most acute during late summer and early fall when streamflow is low and the water temperature high.

Oil-field brine is sometimes added to streams in the Pascagoula basin. The dissolved-solids content of water in Pascagoula River near Benndale and in Red Creek at Vestry is increased at times by the addition of brine that causes wide variations in the day-to-day quality of the water. Water in most of the streams in the area has high color, and some has a low pH.

Local flooding occurs frequently in and around Pascagoula and Moss Point. The low altitude and flatness of the land surface and the occasional intense rainfall make local drainage a difficult problem; however, it is beyond the scope of this report to make a study of this specific problem. Hurricanes and tropical storms occur in the area. Extreme hurricane tides can produce a great inflow of salt water over land as well as in the lower Pascagoula River system.

One of the principal ground-water problems in the Pascagoula area is that of locating an aquifer in the immediate vicinity of the need. The chief aquifers are at certain depth zones, and, because of their discontinuous character, test drilling is needed wherever a water-supply development is proposed. The zones can be traced for 10 miles or more through areas where there is an abundance of sand into areas where there is little sand. This characteristic is especially true of aquifers in the Pascagoula Formation in the vicinity of Pascagoula.

The water-supply problem in the Bayou Casotte industrial area is caused by the absence of the 800-foot sand that is used in Pascagoula and Moss Point. Absence of the 800-foot sand in test wells does not preclude its existence east of Bayou Casotte. In 1961 the industrial area depends entirely on the aquifer in the Graham Ferry Formation. The feasibility of further exploitation of the aquifer will depend upon economic considerations: the cost of lifting water from greater depths as the water level declines and the cost of pipelines to bring the water from areas removed from existing centers of pumpage to localities where the water will be used.

A large quantity of water is stored in the Citronelle Formation, but its use has been slight because of the availability of better quality water at greater depth. Owing to the shallow depth of the Citronelle and the possibility of salt-water encroachment as exploitation is increased, safety measures will be needed to insure its successful development.

METHODS OF STUDY

Appraisal of the water resources of the area included investigations of quantity and quality of streamflow, occurrence, movement, and quality of ground water, and effect of the geology and topography on the relationship of surface- and ground-water movement.

The quantity of surface water was determined by establishing 18 stream-gaging stations to supplement two continuous-record gaging stations already located in the area. Three stations were established on Pascagoula River to determine the increase in flow of the river as it progresses toward Mississippi Sound, and three stations were established to determine the effect of tide on river stage in the lower reaches. Continuous-record gaging stations were established on two major tributaries of the Pascagoula to determine streamflow characteristics of the streams. Ten low-flow partial-record stations were located on other tributary streams to determine the low flows to be expected from these streams and to evaluate the base flow from streams draining different geologic formations.

Daily discharge data for the long-term continuous-record stations were analyzed to determine the frequency of occurrence of various flows, with particular emphasis on the frequency and duration of low flows. Records of the short-term continuous-record and partial-record stations were adjusted to a long-time base period by comparison with the long-term stations in the area. When all records were adjusted to the same base period, low-flow characteristics of streams were compared and the differences in characteristics were related to the variations in surficial geology.

Two daily sampling stations for chemical-quality studies were operated on the main stem of Pascagoula River. The upstream station was established to determine the chemical quality of the river above any possible influence of salt water from Mississippi Sound. Specific conductance was measured on each sample, and composite samples for chemical analyses were prepared by mixing equal volumes of the daily samples for the composite period. The downstream station was established to determine the frequency of salt-water intrusion at that site; here, top and bottom samples were collected once daily. Specific conductance was also measured on each sample from the downstream station, and sufficient chloride determinations were made to establish the relationship between chloride and specific conductance over the range of conductance values. Samples for chemical analyses were collected from the major tributaries to show the chemical quality of water in these streams at the various flows. Analyses of these samples also provide information on areal variation of chemical quality in the Pascagoula River basin.

In order to determine the extent and effects of salt-water intrusion in the tidal reaches of the Pascagoula and Escatawpa Rivers, salinity data were collected under various conditions of streamflow and tide stages. Sampling sites were at 1-mile intervals along these streams; top and bottom samples for chloride determinations were collected, and the specific conductance of the water was measured at depth intervals of 5 feet at these sites.

A geologic map by Brown and others (1944) was deemed essentially correct, and mapping for the present report consisted of refineing the location of formation boundaries. About 40 holes were drilled with an auger to locate formation contacts and determine depth to the water table. Test wells were drilled for stratigraphic information, water samples, paleontologic studies, water levels, and aquifer tests. Most of the drilling was done after the well inventory had been completed. Sample cuttings were used for paleontologic and lithologic studies.

To evaluate the decline in water levels in the several aquifers, water levels were measured in wells in which measurements had been made in earlier years. A network of observation wells was established to map changes in ground-water levels.

The well-numbering system used is a simple grid based on a master grid previously set up for each county of the State (pl. 1). On the county map the grid areas are designated alphabetically, beginning with the letter A in the upper left corner and progressing to the right and downward in normal reading order. To avoid confusion, the letter I is not used. The grid lines usually coincide with township lines, except for partial townships, which are included in an adjoining grid area. Each well has been numbered beginning with 1—for example, A1, A2, A3, and so forth. The same numbers are used in all tables and illustrations throughout the report. Well data will be presented in a separate report.

Interference tests were made to compare the permeability of an aquifer from place to place and the producing capacity of the aquifers. A test pattern comprising five wells was laid out in the Bayou Casotte area to determine the feasibility of using the shallow aquifer, which is subject to salt-water encroachment, as an additional source of supply.

Water samples for chemical analyses were collected from wells in the major aquifers. Samples were also collected periodically from 12 wells to detect any possible salt-water intrusion into the shallow aquifers and any increase in the salinity of water in the deep aquifers caused by the movement of more mineralized water updip. Wells sampled in earlier years were resampled to detect changes in quality that might have occurred through the years.

ACKNOWLEDGMENTS

The writers received whole-hearted cooperation from well owners, city and county officials, industrial personnel, well contractors, and oil company geologists. The writers are especially indebted to Mr. A. W. Head, County Engineer, for the time he gave to the project and his help in arranging for test drilling, interference tests, and other phases of the work. Drillers' logs, sample cuttings, well construction, and water-level data were made available by the following drillers and contractors: J. R. Colville and Sons, Moss Point; L. L. Garland, Ocean Springs; Jack Green, Gautier; Hattiesburg Butane Co., Hattiesburg; Layne-Central Co., Jackson; Sellers Drilling Co., Mandeville, La.; Sutter Well Works, Pass Christian; and C. T. Switzer Well Co., Gulfport.

DESCRIPTION OF AREA

LOCATION

The Pascagoula area is on the Gulf Coastal Plain in extreme southeastern Mississippi. This study includes about 1,200 square miles comprising all of Jackson and George Counties, Miss., and a part of Mobile County, Ala. (fig. 1). Pascagoula, with a population of 16,914 (1960), is the largest city in the area. Three other incorporated towns are Moss Point and Ocean Springs, with populations of 6,497 and 4,900, respectively, and Lucedale in George County, population 1,970.

The economy of the Pascagoula-Moss Point area is primarily industrial. The lumber, paper, fishing, and shipbuilding industries have been important for many years and have been augmented in recent years by various other industries. The chief agricultural crop in Jackson and George Counties is timber, most of which is grown on tree farms. Row crops, beef cattle, and tung nuts are grown in the flat upland area near Lucedale. Large sand and gravel deposits are being excavated in George County for commercial use. The popularity of the coastal belt and the Pascagoula River valley for recreation and fishing has grown through the years.

PHYSIOGRAPHY

Jackson and George Counties are in the East Gulf Coastal Plain. The topography varies from flat to gently rolling terraces near the coast and along the rivers to hilly and deeply dissected uplands in northern George County. The maximum altitude of 320 feet above sea level is on a remnant of the deeply eroded upland surface in northeastern George County. The land surface descends gradually to sea level in a series of steps marked in places by poorly preserved escarpments which are the result of river and marine terracing. The history of terrace development along the Gulf Coast and in the Pascagoula area has been discussed by Doering (1956; 1958) and others.

West of the Pascagoula River in George and northwestern Jackson Counties the land has been maturely dissected by streams that form an intricate dendritic drainage pattern. The Citronelle Formation, which at an earlier time blanketed the area, has been removed from much of the upland surface. Southward the surface becomes progressively more gently rolling and the drainage pattern less well defined. The land surface between the Pascagoula and Escatawpa Rivers is youthful. Broad flat divides 1 to 2 miles wide are underlain by 50 to 100 feet of sand of the Citronelle Formation and separated by deep ravines cut through the formation into the underlying clays of the Pascagoula Formation. Divides east of the Pascagoula River range from 50 to 80 feet higher than those west of the river.

The upland surface contains many small depressions varying in size, shape, and orientation. The depressions are important because many retain water on the surface for eventual recharge to the Citronelle. The depressions are largest and most common on the flat surface of the Citronelle, which lies at an altitude of more than 200 feet in the vicinity of Lucedale. They are smaller, generally circular or ovoid, and fewer on the lower surfaces of the Citronelle that extend from Harleston to Big Point. Few depressions occur west of the river. Numerous small ponds north of Big Point indicate the presence of shallow depressions, but none of the depressions are deep enough to be shown on the map by contour lines. On the terrace south of Big Point the depressions are abundant, and the larger ones are oriented parallel to the escarpment that marks the old valley wall west of Hurley. Depressions are almost absent south of Black Creek and west of Pascagoula River.

The depressions are in sandy terrane. Brown (Brown and others, 1944, p. 21) suggested that some of them, which he called blowouts, are of wind origin. Many of the depressions have low sand ridges around their edges. One and one-half miles southwest of Agricola in the SW¼ sec. 12, T. 3 S., R. 6 W., a concentration of small elliptical dunes and crescent-shaped depressions are oriented toward the northwest and undoubtedly are of wind origin. Depressions on the surface in the vicinity of Lucedale may be of the same origin; their large size, however, suggests that solution may have affected their growth.

Several theories and hypotheses have been advanced by writers to explain the origin of depressions on sandy terrane of the coastal plain. Smith (1931) suggested that solution of aluminum and iron resulted in loss of volume beneath the depressed areas. LeGrand's (1953) theory required the solution of calcareous material such as shells or beds of marl. Rasmussen (1959, p. 23) suggested that the depressions resulted from "* * * removal of colloids and clays in suspension * * * where iron and aluminum are the chief cations." A small amount of calcareous material, probably concretions, is present in sample cuttings at a depth of 100 to 200 feet in wells near Lucedale. However, the first shell beds occur well below the deepest stream channels, and solution of shells is considered unlikely as a cause for loss of volume. Mechanisms suggested by Smith and Rasmussen seem to fit the local conditions.

RIVER SYSTEM

Pascagoula River, the main stream in the area, drains about 9,400 square miles and is formed by the confluence of Leaf and Chickasawhay Rivers near Merrill, Miss., approximately 81 miles upstream from Mississippi Sound (pl. 1). The upland surface in the vicinity of Merrill is about 175 feet above mean sea level; the flood plain about 50 feet, and the thalweg of the Pascagoula River, about 20 feet. The thalweg of the Pascagoula at its mouth is about 30 feet below mean sea level. The river divides at mile 17.7 and forms West Pascagoula River and Pascagoula River. West Pascagoula River is the larger and, during periods of low flow in 1959, was observed to have approximately 50 percent more flow than the Pascagoula River downstream from the division. The thalweg of West Pascagoula River at its mouth is about 20 feet below msl.

The stream valley of Pascagoula River is almost straight; however, the channel meanders within the flood plain. For example, the valley distance between channel miles 25 and 30 is about 1 mile. From mile 81 to mile 18 the flood plain varies in width from 4 to 6 miles and is covered with trees and undergrowth. Many lakes and bayous (old meanders) are in the flood plain between miles 35 and 12, and most are connected to the main channel and subject to overflow at medium stages. Downstream from mile 35 the flood plain does not exceed an altitude of 10 feet. The low-water channels of the Pascagoula and West Pascagoula Rivers are interconnected by many bayous and canals. The flood plain from mile 10 to Mississippi Sound is marshland.

Escatawpa River drains an area of about 1,000 square miles and is the major tributary east of Pascagoula River. The headwaters lie in Washington County, Ala., at an altitude of about 300 feet. The river enters Mississippi at mile 55 and flows southward to mile 10, where it meanders westward to Pascagoula River. Except below mile 10, where the flood plain is mostly marshland, the channel of the Escatawpa is generally well defined. The flood plain is 2 to 3 miles wide except for several constrictions in the middle reach, which are less than a mile wide.

Big, Jackson, and Franklin Creeks, tributaries to Escatawpa River, are important as present and future sources of water supply. These streams flow out of the Alabama hills in fairly well defined channels and are tributary to the river between miles 20 and 14. Altitudes of the land surfaces in the three drainage basins range from 2 to 4 feet at their mouths and from 130 to 300 feet in their headwaters. The channels are generally free of vegetation, and the flood plains are covered with trees and undergrowth. Big Creek, the largest of the three, has a drainage area of 217 square miles of which 103 square miles is upstream from Big Creek Reservoir (fig. 15). Jackson Creek drains an area of 41.0 square miles and flows into Goodes Mill Lake, which is connected to the Escatawpa River. Franklin Creek, the southernmost of the three tributaries, has a drainage area of 31.4 square miles.

In addition to Escatawpa River, Big Creek (drainage area, 51.2 square miles) and Big Cedar Creek (drainage area, 73.8 sq mi) are major tributaries to the Pascagoula from the east. The altitudes of the land surfaces in these basins range from 20 to 320 feet. Big Black Creek is the major tributary from the west to Pascagoula River and drains an area of 1,200 square miles. Altitudes of the land surface in this basin range from 15 to 450 feet. Red Creek, which has a drainage area of 468 square miles, is the major tributary to Big Black Creek.

Bluff Creek, a tributary to West Pascagoula River, drains an area of 142 square miles in the vicinity of Vancleave. Altitudes of the land surface in the basin range from 2 to 150 feet.

Black Creek North and Black Creek South drain a flat swampy area of about 70 square miles lying between Pascagoula and Escatawpa Rivers near Wade. The area, which includes Black Creek Swamp, is covered with trees and swamp vegetation. The streams originate in Black Creek Swamp at an altitude of about 50 feet. Black Creek South flows southward to Escatawpa River and Black Creek North flows westward to Pascagoula River. Both channels are poorly defined.

AREAL GEOLOGY

The oldest unit exposed in the area is the Pascagoula Formation of late Miocene age. The Pascagoula, which underlies the red sandy deposits of the Citronelle Formation and terrace deposits that cap the hills, is exposed in the creeks and along the Pascagoula River. The strike is almost east-west, and the dip is to the south at about 40 feet per mile; hence, the strata exposed in George County disappear beneath the surface in Jackson County. Farther south the Graham Ferry Formation is exposed, and outcrops, which are similar in appearance to those of the Pascagoula Formation, underlie the surficial materials and overlie the beds of the Pascagoula. The geologic map, plate 1, shows the distribution of outcropping units.

Red Creek approximately defines the northern extent of the Graham Ferry west of Pascagoula River. The line drawn on the map is based on projection of the base of the Graham Ferry updip from the outcrop on Pascagoula River where it was first described by Brown (1944, p. 47) and on correlation of the outcrop with the subsurface section as shown in well logs (pl. 2; measured section below).

The presence of the clams, *Rangia johnsoni* and *R. microjohnsoni*, in the outcrop and subsurface is the basis for mapping the Pascagoula Formation in George County. Some geologists place the top of the Pascagoula (Miocene) at the first appearance of the *Rangia johnsoni* (Dall) fauna (Fisk, 1944, fig. 68). The fauna has been described by Johnson (1893) and by Mincher (1941) from the type fossil locality on the left bank of Chickasawhay River in Greene County (SE¼ sec. 28, T. 1 N., R. 7 W.) at Shell Bluff (fig. 23). During periods of low stage, the beds are well exposed half a mile south of U.S. Highway 98 bridge (formerly Miller's bridge) on the right bank of the river, which is the locality noted by Mincher (1941, p. 339). *Rangia johnsoni* (Dall) or *R.* (*Miorangia*) *microjohnsoni* have been found in nine wells in George and Jackson Counties by S. M. Herrick, and their occurrence is shown on figure 23. The fauna was not found in sample cuttings from five wells, although shell fragments from several depths were observed. The absence of *Rangia* does not preclude the presence of the unit. In a general way, the occurrence of the fossils in the various wells shows that the beds dip to the south.

Measured section on right bank of Pascagoula River near Graham Ferry (SW¼NE¼, sec. 24, T. 5 S., R. 7 W.)

	Feet
Citronelle Formation:	
Sand and pea gravel, reddish, to top of bluff	70
Graham Ferry Formation:	
Clay, blue	3
Sand, gray, mottled, fossiliferous in upper part	7
Clay, gray, containing ferruginous nodules	½
Sand, gray having bluish streaks where clayey; medium-grained, cross-bedded. Apparently unfossiliferous	9
Clay, gray	1

The southward dip of the top of the *Heterostegina* zone in the lower part of the Catahoula Sandstone from northern George County to central Jackson County averages 45 feet per mile (fig. 23). The dip from central Jackson County to Horn Island averages 83 feet per mile.

Gravell and Hanna (1938, p. 995) likewise showed that the dip of the beds steepened midway in Jackson County. This determination of dip is presumed to be more accurate than that based on *Rangia johnsoni* (Dall), which averages 25 feet per mile from the outcrop in Greene County to well N66 in Ocean Springs. The average dip of the contact between a clay bed overlying a bed of fossiliferous sand in the Graham Ferry Formation is 19 feet per mile. The beds are exposed for 3 miles along the bluff on the west side of the river. Average dip of the base of the Citronelle Formation from well C17 in George County to well Q85 in Jackson County is 8 feet per mile south. From these figures it is clear that the shallow strata dip less, owing to their shorter periods of subsidence, than do the deeper strata.

Beds in the bluff at Graham Ferry have been offset 10 feet, the downdropped block being on the north. This offset was determined from measurement of seven sections along the river bluff. Faulting may explain the high area that includes Parkers Island in the Pascagoula River valley east of Graham Ferry and greater depth of alluvial deposits on the west side of the valley (pls. 1, 3). No other faults have been observed in the area, although it is likely that others exist.

Fisk (1944, p. 9) presented a map of probable fault zones based on drainage patterns in the central Gulf Coastal Plain. The Lake Borgne fault zone, according to Fisk's map, extends northeast through George County. The alinement of the fault at Graham Ferry with the north side of Parker's Island and with a stream flowing southwest in Harrison County toward Gulfport indicates the possibility of a fault having the same orientation as Fisk's Lake Borgne fault zone.

Correlation of scarps in the area and the flat surfaces bounded by them with terraces elsewhere has been suggested by several writers. Remnants of escarpments generally parallel Pascagoula River. Bases of the scarps range in altitude from 50 to 220 feet above sea level (pl. 1). The most prominent scarp bounds Black Creek Swamp west of Hurley; it rises from 40 to 70 feet above sea level and extends northwest, where it loses its identity near Indian Creek. The fact that all the scarps are parallel with the valley of Pascagoula River shows that the river has gradually migrated westward to its present position. The high terrace mapped by Brown (Brown and others, 1944, p. 21) is included with the Citronelle Formation because the entire mass of sand and gravel extending from Big Point at the southern end of the Citronelle outcrop to the Greene County line on the north seems to be a hydrologic unit.

After the Hurley-Big Point surface was formed, a considerable adjustment in the base level of the Pascagoula River occurred, and entrenchment of the valley began. The scarp west of Hurley marks the boundary of a valley that was cut to a depth of 100 feet below the Hurley surface, 70 feet below the Wade surface, and 30 feet below the present flood plain at the latitude of Graham Ferry. The deepest known cut is at the extreme west side of the valley, where the bottom of the alluvium is about 20 feet below the valley floor farther east (pl. 3). When cutting ceased, the valley was filled with sand and gravel to a depth of at least 70 feet at Wade and probably 80 to 100 feet near the coast. The present flood plain came into being when adjustment of the river to a new base level caused entrenchment of the valley as a result of the removal of about 40 feet of alluvial material and the preservation of the terrace. The terrace contains many physiographic features that clearly show the fluvial origin of the deposits. Distributary channels marked by lines of natural levees, oxbow lakes, and long narrow depressions mark old sloughs or abandoned channels of the river.

At the time the Pascagoula valley was being alluviated, the shoreline of the Gulf of Mexico may have extended about 5½ miles north of Escatawpa, where there is an escarpment more than 10 feet high. South of the shoreline, where the water was brackish, an estuary may have been bordered by swamps covering the area as far south as Moss Point and Orange Grove. Foraminifera and shells are found in cuttings from wells drilled through the terrace deposits as far north as Orange Grove, but they have not been found in sample cuttings from wells drilled in the area between Escatawpa River and the old shoreline. The present land surface was a sea-floor plain and has been tentatively correlated with the Pamlico Plain (Brown and others, 1944, p. 24).

The cutting of the Pascagoula valley resumed when the terrace was relatively uplifted and the Pamlico Plain emerged. The Pascagoula River, or perhaps one branch of it, meandered eastward, joined the Escatawpa near Orange Grove, and built a delta into the gulf in the vicinity of Bayou Cumbest. Scars of the meanders are prominent north of Escatawpa and south of Orange Grove. Later, Pascagoula River, abandoning its former course cut through at its present location and Escatawpa River cut through between Moss Point and Escatawpa to join the Pascagoula north of Moss Point, as it does today.

CLIMATE

Mississippi's humid and semitropical climate is determined primarily by the huge land mass to the north, the Gulf of Mexico to the south, and the subtropical latitude. The varied topography influences many local climatic differences. Geographic distribution of the mean annual precipitation in Mississippi is shown by figure 2.

The average annual precipitation on the coast is about 60 inches.

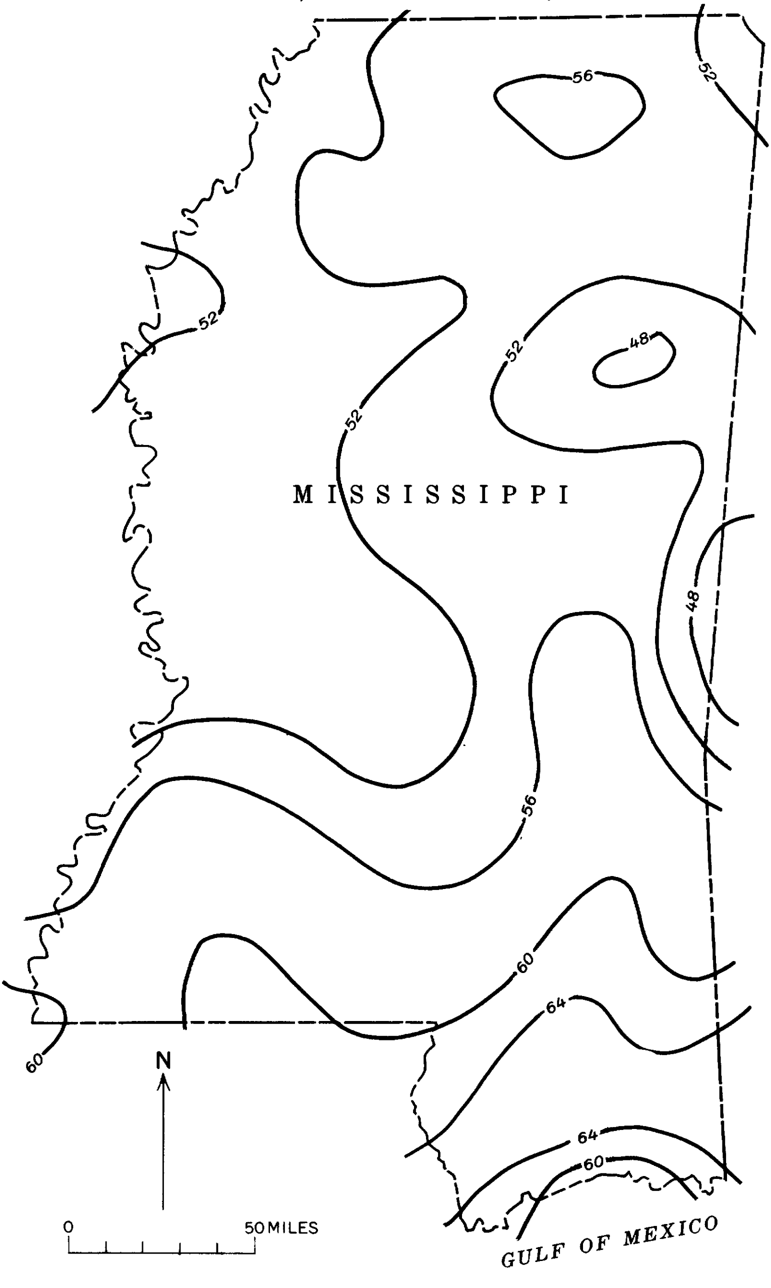

FIGURE 2.—Mean annual precipitation, in inches. Extracted from U.S. Weather Bureau, 1959, "Climates of the States." Based on period 1931–55.

A few miles inland lies a belt about 25 miles wide in which the average annual precipitation exceeds 64 inches, but farther inland the average precipitation is 60 inches and less. Annual rainfall on the Pascagoula

River basin is about 58 inches on the average. Measurable snow or sleet has fallen in Biloxi on the coast only 4 times in the past 60 years. Snowfall occurs more often in the headwaters of the Pascagoula basin, but is not important in the climate of the area.

The mean annual temperature in the river basin is about 66°F; the mean monthly temperature ranges from 81°F in July and August to 50°F in December. Along the Gulf Coast the mean monthly temperature ranges from 82°F in July and August to 54°F in January; on the average, the first winter freeze occurs December 3 and the last freeze on February 25. An average of 11 freezes occurs during the winter.

Tropical storms and hurricanes cross the Mississippi coast occasionally. The movement of hurricanes in Mississippi has been described by Sanders (1959) as follows:

> Hurricanes which move inland over southeast Louisiana may be as damaging on the Mississippi coast as those which cross the coast line. This is especially true of those moving from the southeast because of the usually more severe winds in the northeast quadrant and because of the high seas which move across Mississippi Sound and pile up on the shore. Those which move westward offshore often cause tide and wind damage on the coast. Those which move northeastward across or south of the Louisiana Delta and move inland between Mobile and Panama City, are usually less damaging because winds are offshore and tides are subnormal. Hurricanes which move inland on the Alabama coast may affect Mississippi only slightly because of less intense and offshore winds in their western portions.

Hurricanes have affected the Mississippi coast 19 times during the period 1875–1960. Eleven hurricanes have occurred in September, four in August, two in October, and one each in June and July. Perhaps the worst was the 1906 hurricane, which caused damage as far as 100 miles inland.

Evaporation is difficult to determine quantitatively. Most research is limited to studies of evaporation from free water surfaces. On the basis of these studies, the U.S. Weather Bureau has prepared maps showing variation in average annual lake evaporation, which ranges from 40 inches in northeastern Mississippi to 48 inches on the Gulf Coast (fig. 3). More than half the annual evaporation from water surfaces takes place from May to October, because of the higher temperature during this period. Figure 3 also shows the variation in Mississippi of average May–October evaporation in percent of annual. The May–October percentage of annual evaporation increases with distance from the coast, primarily because of the more uniform seasonal climate on the coast.

USE OF WATER

The use of water has increased steadily through the years. Table 1 presents data on sources of supply and use of water in 1958. The

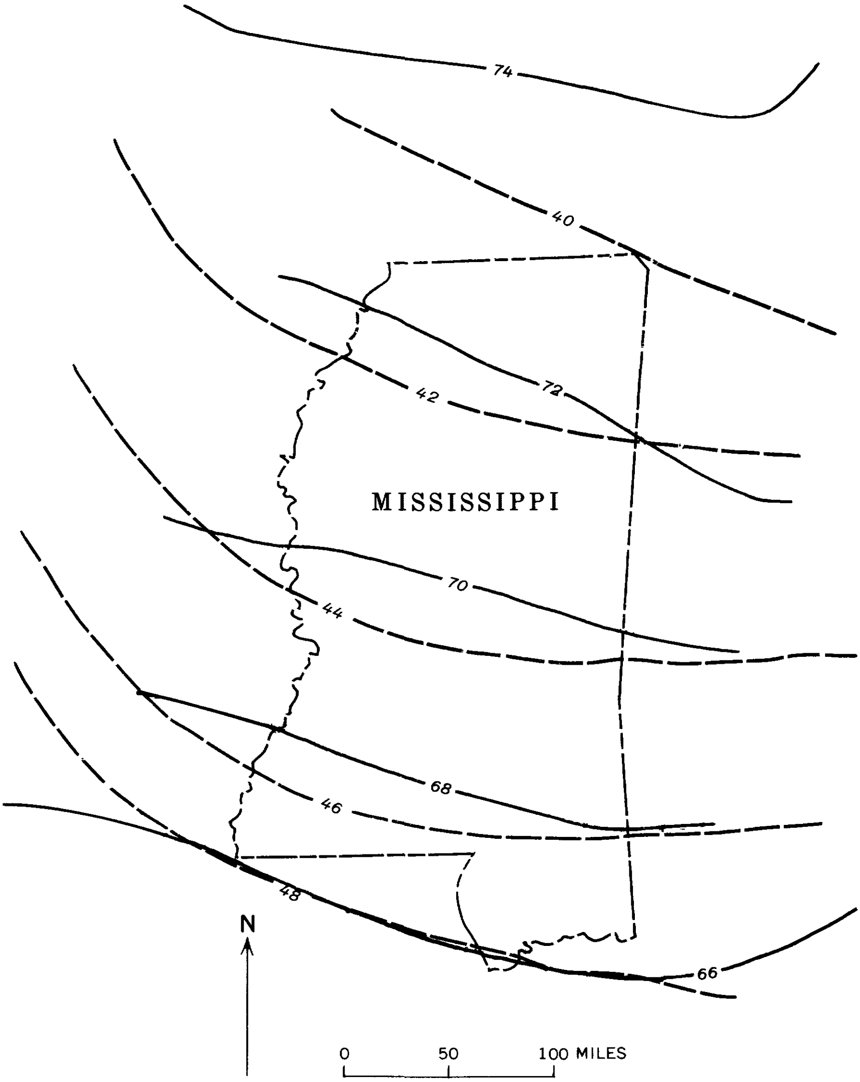

FIGURE 3.—Average annual lake evaporation, in inches (broken lines), and average May–October evaporation, in percent of annual (solid lines). Extracted from U.S. Weather Bureau Technical Paper 37 (based on period 1946–55). Seasonal percent based primarily on pan data, but limited testing indicates that the percentage values are applicable to lake evaporation, constant heat storage being assumed.

Pascagoula-Moss Point area ranks near the top in the State in the use of and need for water. The paper industry uses the largest volume of water (about 50 mgd) for processing, cooling, and waste dilution. Until the early 1950's, most of the ground water pumped was used by municipalities and by the fishing and allied industries. After 1950, four manufacturing firms were established in the area, each requiring from 0.5 to 1.5 mgd in continuous operations. In addition to the use of fresh water in manufacturing plants, about 10 mgd of salt water is pumped from Mississippi Sound for cooling. Coinciding with industrial expansion and the accompanying water requirements has been the increased municipal requirement brought about by population growth in the Pascagoula-Moss Point area.

Little change has occurred in water requirements inland from the coast. Prior to 1950 the city of Lucedale depended on springs flowing from the Citronelle Formation; these springs have since been replaced by wells as the source of supply. Because most of the rural area is devoted primarily to agriculture and logging operations, water requirements are small. The possibility of obtaining a ground-water supply for pasture irrigation was investigated on one of the large farms in George County. No large-scale irrigation is practiced in the area.

TABLE 1.—*Source and average daily use of water in Jackson and George Counties in 1958 (in thousands of gallons)*

Source	Average daily use [1]				
	Municipal	Subdivision	Industrial	Total	Percent of total
Ground Water:					
Citronelle Formation	0	0	820	820	1.4
Graham Ferry Formation	1,900	20	4,720	6,640	11.2
Pascagoula Formation:					
500-foot sand	240	70	0	310	.6
600- and 800-foot sand	1,540	260	1,160	2,960	5.0
Hattiesburg Formation	120	0	0	120	.2
Total ground water	3,800	350	6,700	10,850	18.4
Surface Water:					
Escatawpa River and Franklin Creek	0	0	48,200	48,200	81.6
Total ground and surface water	3,800	350	54,900	59,050	100.0

[1] Rural supplies are not included.

SOURCES OF SUPPLY

Precipitation is the ultimate source of all fresh water. Part of the precipitation runs directly off the land surface into streams; part is temporarily retained in lakes and swamps, or on vegetation, and is subsequently evaporated; and the remainder seeps into the ground.

Of the water that seeps into the ground, part adheres to soil particles and remains in the soil mantle until evaporated and part continues to move by gravity, until it reaches the zone of saturation and becomes ground water. Ground water moves continually as it percolates to lower elevations. Some of the water eventually will return to the land surface as seeps or springs and be discharged into surface channels. The discharge of these seeps and springs constitutes the entire flow of most streams in the Pascagoula area during extended periods of dry weather.

The sources of water for the Pascagoula area are: (1) Pascagoula

River, (2) tributaries to Pascagoula River, and (3) the ground-water reservoirs.

FACTORS AFFECTING QUANTITY AND DISTRIBUTION

More than any other factor, climate in the source area influences the quantity of water available in any particular area. The availability of ground water is influenced by the amount of infiltration that occurs through the soil mantle and the capacities of the aquifers to store and transmit water. Surface-water supply is affected by the available surface storage.

CLIMATE

Precipitation and other climatic factors such as temperature, evaporation, and transpiration influence the availability and distribution of water supply. Hurricanes affect the supply for brief periods.

PRECIPITATION

In this warm climate, practically all the precipitation occurs as rain. The quantity and distribution of rainfall influence the amount and rate of streamflow. During the period 1900–60, annual precipitation in the Pascagoula basin ranged from 39 to 80 inches. During the period 1931–60, the annual runoff of the Pascagoula River at Merrill ranged from 9.5 to 31.9 inches. The variability of annual precipitation and runoff is shown in figure 4. Persistence is the tendency for a series of wet years to be grouped together and a series

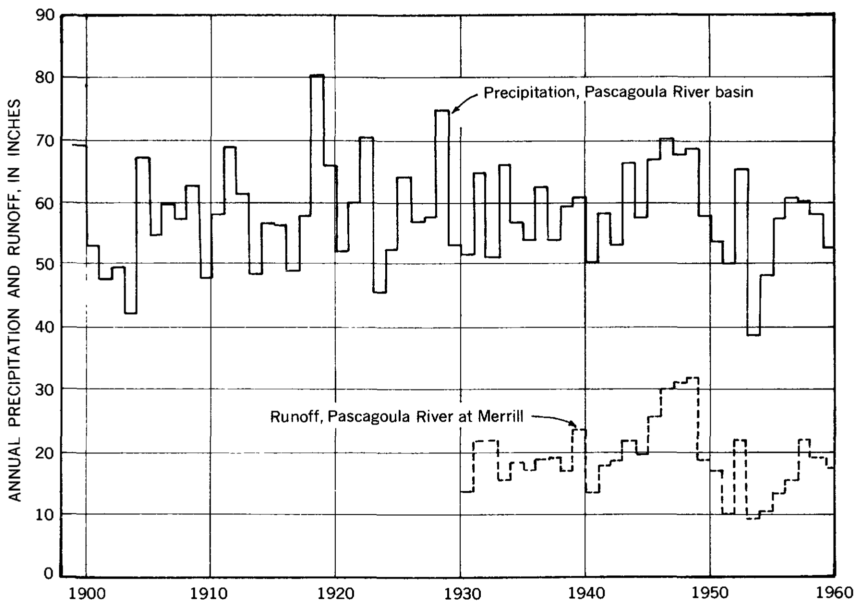

FIGURE 4.—Annual precipitation and runoff, Pascagoula River basin.

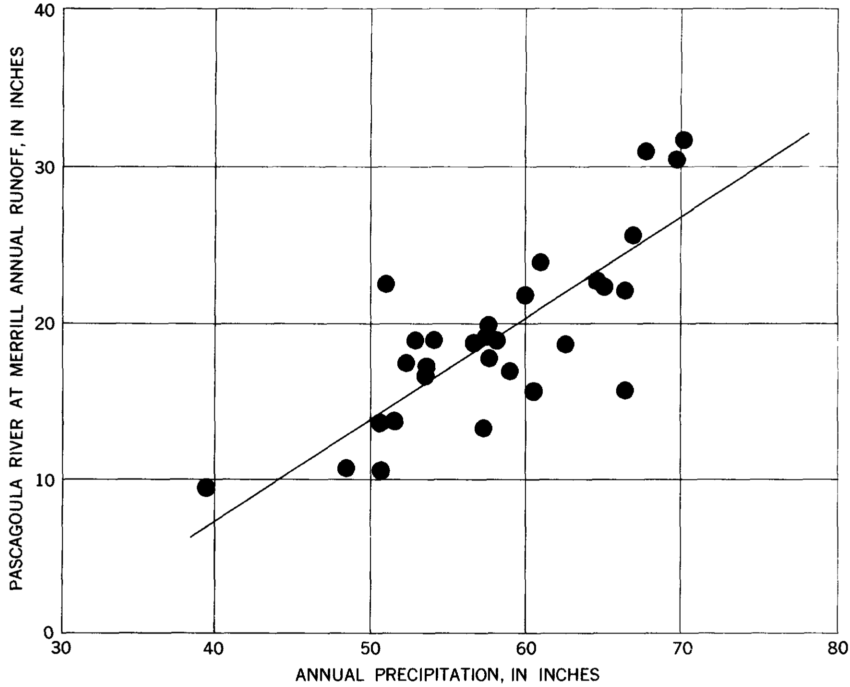

FIGURE 5.—Relation of precipitation to runoff, Pascagoula River basin, based on period 1931–60.

of dry years to be grouped together. Persistence of the annual precipitation and runoff data is not as pronounced in the Pascagoula basin as in other areas; however, figure 4 does illustrate this tendency, although most of the wet- and dry-year groups contain years that deviate from the pattern.

The difference between precipitation and runoff is due to total evaporation and seepage to ground water not returned to streams. Total evaporation is water returned to the atmosphere by (1) transpiration from vegetation and building of plant tissue, (2) evaporation from water surfaces, moist soil, and snow, and (3) interception. Runoff is the residual component of precipitation after total evaporation and ground-water seepage requirements have been met. The precipitation-runoff relationship in the Pascagoula basin is shown in figure 5. Generally, the ratio of annual runoff to annual precipitation increases as annual precipitation increases. During extremely wet years runoff is about 40 percent of the annual precipitation (70 inches or more) and in extremely dry years runoff is about 25 percent of the annual precipitation (less than 40 inches). However, some years having about the same rainfall will have more than 100 percent difference in runoff because of distribution of the rainfall and temperature variations.

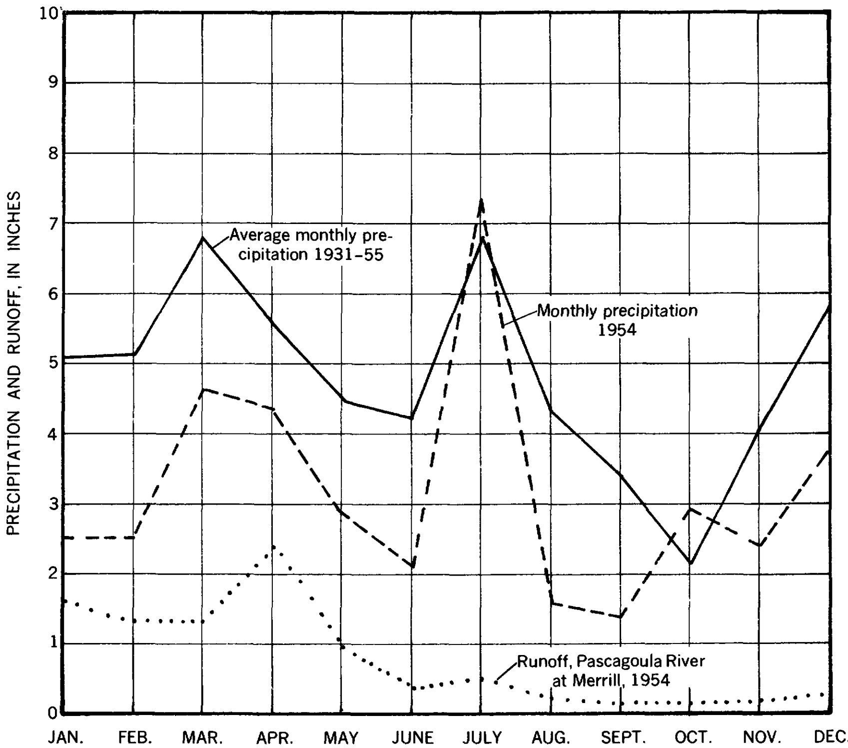

FIGURE 6.—Monthly precipitation and runoff, Pascagoula River basin.

Monthly rainfall is more variable than annual rainfall. Figure 6 shows the average monthly rainfall for eight weather stations in the Pascagoula basin during the period 1931–55. Usually, March and July are the wettest months and October is the driest month. The years 1952, 1954, and 1956 were fairly dry years in the area and in most of Mississippi. The 1954 monthly rainfall in the basin is shown in figure 6 for comparison with the monthly averages. The 1954 monthly runoff for Pascagoula River at Merrill is also shown in figure 6. During the rainy season (winter and spring) runoff is about 50 percent of the precipitation, and during the dry season (summer and fall) runoff is less than 10 percent of the precipitation. It is evident that a variable relation exists between rainfall and runoff and that precipitation alone should not be used as a reliable index of runoff.

The more intensive rains generally are associated with thunderstorms; tropical storms usually cause heavier rains over longer periods of time. From the beginning of record through 1950, the heaviest 24-hour rainfall recorded in the State was 12.35 inches at Merrill on July 5, 1916, during a hurricane. During 1955, a 24-hour rainfall of 13.36 inches was recorded in Mobile, Ala. Rainfalls of this intensity are rare and result in extremely high rates of runoff in streams draining the affected area. Unusually heavy rainfall resulting in floods occurred in the upper reaches of the Pascagoula basin during February 1961. The flood on the lower reaches of the river system was not as great because of the rainfall distribution.

TEMPERATURE

Temperature in the Pascagoula River basin influences runoff from the basin, but to a less degree than does precipitation. The ratio of runoff to precipitation decreases in the summer owing to higher evaporation and transpiration losses (fig. 6). Evaporation and transpiration are directly related to temperature.

HURRICANES

Hurricanes influence the water resources of the area by causing intense rainfall and high tides. As noted above, the maximum 24-hour rainfall recorded in Mississippi occurred at Merrill during the 1916 hurricane, and the rainfall produced the second highest known flood on the main stem Pascagoula River. This hurricane produced a tidal stage of 7.0 feet above msl in the Escatawpa River in the vicinity of the bridge on State Highway 63 at Moss Point; the 1947 hurricane produced a stage of 5.3 feet at the same location. The 1947 hurricane produced a tidal stage of 7.7 feet in the mouth of the Pascagoula River, where the mean high tide is 1.1 feet. Hurricane Ethel, in September 1960, produced a tidal stage of 4.5 feet at this location. Tide waters from Hurricane Ethel reached an elevation of 4.3 feet in the Bayou Casotte industrial area near the plant of H. K. Porter Co., Inc.

In addition to flood damage, hurricane tides move large quantities of salt water up the Pascagoula River system. Prior to hurricane Ethel, salt water was at about mile 13 in the Pascagoula River; the day after, it was observed at mile 17 and was receding. The exact penetration of salt water during this hurricane is not known, but probably was not beyond mile 18.

EVAPORATION AND TRANSPIRATION

Evaporation is the water vaporized from water surfaces and moist soils. Temperature, relative humidity, and wind are the major climatic factors influencing evaporation. In the Pascagoula area, the average annual evaporation from lakes is about 48 inches, and the average May to October evaporation from a shallow lake is approximately 66 percent of the average annual evaporation, or 32 inches. These data are averages but are adequate for use in the preliminary design study of a reservoir. However, a major project would require a more reliable estimate of evaporation losses; this estimate could be obtained from a detailed study of the climatic factors at the proposed reservoir site.

Transpiration is the process by which water vapor escapes from the living plant, principally through the leaves, and enters the atmosphere. Transpiration depends upon the availability of water, atmospheric conditions, and the nature of vegetation. Water is usually abundant in the Pascagoula area. Atmospheric conditions cause offsetting influences on transpiration: the prevalent high humidity tends to lower transpiration, but the high average temperature during the growing season, about 80° F, and the prevalent coastal winds, in spite of the high humidity, tend to increase transpiration. The vegetation of the area probably is characterized by high transpiration. Water-supply studies involving surface storage or transportation in open channels should include allowances for transpiration by vegetation in and adjacent to a reservoir or channel.

INFILTRATION

Infiltration is defined (Langbein and Iseri, 1960, p. 12) as "The flow of a fluid into a substance through pores or small openings. It connotes flow into a substance in contradistinction to the word 'percolation' which connotes flow through a porous substance."

The upland surfaces in the study area are conducive to infiltration, where they are broad and flat and are underlain by unconsolidated fine to coarse sand. Lower surfaces, valley walls and stream bottoms, are composed mostly of clay, silt, and fine sand (pl. 1). The section in much of the upland is characterized by the log of an auger hole 16 feet deep that showed reddish-brown coarse sand containing a few thin clay streaks extending from the surface to the bottom of the hole. A sandy material also underlies the broad terrace south of Wade to Escatawpa.

Only a few inches to a few feet of compact material having a lower infiltration capacity than the sand just described occurs above the more permeable material. The circular depressions on the uplands contain ponds after heavy rains; many of the ponds become dry within a few days after the rains. Clayey material may exist beneath the depressions, but it probably is no more than a few feet thick. Although infiltration-capacity data are not available, it is clear from the data at hand that a large part of the upland and terrace surfaces are composed of material conducive to ready infiltration.

AQUIFER STORAGE AND MOVEMENT OF WATER

An aquifer is a formation, group of formations, or part of a formation that is water-bearing. The porosity is a measure of the quantity of water in storage in an aquifer and is determined by the physical character of the aquifer. The aquifers in this area are composed of unconsolidated sand or sand and gravel of different degrees of sorting; therefore, the quantity of water in storage varies. All sediments lying below the water table are in the zone of saturation, and a vast quantity of water is in storage and is readily available for development. Part of the water contained in fine-grained materials, which are clay and silt comprising the confining beds (aquicludes), becomes available over a long period of time as pumping lowers the hydrostatic pressure in the aquifer and permits vertical movement of water from the aquiclude into the aquifer. For this reason, an additional quantity of water is available to augment the supply actually contained in an aquifer.

In localities where the land is only a few feet above sea level, the water table is near the surface and little or no room is available for additional water storage. In the uplands the water table in the surficial deposits is as much as 60 feet below the surface, and, although the quantity of water in storage is large, the available storage above the water table in places exceeds the saturated thickness. If necessary, part of this available storage could be used for artificial recharge of sands that are unsaturated because of the topographic position of the aquifer.

Movement of ground water through the area is from high elevation to low elevation and eventual discharge in the Gulf of Mexico. In the aquifer outcrop, water is unconfined and the water surface is the water table. When the aquifer dips below the surface and the water in the aquifer is confined between relatively impermeable beds, artesian conditions are created that cause the water level in a well to rise above the top of the aquifer. The height at which water stands above the top of the aquifer is an imaginary surface known as the piezometric surface. Three piezometric maps (pls. 4–6) are included in this report to illustrate the direction of movement of water in three of the aquifers. The contours on the maps connect points at which water in the aquifer will stand at the same altitude. Ground water flows in the direction of slope of the piezometric surface or water table, and the rate of slope is the hydraulic gradient.

Permeability is a measure of the ability of 1 square foot of an aquifer to transmit water, whereas transmissibility is a measure of the ability of the entire aquifer to transmit water. Yield and specific-capacity data for a well are useful, but they do not adequately describe the transmissibility or the interference between wells that results from ground-water withdrawals. The coefficients of transmissibility and storage are determined from aquifer tests.

The coefficient of transmissibility was determined by the Theis graphical method from data obtained in aquifer tests (Wenzel, 1942, p. 87–90). Interpretations based on the results of eight aquifer tests

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are shown graphically in figures 24, 27, and 30 and are discussed in the sections describing the aquifers.

Ground-water losses include natural and artificial discharge. Natural losses include: the consumption of water by plants whose roots reach down to or near the water table, discharge of water to the Gulf through the subaqueous outcrop on the continental slope, and upward leakage of water through the overlying beds into the Gulf. Losses occur also along stream channels in the uplands where ground water is discharged in springs at the contact between coarse sandy deposits of the Citronelle Formation and clays of the Pascagoula and Graham Ferry Formations beneath. Swampy conditions are common in this area.

Many wells are allowed to flow unrestricted, and much of the water goes to waste. On the basis of an assumed average flow of 10 gpm from each of 230 known wells in the project area, the discharge is 3 mgd, more than enough to supply Pascagoula. This loss is diminishing as water levels continue to decline, and it eventually will be negligible as artesian pressures decline below the land surface.

SURFACE STORAGE

Storage of water on the land surface can be divided into two categories, manmade and natural. In the Pascagoula area the only manmade storage facility of consequence is Big Creek Reservoir, formed by a dam on Big Creek (tributary to Escatawpa River) near Hamilton, Ala. The drainage area of Big Creek at the dam site is 103 square miles. The reservoir is a source of the water supply for Mobile, Ala.

Big Creek Reservoir stores 17.4 billion gallons of water and has a surface area of approximately 3,600 acres. An additional 2 billion gallons of water can be stored by maintaining the reservoir level 2 feet higher than in 1961. The entire flow of Big Creek is not retained in the reservoir, and excess waters are released through a gated spillway. The amounts of water withdrawn for the Mobile water-supply system and the amounts released to Big Creek are compared below for the years 1957–60.

Year	*Withdrawals (million gallons)*	*Releases (million gallons)*
1957	29, 200	21, 400
1958	29, 500	23, 400
1959	30, 800	31, 400
1960	30, 100	19, 000

During the period 1957–60, water was withdrawn from the reservoir at an average rate of about 125 cfs (80 mgd). The natural daily flow of Big Creek in the reservoir vicinity was less than 125 cfs about 30 percent of the time. Water has been released from Big Creek

Reservoir during every month of the year, although during some years there were no releases during periods of dry weather. A monthly tabulation of releases from the reservoir during the period 1958–60 are shown in the following table.

Year	Water released from Big Creek Reservoir, in millions of gallons											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1958	3,500	3,760	2,480	1,500	2,590	1,380	3,600	2,870	1,690	0	0	0
1959	0	3,160	2,680	3,800	3,700	3,100	3,000	2,700	2,370	5,100	900	840
1960	3,800	1,780	1,450	2,370	4,700	0	1,200	2,260	1,160	0	0	300

During this study, streamflow data for Big Creek downstream from the reservoir (pl. 1, station Q) were obtained during periods of no release from the reservoir; therefore, the data indicate streamflow yield of the basin below the reservoir. A reduction in releases from the reservoir would not affect the interpretations made in a subsequent section (p. 37–51).

About a hundred farm ponds are in the Pascagoula area and are used primarily as a water supply for domestic animals. The effect of these ponds on the yield of streams is negligible.

Most of the natural storage of surface water in the area is in lakes, although a small amount of water is stored in depressions (east of the Pascagoula River). Jackson County has more named lakes within its boundaries than any other county in the State; most of these lakes are old meanders of Pascagoula and Escatawpa Rivers and many are still connected to the parent river. Water from Mississippi Sound penetrates into lakes in the lower reaches of these rivers. (See p. 77, 78.)

Large quantities of water are evaporated from the surfaces of all the lakes during extended periods of hot weather, and the low-flow yields of streams connected to the lakes are affected. The degree to which the yield of such a stream is affected depends upon the relative yield of the stream and the lake area to which it is connected.

FACTORS AFFECTING THE WATER QUALITY

PRECIPITATION

Inasmuch as precipitation is the source of practically all available water, the original water quality is the quality of the rainfall. In the project area the amounts of dissolved minerals in rainwater are variable and probably are dependent upon the origin and wind characteristics of individual storms. The following table shows the results of partial analyses made on three samples of rainwater collected in the Pascagoula area.

Results, in parts per million, of analyses of rainwater samples

Constituent	Sample		
	1	2	3
Calcium		4.6	1.8
Magnesium		4.7	2.0
Sulfate		13	5.2
Chloride	6.0	76	24
Specific conductance (micromhos at 25°C)	35	286	105

1. Collected northeast of Pascagoula, Miss., Aug. 23, 1960. Wind south-southwest at 5–15 mph.
2. Collected at Biloxi, Miss., Sept. 15, 1960. Wind east at 30 mph. Sample taken at 10:00 a. m. before arrival of the eye of hurricane Ethel.
3. Collected northeast of Pascagoula, Miss., Sept. 15, 1960. Wind southwest. Sample taken during latter part of rain from hurricane Ethel.

Although the analyses of these samples emphasize the variability in quality of rainwater, none are representative of the long-term quality of rainwater in the area. Junge and Werby (1958) show that for the area along the Mississippi Gulf Coast, the average concentrations of sodium and chloride in rainfall for the year July 1955 to June 1956 ranged from 0.6 to 1.0 milligrams per liter (same as parts per million). They state that the quantities of these components rapidly decline from the coast to inland areas.

The long-term effect of rainfall on the quality of the water supply probably is insignificant. The effects of rainfall of a poorer quality such as the precipitation accompanying hurricane Ethel, would be more pronounced in surface water than in ground water. Even the surface-water effects would be of short duration because most of the rainfall returns to the Gulf as direct runoff.

GEOLOGIC EFFECTS

To a large extent, the mineral content of earth materials in the area controls the chemical quality of both surface and ground waters. Rainfall usually has a very low dissolved-solids content when it reaches the ground, and any increase in the dissolved solids depends primarily upon the composition and solubility of the rocks and soil and the length of time the water remains in contact with them. Therefore, the chemical character of surface and ground waters reflects the geologic environments through which the water has passed.

Water in recharge areas has been in contact with earth materials a relatively short time and usually is less mineralized; as water moves deeper into an aquifer and down dip from the recharge area, its dissolved-solids content increases. Several things alter the chemical character of water as it moves through an aquifer. Decomposition of carbonaceous material in the aquifer increases the color and the carbon dioxide content of the water at some locations. In the deeper aquifers, calcium in solution is exchanged for the sodium of base-exchange minerals in the aquifer material. Depositional environment of part of the sediments was such that salty or brackish water has been trapped in them. Because of differences in permeability and the lenticular nature of the sands, trapped salt water has been more completely flushed from some aquifers than from others.

Water in the ground has a fairly constant temperature at a particular depth. Near the surface, the temperature of ground water is very near the mean annual air temperature; temperatures increase with depth below land surface, and the rate of increase is the temperature gradient. The gradient in the Pascagoula area is about 1.2° F per hundred feet.

The chemical quality of Pascagoula River is largely determined by the geologic units cropping out in the headwater areas of the Leaf and Chickasawhay Rivers. That these outcropping strata contain appreciable amounts of soluble material is reflected in the dissolved-solids content of Pascagoula River. The tributary streams of the Pascagoula, however, drain surface deposits that contain very little soluble material; therefore, the water of the Pascagoula tributaries has a lower and more uniform dissolved-solids content than that of the Pascagoula itself. Even at base-flow, when most of the flow represents ground-water discharge, there is no appreciable increase in the dissolved-solids content of the tributaries.

The nature and erodibility of the surface material affect the sediment yield of a stream. Because the surficial materials in the headwaters of the Leaf and Chickasawhay Rivers generally are finer grained than the materials in the project area, the sediment concentration in the Pascagoula River is greater than in its tributaries.

SALT-WATER INTRUSION

Salt-water intrusion affects the chemical quality in the tidal reaches of Pascagoula and Escatawpa Rivers. The chemical quality of water at any point in the tidal reaches varies widely, depending upon the tide conditions and the amount of fresh-water discharge. A zone of salt-water diffusion apparently exists in the sands of the Citronelle Formation and terrace deposits where they are adjacent to the coast and to the tidal reaches of the streams. No evidence was found of salt-water intrusion in the deeper aquifers. However, some of the sediments in these aquifers have not been completely flushed of salty water trapped in them at the time of deposition.

MUNICIPAL, INDUSTRIAL, AND OIL-FIELD WASTES

The quality of surface water is adversely affected by additions of municipal and industrial waste and oil-field brines. Excessive amounts of organic waste from municipal sewage and industrial effluents can deplete the dissolved oxygen in the surface water and may also cause objectionable odors. Industrial effluents can raise the water temperature or can add harmful chemicals to the water, and thereby make it unsuitable for certain uses downstream. The discharge of oil-field brine into Pascagoula River and Red Creek has increased, at times, the dissolved-solids content of the water; if enough brine from this or other sources is added, the water will be unsuitable for many uses.

RELATION OF QUALITY OF WATER TO USE REQUIREMENTS

An adequate water supply is a determining factor in the selection of an industrial site. Sharing importance with quantity of water is the chemical quality, temperature, degree of pollution and, in most surface supplies, the suspended sediment carried by the stream.

Chemical analyses of water for municipal or industrial uses are necessary to determine whether the water is suitable for specific purposes, and, if not, to determine the type and cost of treatment necessary to make it satisfactory. The analyses aid in determining the suitability of water for drinking, steam production and heating, manufacturing, laundering, or other uses. Comprehensive analyses can also be used to determine the cost of softening water, its scale-forming properties, or its tendency to corrode plumbing.

Information on water hardness is of great importance. In domestic use, water hardness is recognized by the difficulty of obtaining a lather without an excessive consumption of soap, the insoluble sticky curd that results in washing processes using soap, and the scale formed in vessels in which the water is boiled. Industry gives much attention to hardness of water because of its affects on manufacturing processes and products. Hardness is the property of water attributable to the presence of calcium and magnesium salts. Other constituents such as iron, manganese, aluminum, barium, strontium, and free acid also cause hardness of water, but generally they are not present in sufficient quantities to have an appreciable effect. Water having a hardness of less than 60 ppm usually is rated as soft, and it is suitable for most purposes. Hardness ranging from 61 to 120 ppm may be considered moderate, but it does not seriously interfere with the use of water except in high-pressure boilers and in some industrial processes. Water having a hardness ranging from 121 to 180 ppm is hard, and, in the upper ranges, laundries and industries may soften the supply profitably. Water having a hardness greater than 181 ppm is very hard and usually is softened before being used.

Iron and manganese in excess of 0.3 ppm in water are objectionable for several reasons. Excessive amounts of these constituents leave a reddish-brown stain on white porcelain or enamelware, fixtures, and clothing or other fabrics, and interfere with dyeing, tanning, paper manufacturing, and the processing of many other products.

Sediment and color in water have a pronounced effect on its quality. Sediment is composed of such materials as sand, clay, silt, and finely divided organic material. If water containing sediment is not clarified before it is used, the abrasive action on pumps, valves, and turbine blades may be very costly.

The color of water is due only to substances in solution. Color in water may be of natural origin or may be due to the works of man, and may be of mineral, animal, or vegetable origin. It may be caused by metallic substances, humic material, peat, algae, weeds, or microscopic organisms. Industrial waste may also be the cause of color in water. Highly colored water may foam in boilers and can stain processed products. Color is objectionable in public water supplies for aesthetic reasons.

Generally accepted chemical specifications have been established for water used domestically and are independent of any sanitary standards established for the protection of the public health. The United States Public Health Service (1946) established chemical and physical specifications for drinking water used on interstate carriers, as follows:

Constituent	*Recommended limits (parts per million)*
Iron and manganese together	0.3
Magnesium	125
Chloride	250
Sulfate	250
Fluoride	1.5
Lead	.1
Color	[1] 20
Dissolved Solids	[2] 500

[1] Expressed in units on the cobalt scale.
[2] 1,000 ppm permitted if no other water is available.

These limits have since been adopted as standard for public water supplies by the American Water Works Association and by most municipalities.

Water containing less than 500 ppm of dissolved solids generally is satisfactory for most domestic and industrial uses; however, excessive iron content or hardness may cause difficulty in some uses. Water containing more than 1,000 ppm of dissolved solids is likely to include certain constituents that make it unsuitable for domestic or industrial uses. The chemical requirements for water used by different industries are so variable that it is impossible to establish specifications for all uses. In general, most industries require clear water that is low in total mineral content and hardness. Water temperature is also an important factor in determining the value of water for industrial use. The requirements of chemical quality of water for various industrial processes are given in table 2.

The suitability of water for irrigation depends not only on the

TABLE 2.—*Water quality tolerances for industrial applications*

[American Water Works Association (1950, p. 67, table 3-4). Remarks: A, no corrosiveness; B, no slime formation; C, conformance to Federal drinking-water standards; D, Al_2O_3 less than 8 ppm, SiO_2 less than 25 ppm, Cu less than 5 ppm. Chemical constituents in parts per million]

Industrial use	Turbidity	Color	Fe	Mn	Fe+Mn	Hardness	Alkalinity	pH	Total solids	Remarks
Air conditioning [1]	------	------	0.5	0.5	0.5	------	------	------	------	A, B
Baking	10	10	.2	.2	.2	(2)	------	------	------	C
Boiler feed:										
0–150 psi	20	80	------	------	------	75	------	8.0+	3,000–1,000	
150–250 psi	10	40	------	------	------	40	------	8.5+	2,500–500	
250 psi and up	5	5	------	------	------	8	------	9.0+	1,500–100	
Canning:										
Legumes	10	------	.2	.2	.2	25–75	------	------	------	C
General	10	------	.2	.2	.2	------	------	------	------	C
Carbonated beverages [3]	2	10	.2	.2	.3	250	50	------	850	C
Confectionery	------	------	.2	.2	.2	------	------	(4)	100	
Cooling [5]	50	------	.5	.5	.5	50	------	------	------	A, B
Ice (raw water) [6]	1–5	5	.2	.2	.2	------	30–50	------	300	C
Laundering	------	------	.2	.2	.2	50	------	------	------	
Plastics, clear, uncolored	2	2	.02	.02	.02	------	------	------	200	
Paper and pulp: [7]										
Groundwood	50	20	1.0	.5	.0	180	------	------	------	A
Kraft pulp	25	15	.2	.1	.2	100	------	------	300	
Soda and sulfite	15	10	.1	.05	.1	100	------	------	200	
Light paper, HL-grade	5	5	.1	.05	.1	50	------	------	200	B
Rayon (viscose) pulp:										
Production	5	5	.05	.03	.05	8	50	------	100	D
Manufacture	.3	------	.0	.0	.0	55	------	7.8–8.3	------	
Tanning [8]	20	10–100	.2	.2	.2	50–135	135	8.0	------	
Textiles:										
General [9]	5	20	.25	.25	------	20	------	------	------	
Dyeing	5	5–20	.25	.25	.25	20	------	------	------	
Wood scouring [10]	------	70	1.0	1.0	1.0	20	------	------	------	
Cotton bandage	5	5	.2	.2	.2	20	------	------	------	

[1] Waters having algae and hydrogen sulfide odors are most unsuitable for air conditioning.
[2] Some hardness desirable.
[3] Clear, ordorless, sterile water for syrup and carbonation. Water consistent in character. Most high-quality filtered municipal water not satisfactory for beverages.
[4] Hard candy requires pH of 7.0 or greater, for low value favors inversion of sucrose and causes sticky product.
[5] Control of corrosion is necessary as is also control of organisms, such as sulfur and iron bacteria, which tend to form slimes.
[6] Calcium bicarbonate is particularly troublesome. Magnesium bicarbonate tends to greenish color. Carbon dioxide assists to prevent cracking. Sulfates and chlorides of Ca, Mg, Na should each be less than 300 ppm (white butts).
[7] Uniformity of composition and temperature desirable. Iron objectionable because cellulose absorbs iron from dilute solutions. Manganese very objectionable; clogs pipelines and is oxidized by chlorine to permanganates, which cause reddish color.
[8] Excessive iron, manganese, or turbidity creates spots and discoloration in tanning of hides and leather goods.
[9] Constant composition; residual alumina less than 0.5 ppm.
[10] Calcium, magnesium, iron, manganese, suspended matter, and soluble organic matter may be objectionable.

dissolved constituents in the water but also on the drainage characteristics of the land, permeability of the soil, chemical reactions in the soil solution, amount of water to be applied, and the type of crop to be grown. Some of the chemical-quality factors that determine the suitability of a water for irrigation are the total salt content, the amounts of some constituents in the water and the relative proportions of some of the ions in solution. Generally, water used for irrigation should have a moderate to low total salt content. The percent sodium should not exceed 50 to 60, depending upon the total salt content.

SURFACE WATER

An abundant supply of surface water of good quality is available in the Pascagoula area. During an average year, approximately 4 trillion gallons of water flow, at an average rate of about 16,000 cfs (10,000 mgd), into Mississippi Sound from Pascagoula River. The quantity and quality of streamflow, however, varies with time and place, and this variability requires the collection and interpretation of considerable data to appraise adequately the surface-water resources of the area. The stream-gaging and water-quality stations are listed in table 3 in downstream order by USGS national order number.

VARIABILITY OF STREAMFLOW

Streamflow records in the Pascagoula area were analyzed to determine quantitatively the variability of surface water with time and place. The variability of flow at Merrill can be determined by study of the 30 years of daily-discharge record at this location. Graphical presentations (discharge hydrographs) of some of these data are shown in figures 7 and 8. The variation in daily discharge during the years of maximum and minimum discharge are shown in figure 7. Streamflow is quite variable even during dry years; the year 1954 had a range

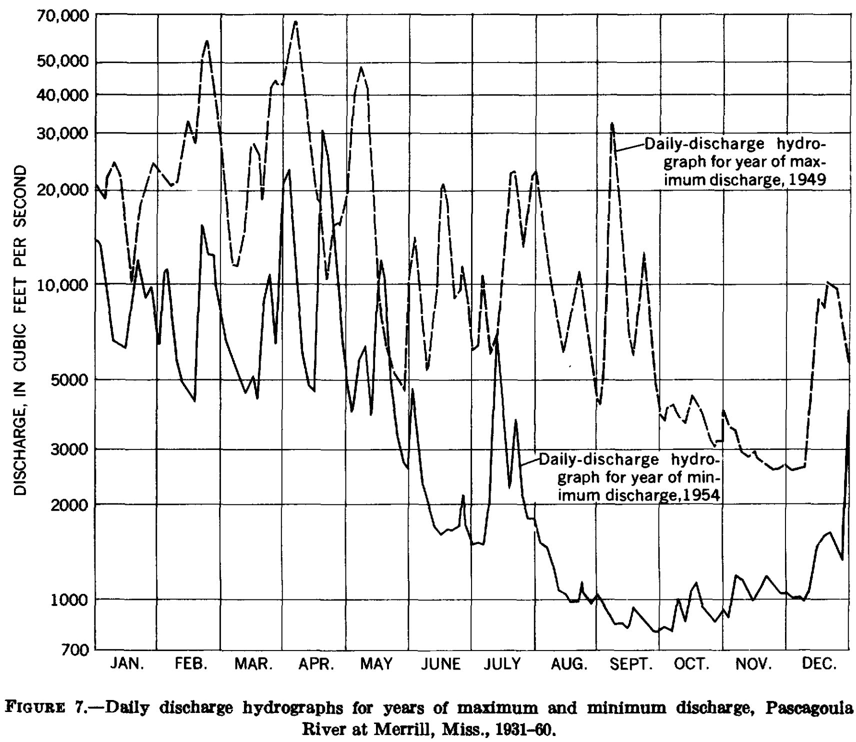

FIGURE 7.—Daily discharge hydrographs for years of maximum and minimum discharge, Pascagoula River at Merrill, Miss., 1931–60.

TABLE 3.—*Stream-gaging stations and sites for sampling quality of water in the Pascagoula area*

[Type of record: a, continuous-record gaging station; b, continuous-record gage-heights and periodic low-flow discharge measurements; c, once-daily gage-heights and periodic low-flow discharge measurements; d, low-flow partial-record station; e, continuous gage-height station (tide gage); q, daily chemical-quality samples; s, periodic sediment samples; u, periodic chemical-quality samples]

National order No.	Reference letter (pl. 1)	Station	Drainage area (sq mi)	Length of record	Type of record		Location
					Streamflow	Chemical quality	
02B4790.00	A	Pascagoula River at Merrill, Miss	6,600	Dec. 1930 to Dec. 1960.	a		SW¼ sec. 18, T. 1 S., R. 7 W., at bridge on old State Highway 15, half a mile west of Merrill.
02B4790.20	B	Pascagoula River near Benndale, Miss.	6,690	July 1958 to Sept. 1960.		q, s	On line between secs. 15 and 22, T. 2 S., R. 8 W., at bridge on State Highway 26, 2.1 miles east of Benndale.
02B4790.50	C	Big Creek near Crossroads, Miss	44.6	June 1958 to Dec. 1960.	d	u	SW¼ sec. 9, T. 2 S., R. 7 W., at bridge on State Highway 26, 1 mile east of Crossroads.
02B4790.60	D	Pascagoula River at Hardwood Railroad Crossing, Miss.	6,780	Sept. 1958 to Dec. 1960.	c		On line between secs. 8 and 9, T. 3 S., R. 7 W., at site of dismantled Hardwood Railroad Crossing, 2.3 miles west of Basin.
02B4790.70	E	Big Cedar Creek near Wade, Miss	64.3	June 1958 to Dec. 1960.	d	u	NE¼ sec. 37, T. 4 S., R. 6 W., at bridge on Old River Road, 5.2 miles north of Wade.
02B4790.80	F	Pascagoula River below mouth of Big Cedar Creek, Miss.	6,910	Sept. 1958 to Dec. 1960.	c		SW¼ sec. 29, T. 4 S., R. 6 W., at fishing camp, 200 feet downstream from mouth of Big Cedar Creek.
02B4790.90	G	Black Creek North near Wade, Miss	15.6	Oct. 1952 to Dec. 1960.	d	u	NW¼ sec. 22, T. 4 S., R. 6 W., at bridge on State Highway 63, 3.5 miles north of Wade.
02B4791.70	H	Big Black Creek near Benndale, Miss.	710	July 1958 to Dec. 1960.	d	u	SW¼ sec. 14, T. 3 S., R. 8 W., at bridge on State Highway 57, 7.6 miles south of Benndale.
02B4793.00	I	Red Creek at Vestry, Miss	416	July 1958 to Dec. 1960.	a	u	SW¼ sec. 34, T. 3 S., R. 8 W., at bridge on county highway, 0.5 mile north of Vestry.
02B4793.10	J	Pascagoula River at Graham Ferry near Wade, Miss.	8,150	Aug. 1958 to Nov. 1960.	b		N½ sec. 38, T. 5 S., R. 7 W., at Graham Ferry, 4.7 miles southwest of Wade.
02B4793.30	K	Pascagoula River at Cumbest Bluff, Miss.	8,170	Aug. 1958 to Nov. 1960.	e		NW¼ sec. 27, T. 5 S., R. 6 W., at Cumbest Bluff, and 0.6 mile west of Three Rivers.
02B4793.40	L	Pascagoula River near Coll Town, Miss.	8,180	Aug. 1958 to Nov. 1960.	e		NW¼ sec. 42, T. 6 S., R. 6 W., 0.5 mile upstream from division of Pascagoula and West Pascagoula Rivers, and 2.8 miles west of Coll Town.
02B4793.43	M	Pascagoula River near Escatawpa, Miss.		Nov. 1958 to Sept. 1960.		q	NW¼ sec. 35, T. 6 S., R. 6 W., at fishing camp, 3 miles north of Escatawpa.
02B4795.00	N	Escatawpa River near Wilmer, Ala	506	Aug. 1945 to Dec. 1960.	a		NW¼ sec. 19, T. 2 S., R. 4 W., at bridge on U.S. Highway 98, 4 miles west of Wilmer.
02B4796.00	O	Escatawpa River near Hurley, Miss	639	July 1958 to Dec. 1960.	a	u	NE¼ sec. 12, T. 5 S., R. 5 W., at bridge on county highway, 4.2 miles southeast of Hurley.
02B4800.00	P	Big Creek near Mobile, Ala.[1]	84	Nov. 1944 to Sept. 1950.	a		NW¼ sec. 1, T. 4 S., R. 4 W., at a bridge on county road, 19 miles west of Mobile.
02B4800.50	Q	Big Creek near Big Point, Miss	[2] 112	June 1958 to Dec. 1960.	d	u	NW¼ sec. 8, T. 6 S., R. 4 W., 0.4 mile downstream from Collins Creek, and 5 miles southeast of Big Point.
02B4801.00	R	Jackson Creek near Orange Grove, Miss.	37.2	June 1958 to Dec. 1960.	d	u	NE¼ sec. 19, T. 6 S., R. 4 W., at bridge on county highway, 6.8 miles north of Orange Grove.

02B4801.50	S	Franklin Creek near Grand Bay, Ala.	16.4	June 1958 to Dec. 1960.	d	u	NW¼ sec. 4, T. 7 S., R. 4 W., at bridge on county highway, 2.6 miles west of Grand Bay.
02B4802.00	T	Black Creek South at Helena, Miss.	40.4	Sept. 1953 to Dec. 1960.	d	u	NE¼ sec. 29, T. 6 S., R. 5 W., at Mississippi Export Railroad bridge, at Helena.
02B4802.10	U	Pascagoula River at U.S. Highway 90 at Pascagoula, Miss.		July 1958 to Dec. 1960.	e		Sec. 7, T. 8 S., R. 6 W., at bridge on U.S. Highway 90, at Pascagoula.
(3)	V	Pascagoula River at mouth at Pascagoula, Miss.		July 1940 to Dec. 1960.	e		Sec. 6, T. 8 S., R. 6 W., at Ingalls' shipyard at Pascagoula.
02B4802.50	W	Bluff Creek near Vancleave, Miss.	50.7	July 1958 to Dec. 1960.	d	u	SE¼ sec. 6, T. 6 S., R. 7 W., 2.4 miles northwest of Vancleave.
02B4802.60	X	Moungers Creek near Vancleave, Miss.	30.6	Oct. 1958 to Dec. 1960.	d	u	SE¼ sec. 27, T. 5 S., R. 7 W., at county highway bridge, 3.4 miles north of Vancleave.

[1] Site now inundated by Big Creek Reservoir.
[2] Drainage area downstream from Big Creek Reservoir.
[3] Corps of Engineers gage.

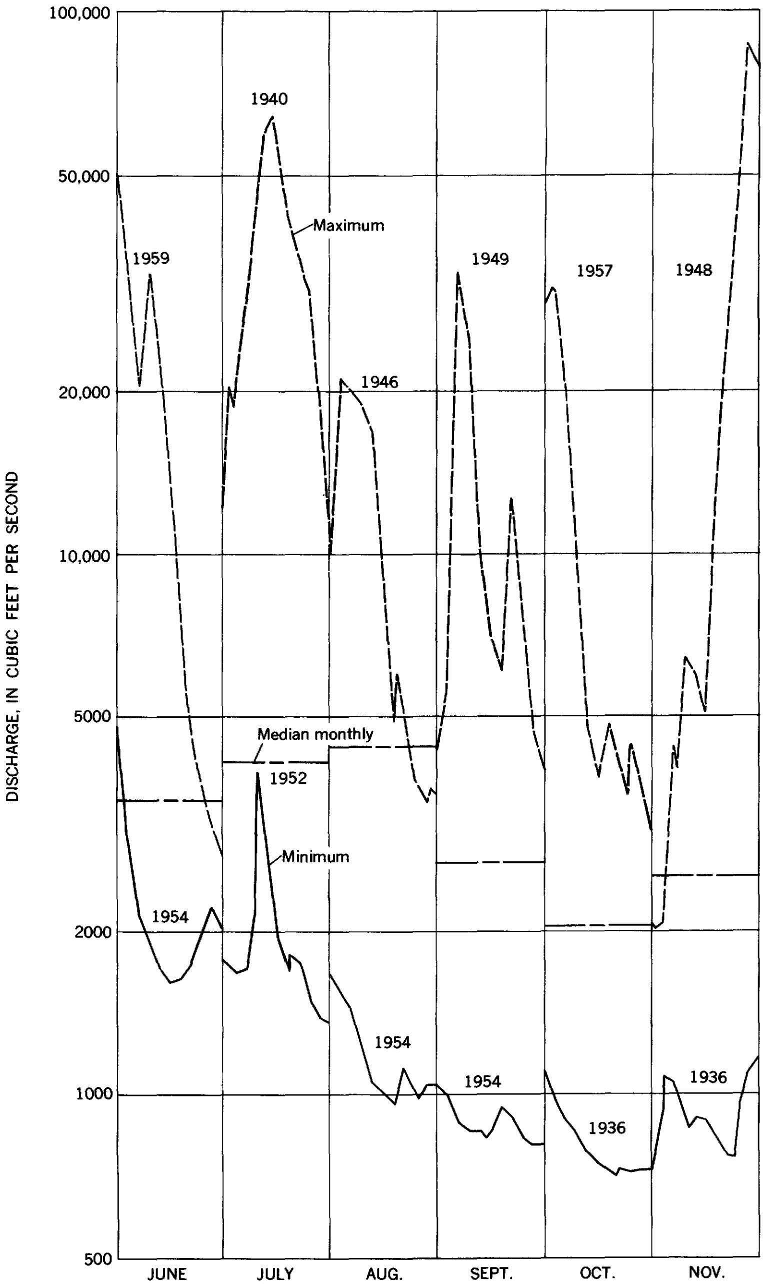

Figure 8.—Daily discharge hydrographs for months of maximum and minimum discharge, June to November 1931–60, Pascagoula River at Merrill, Miss.

in daily discharge from 31,200 to 805 cfs. Further evidence of the variability of daily streamflow can be seen in figure 8, which shows daily discharge hydrographs for the months of maximum and minimum discharge, June to November 1931–60. Also shown, for comparison with the extremes, are the computed median discharges for each month. The streamflow pattern of Pascagoula River at Merrill in past years can be determined from these hydrographs.

The streamflow records collected during this study (1958–60) are in themselves too short for an accurate appraisal of stream characteristics. In a short period of record a stream may experience more than its share of flood or low flows. The monthly mean discharges for the Pascagoula River at Merrill during 1959 and 1960 are compared with the median monthly mean discharges of record in the following table.

Year	Mean discharge for indicated month (cfs)											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1959	8,067	16,910	10,790	13,060	5,800	18,010	5,944	4,282	3,798	8,314	10,550	6,743
1960	10,820	19,320	17,850	17,430	13,560	2,262	2,147	5,355	3,220	2,787	4,036	3,098
Median (1931–60)	9,857	16,800	19,450	14,140	7,208	3,486	4,106	4,382	2,698	2,056	2,535	6,584

The data show that montly discharges during periods of low flow in 1959 and 1960 were generally higher than median. Adjustment to a long time base period was required to evaluate the low-flow data collected during this short period of above-median streamflow. Probable future flows of streams are estimated on the basis of streamflow records adjusted to a common base period. Probabilities of future flows have been estimated through use of flow-duration and low-flow frequency curves. Explanations and examples of these curves are presented in the following section, and the data developed for stations in the area are presented in tabular form. Streamflow information related to the magnitude and frequency of floods, average minimum flow as defined by the Mississippi water law, and tide characteristics are also included in the next section.

STREAMFLOW CHARACTERISTICS

FLOW DURATION

Flow-duration data for continuous-record gaging stations were computed from the daily discharges by the total-period method. Flow-duration curves based on these data show, without regard to chronological order, the flow characteristics of a stream throughout the range of discharge.

A flow-duration curve developed for the Pascagoula at Merrill from data collected during the past 30 years represents only a sample of the long-term flow characteristics of the stream. A particular stream can have higher or lower flows in critical periods than other streams in the area. If the record at Merrill is to be used for predicting future flows, it should be adjusted to allow for these chance occurrences. Flow-relationship curves were developed from data collected at Merrill and other long-term continuous-record stations in Mississippi and adjacent states. Each flow-relationship curve was based on flow-duration data computed for a common period of record at the two stations being related. Duration data were transposed through these curves of relation and adjusted data were determined for each station. The adjusted flow-duration curve for Pascagoula River at Merrill is shown in figure 9. The base period 1929–57 (used in another study) was used to avoid the lengthy recomputations that would be necessary to adjust the data to a new base period. Flow-duration data for Pascagoula River at Merrill were computed for the period 1931–60 and plotted in figure 9 for comparison with the adjusted curve. There is little difference between the two sets of data.

Flow-duration data were computed by techniques described by Searcy (1959), for the other continuous-record and partial-record stations in the area. Because of the scant data at the short-term continuous- and partial-record stations, only the lower end of the flow-duration curves could be estimated for these locations.

A tabulation of adjusted flow-duration data for stations in the area is shown in table 4. These data can be plotted on logarithmic-probability paper similar to that used in figure 9, if graphical presentation is desired. If no man-made or unusual climatological changes occur, the data in table 4 are reliable predictions of the future flow patterns of the streams in the area.

Flow-duration data for stations on the main stem Pascagoula River show the progressive increase in flow of the river from the station at Merrill to the station at Graham Ferry. Comparison of discharges that are equaled or exceeded 95 percent of the time indicates about 10 percent increase in discharge from Merrill to Hardwood Railroad Crossing, about 10 percent increase from Hardwood Railroad Crossing to "below mouth of Big Cedar Creek," and about 25 percent increase from "below mouth of Big Cedar Creek" to Graham Ferry. Most of of the increase in discharge in the lowest reach is due to inflow from Big Black Creek, and about 60 percent of the increase in discharge in the other two reaches is due to tributary inflow.

The increase in discharge of Pascagoula River from Graham Ferry to its mouth was not determined quantitatively; however, study of the topography and surficial geology of the area indicates that most of the increase is due to tributary inflow. Tributary inflow, most of

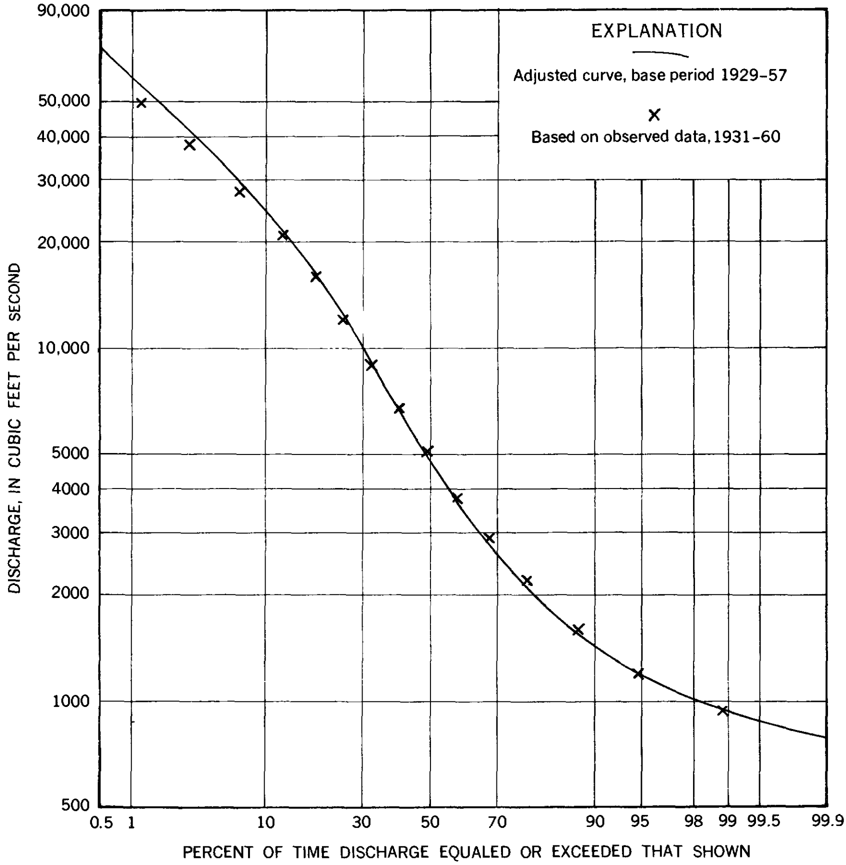

FIGURE 9.—Duration curve of daily flow, Pascagoula River at Merrill, Miss.

which is from Escatawpa River, increases the discharge about 20 percent.

Flow-duration data in table 4 are also excellent tools for comparing flow characteristics of different streams. The data have been adjusted to the same base period, and so removal of the effect of drainage area (dividing discharge by drainage area), permits direct comparison. The lower end of flow-duration curves for the stations on Big Cedar Creek, Black Creek North, Bluff Creek, Franklin Creek, and Escatawpa River (station near Hurley) are shown in figure 10. These stations were selected to show the variation in base flow of streams in the area. Franklin and Big Cedar Creeks have much higher streamflow yields per square mile than the other streams shown in figure 10. The slopes of the flow-duration curves of these two streams are flatter than those of the low-yielding streams. Slope of the duration curve is a measure of the variability of that stream. Thus,

TABLE 4.—*Duration table of daily flow for streamflow stations in the Pascagoula area*

[Data are adjusted to period October 1928 to September 1957 on basis of relation to data at other gaging stations]

Reference letter (pl. 1)	Station name	Drainage area (sq mi)	Flow, in cubic feet per second, equaled or exceeded for indicated percent of time																
			99.5	99	98	95	90	80	70	60	50	40	30	20	10	5	2	1	0.5
A	Pascagoula River at Merrill, Miss.	6,600	870	930	1,010	1,180	1,430	1,970	2,600	3,490	4,750	6,700	9,980	15,100	24,200	32,800	46,300	59,000	71,000
C	Big Creek near Crossroads, Miss.	44.6		18	20	23	27	35	43	52	64								
D	Pascagoula River at Hardwood Railroad Crossing, Miss.	6,780		1,020	1,110	1,300	1,590	2,140	2,800	3,690	4,990								
E	Big Cedar Creek near Wade, Miss.	64.3		42	44	49	56	67	78	92	108								
F	Pascagoula River below mouth of Big Cedar Creek, Miss.	6,910		1,150	1,240	1,440	1,730	2,320	3,020	3,990	5,320								
G	Black Creek North near Wade, Miss.	15.6		.7	.8	1.1	1.5	2.6	4.0	6.1	9.4								
H	Big Black Creek near Benndale, Miss.	710		160	178	218	270	370	484	628	810								
I	Red Creek at Vestry, Miss.	416		104	116	139	170	232	300	388	500								
J	Pascagoula River at Graham Ferry, Miss.	8,150		1,420	1,530	1,780	2,130	2,860	3,710	4,890	6,600								
N	Escatawpa River near Wilmer, Ala.	506	54	62	72	93	120	172	237	329	451	618	867	1,300	2,250	3,520	5,900	8,220	11,300
O	Escatawpa River near Hurley, Miss.	639		144	160	195	240	328	428	543	700								
Q	Big Creek near Big Point,[1] Miss.	[2] 112		74	78	87	99	119	139	160	186								
R	Jackson Creek near Orange Grove, Miss.	37.2		24	26	28	32	38	45	53	62								
S	Franklin Creek near Grand Bay, Ala.	16.4		15	16	17	19	22	25	28	32								
T	Black Creek South at Helena, Miss.	40.4		.8	1.0	1.5	2.2	4.1	6.8	11	18								
	Escatawpa River at mile 14 near Orange Grove,[3] Miss.	875		249	272	320	382	500	625	775	955								
W	Bluff Creek near Vancleave, Miss.	50.7		7.3	8.4	11	14	20	27	36	48								
X	Moungers Creek near Vancleave, Miss.	30.6		.6	.8	1.1	1.7	3.2	5.4	8.7	14								

[1] Flow-duration data at this location represents streamflow yield of Big Creek downstream from the reservoir.
[2] Drainage area Downstream from Big Creek Reservoir.
[3] Not a streamflow station; a few tide-affected measurements were obtained at this location. Estimates of duration of flows based on these measurements and the combined flows of Escatawpa River near Hurley, and Big, Jackson and Franklin Creek.

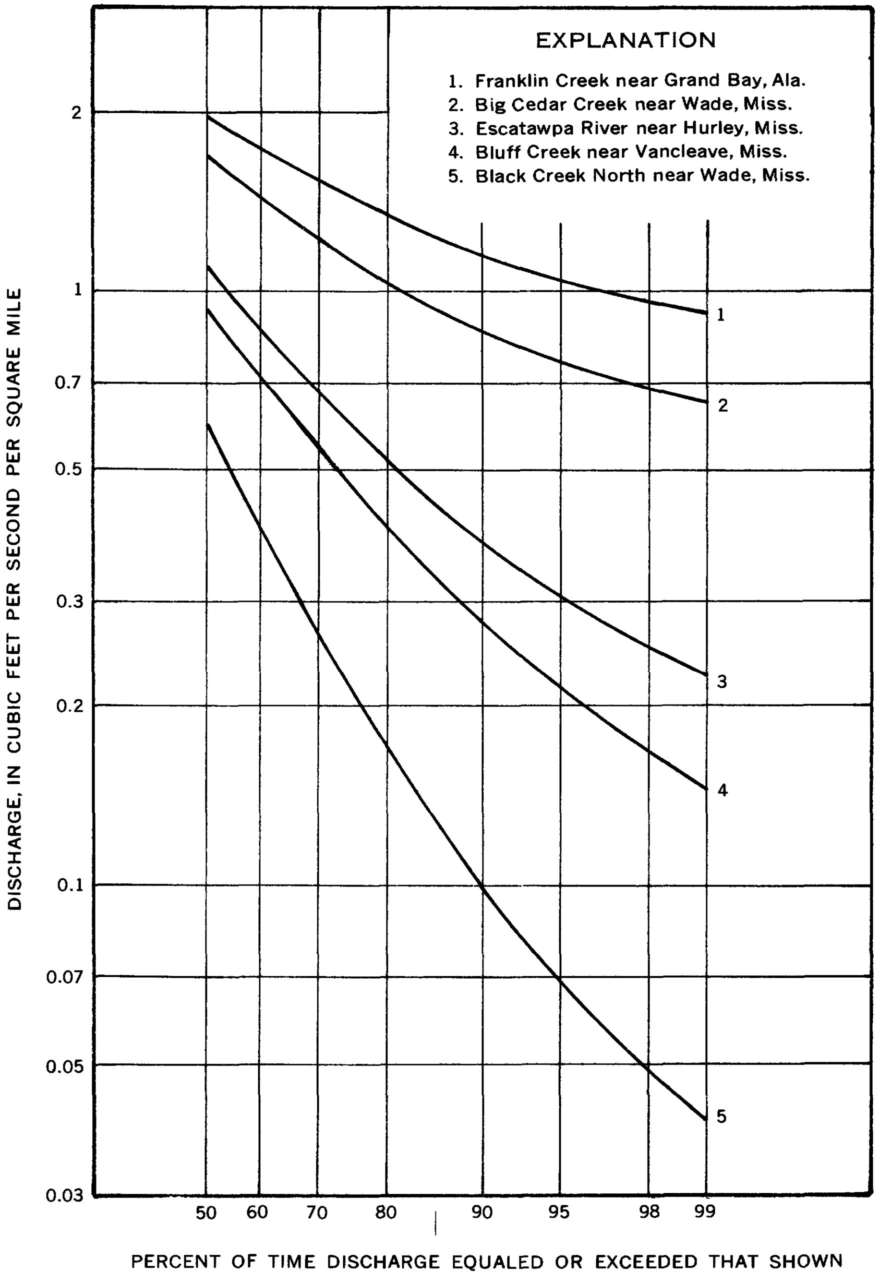

FIGURE 10.—Duration curves of daily flow for selected streams, Pascagoula River basin, Miss., based on data adjusted to period 1929–57.

in this area, it appears that the tributary streams having high streamflow yields vary less in base flow than streams having lower yields.

Although the information shown in figure 10 is expressed as discharge per square mile, it is not meant to imply that each drainage basin has uniform yield. The streamflow yields of segments of individual streams vary due to differences in topography, channel incision, and, in some places, surficial geology. Care should therefore be exercised in the extrapolation of flow-duration data to an ungaged site solely on the basis of size of drainage area.

The adjusted flow-duration curve is representative of the flow pattern over a long period of time. The duration curve for any particular year can deviate from this pattern, as shown in figure 11. For example, the discharge equaled or exceeded 90 percent of the time during 1954 was 1,000 cfs; during 1959–60, 2,300 cfs; and during the

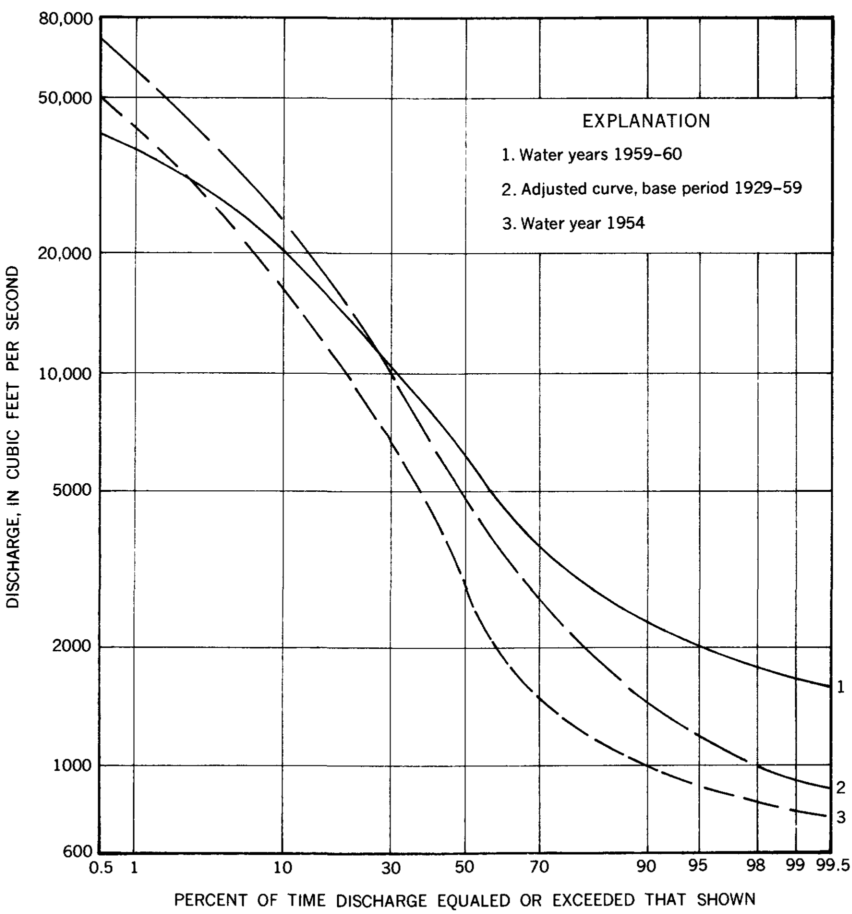

FIGURE 11.—Duration curves of daily flow, Pascagoula River at Merrill, Miss.

base period, 1,500 cfs. The adjusted flow-duration curve can therefore be used to estimate the probable future flow on a long-time basis, but individual years will deviate considerably from the long-time period. Thus, it is not possible to tell from the adjusted curve whether daily discharges less than 900 cfs, which occur 1 percent of the time, will occur during one severe drought or during several droughts occurring in different years. The low-flow frequency curve largely overcomes the limitations of the flow-duration curve.

LOW FLOW

Statistical studies are made of streamflow records to determine the probable frequency of occurrence of future low flows. To furnish information on the magnitude and duration of river discharge during periods of low flow, records of stations in Mississippi were analyzed to determine the lowest mean discharge for periods of 7, 15, 30, 60, 120, and 183 consecutive days for each climatic year of record. At each station and for each period of consecutive days, the data were assigned order numbers beginning with the lowest flow as order number 1. The assigned order numbers were converted to recurrence interval from the formula:

$$\text{Recurrence interval} = \frac{N+1}{M}$$

where

Recurrence interval value in years = the long-time average interval between annual minimum discharge equal to or less than the given minimum;

N = number of years of record; and

M = assigned order number.

As for flow-duration data, the individual station data were adjusted to the base period 1929–57 by comparison with records at long-term gaging stations. Low-flow data for Pascagoula River at Merrill are shown as a family of curves on the logarithmic-frequency paper in figure 12. Low-flow frequency data for all streamflow stations in the area are shown in table 5. Frequency data for partial-record stations were computed for periods of 7, 15, and 30 days only, because of scant data. If graphical presentation is desired, the data in table 5 can be plotted on graph paper similar to that used in figure 12. The frequency data presented in the table are estimates of the probable frequency of occurrence of low flows at the indicated locations, provided no appreciable climatological or man-made changes occur upstream.

Frequency data in table 5 indicate that during a 50-year drought the base flow of many streams in the area would be well sustained. The largest flow would be in the Pascagoula River, where a minimum

TABLE 5.—*Magnitude and frequency of annual low flow at streamflow stations in the Pascagoula area*

[Data are adjusted to period April 1929 to March 1958 on basis of relation to data at other gaging stations]

Reference letter (pl. 1)	Station name	Drainage area (sq mi)	Period (consecutive days)	Annual low flow, in cubic feet per second, for indicated recurrence interval, in years						
				1.03	1.2	2	5	10	20	50
A	Pascagoula River at Merrill, Miss	6,600	7	2,560	1,730	1,230	962	861	774	670
			15	2,740	1,840	1,290	1,020	904	808	703
			30	3,090	2,030	1,400	1,070	948	848	740
			60	4,090	2,580	1,690	1,220	1,050	940	808
			120	5,630	3,500	2,240	1,590	1,360	1,200	1,030
			183	7,900	4,800	3,030	2,080	1,730	1,520	1,280
C	Big Creek near Crossroads, Miss	44.6	7	48	33	24	18	15	13	11
			15	52	36	25	19	16	14	11
			30	58	39	27	21	18	15	12
D	Pascagoula River at Hardwood Railroad Crossing, Miss	6,780	7	2,740	1,870	1,330	1,060	940	840	735
			15	2,940	1,990	1,400	1,110	1,000	890	770
			30	3,260	2,180	1,510	1,170	1,040	940	810
			60	4,300	2,710	1,800	1,310	1,150	1,030	890
			120	5,900	3,690	2,380	1,700	1,470	1,300	1,120
			183	8,200	5,000	3,130	2,200	1,860	1,610	1,400
E	Big Cedar Creek near Wade, Miss	64.3	7	86	66	50	41	36	32	27
			15	92	70	53	44	38	34	29
			30	98	75	57	47	41	36	31
F	Pascagoula River below mouth of Big Cedar Creek, Miss	6,910	7	2,990	2,060	1,500	1,190	1,070	960	845
			15	3,110	2,180	1,580	1,260	1,120	1,020	890
			30	3,520	2,390	1,690	1,310	1,190	1,070	930
			60	4,500	2,980	2,000	1,480	1,290	1,160	1,000
			120	6,200	4,000	2,620	1,900	1,630	1,470	1,280
			183	8,600	5,400	3,490	2,450	2,070	1,800	1,580
G	Black Creek North near Wade, Miss	15.6	7	5.7	2.5	1.2	.6	.4	.3	.2
			15	6.7	3.0	1.4	.7	.5	.4	.2
			30	8.4	3.7	1.7	.9	.6	.4	.3
H	Big Black Creek near Benndale, Miss	710	7	535	337	218	153	123	101	77
			15	595	371	241	169	136	111	85
			30	670	414	264	185	149	122	93
			60	870	530	332	226	183	150	116
			120	1,300	800	510	348	290	245	195
			183	1,930	1,180	740	500	414	352	283
I	Red Creek at Vestry, Miss	416	7	339	214	139	98	80	66	51
			15	375	238	154	109	88	72	56
			30	418	261	168	118	96	79	62
			60	530	335	214	144	118	97	75
			120	760	490	315	217	180	153	124
			183	1,100	700	448	304	249	211	173

J	Pascagoula River at Graham Ferry near Wade, Miss	8,150	7	3,670	2,540	1,840	1,470	1,320	1,190	1,040
			15	3,900	2,690	1,930	1,540	1,390	1,250	1,090
			30	4,380	2,960	2,080	1,600	1,450	1,300	1,150
N	Escatawpa River near Wilmer, Ala	506	7	300	171	102	66	50	38	27
			15	342	193	113	74	56	43	30
			30	393	218	124	82	63	49	35
			60	528	302	166	106	82	63	45
			120	702	435	245	148	120	98	75
			183	894	616	376	224	170	138	107
O	Escatawpa River near Hurley, Miss	639	7	500	320	212	150	120	97	74
			15	565	355	231	163	131	107	81
			30	620	388	253	180	146	118	90
			60	800	505	322	221	179	146	112
			120	1,020	650	418	292	246	208	168
			183	1,450	905	575	390	320	273	223
Q	Big Creek near Big Point, Miss.[1]	[2] 112	7	150	113	87	69	62	55	48
			15	158	120	92	74	66	59	51
			30	171	129	98	79	70	63	54
R	Jackson Creek near Orange Grove, Miss	37.2	7	52	39	30	24	21	18	16
			15	55	41	31	25	22	20	16
			30	60	44	33	26	23	21	17
S	Franklin Creek near Grand Bay, Ala	16.4	7	27	22	18	15	14	13	11
			15	28	23	19	16	14	13	12
			30	30	24	20	17	15	14	12
	Escatawpa River at mile 14 near Orange Grove, Miss.[3]	875	7	715	492	345	258	215	180	143
			15	795	535	370	278	232	195	155
			30	860	580	406	303	252	212	168
T	Black Creek South at Helena, Miss	40.4	7	10	4.0	1.7	.8	.5	.4	.2
			15	13	4.9	2.0	.9	.6	.4	.3
			30	17	6.2	2.6	1.2	.8	.5	.3
W	Bluff Creek near Vancleave, Miss	50.7	7	31	18	11	6.9	5.4	4.3	3.2
			15	35	20	12	7.7	6.0	4.8	3.5
			30	40	23	14	8.6	6.7	5.3	3.9
X	Moungers Creek near Vancleave, Miss	30.6	7	7.0	2.8	1.2	.6	.4	.2	.2
			15	8.4	3.4	1.4	.7	.4	.3	.2
			30	11	4.2	1.8	.8	.5	.4	.2

[1] Low-flow data at this location represents streamflow yield of Big Creek downstream from the reservoir.
[2] Drainage area downstream from Big Creek Reservoir.
[3] Not a streamflow station; a few tide-affected measurements were obtained at this location. Estimates of frequency of low flow based on these measurements and the combined flows of Escatawpa River near Hurley, and Big, Jackson, and Franklin Creeks.

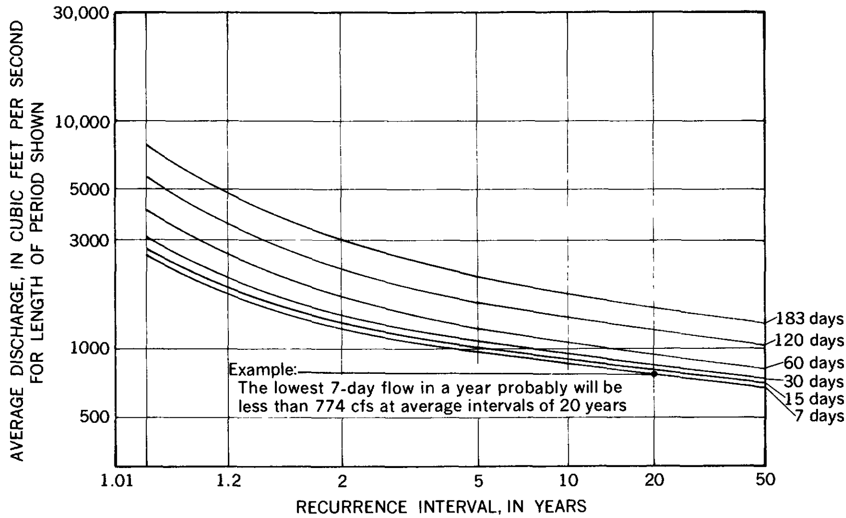

FIGURE 12.—Magnitude and frequency of annual low flows, Pascagoula River at Merrill, Miss., based on data adjusted to period 1929–57.

7-day flow of about 1,000 cfs could be expected at Graham Ferry. The Escatawpa River would have a minimum 7-day flow of about 140 cfs in the vicinity of Orange Grove. Franklin, Jackson, and Big (tributary to Escatawpa River) Creeks would probably have 7-day minimum flows of 10, 15, and 50 cfs, respectively. The Big Creek flow is based on the drainage area below Big Creek Reservoir. Flow from Black Creek Swamp during a 50-year drought would be negligible, as would the flows from Bluff and Moungers Creeks. All streams in the Pascagoula area might not have the same frequency of drought during the same year. A widespread drought would result in extreme low flows on a large river such as the Pascagoula, but some of the tributary streams in the area might not be having a drought of equal severity.

Low-flow frequency data indicate the differences in base flow of the many streams in the area that were shown by the flow-duration curves in figure 10. At all streamflow stations the minimum 7-day flows having recurrence intervals of 2 and 10 years and the minimum 30-day flows having recurrence intervals of 2 and 10 years were converted to cubic feet per second per square mile and are shown in table 6; base-flow yields of the streams can thus be compared in terms of magnitude and frequency without regard to the size of the drainage area.

The frequency data in table 6 show differences in the variability in base flow of individual streams. These differences were indicated by the variability in the slopes of flow-duration curves shown in figure 10.

TABLE 6.—*Low-flow yields of streams in the Pascagoula area*

[Data are adjusted to period 1929–57 on basis of relation to data at other gaging stations]

Reference letter (pl. 1)	Station name	Drainage area (sq mi)	Annual low flow, in cubic feet per second per square mile for indicated period of consecutive days and for indicated recurrence interval, in years: 7 days, 2 years	7 days, 10 years	30 days, 2 years	30 days, 10 years
A	Pascagoula River at Merrill, Miss	6,600	0.19	0.13	0.21	0.14
C	Big Creek near Crossroads, Miss	44.6	.54	.34	.61	.40
D	Pascagoula River at Hardwood Railroad Crossing, Miss.	6,780	.20	.14	.22	.15
E	Big Cedar Creek near Wade, Miss	64.3	.78	.56	.89	.64
F	Pascagoula River below mouth of Big Cedar Creek, Miss.	6,910	.22	.15	.24	.17
G	Black Creek North near Wade, Miss	15.6	.08	.03	.11	.04
H	Big Black Creek, near Benndale, Miss.	710	.31	.17	.37	.21
I	Red Creek at Vestry, Miss	416	.33	.19	.40	.23
J	Pascagoula River at Graham Ferry near Wade, Miss.	8,150	.23	.16	.26	.18
N	Escatawpa River near Wilmer, Ala	506	.20	.10	.25	.12
O	Escatawpa River near Hurley, Miss	639	.33	.19	.40	.23
Q	Big Creek near Big Point, Miss [1]	[2] 112	.78	.55	.88	.62
R	Jackson Creek near Orange Grove, Miss.	37.2	.81	.56	.89	.62
S	Franklin Creek near Grand Bay, Ala	16.4	1.10	.85	1.22	.91
	Escatawpa River at mile 14 near Orange Grove, Miss. [3]	875	.39	.25	.46	.29
T	Black Creek South at Helena, Miss	40.4	.04	.01	.06	.02
W	Bluff Creek near Vancleave, Miss	50.7	.22	.11	.28	.13
X	Moungers Creek near Vancleave, Miss.	30.6	.04	.01	.06	.02

[1] Low-flow data at this location represents streamflow yield of Big Creek downstream from the reservoir.
[2] Drainage area downstream from Big Creek Reservoir.
[3] Not a streamflow station; a few tide-affected measurements were obtained at this location. Estimates of frequency of low flow based on these measurements and the combined flows of Escatawpa River near Hurley, and Big, Jackson, and Franklin Creeks.

An index for comparing the variability of base flow was arbitrarily chosen as the ratio of the minimum 7-day flow having a recurrence interval of 2 years (7-day Q_2) to the minimum 7-day flow having a recurrence interval of 10 years (7-day Q_{10}). The ratios of 7-day Q_2 to 7-day Q_{10} were determined for most gaging stations in the area and plotted against the 7-day Q_2 (fig. 13). The Pascagoula River was excluded because of its large drainage area. Streams of this size in humid areas attain base flow less frequently than the smaller tributary streams.

A definite relationship is shown in figure 13 between streamflow yield and variability of base flow of the individual tributary streams in this area. Franklin Creek has a high 7-day Q_2 of 1.10 cfs per sq mi and a low variability ratio of 1.29 (1.00 indicates no variability in base flow); Moungers Creek has a low 7-day Q_2 of 0.04 cfs per sq mi and a high variability ratio of 3.00.

FACTORS AFFECTING LOW FLOW

The base flow of streams in the Pascagoula area is derived primarily from the Citronelle Formation, the terrace deposits, and the alluvial

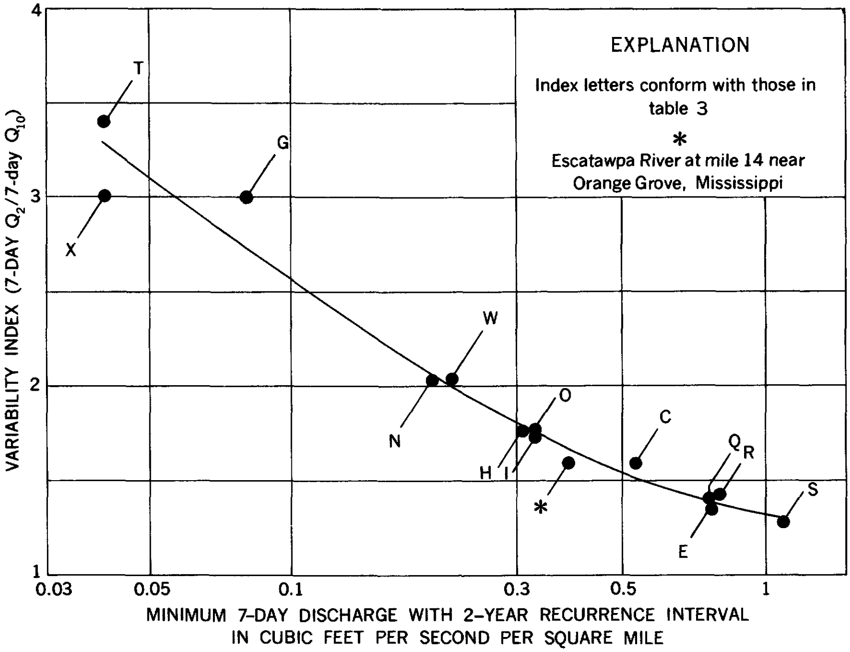

FIGURE 13.—Relation of streamflow yield to variability index in Pascagoula area.

fill. The Graham Ferry and Pascagoula Formations contribute little to the base flow. Variation in base discharge among the streams tributary to the Escatawpa and Pascagoula Rivers can be attributed in part to several geologic factors.

Ground-water discharge to a stream is dependent upon (1) the porosity and permeability of the aquifer; (2) relation of the altitudes of the base of the aquifer, the water table, and the surface water in the stream; and (3) the slope of the water table toward the stream. Generally, within areas of similar surficial geology, the altitude of the water table is directly related to the altitude of the land surface. The aquifers are not homogeneous units. For example, the Citronelle Formation and related terrace deposits are not lithologically uniform; they consist of clay, silt, fine to coarse sand, and gravel in varying proportions. The proportions of these materials determine the porosity and permeability, which are measures of the ability of an aquifer to store and yield water.

For selected streams, the relation between stream discharge and areal distribution of the Citronelle Formation is shown in figure 14. The percentage of the drainage area covered by the Citronelle was plotted against the 7-day Q_{10}.

Base flows of the streams east of Pascagoula River are higher than those west of the river. Generally, the areal distribution of the

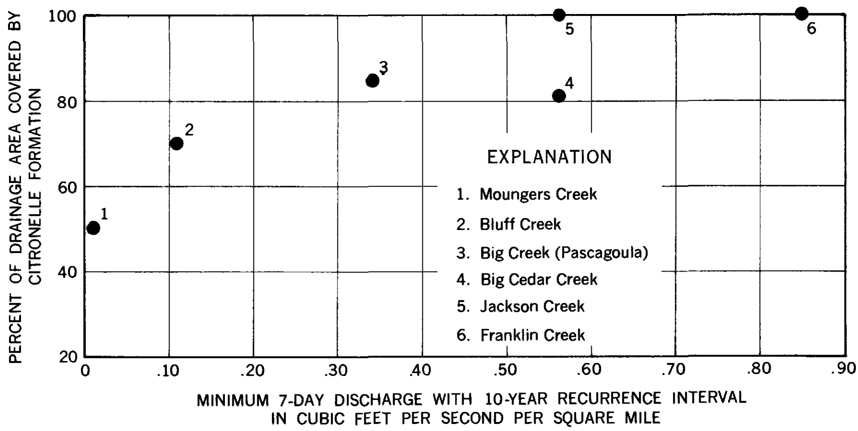

FIGURE 14.—Plot showing relation of base flow in selected streams to areal coverage of basin by Citronelle Formation.

Citronelle Formation in tributary basins east of the Pascagoula (including tributary basins to the Escatawpa River) is greater than in tributary basins west of the Pascagoula. However, the graph in figure 14 indicates that areal coverage by the aquifer is only one factor controlling base flow. The percentage of surface area covered by the Citronelle Formation in Big Creek basin is greater than in Big Cedar Creek basin. However, Big Creek (tributary to Pascagoula River) has only 60 percent as much base flow per square mile as Big Cedar Creek. The more mature dissection of the land surface in the Big Creek basin indicates that the volume of Citronelle above the elevation of the stream bed is less than in Big Cedar Creek basin; there are resultant lower base flows in Big Creek. Thus, within areas of similar surficial geology, topography can be an important factor controlling base flow.

Ground-water discharge to the main stem of Escatawpa River is much larger in the reach from Wilmer to Hurley, owing to the steeper hydraulic gradient that results from higher land surfaces, than in the reach downstream from Hurley. Generally, water contributed from east of the river is greater than that from the west because of the higher altitude of the land surface adjacent to the river. Most of the ground water gained by Escatawpa River downstream from Hurley is contributed by tributary streams entering the river from the east. Little ground water is gained in this reach of the river channel, compared to the gains elsewhere.

Ground-water discharge to the main-stem Pascagoula River follows generally the same pattern as discharge to the main-stem Escatawpa River. About 40 percent of the total increase in base flow in the reach between Merrill and below the mouth of Big Cedar Creek is due to ground-water discharge (p. 37–43). Tributary streams from the east have higher base flows per square mile than those from the west; therefore, it is assumed that ground-water discharge to the river from the east is greater than that from the west. Discharge to the river downstream from Graham Ferry probably is much less than that in the upper reach because the altitude of the land surface is lower, the slope of the water table is flatter, and the flood plain is considerably wider and of a swampy nature.

AVERAGE MINIMUM FLOW

Average minimum flow for a given stream at a given point is defined in the Mississippi water law as "the average of minimum daily flow occurring during each of the five lowest years in the preceding twenty consecutive years." The law further states that determination of average minimum flow "shall be based upon available streamflow data, supplemented, when available data is incomplete, by reasonable calculations." The term "average minimum flow" as defined above will be used without further qualification. The period 1941–60 was used for determinations of average minimum flow of streams in the Pascagoula area.

Pascagoula River at Merrill is the only gaging station in the area having 20 years of daily streamflow record. The average minimum flow at this location was computed to be 887 cfs. Calculations of average minimum flow at other stations were made in the following manner: for Escatawpa River near Wilmer average minimum flow was estimated to be 54 cfs by transposing the average minimum flow at Merrill through the Merrill-Wilmer relationship curve that was based on low-flow frequency data. The average of the five lowest annual minimum daily discharges during the period of record (1946–60) at Wilmer was 62 cfs. However, the discharge of 54 cfs, based on the 20-year record at Merrill, was used as the average minimum flow at Wilmer and is considered a reliable calculation.

The Wilmer discharge of 54 cfs was transposed to selected stations in the area through the appropriate low-flow frequency relationship curves, and was further transposed from the selected stations to the other stations in the area. The calculated average minimum flow for each streamflow station in the area is shown in table 7. Also shown for comparative purposes is the value of average minimum flow in cubic feet per second per square mile. On the main stem Pascagoula and Escatawpa Rivers, reasonably accurate interpolations of average minimum flow can be made for sites between gaging stations on the basis of drainage area, if allowances are made for differences in yields of tributary inflow.

The annual minimum daily flows of streams in the area are primarily ground-water discharge. During wet years, Pascagoula River

TABLE 7.—*Estimated average minimum flow, 1941–60, at streamflow stations in the Pascagoula area*

Reference letter (pl. 1)	Station	Estimated average minimum flow (cfs)	Estimated average minimum flow (cfs per sq mi)
A	Pascagoula River at Merrill, Miss	[1] 887	[1] 0.134
C	Big Creek near Crossroads, Miss	16	.359
D	Pascagoula River at Hardwood Railroad Crossing, Miss	980	.145
E	Big Cedar Creek near Wade, Miss	37	.575
F	Pascagoula River below mouth of Big Cedar Creek, Miss	1,100	.159
G	Black Creek North near Wade, Miss	.5	.032
H	Big Black Creek near Benndale, Miss	130	.183
I	Red Creek at Vestry, Miss	84	.202
J	Pascagoula River at Graham Ferry near Wade, Miss	1,360	.167
N	Escatawpa River near Wilmer, Ala	54	.107
O	Escatawpa River near Hurley, Miss	128	.200
Q	Big Creek near Big Point, Miss	65	.580
R	Jackson Creek near Orange Grove, Miss	22	.591
S	Franklin Creek near Grand Bay, Ala	14	.854
T	Black Creek South at Helena, Miss	.6	.013
W	Bluff Creek near Vancleave, Miss	5.8	.114
X	Moungers Creek near Vancleave, Miss	.4	.013

[1] Not an estimate; computed on the basis of 20 years of daily streamflow record.

may not recede to base flow; however, the annual minimum flows that are used for the computation of average minimum flow are probably base flow, even on this large river. The long-time cyclic effect or persistence of rainfall is reflected in the ground-water discharge to the stream; thus, there is a tendency for years of low annual minimum daily flow to be grouped together. For example, the annual minimum daily discharge at Merrill during the period 1931–60 was less than 1,000 cfs during the years 1936–38, 1941, 1952, 1954–56.

FLOODFLOW

Flood data are necessary for proper design and location of structures on flood plains. Flood data represent past events and may be used in the form of flood-frequency curves to predict future events. Such curves applicable to streams in the Pascagoula area were extracted from "Floods in Mississippi, Magnitude and Frequency," by Wilson and Trotter (1961), and are shown herein. The magnitude and frequency of floods may be estimated from these curves by using the variables of size, shape, and location of the drainage basin.

FLOOD-FREQUENCY CURVES

Peak discharge of floods at 174 sites on streams in Mississippi were correlated with drainage area and a basin shape factor using graphical multiple correlation techniques. The basin shape factor used was a ratio of the length that floodwaters must flow divided by the average width of the basin. The ratio was computed by using the formula

$$r=\frac{L^2}{A}, \text{ or } r=\frac{L}{W}$$

where

r=ratio; the basin shape factor;

L=maximum length, in miles, that floodwaters flow;

A=drainage area, in square miles, of the basin;

W=average width, in miles, of the basin, equivalent to A/L.

A study of the correlations indicated that, after both drainage area and basin shape had been considered, significant errors of estimate of the peak discharges remained. Some of this scatter undoubtedly can be attributed to chance and errors in method; however, a large part of it is the result of factors such as geographic location, slope, geology, and soil types not evaluated in the correlations. Many of these factors were found to be similar in various geographic areas in Mississippi. Largely through trial and error, the State was divided into five hydrologic areas, two of which are in the Pascagoula area (fig. 15).

The family of curves applicable to each of the hydrologic areas in the study basin are shown in figures 16 and 17. It was impractical to incorporate the effect of basin shape into these curves; therefore the curve showing that effect is presented separately in figure 18. In the Pascagoula area larger floods usually overtop the banks and flow along the valley; therefore, the length of floodwater flow is measured as valley length, rather than channel length.

USE OF FLOOD-FREQUENCY CURVES

Flood-frequency curves may be used to estimate the magnitude and frequency of floods on most streams in the Pascagoula area. Methods presented herein are not applicable for regulated streams or for extremely small drainage areas. Neither do the curves apply to estuarial sites near the mouths of Pascagoula and Escatawpa Rivers where unusual flood discharges result from hurricane tides moving water into storage. Similarly, the curves do not apply near mouths of streams draining into larger streams, because the rate of rise or fall of the larger streams may cause variable backwater and storage at places in question.

To illustrate the use of these curves, the frequency of a measured peak discharge of Franklin Creek has been determined. A peak discharge of 2,570 cfs was measured April 12, 1961 at the partial-record station on Franklin Creek (pl. 1, station S). The following steps were taken to determine the probable frequency of this flood:

1. From the Geological Survey Hurley and Grand Bay 15-minute quadrangles, the drainage area was measured by planimeter as 16.4 square miles.
2. The maximum length floodwaters must travel was measured on the maps; the valley length was found to be 7.3 miles.

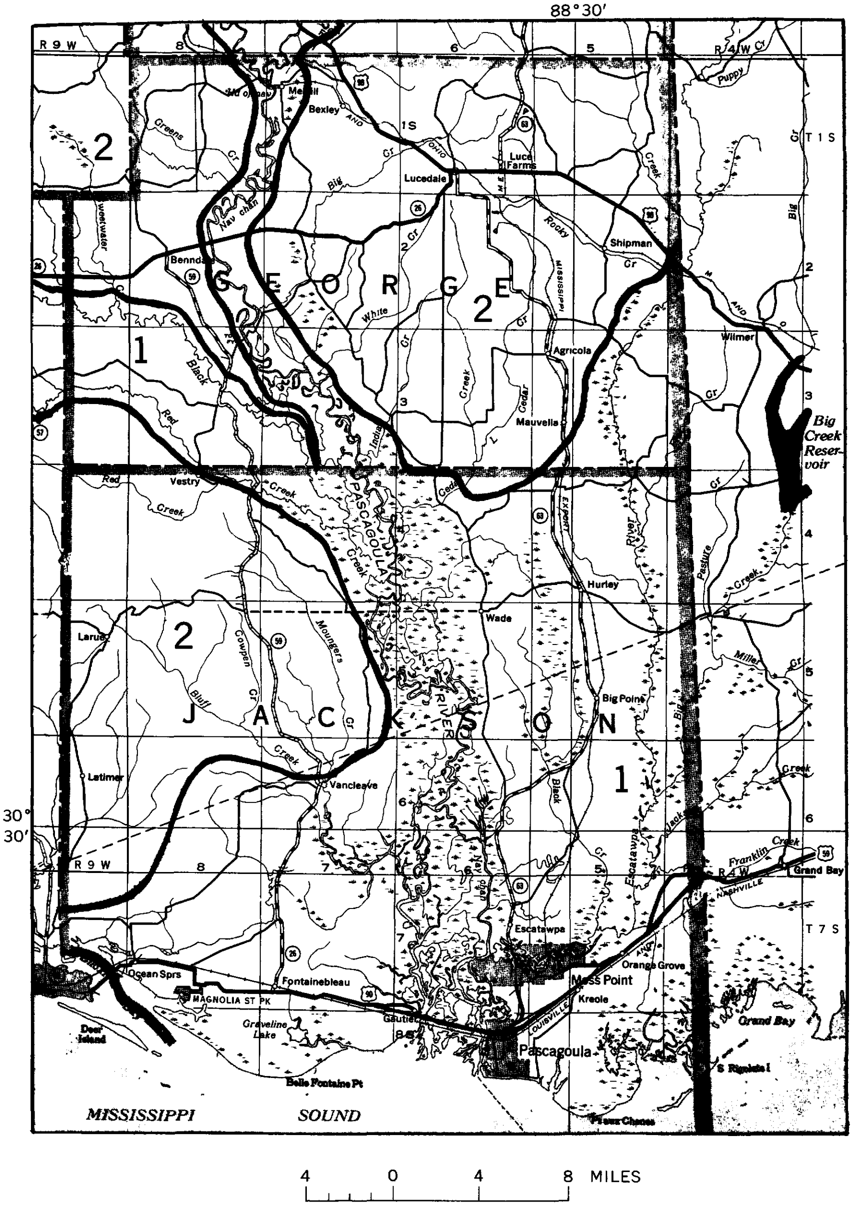

FIGURE 15.—Map of Pascagoula area showing location of hydrologic areas 1 and 2.

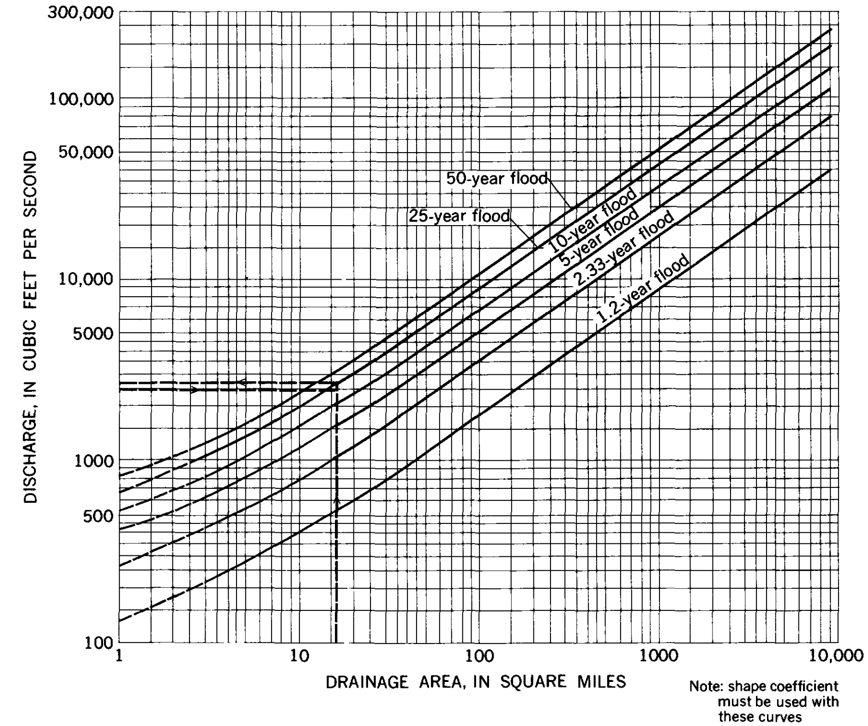

FIGURE 16.—Flood-frequency curves for hydrologic area 1.

3. The length/width ratio was computed from the formula $r=\frac{L^2}{A}=\frac{(7.3)^2}{16.4}=3.25$. From the curve in figure 18 and the length/width ratio of 3.25, the shape coefficient of 1.04 was determined.
4. The measured discharge of 2,570 cfs was divided by the shape coefficient (1.04); this computation gives an adjusted discharge of 2,470 cfs for a basin having an average shape.
5. It was determined from the map on figure 15 that Franklin Creek drainage basin was in hydrologic area 1.
6. It was determined from figure 16 that for a drainage area of 16.4 square miles a flood of 2,470 cfs might be expected once in a period of about 16 years.

The magnitude of a 25-year flood at the same location on Franklin Creek was determined by using a procedure somewhat the reverse of that outlined above (the drainage area, length to width ratio, and shape coefficient are the same as those determined previously): The 25-year flood was determined from figure 16 as 2,740 cfs. This value is for an average-shaped drainage basin and was adjusted for Franklin Creek basin by multiplying 2,740 cfs by the shape coefficient (1.04);

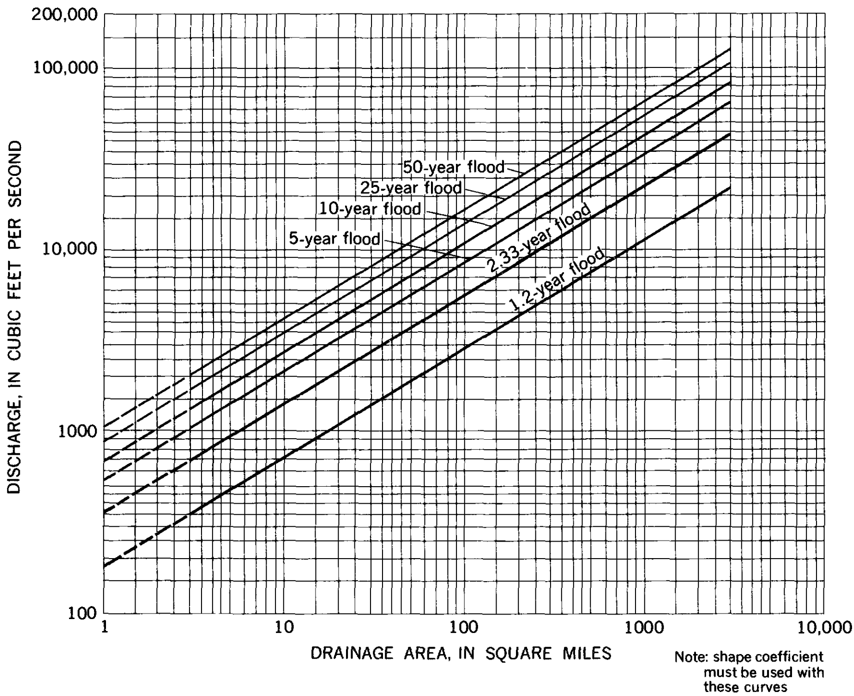

FIGURE 17.—Flood-frequency curves for hydrologic area 2.

a value of 2,850 cfs was thus obtained as the magnitude of a 25-yea flood at the partial-record station on Franklin Creek.

FLOOD PROFILES

The six highest floods on the main-stem Pascagoula River during this century, listed in order of magnitude, occurred during April 1900, July 1916, February–March 1961, April 1912, December 1919, and April 1938. The peak discharge of the February–March 1961 flood at Merrill was determined to have a recurrence interval of about 50 years. Elevation of the crest of the 1961 flood was determined at several locations by a level survey of floodmarks along the river. A profile of the 1961 flood is shown in figure 19. This figure also shows a profile of the 1938 flood, which was determined by the Corps of Engineers. The approximate elevations of the crests of the 1900 and 1916 floods were determined at a few locations on the basis of information obtained from local residents and are noted on the profile.

The river mileage shown in figure 19 was determined by measuring along the mapped low-water channel. Some breaks in the profile are due to constrictions in the valley, particularly in the reach between Cumbest Bluff and Coll Town. A great difference in channel and valley length also occurs in the vicinity of Cumbest Bluff between

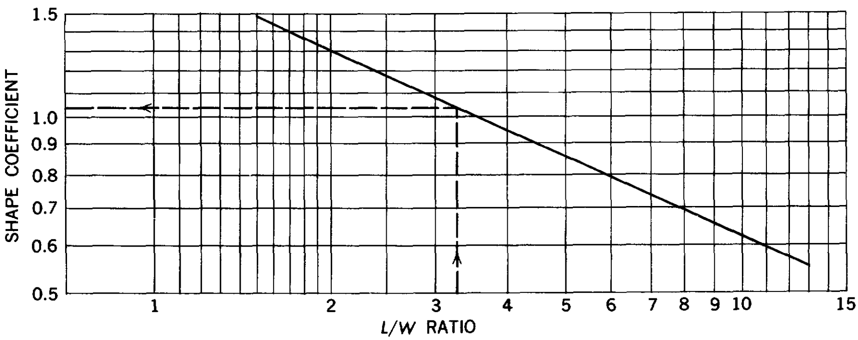

FIGURE 18.—Shape coefficient curve for hydrologic areas 1 and 2.

miles 30 and 25, where the channel meanders from the west to the east side of the valley, a distance of about 5 miles along the channel and about 1 mile along the valley.

TIDAL CHARACTERISTICS

Tides in the mouth of Pascagoula River are usually diurnal (one high and one low tide during a lunar day), except at the moon's quadrature (the position of half moon that occurs once in about 14 days) when two highs and lows (neap tides) occur, often with little change in elevation. Spring tides, which occur at new and full moon, are the highest tides and also have the greatest amplitudes. The amplitudes gradually diminish from spring to neap tides. In the mouth of the Pascagoula the maximum fluctuation in spring tides is about 3 feet, and the minimum fluctuation in neap tides is about 0.1 foot.

Another element of tidal fluctuation is the seasonal variation in elevation of the mean tide as shown by the records of the Corps of Engineers gage at the mouth of Pascagoula River. During most of the years of complete record, 1941–60, the highest monthly mean tides occurred in September (0.85 ft above msl) and October (0.70 ft above msl) and the lowest, in January (0.02 ft above msl) and February (0.05 ft above msl). The high tides occurring during September and October generally are higher than those of other months. Mean tide at the mouth of Pascagoula River during the period 1941–60 was 0.39 foot above mean sea level.

During 1940–60, the annual maximum tides in the mouth of Pascagoula River ranged from 2.35 to 7.68 feet above mean sea level. The highest tide occurred as the result of the September 1947 hurricane, and 10 of the annual maximum tides were influenced by tropical cyclones. (See section on "Hurricanes," p.23). Annual maximum tides have occurred in August, September, or October during 14 of the 21 years of record. The annual minimum tides observed in the mouth of

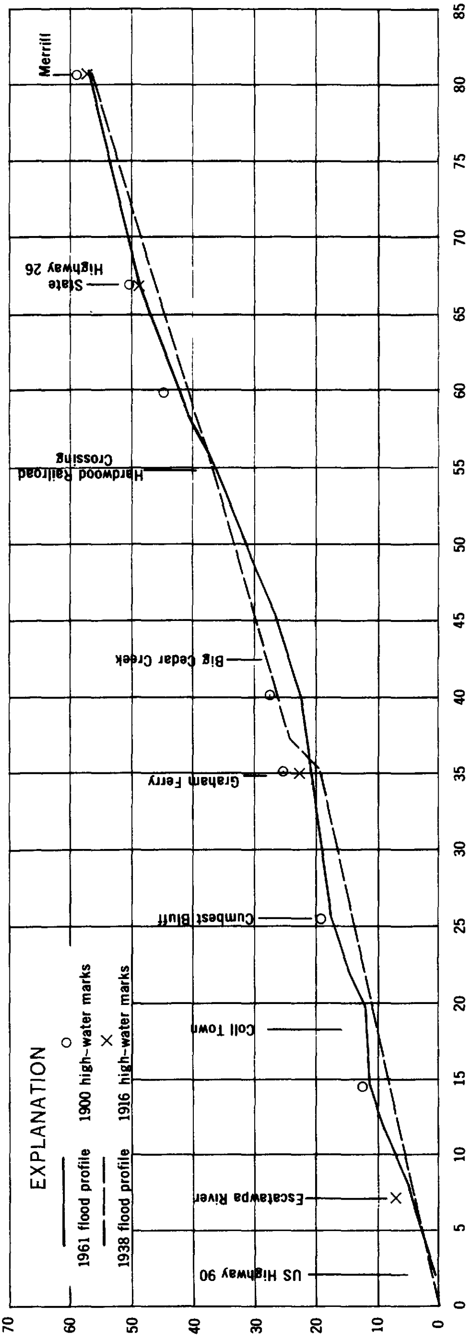

FIGURE 19.—Flood profiles of Pascagoula River.

the river ranged from 2.82 to 1.58 feet below mean sea level and usually occurred during the period December to February.

The U.S. Geological Survey operated four recording gages in the lower Pascagoula River to augment the data obtained from the Corps of Engineers tide gage during this study. All five gages showed tidal effects, and the stage hydrographs were of the same general shape and trend. Time lag of the tide between the gages varied depending upon the magnitude of the tide and river discharge at the time. The amplitude of the tide decreased as it moved upstream.

Normal tidal fluctuations in Mississippi Sound affect the stage and discharge of Pascagoula River during low-flow periods to at least mile 42, but not above mile 53. Escatawpa River is also tide-affected, and, during periods of low river discharge, normal tide effect may extend to mile 20, but not above mile 25. Tide effect was observed on Bluff Creek (a tributary to West Pascagoula River) in the vicinity of Vancleave. Three Escatawpa River tributaries were also affected by tides: the lower reaches of Franklin and of Jackson Creeks and Black Creek South (drainage from Black Creek Swamp) in the vicinity of Helena.

Quantitative values of tide effect on river stage and discharge were determined at the three upper tide stations on the main-stem Pascagoula River. At the Graham Ferry station during periods of low flow, the change in river stage during a spring tidal cycle (a lunar day) was as much as 0.6 foot; at Cumbest Bluff station, 1.9 feet; and at Coll Town station, 2.4 feet. Tide effect on river stage became negligible when the elevation of the river stage was 6.0, 5.5, and 5.0 feet above mean sea level at the respective stations. Continuous measurements of discharge were made at the three stations during a complete tidal cycle to determine the variation in discharge. (See following table.)

Station	Tidal cycle measurements					
	Date	Discharge, in cubic feet per second			Stage in feet above mean sea level	
		Maximum	Minimum	Average	Maximum	Minimum
	1958					
Pascagoula River at Graham Ferry	Oct. 29–30	3,400	2,900	3,120	2.78	2.29
Pascagoula River at Cumbest Bluff.	Oct. 27–28	4,100	2,800	3,290	1.86	0.90
	Nov. 12–13	4,700	2,300	3,480	2.44	1.03
Pascagoula River at Coll Town	Oct. 22–23	4,700	3,400	3,930	1.49	1.00
	Nov. 10–11	6,200	2,800	4,180	1.85	0.19

These specific examples show that tidal influence diminishes as the distance from the mouth of the river increases, and indicate the amount of variation in stage and discharge due to tide at the three locations on the main stem. Effects of spring and neap tides are also indicated by comparing the two tidal cycle measurements, made during periods of nearly equal river discharge, at Coll Town. The measurement of November 10–11, 1958, was influenced by a spring tide, and that of October 22–23, 1958, by a neap tide.

The effect of tides on salt-water penetration in the lower Pascagoula River system is discussed in the section "Salt-water intrusion."

QUALITY OF SURFACE WATER

PASCAGOULA RIVER

CHEMICAL QUALITY

The quality of water in Pascagoula River near Benndale is considered representative of the chemical characteristics that exist in the stream above the zone of salt-water intrusion. Analyses of samples collected near Benndale indicate that in the fresh-water reach of the stream the dissolved solids usually are low and, at times, are characterized by large daily variations. These variations are less pronounced in the lower part of the fresh-water reach of the stream because the downstream inflow of tributaries tends to lower the dissolved-solids content and thus to lower the extremes of daily variations.

Results of the analyses of samples collected at the station near Benndale are shown in table 8. These analyses show the dissolved-solids content ranging from 65 to 265 ppm and hardness ranging from 11 to 28 ppm. For the period of record, the dissolved solids and hardness averaged 100 ppm and 18 ppm, respectively.

Because specific-conductance values depend on the quantity and degree of ionization of the dissolved-mineral constituents, these values are indicative of the dissolved-solids content of the water. The relation of dissolved solids to specific conductance is shown in figure 20. Values for dissolved solids are shown as residue at 180°C and as calculated from the determined constitutents. The difference between the two values is an indication of organic matter in the water. The distribution of daily specific-conductance values in table 9 shows that most of the time the dissolved solids are low and that the higher values do not occur frequently. Table 9 shows that the median (50 percent) value for specific conductance is 100 micromhos and the estimated dissolved-solids content is 81 ppm. In 75 percent of the samples, the specific conductance (160 micromhos) and estimated dissolved-solids content (112 ppm) were only slightly higher than the averages.

The changes in concentration of the various ions in solution as the dissolved solids increase are illustrated in figures 21 and 22. In these illustrations the total concentration is the sum of the ionized con-

TABLE 8.—*Chemical analyses, in parts per million, of water from Pascagoula River near Benndale, Miss., August 1958 to September 1960*

Date of collection	Mean discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Copper (Cu)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Dissolved solids: Residue at 180° C	Dissolved solids: Calculated from determined constituents	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25° C)	pH	Color
1958																						
Aug. 1-7	14,490	1.8	0.42	------	------	5.6	1.2	8.6	1.6	16	2.0	17	0.0	2.0	------	78	48	19	6	82	6.7	60
Aug. 8-27	5,060	3.1	.68	------	------	7.2	.9	19	2.1	20	7.2	29	.0	1.2	------	98	80	22	5	133	7.0	45
Aug. 28-31	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
Sept. 1-17	2,646	6.5	.29	------	------	5.9	1.7	37	1.2	24	4.2	56	.0	.7	------	158	126	22	2	242	6.7	15
Sept. 18-30	20,360	1.8	.41	------	------	3.6	.5	8.2	1.2	12	2.2	12	.0	.9	------	65	37	11	1	73	6.3	40
Oct. 1-10	8,109	6.0	.10	0.00	0.12	5.6	1.1	16	1.4	20	3.0	24	.2	1.5	0.09	96	69	18	2	118	7.2	40
Oct. 11-31	2,895	7.2	.08	.00	.07	7.0	1.0	14	1.2	25	3.8	20	.3	1.4	.08	88	68	22	1	113	6.7	30
Nov. 1-30	2,784	4.7	.07	.00	.07	5.9	1.1	13	1.3	20	3.0	19	.2	1.7	.13	80	60	19	2	104	6.9	22
Dec. 1-31	3,753	3.9	.32	------	------	5.6	1.3	12	1.5	18	3.8	19	.1	1.7	------	82	58	20	4	98	7.1	30
1959																						
Jan. 1-31	8,067	3.0	.18	.00	.12	5.2	1.2	8.4	1.5	16	4.8	14	.2	1.2	.01	79	48	18	5	96	6.9	45
Feb. 1-28	16,910	2.6	.12	.00	.12	4.8	1.0	6.5	1.1	12	4.0	11	.1	1.0	.00	66	38	16	6	80	5.8	45
Mar. 1-31	10,790	2.6	.15	.00	.13	5.1	.8	7.2	1.0	14	3.6	12	.1	1.4	.00	68	41	16	4	82	6.5	45
Apr. 1-30	13,060	2.3	.23	.00	.18	5.9	.9	9.1	1.1	17	3.0	15	.1	1.6	.01	78	48	18	4	95	6.5	50
May 1-31	5,800	7.9	.25	.00	.00	6.9	.9	20	1.4	24	4.8	29	.0	1.7	.00	104	85	20	1	147	6.7	25
June 1-30	18,010	5.5	.34	.00	.00	5.8	.4	15	1.2	18	4.0	22	.0	2.0	.00	86	65	16	1	110	6.7	40
July 1-31	5,944	5.0	.26	.00	.00	5.5	1.0	27	1.8	18	4.8	40	.0	2.1	.00	119	96	18	2	181	6.7	40
Aug. 1-31	4,282	7.4	.34	.00	.00	6.0	1.3	27	1.8	20	4.8	42	.0	2.0	.00	128	102	20	4	191	7.0	40
Sept. 1-30	3,798	4.7	.06	.00	.06	5.4	1.8	20	.1	17	4.4	32	.2	1.9	------	111	79	21	7	150	6.6	45
Time-weighted average	18,135	4.6	0.24	------	------	5.7	1.1	16	1.3	18	4.1	25	0.1	1.6	------	94	68	18	4	126	------	38
Oct. 1-31	8,314	2.7	0.07	0.00	0.06	3.8	1.2	10	0.2	13	3.6	16	0.2	1.9	------	77	46	14	4	87	6.1	40
Nov. 1-30	10,550	3.9	.12	.00	.02	4.0	1.8	9.5	.2	18	4.4	13	.2	1.6	------	73	48	18	2	82	7.9	40
Dec. 1-31	6,743	5.9	.12	.00	.06	5.4	1.7	12	.2	16	4.6	18	.2	2.0	------	109	58	20	8	99	6.7	40
1960																						
Jan. 1-31	10,820	1.2	.00	.00	.00	5.7	1.2	8.8	1.1	16	5.4	15	.0	.7	------	76	47	19	6	86	6.5	12
Feb. 1-29	19,320	4.8	.04	.00	.00	5.6	.4	6.5	1.2	13	4.4	11	.0	.8	------	66	41	16	5	72	6.4	15
Mar. 1-31	17,850	4.5	.00	.00	.00	5.9	.8	7.2	1.0	14	5.0	12	.0	1.0	------	70	44	18	6	78	6.7	20
Apr. 1-30	17,430	4.4	.04	.00	.00	6.5	.8	11	1.7	22	3.8	16	.0	.9	------	75	56	20	2	98	6.6	18
May 1-31	13,560	2.0	.04	.00	.00	5.7	1.2	19	2.5	18	3.8	31	.0	.8	------	100	75	19	4	143	6.8	16

June 1-10	2,901	2.5	.00	.00	.00	9.5	1.0	32	2.2	30	5.0	50	.0	.5	------	145	118	28	3	223	7.0	10
June 11-20	1,960	2.1	.01	.00	.00	7.9	1.0	58	2.6	24	5.8	90	.0	.6	------	204	180	24	4	353	6.8	8
June 21-30	1,926	1.9	.02	.00	.00	7.7	1.3	73	2.8	24	6.0	115	.0	.6	------	259	220	24	5	438	6.8	8
July 1-10	1,913	3.2	.01	.00	.00	7.9	.6	58	2.5	24	5.0	91	.0	.5	------	204	181	22	2	358	6.9	8
July 11-31	2,259	2.5	.00	.00	.00	7.9	.6	43	2.1	20	6.4	67	.0	.8	------	164	140	22	6	273	6.5	8
Aug. 1-6	2,147	1.2	.00	.00	.00	7.2	1.7	90	2.6	20	4.2	145	.0	.6	------	265	262	25	8	449	6.7	8
Aug. 7-10	3,070	.7	.00	.00	.00	5.2	.9	30	2.0	14	5.2	47	.0	1.2	------	123	99	16	5	200	6.8	10
Aug. 11-15	2,974	2.1	.04	.00	.00	6.2	.4	53	2.1	18	5.6	81	.0	.7	------	184	160	17	2	309	6.9	15
Aug. 16-20	5,296	.5	.02	.00	.00	6.4	.2	28	1.8	10	5.2	46	.0	1.6	------	126	95	17	9	190	6.5	18
Aug. 21-31	9,045	.9	.02	.00	.00	4.8	.7	12	1.5	10	6.8	18	.0	2.1	------	81	52	15	7	103	6.5	18
Sept. 1-30	3,220	1.6	.00	.00	.00	7.7	.3	23	1.5	18	4.4	38	.0	.5	------	110	86	20	5	161	6.8	15
Time-weighted average	9,760	3.1	0.04	0.00	0.01	6.0	1.0	21	1.4	17	4.7	33	0.1	1.1	------	107	79	19	5	148	-----	21

[1] Mean discharge for water year, October 1953 to September 1959, was 8,062 cfs.

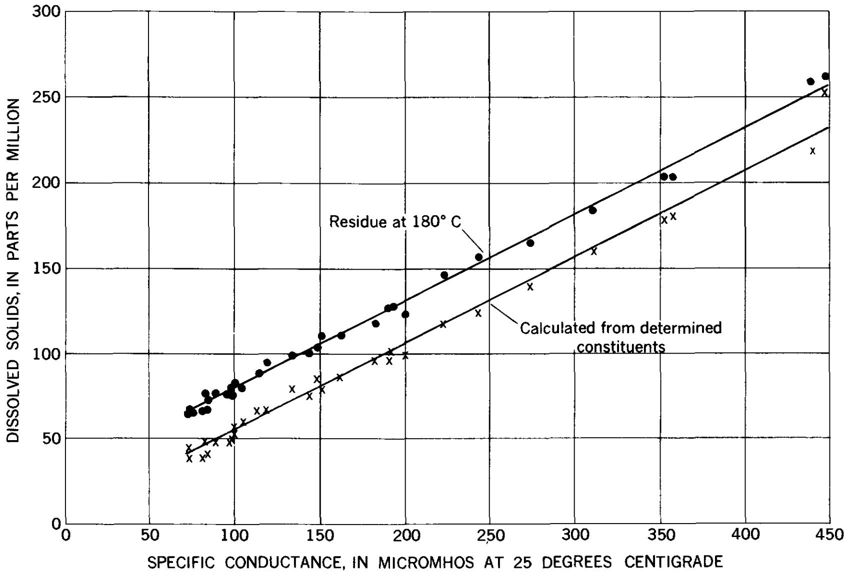

FIGURE 20.—Relation of dissolved solids to specific conductance, Pascagoula River near Benndale, Miss.

stituents. The illustrations show that increases in total concentration are due principally to increases in the concentrations of sodium and chloride. Calcium plus magnesium and also bicarbonate increase slightly, and sulfate remains fairly constant throughout the range of total concentration values.

Some of the analysed samples show a relatively high iron content. All the samples showing high iron content also have a high color, which is probably a result of the leaching of iron from the organic color complex during the analysis.

Very little relation exists between the day-to-day quality variation and streamflow. However, compositing the daily samples tends to even out daily variations, and there is a marked relation between the composited samples and streamflow. The relation between streamflow and specific conductance is shown in plate 7. This illustration shows that specific-conductance values, except for daily fluctuations,

TABLE 9.—*Percent of daily samples having specific-conductance and dissolved-solids (estimated) values equal to or less than shown; Pascagoula River near Benndale, Miss., Aug. 1, 1958, to Sept. 30, 1960*

	Percent of samples						
	1	10	25	50	75	90	99
Specific conductance...micromhos at 25°C ..	40	64	80	100	160	250	455
Estimated dissolved solids ppm residue on evaporation..	51	63	71	81	112	157	260

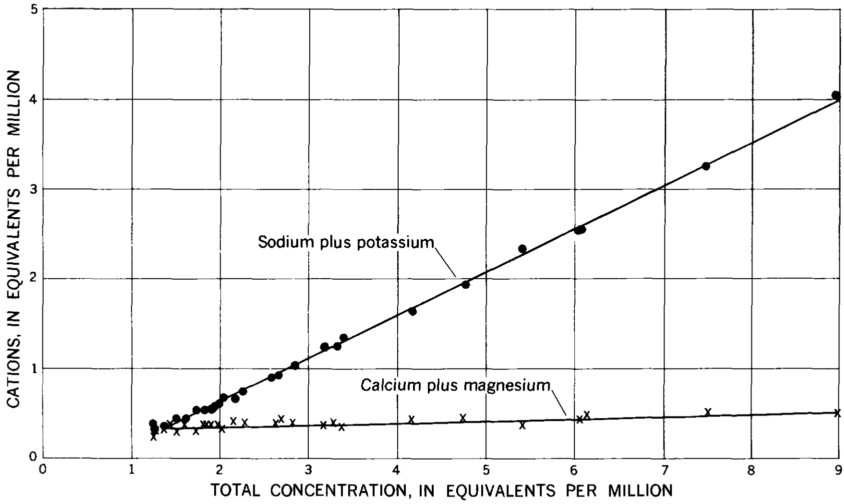

FIGURE 21.—Relation of cations to total concentrations, Pascagoula River near Benndale, Miss.

vary inversely with streamflow, and the higher conductance values usually occur during summer when streamflow is low.

The manner in which the quality varies daily plus the fact that changes in dissolved-solids content are essentially changes in sodium chloride indicate that brine from oil-field operations in the Chickasawhay and Leaf River drainage basins is getting into the rivers.

TEMPERATURE

Temperature of a water supply is an important consideration, particularly for water used by industry for cooling. The temperature

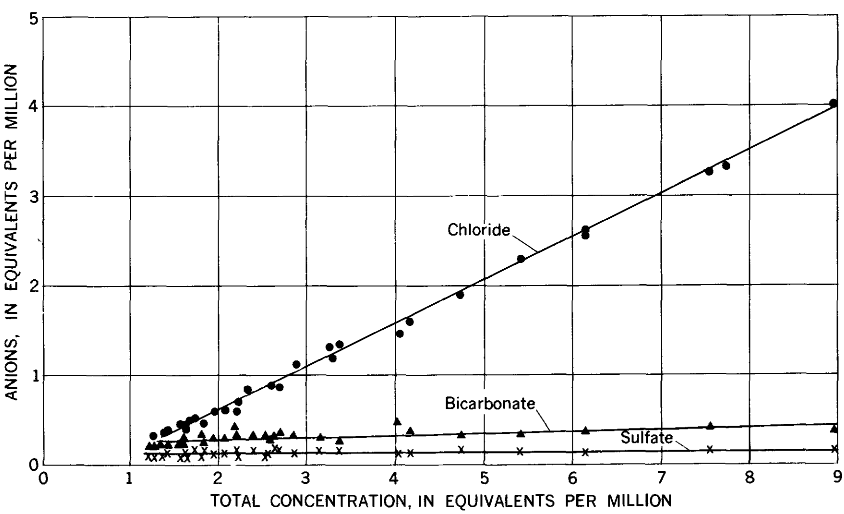

FIGURE 22.—Relation of anions to total concentrations, Pascagoula River near Benndale, Miss.

of water in the Pascagoula near Benndale was measured once daily from August 1, 1958, to September 30, 1960, and the readings are shown in table 10. The daily water temperatures ranged from 38°F to 91°F, and the monthly average temperatures ranged from 46°F to 88°F. The following table shows the frequency with which these water temperatures occurred during this period.

Percent of daily samples in which water temperatures equaled or exceeded that shown

	Percent of samples						
	1	10	25	50	75	90	99
Water temperature °F	90	84	79	68	56	47	40

SEDIMENT

Suspended sediment concentration in Pascagoula River is low. The results of analyses of random samples collected at various stream discharges are shown in table 11. Sediment concentration in the Pascagoula is related more to the manner in which the river stage changes than to the volume of water discharged. For example, the April 23, 1959, sample was collected when the river was rising. The mean daily discharge was 16,000 cfs and the sediment concentration was 165 ppm. On June 9, 1959, the mean daily discharge was 21,300 cfs, but the river was falling and the sediment concentration was down to 68 ppm. Analysis of the sediment material indicates that approximately 10 percent of it is organic and 90 percent is inorganic. Approximately 6 percent of the inorganic residue is soluble in hydrochloric acid. The remaining residue is presumed to be insoluble silicates.

TRIBUTARIES OF THE PASCAGOULA RIVER

CHEMICAL QUALITY

The dissolved-solids content of water in the tributary streams are low and, with the exception of Red Creek, are fairly uniform in composition. Discharge of oil-field brine into Red Creek is reflected by a higher and more variable sodium and chloride content in Red Creek than in the other streams. Analyses of samples collected from these streams are shown in table 12. A comparison of dissolved-solids values and stream discharge indicates that in Red Creek the dissolved solids generally increased as streamflow increased, and in the other streams the dissolved solids remained fairly constant throughout the range of streamflow sampled. The dissolved-solids content of these streams was determined by the residue method, and, except for Red Creek, ranged from 20 to 52 ppm, and the calculated values ranged from 11 to 23 ppm. In Red Creek the dissolved-solids content

TABLE 10.—*Temperature (°F) of water, Pascagoula River near Benndale, Miss., August 1958 to September 1960*

Day	A	S	O	N	D	J	F	M	A	M	J	J	A
1	80	85	76	63	54	50	52	55	64	75	70	82	77
2	81	86	72	60	54	50	50	------	66	75	65	80	77
3	81	81	70	61	58	50	51	52	67	73	67	79	77
4	82	82	70	60	55	50	51	56	65	74	68	79	76
5	84	83	71	61	62	47	51	49	64	74	68	76	78
6	84	84	71	62	54	43	50	46	67	74	69	75	78
7	85	85	73	60	53	44	49	------	68	73	69	78	78
8	84	85	72	63	58	47	49	53	70	75	68	77	77
9	83	85	72	64	54	45	50	58	70	73	70	77	77
10	84	84	72	64	53	46	54	56	70	70	69	75	77
11	85	84	74	64	49	47	55	57	68	71	69	77	------
12	84	84	70	63	50	45	56	59	65	73	70	75	76
13	84	82	72	64	49	50	58	60	62	73	------	81	75
14	85	84	72	65	48	49	58	58	61	73	71	79	73
15	85	78	72	67	45	50	58	59	60	74	72	81	74
16	84	81	72	67	45	49	60	58	59	73	71	80	73
17	83	84	73	70	46	46	59	55	60	76	72	80	73
18	84	80	73	72	45	46	60	57	62	74	74	81	75
19	85	81	70	67	46	46	55	56	65	75	74	77	74
20	85	80	72	65	48	47	54	56	66	74	74	78	75
21	85	80	74	63	46	53	52	59	65	70	78	78	76
22	84	76	73	61	46	52	53	60	64	73	77	75	74
23	82	75	73	58	48	46	55	61	63	73	77	76	73
24	82	76	72	57	53	47	55	59	64	72	76	75	74
25	81	76	72	63	50	------	54	62	63	72	75	74	74
26	81	77	67	65	51	48	53	63	63	71	76	75	------
27	80	78	68	65	49	48	54	59	64	71	77	76	76
28	82	76	66	60	50	49	53	63	65	72	77	76	77
29	81	76	67	55	53	50	------	63	68	71	76	77	77
30	84	75	62	55	50	51	------	64	69	70	79	78	76
31	84	------	62	------	------	50	------	64	------	71	------	78	71
Average	83	81	71	63	51	46	52	58	65	74	72	78	75
	S	O	N	D	J	F	M	A	M	J	J	A	S
1	76	71	68	38	------	52	49	59	------	------	91	87	84
2	76	------	51	45	------	49	51	59	70	85	90	87	85
3	74	71	53	45	51	50	50	65	73	80	90	85	83
4	75	70	55	44	53	52	48	65	72	81	89	85	85
5	.77	------	56	49	51	54	47	64	70	82	88	83	84
6	74	------	51	50	------	53	46	65	70	83	88	85	86
7	75	65	49	50	53	54	46	65	67	81	89	87	78
8	73	------	47	50	49	44	46	66	67	82	89	86	83
9	------	66	44	51	48	54	47	65	67	84	87	88	84
10	72	65	43	58	50	56	48	64	67	83	88	87	86
11	68	65	42	56	51	55	50	65	66	84	87	87	87
12	67	66	43	55	54	53	50	65	65	83	88	86	83
13	64	65	44	46	55	51	48	65	64	82	89	84	81
14	64	67	45	45	58	48	51	67	64	81	89	85	82
15	63	55	43	54	60	47	52	67	66	82	88	83	77
16	65	56	44	55	58	47	54	67	67	83	89	83	75
17	69	55	42	56	56	48	51	68	69	84	90	84	78
18	66	54	40	55	56	49	51	67	70	83	89	85	77
19	67	56	39	46	52	48	50	67	74	82	90	82	79
20	66	56	43	54	50	49	52	68	75	83	84	83	79
21	69	55	44	54	48	47	52	69	76	83	------	82	78
22	69	58	43	53	46	49	51	70	79	84	87	80	83
23	68	54	45	53	46	49	50	72	78	84	87	82	85
24	68	50	45	52	45	48	53	78	81	85	89	83	83
25	67	52	44	52	44	50	58	77	83	84	87	80	79
26	------	51	45	55	44	------	57	78	81	85	87	81	78
27	65	51	46	55	47	46	58	78	80	84	89	83	80
28	67	50	43	56	55	47	61	77	80	86	89	81	77
29	69	49	40	50	51	43	61	77	80	90	88	84	76
30	------	51	38	53	50	------	60	78	79	88	88	85	77
31	------	51	------	52	48	------	60	------	84	------	87	85	------
Average	69	58	46	51	51	50	52	69	73	83	88	84	81

TABLE 11.—*Analyses of suspended-sediment samples, Pascagoula River near Benndale, Miss.*

Date	Mean discharge (cfs)	Suspended sediment (ppm)	Date	Mean discharge (cfs)	Suspended sediment (ppm)
1959			*1960*		
Apr. 23	16,000	165	Jan. 4	8,100	32
June 9	21,300	68	Feb. 1	14,600	78
July 29	8,100	34	Feb. 9	30,100	199
Aug. 4	7,540	81	Mar. 1	12,400	21
Aug. 12	4,300	37	Mar. 16	14,000	47
Aug. 26	2,570	27	Mar. 18	24,100	142
Aug. 31	2,150	17	Apr. 2	24,100	67
Sept. 3	3,230	33	Apr. 4	30,800	83
Sept. 16	6,290	28	Apr. 6	42,800	94
Sept. 28	3,120	31	Apr. 18	8,100	30
Sept. 30	2,400	26	Apr. 26	5,380	17
Oct. 21	6,290	39	May 2	5,140	22
Oct. 22	15,700	320	May 9	31,600	91
Nov. 2	11,400	83	May 19	7,540	36
Nov. 5	6,420	44	June 2	3,010	18
Nov. 24	5,510	13	June 13	2,100	59
Nov. 25	5,380	20	June 16	1,850	17
Dec. 1	5,020	10	July 7	1,800	19
			July 15	2,150	13
			July 21	2,770	15
			July 28	1,970	15

of the water determined by the residue method ranged from 41 to 70 ppm, and the calculated values ranged from 26 to 47 ppm.

TEMPERATURE

Temperature data for these streams, which are shown in table 13, were collected in conjunction with streamflow measurements and the chemical-quality sampling program. The data do not necessarily reflect maximum and minimum temperatures that occurred; however, they are indicative of the range in water temperatures for various times of the year.

ESCATAWPA RIVER

CHEMICAL QUALITY

The dissolved-solids content of Escatawpa River water above the zone of salt-water intrusion and industrial pollution is low and uniform in composition. The color is variable, depending on the amount of swamp water moving into the river. Higher colors usually occur with higher streamflows, which flush out some of the highly colored swamp water. Analyses of samples from Escatawpa River near Hurley, shown in table 14, are representative of quality conditions that existed in the fresh-water reach of the stream and indicate no significant changes in either the composition or concentration of dissolved solids at various streamflows. The dissolved-solids content of the samples ranged from 24 to 38 ppm, and hardness ranged from 3 to 7 ppm.

TEMPERATURE

Miscellaneous water temperature data, available for two locations on Escatawpa River, are shown in table 15. The table does not show maximum or minimum temperatures, but the data indicate that the maximum summer water temperatures exceed 80°F and the minimum winter water temperatures are about 40°F.

POLLUTION

Below mile 6, several industrial plants empty organic and inorganic wastes into Escatawpa River; this waste increases the dissolved and suspended solids in the stream. Some of this waste is partially treated to remove suspended solids and reduce the amount of oxidizable material, while some receives no treatment before being discharged into the river. Most of the waste contains oxidizable material, and, at times, this material reduces the dissolved-oxygen content of Escatawpa River to zero. On September 1, 1959, the dissolved-oxygen content of Escatawpa River at mile 6 was 8.0 ppm, and the chemical oxygen demand (COD) was 6.8 ppm, while at the mouth of the river the dissolved-oxygen content was zero and the COD was 60 ppm.

The Mississippi Game and Fish Commission (Joe B. Sills, written commun., Mar. 20, 1961) states that the only time any of the pollutants cause trouble is when the streamflow is low and the water is warm. Generally, the pollution is handled satisfactorily except when the above conditions exist.

TRIBUTARIES OF THE ESCATAWPA RIVER

CHEMICAL QUALITY

The quality of water in the tributary streams is similar to the quality in the fresh-water reach of Escatawpa River. Results of analyses of water from these streams show that the dissolved-solids content is low (table 14). No significant changes in either quantity or composition of the water occurred throughout the ranges of streamflows sampled. The dissolved-solids content, determined from residue at 180°C, ranged from 23 to 44 ppm; however, the values calculated from the determined constituents indicate a range from 11 to 28 ppm.

TEMPERATURE

Water temperature records for these streams are shown in table 15. A comparison of these temperatures with the water temperature of Escatawpa River for the same day indicates that, in summer, water temperatures in some of the streams may be as much as 10°F lower than that for Escatawpa River. For example, on June 15, 1960, the water temperature in Jackson Creek was 72°F, in Franklin Creek 71°F, and in Escatawpa River 82°F. The sampling sites on Jackson and Franklin Creeks are closer to the source of spring discharge than the site on Escatawpa River.

BLACK CREEK SWAMP

CHEMICAL QUALITY

The water quality in streams draining Black Creek Swamp differs from that in other streams in the area principally in its higher color

TABLE 12.—*Chemical analyses, in parts per million, of water from tributary streams of the Pascagoula River*

Date of collection	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Copper (Cu)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Residue at 180° C	Dissolved solids: Calculated from determined constituents	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25° C)	pH	Color
Big Black Creek near Benndale, Miss.																					
Feb. 6, 1958	[1] 785	4.8	0.00	------	------	1.4	0.8	2.7	0.4	6	1.4	3.5	0.5	0.3	33	19	7	2	27	6.6	28
Aug. 21, 1958	504	6.5	.11	------	------	1.4	1.0	2.2	.5	6	1.6	4.0	.3	.9	50	22	8	2	28	6.2	65
Oct. 17, 1958	----------	4.3	.21	------	------	1.4	.4	2.8	.6	8	.4	2.5	.0	.1	44	17	5	0	27	5.5	10
May 5, 1959	547	2.3	.04	------	------	1.4	.5	3.1	.6	7	2.4	3.8	.0	1.3	35	19	6	0	31	5.8	35
Nov. 24, 1959	791	5.3	.10	------	------	.6	.8	2.2	.6	7	.2	3.5	.0	.2	32	17	5	0	25	6.2	10
Apr. 18, 1960	1,260	4.2	.07	0.01	0.00	1.4	.3	4.0	.3	6	2.0	3.5	.1	1.2	31	20	4	0	30	5.7	35
Jan. 10, 1961	3,640	3.9	.17	.24	.00	1.2	.9	2.0	.4	5	2.8	3.5	.1	.9	36	18	6	2	27	5.6	70
Red Creek near Vestry, Miss.																					
Feb. 6, 1958	[1] 450	5.6	0.00	------	------	1.2	1.4	5.8	0.5	7	2.4	9.5	0.5	0.4	41	31	9	4	46	6.4	35
Aug. 21, 1958	643	4.5	.13	------	------	1.8	.6	4.6	.9	3	1.8	9.0	.5	.8	65	26	7	4	42	5.5	60
Oct. 15, 1958	255	3.1	.15	------	------	1.8	.2	7.0	.7	6	1.4	12	.0	.2	46	30	6	0	52	5.5	10
May 5, 1959	297	2.8	.04	------	------	1.6	.8	6.1	.7	7	.2	10	.0	1.2	44	27	8	2	51	5.8	25
Nov. 24, 1959	481	6.9	.06	------	------	1.8	1.2	7.0	.8	5	2.4	14	.0	.4	53	37	10	6	61	5.8	15
Apr. 18, 1960	1,310	5.2	.05	0.01	0.06	2.2	.6	9.3	.1	4	1.8	17	.2	1.0	60	40	8	4	75	5.6	40
Jan. 10, 1961	1,800	4.8	.10	.05	.00	3.1	1.2	11	.4	3	2.0	22	.2	.8	70	47	12	10	86	5.6	70
Moungers Creek near Vancleave, Miss.																					
Aug. 21, 1958	34.9	5.1	0.21	------	------	1.4	0.3	2.4	0.3	4	1.0	3.5	0.3	0.7	49	17	4	1	22	5.4	60
Oct. 15, 1958	----------	2.9	.28	------	------	.8	.3	2.9	.6	4	1.6	4.2	.0	.5	32	16	3	0	26	5.5	10
May 5, 1959	6.43	1.9	.05	------	------	.7	.5	2.4	.2	3	.2	4.5	.0	1.0	29	13	4	1	27	5.2	25
Nov. 24, 1959	12.9	5.0	.00	------	------	.7	.3	2.7	.1	4	.2	4.2	.0	.6	30	16	2	0	22	5.1	15
Apr. 25, 1960	8.52	4.3	.12	0.01	0.00	.7	.2	3.2	.0	1	1.6	3.5	.1	1.0	25	15	2	2	21	5.0	40
Jan. 10, 1961	55.3	5.0	.16	.12	.00	.9	1.2	2.8	.0	2	4.4	4.5	.3	1.0	38	21	12	10	33	4.9	80

Bluff Creek near Vancleave, Miss.

Aug. 21, 1958	56.5	5.6	0.19	------	------	1.2	0.8	2.5	0.5	7	1.2	4.2	0.5	0.8	52	21	6	1	23	5.5	60
Oct. 15, 1958	24.6	3.4	.30	------	------	1.0	.2	2.8	.5	4	2.0	4.2	.0	.2	34	17	4	0	24	5.8	12
May 5, 1959	26.4	2.9	.04	------	------	.9	.4	2.8	.6	6	.2	4.0	.1	1.0	32	16	4	0	27	5.8	25
Nov. 24, 1959	41.6	2.4	.16	------	------	3.0	.0	2.4	.7	10	.0	3.0	.0	.1	36	17	8	0	27	6.3	10
Apr. 26, 1960	34.4	4.7	.08	0.01	0.02	.8	.2	3.8	.0	3	1.2	4.5	.1	.8	33	18	3	0	24	5.3	35
Jan. 10, 1961	----------	5.7	.20	.22	.00	1.6	1.0	2.8	.0	3	4.0	5.0	.2	1.0	41	23	8	6	31	5.3	80

Big Creek near Crossroads, Miss.

Aug. 19, 1958	61.6	5.6	0.16	------	------	1.7	0.5	2.2	0.4	6	0.4	3.8	0.3	0.8	46	19	6	1	23	5.8	60
Oct. 15, 1958	43.2	2.4	.37	------	------	1.3	.1	2.3	.4	5	.8	3.5	.0	.4	26	14	4	0	27	5.4	12
May 6, 1959	42.2	1.8	.05	------	------	1.1	.5	2.4	.4	6	.4	3.2	.0	1.6	27	14	4	0	29	5.6	30
Nov. 24, 1959	62.4	4.7	.09	------	------	.8	.6	2.4	.6	6	2.0	3.5	.0	.2	24	18	4	0	26	5.8	10
Apr. 26, 1960	52.6	3.6	.12	0.00	0.05	1.0	.2	3.4	.0	5	.0	3.5	.1	1.6	24	16	4	0	22	6.2	35
Jan. 10, 1961	77.2	4.8	.09	.02	.00	.8	.8	2.1	.0	4	2.0	3.5	.1	.5	23	17	6	2	21	6.1	30

Big Cedar Creek near Wade, Miss.

Aug. 22, 1958	98.7	4.6	0.12	------	------	1.1	0.5	1.8	0.4	4	1.4	3.0	0.3	0.7	38	16	4	1	20	5.7	45
Oct. 15, 1958	71.0	1.7	.26	------	------	.7	.4	1.9	.6	3	2.2	3.0	.0	.2	22	12	3	0	20	5.4	10
May 6, 1959	70.9	2.0	.03	------	------	.8	.3	1.6	.3	4	.2	3.2	.0	.9	20	11	3	0	22	5.6	10
Nov. 23, 1959	101	4.5	.04	------	------	.6	.6	1.8	.6	4	.6	3.0	.1	.6	20	14	4	0	19	6.1	15
Apr. 26, 1960	94.2	4.2	.07	0.00	0.06	1.0	.3	2.6	.3	4	1.2	3.2	.1	1.2	37	16	4	0	23	5.2	35
Jan. 10, 1961	122	5.5	.04	.00	.02	.8	1.0	1.8	.2	4	1.4	4.0	.1	.9	22	18	6	2	21	5.6	35

[1] Estimated on basis of correlation with nearby gaging stations.

and lower pH values. Higher color results from decay of vegetable matter in the swamp, and the lower pH values probably result from organic acids produced by the decaying vegetable matter. Results of the analyses of samples collected from the two principal streams draining the swamp show the concentrations of the principal constituents to be low (table 16), and of about the same values as found in

TABLE 13.—*Water temperature of tributary streams of the Pascagoula River*

Date	Time	Temperature (°F)	Date	Time	Temperature (°F)
Big Black Creek near Benndale, Miss.					
1958			*1960*		
Feb. 6	2:30 p.m.	52	Apr. 18	6:10 p.m.	75
Oct. 6	3:30 p.m.	68	June 23	1:30 p.m.	84
1959			*1961*		
May 5	3:10 p.m.	78	Jan. 10	1:45 p.m.	48
May 19	4:25 p.m.	77			
June 26	2:50 p.m.	81			
Sept. 22	5:25 p.m.	80			
Nov. 24	3:35 p.m.	61			
Red Creek near Vestry, Miss.					
1958			*1959*—Con.		
Feb. 6	2:45 p.m.	52	Sept. 22	3:30 p.m.	78
Oct. 5	12:35 p.m.	68	Nov. 24	2:00 p.m.	62
Oct. 15	12:30 p.m.	68			
Dec. 30	1:50 p.m.	43	*1960*		
			Jan. 4	4:25 p.m.	50
1959			June 23	11:40 a.m.	82
Mar. 20	4:15 p.m.	48			
Apr. 24	11:15 a.m.	55	*1961*		
May 5	1:10 p.m.	70	Jan. 10	3:30 p.m.	48
June 30	3:10 p.m.	74			
Moungers Creek near Vancleave, Miss.					
1958			*1959*—Con.		
July 3	11:45 a.m.	74	Sept. 22	11:15 a.m.	76
Oct. 6	1:10 p.m.	68	Nov. 24	11:50 a.m.	62
Oct. 20	3:30 p.m.	70			
Nov. 20	12:20 p.m.	58	*1960*		
			Apr. 25	5:00 p.m.	72
1959			May 25	5:45 p.m.	70
May 5	11:30 a.m.	67	June 2	5:55 p.m.	82
May 19	11:50 a.m.	66			
June 30	11:05 a.m.	70	*1961*		
			Jan. 10	4:00 p.m.	48
Bluff Creek near Vancleave, Miss.					
1958			*1960*		
July 3	10:10 a.m.	74	Apr. 26	10:00 a.m.	68
Aug. 7	11:10 a.m.	75	June 2	3:55 p.m.	72
Aug. 21	11:00 a.m.	77	June 10	12:45 p.m.	79
Oct. 6	11:45 a.m.	68	June 17	8:55 a.m.	76
Oct. 15	10:00 a.m.	67			
			1961		
1959			Jan. 10	4:55 p.m.	49
May 5	9:55 a.m.	64			
May 19	10:30 a.m.	63			
June 30	9:45 a.m.	65			
Aug 24	10:05 a.m.	59			
Sept. 22	9:50 a.m.	72			
Nov. 24	10:20 a.m.	62			

TABLE 13.—*Water temperature of tributary streams of the Pascagoula River*—Con.

Date	Time	Temperature (°F)	Date	Time	Temperature (°F)
Big Creek near Crossroads, Miss.					
1958			*1960*		
Aug. 19	2:10 p.m.	76	Apr. 26	1:25 p.m.	68
Sept. 3	5:00 p.m.	74	June 2	1:55 p.m.	72
Oct. 6	4:55 p.m.	67	June 8	4:50 p.m.	75
Oct. 15	2:00 p.m.	65	June 23	5:30 p.m.	74
Nov. 4	1:55 p.m.	57			
Nov. 7	1:30 p.m.	58	*1961*		
			Jan. 10	12:15 p.m.	45
1959					
May 6	2:50 p.m.	68			
Sept. 3	12:35 p.m.	75			
Sept. 23	12:55 p.m.	71			
Nov. 24	3:45 p.m.	62			
Big Cedar Creek near Wade, Miss.					
1958			*1960*		
July 2	4:40 p.m.	75	Apr. 26	2:00 p.m.	69
Oct. 15	3:25 p.m.	67	June 23	3:40 p.m.	76
Nov. 4	3:30 p.m.	58			
			1961		
1959			Jan. 10	10:50 a.m.	48
May 6	4:15 p.m.	70			
Sept. 23	11:15 a.m.	73			
Nov. 23	3:35 p.m.	63			

other streams in this area. The dissolved-solids content in these two streams, as residue at 180°C, ranged from 18 to 60 ppm, and the calculated values ranged from 10 to 20 ppm. Differences in the two sets of values indicate that organic material is present in the water.

Random readings of water temperature in the two streams indicate that summer temperatures may exceed 80°F. Temperatures are shown in table 17.

SALT-WATER INTRUSION

In the tidal reaches of Pascagoula and Escatawpa Rivers, the downstream flow is interrupted periodically by flood tide, and, until the tide ebbs, saline water from the Mississippi Sound flows upstream. The saline water, which is more dense than fresh water, flows upstream as a wedge under the fresh river water.

EXTREMES IN PENETRATION

The extent of salt-water intrusion into the rivers depends principally upon the following important factors: (1) fresh-water discharge, (2) tidal stage, and (3) shape and configuration of the river channel. Of these, fresh-water discharge is predominant. The end of the salt-water wedge rarely reaches a steady state, but moves up or down the river in response to changes in discharge and tide. River discharge and tide may change at about the same time; consequently, it is difficult to establish a quantitative relationship between these factors and position of the salt front.

TABLE 14.—*Chemical analyses, in parts per million, of water from the Escatawpa River and tributaries*

Date of collection	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Copper (Cu)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Residue at 180° C	Dissolved solids: Calculated from determined constituents	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25° C)	pH	Color
Escatawpa River near Hurley, Miss.																					
Feb. 6, 1958	[1] 960	4.6	0.00	------	------	1.0	0.5	2.5	0.3	4	2.0	3.5	0.5	0.2	29	17	4	1	22	6.3	35
Aug. 22, 1958	831	4.6	.15	------	------	1.0	.8	2.1	.5	4	1.6	3.8	.3	.6	38	18	6	2	24	6.2	60
Oct. 15, 1958	422	1.8	.17	------	------	.9	.3	2.8	.4	4	1.2	3.5	.0	.5	29	14	3	0	25	5.3	12
May 4, 1959	505	1.8	.04	------	------	1.0	.4	2.5	.3	4	.2	4.2	.0	1.0	28	13	4	0	25	5.6	25
Nov. 23, 1959	644	.0	.00	------	------	.6	.5	2.6	.0	4	.2	4.5	.0	.2	30	11	4	0	25	5.6	10
Apr. 26, 1960	623	4.2	.12	0.01	0.00	.6	.5	4.1	.0	6	.2	4.0	.2	.9	28	18	4	0	26	6.0	45
Sept. 1, 1960	359	3.9	.00	.00	.00	1.7	.4	3.0	.3	6	2.8	2.0	.0	.2	34	17	6	0	25	6.0	7
Sept. 28, 1960	496	3.9	.00	.00	.00	1.4	.1	2.8	.3	6	1.8	3.0	.0	.6	29	17	4	0	26	6.0	6
Oct. 4, 1960	397	4.1	.00	.00	.00	1.0	.5	2.8	.3	6	.2	4.2	.0	.2	30	16	4	0	26	6.1	10
Oct. 28, 1960	274	.9	.00	.00	.00	1.6	.3	3.3	.4	8	2.4	1.5	.1	.1	31	14	5	0	28	6.0	8
Jan. 9, 1961	1,370	4.5	.11	.08	.00	.9	1.2	2.0	.0	4	2.8	4.0	.1	.8	24	18	7	4	25	5.8	70
Big Creek near Big Point, Miss.																					
Aug. 22, 1958	[1] 185	2.9	0.15	------	------	1.1	0.6	3.5	0.5	4	1.0	5.5	0.4	1.1	44	19	5	2	32	5.4	50
Oct. 15, 1958	126	2.4	.33	------	------	1.0	.1	3.8	.3	5	1.2	5.0	.0	.4	29	17	3	0	26	6.1	10
May 4, 1959	148	1.8	.04	------	------	1.0	.4	3.6	.4	6	.4	5.2	.0	.8	28	17	4	0	30	5.7	25
Nov. 23, 1959	153	4.1	.04	------	------	1.6	.5	5.9	.8	6	1.6	9.0	.0	.5	43	28	9	5	46	5.8	15
Apr. 26, 1960	159	3.2	.07	0.00	0.00	.8	.4	3.6	.3	4	1.4	5.0	.1	1.0	28	18	4	0	29	5.4	30
Jan. 9, 1961	327	4.5	.11	.08	.00	.9	1.4	2.9	.0	4	3.2	5.0	.1	.9	32	21	8	4	29	5.8	60

Jackson Creek near Orange Grove, Miss.

Feb. 6, 1958	[1] 80	6.1	0.00	------	------	1.6	1.0	3.0	0.3	4	1.4	5.0	0.5	0.8	29	22	8	4	25	6.2	40
Aug. 18, 1958	85.7	2.8	.26	------	------	1.1	.5	2.7	.6	4	.6	4.5	.6	1.5	43	17	4	1	28	5.3	80
Oct. 15, 1958	47.3	2.0	.18	------	------	1.0	.2	2.6	.7	2	.4	4.5	.0	.2	23	13	4	2	26	5.2	6
May 4, 1959	45.2	1.5	.04	------	------	.9	.4	2.6	.3	4	.2	4.2	.0	1.6	25	14	4	0	28	5.5	25
Nov. 23, 1959	60.7	1.4	.04	------	------	1.0	.2	2.7	.0	4	.0	4.5	.0	.6	28	12	4	0	23	5.8	15
Apr. 26, 1960	48.6	2.3	.06	0.01	0.08	.8	.5	3.9	.0	3	.0	4.8	.1	1.5	26	16	4	2	26	5.9	40
Jan. 9, 1961	92.8	4.3	.15	.00	.00	2.1	.2	2.9	.2	3	1.6	6.0	.2	1.3	38	20	6	4	33	5.3	70

Franklin Creek near Grand Bay, Ala.

Aug. 18, 1958	34.7	5.5	0.13	------	------	0.7	1.2	2.8	0.2	3	3.2	4.5	0.3	0.8	39	21	6	4	27	5.4	65
Oct. 15, 1958	24.4	2.3	.11	------	------	.7	.4	2.8	.4	1	.6	5.0	.0	.4	25	13	3	2	26	5.3	7
May 4, 1959	23.9	1.8	.03	------	------	.7	.6	2.6	.3	3	.2	4.8	.0	1.4	25	14	4	2	26	6.3	20
Nov. 23, 1959	28.6	.0	.00	------	------	.6	.5	2.6	.1	4	.2	4.8	.0	.1	30	11	4	0	26	5.2	10
Apr. 26, 1960	25.4	2.9	.04	0.01	0.00	.8	.6	4.0	.0	3	1.0	4.8	.1	1.3	36	17	4	2	31	5.2	30
Jan. 9, 1961	59.9	5.2	.14	.12	.00	1.2	.8	3.3	.0	3	4.0	3.0	.3	1.4	40	21	6	4	35	5.2	80

[1] Estimated on basis of correlations with nearby gaging stations.

TABLE 15.—*Water temperature of the Escatawpa River and tributaries*

Date	Time	Temperature (°F)	Date	Time	Temperature (°F)
Escatawpa River near Wilmer, Ala.					
1958			*1959*		
Aug. 20	12:35 p.m.	81	May 4	5:45 p.m.	70
Sept. 4	5:55 p.m.	78	Aug. 31	4:05 p.m.	84
Oct. 3	12:55 p.m.	67	Dec. 1	3:50 p.m.	47
Nov. 3	1:40 p.m.	59	*1960*		
			June 16	12:05 p.m.	81
Escatawpa River near Hurley, Miss.					
1958			*1960*		
Feb. 6	11:05 a.m.	52	Jan. 4	11:20 a.m.	51
Oct. 6	4:20 p.m.	69	Apr. 26	1:05 p.m.	75
Oct. 13	10:55 a.m.	67	May 19	10:35 a.m.	72
Nov. 3	11:40 a.m.	60	May 25	4:35 p.m.	80
Dec. 30	11:00 a.m.	42	June 6	11:00 a.m.	79
			June 10	1:25 p.m.	81
1959			June 15	3:45 p.m.	82
Mar. 20	12:45 p.m.	49	Sept .1	3:50 p.m.	82
May 4	3:45 p.m.	70	Sept. 28	2:25 p.m.	77
June 29	3:40 p.m.	62	Oct. 4	1:45 p.m.	76
Aug. 31	1:50 p.m.	82	Oct. 28	----------	68
Nov. 23	2:10 p.m.	61			
			1961		
			Jan. 9	1:55 p.m.	49
Big Creek near Big Point, Miss.					
1958			Sept. 22	12:15 p.m.	73
July 2	2:15 p.m.	75	Nov. 23	12:00 m	62
Sept. 4	4:00 p.m.	74			
Oct. 6	2:25 p.m.	69	*1960*		
Oct. 15	12:45 p.m.	65	Apr. 26	12:25 p.m.	70
Nov. 3	3:40 p.m.	58	May 25	1:55 p.m.	74
			June 15	1:50 p.m.	76
1959			June 23	12:45 p.m.	76
May 4	12:55 p.m.	64			
June 29	10:25 a.m.	64	*1961*		
Aug. 24	1:20 p.m.	76	Jan. 9	12:00 m	50
Jackson Creek near Orange Grove, Miss.					
1958			Sept. 22	10:45 a.m.	72
Feb. 6	11:05 a.m.	55	Nov. 23	10:50 a.m.	62
July 2	12:30 p.m.	73			
Sept. 4	2:45 p.m.	73	*1960*		
Oct. 6	12:50 p.m.	68	Apr. 26	11:10 a.m.	68
Oct. 15	11:30 a.m.	65	May 25	12:50 p.m.	72
Nov. 3	4:45 p.m.	59	June 3	11:50 a.m.	72
			June 15	12:25 p.m.	72
1959			June 23	11:30 a.m.	74
May 4	11:20 a.m.	62			
June 29	9:15 a.m.	62	*1961*		
Aug. 24	11:45 a.m.	75	Jan. 9	10:00 a.m.	49
Franklin Creek near Grand Bay, Ala.					
1958	10:55 a.m.	73	Sept. 22	9:20 a.m.	71
July 2	1:20 p.m.	73	Nov. 23	9:40 a.m.	64
Sept. 4	11:25 a.m.	68			
Oct. 6	10:15 a.m.	66	*1960*		
Oct. 15	5:40 p.m.	58	Apr. 26	10:05 a.m.	68
Nov. 3			May 25	11:35 a.m.	70
			June 15	11:15 a.m.	71
1959	9:50 a.m.	63	June 23	10:15 a.m.	72
May 4	8:10 a.m.	61			
June 29	10:20 a.m.	74	*1961*		
Aug. 24			Jan. 9	10:30 a.m.	51

TABLE 16.—*Chemical analyses, in parts per million, of water from streams draining Black Creek Swamp*

Date of collection	Discharge (cfs)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Copper (Cu)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Residue at 180° C	Dissolved solids: Calculated from determined constituents	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25° C)	pH	Color
Black Creek North near Wade, Miss.																					
Aug. 22, 1958	7.31	4.2	0.36	------	------	1.1	0.5	2.3	0.2	2	1.8	4.5	------	1.5	40	18	4	3	27	4.8	180
Oct. 15, 1958	3.23	2.3	.15	------	------	.7	.3	2.6	.1	1	2.4	4.0	0.0	.4	32	14	2	2	21	5.0	45
May 5, 1959	4.98	1.7	.06	0.00	0.00	.7	.3	2.3	.1	2	.2	4.0	.1	1.7	27	12	2	1	25	4.8	80
Nov. 23, 1959	12.7	4.7	.15	------	------	.3	.7	2.1	.1	2	.8	3.8	.0	.8	40	14	4	2	24	5.1	90
Apr. 26, 1960	6.00	3.7	.20	.00	.08	.8	.3	3.2	.0	2	.0	3.5	.1	2.8	38	16	3	2	23	4.8	100
Jan. 10, 1961	60.0	4.7	.21	.08	.00	1.4	.5	2.4	.0	0	1.2	4.0	.3	1.5	44	16	6	6	37	4.4	160
Black Creek South at Helena, Miss.																					
Feb. 4, 1958	[1] 50	3.0	0.00	------	------	0.8	0.7	2.7	0.0	2	2.0	3.5	------	0.2	44	14	5	4	33	4.7	90
Aug. 22, 1958	[1] 35	3.7	.64	------	------	1.7	.1	2.0	.2	2	1.4	3.5	------	1.8	60	16	4	3	25	4.9	180
Oct. 15, 1958	2.97	1.8	.59	------	------	.6	.9	3.1	.3	2	1.6	4.5	0.0	1.0	50	15	5	4	29	5.0	80
May 6, 1959	10.2	1.3	.16	0.00	0.00	1.0	.4	2.3	.1	1	.2	4.5	.1	1.4	18	12	4	3	27	4.7	140
Nov. 25, 1959	15.8	4.1	.00	------	------	2.7	.1	2.2	.4	2	.0	8.0	.1	.8	50	19	7	6	28	5.0	150
Apr. 26, 1960	13.1	1.4	.00	------	------	.6	.3	2.4	.0	3	.4	3.0	.0	.1	54	10	2	0	22	5.2	170
Jan. 9, 1961	109	4.3	.16	.00	.00	1.4	.8	2.9	.0	2	4.2	4.5	.1	1.1	36	20	7	6	35	4.7	70

[1] Estimated on basis of correlation with nearby gaging stations.

TABLE 17.—*Water temperature of streams draining Black Creek Swamp, Miss.*

Date	Time	Temperature (°F)	Date	Time	Temperature (°F)
Black Creek North near Wade, Miss.					
1958			*1960*		
Oct. 7	12:05 p.m.	68	Apr. 26	4:05 p.m.	69
			May 27	11:30 a.m.	70
1959			June 2	5:00 p.m.	74
May 5	5:05 p.m.	70	June 23	2:45 p.m.	76
Sept. 22	4:20 p.m.	68	*1961*		
Nov. 23	4:05 p.m.	62	Jan. 10	8:55 a.m.	44
Black Creek South at Helena, Miss.					
1958			*1959*—Con.		
Feb. 4	5:00 p.m.	48			
July 7	11:30 a.m.	78	Nov. 25	10:20 a.m.	58
1959			*1960*		
May 6	6:00 p.m.	64	Apr. 26	2:45 p.m.	71
May 19	12:20 p.m.	73	June 15	4:45 p.m.	83
June 29	5:10 p.m.	63			
Sept. 23	5:35 p.m.	74	*1961*		
			Jan. 9	2:30 p.m.	48

Changes in fresh-water flow generally will cause the salt front to advance or retreat, the distance of the advance or retreat depending upon the magnitude and duration of the change. From October 15, 1958, to January 15, 1959, discharge of the Pascagoula at Merrill ranged from 2,200 to 6,700 cfs, and the salt front was in the vicinity of mile 13.5. Fresh-water discharge during this period was changing constantly, but the magnitude and duration of the changes were not sufficient to cause appreciable movement of the salt front. The discharge of 6,700 cfs forced the salt front downstream and caused the chloride content at mile 12.2 to drop from 11,700 to 208 ppm; however, the increase in discharge was of short duration. On the following day the salt front moved back upstream and the chloride content increased to 4,830 ppm at mile 12.2.

From January 15 to April 30, 1959, the average discharge at Merrill exceeded 10,000 cfs, a discharge of sufficient magnitude and duration to force the salt front downstream as far as mile 4. Changes in daily discharge allowed the salt front in the Pascagoula River to vary between mile 4 and mile 8.

Tidal effect on salt-water penetration in the lower Pascagoula River system is difficult to evaluate quantitatively; however, the effect of normal tides on the maximum penetration is minor. A discussion of tidal characteristics is given on p. 56–59. Daily changes in tide produce fluctuations in location of the salt front in Pascagoula and Escatawpa Rivers, but the front does not extend as far upstream as the tidal effects. During flood tide, the salt front moves upstream; as the tide ebbs, the front moves downstream. During spring tide the difference between high and low tide may be as much as 3 feet, and during neap tide the difference may be only a few tenths of a foot. Thus, for a given river discharge, the salt front moves back and forth through a greater distance during a spring tidal cycle than during a neap tidal cycle. At the mouth of the Pascagoula, mean high and low tides for the years 1942 through 1960 were 1.10 feet above and 0.29 foot below mean sea level. These figures are indicative of the usually low range in tides at this location. Yearly maximum high tides commonly exceed 3.0 feet, but the higher maximums are associated with tropical cyclones.

A cyclonic tide causes the salt front to advance upstream in response to the higher tide stage, but the effect is short lived because the increased river discharge produced by storm rainfall forces the salt front downstream. For example, before hurricane Ethel on September 15, 1960, the salt front was in the vicinity of mile 13; the hurricane tide (4.5 feet above msl at the mouth of Pascagoula River) caused the front to move upstream, and on the day after the hurricane it was at mile 17. Rainfall generated by the hurricane increased the discharge at Merrill from 2,420 cfs on September 15, to 9,150 cfs on September 17 and forced the salt front downstream to mile 9 on September 18.

The channel geometry of Pascagoula and Escatawpa Rivers is similar and affects the extent of salt-water penetration. The thalweg of Pascagoula River is very irregular, ranging in elevation from 12 to 60 feet below mean sea level between miles 2 and 3 and from 26 to 36 feet below mean sea level between miles 6 and 7. A graphical plot of the thalweg indicates that both river beds are a series of irregular depressions separated by short lengths of elevated channel or ridges. The salt front moves upstream into a depression and does not advance further until sufficient fresh water has been displaced to allow the wedge to attain the elevation of the upstream ridge. The wedge then spills into the next depression and the process is repeated. The volume of a depression and the elevation of the upstream ridge are channel-shape factors that partially control the extent of salt-water penetration in the Pascagoula and Escatawpa.

Tributaries and numerous oxbow lakes connected to the river also influence the extent of salt-water penetration. These tributaries and lakes function as storage reservoirs for considerable amounts of salt water. The best example is Three Rivers Lake, an old course of Pascagoula River, whose lower end is connected to the river channel at mile 13.2 and whose upper end is connected only during periods of flood flow. Consequently, there is no appreciable fresh-water flow through the lake except during periods of high streamflow.

The bottom of Three Rivers Lake at its mouth is about 30 feet below mean sea level, approximately the same elevation as the thalweg of the river channel. The lake bottom is about 50 feet below mean sea level in some places.

When the salt front reaches mile 13.2 in the river, most of the saline water spills into the lake; only a small part continues to move farther up the river channel. Vertical stratification of chloride in the lake is similar to that in the river, but it probably is a result of turbulence created by thermal differences in the lake or by wind actions on the lake surface eroding the salt-water interface. Chloride concentrations as high as 12,700 ppm have been observed in the lower 15 to 20 feet of water in the lake.

Salt water continues to spill into Three Rivers Lake until an increase in streamflow forces the salt wedge in the river downstream from the mouth of the lake. If the increase in streamflow is not sufficient to produce a river stage that will inundate the land separating the river and the upper end of the lake, salt water will "leak out" of the lake into the river channel and move downstream. This condition was observed several times during this study and is responsible for increases noted in bottom salinity from about mile 10 to mile 13.2 and for absence of the salt front in the river channel beyond mile 13.2. (See pl. 8.)

When the river flows through the lake, the fresh water flushes salt water from the lake into the river and downstream to the location of the salt wedge at that time. The flushing of Three Rivers Lake can be complete or partial, depending upon the increase in river discharge and the tidal conditions at the time.

Maximum penetration of the salt front in Pascagoula River under normal tidal conditions during this study reached mile 14.5, when the discharge at Merrill was 1,650 cfs. Information obtained by other organizations show that on November 4, 1954, the salt front was at mile 15.4. The discharge at Merrill for this date was 940 cfs. This observation of salt-water penetration was made during an extended period of low flow. At Merrill the minimum 120-day discharge of record occurred between August 10 and December 13, 1954, when the daily discharge ranged from 805 to 1,200 cfs and averaged 982 cfs. This 120-day minimum discharge has a recurrence interval greater than 50 years (fig. 12). High tide on November 4, 1954, at the mouth of Pascagoula River was 1.35 feet above msl; however, the highest tide during the period was 2.65 feet on September 16 when the discharge at Merrill was 855 cfs. These data and study of the stream-bed profiles in the reaches upstream from mile 15 indicate that salt-water did not penetrate beyond mile 17.5 during 1954. Salt-water penetration beyond mile 17.5 would be a rare event that would result from a simultaneous occurrence of low-river discharge and high tide.

A comparison of the fresh-water discharge at Merrill with location of the salt front indicates, generally, that when the discharge at Merrill is more than 10,000 cfs, the salt front in the river will be below mile 8; more than 6,000 cfs, below mile 9; more than 4,000 cfs, below mile 11.5; and more than 1,500 cfs, below mile 15. The percent of time that the daily discharge at Merrill equals or exceeds these values was determined from the flow-duration curve shown in figure 9, and the previous sentence is restated in terms of percent of time as follows: About 30 percent of the time the salt front in the Pascagoula River is below mile 8; about 40 percent of the time, below mile 9; about 55 percent of the time, below mile 11.5, and about 89 percent of the time, below mile 15. Observations made during this study indicate that the salt front penetrated less distance up West Pascagoula River than up the mainstem Pascagoula. Should the salt front reach the point of division of the rivers, it would probably attain this location through the Pascagoula River, and then a part of the front would be eroded into the upper reaches of the West Pascagoula.

Records collected at the station on Pascagoula River near Escatawpa (mile 12.2) are indicative of the amount of time the salt front was above or below this location. The following table shows that 75 percent of the top samples had specific conductance values less than the maximum values observed in the fresh-water reach.

Percent of daily samples having a specific conductance equal to or less than that shown, Pascagoula River near Escatawpa, Miss., November 1958 to September 1960

	Percent of samples						
	1	10	25	50	75	90	99
Top sample..........micromhos at 25° C..	46	64	78	125	490	1,250	14,900
Bottom sample..........do....	46	64	78	125	8,000	24,500	33,000

As the salt wedge moves under the fresh water, specific conductance values of the bottom samples are more indicative of salt-water penetration. The distribution of specific conductance values of the bottom samples indicates that between 50 and 75 percent of the samples were fresh water. The distribution curve shows that 68 percent of the bottom samples had a specific conductance of 500 micromhos or less.

The observed maximum penetration of the salt front in Escatawpa River during this study reached mile 13.3, and this penetration was a result of the tide produced by hurricane Ethel. Another organization observed the salt front at mile 15.5 on September 16, 1954. This observation was made during an extended period of extreme (record) low flows in the river and on the date of the highest tide (2.65 ft). Location of the salt front at mile 15.5 during this combination of events indicates that an extremely high tide would have to occur during a period of extremely low flow for the salt front to penetrate beyond this point.

Although not subject to rigid limits, a general relation exists between the location of the salt front in Escatawpa River and the fresh-water discharge near Hurley. Generally, when the river discharge near Hurley is more than 1,000 cfs, the salt front will be below mile 7; more than 600 cfs, below mile 11; more than 300 cfs, below mile 12.5; and more than 125 cfs, below mile 16. The percent of time that the daily discharge at Hurley equals or exceeds these values was determined from a flow-duration curve based on data shown in table 4, and the previous sentence is restated in terms of percent of time as follows: About 40 percent of the time the salt front in Escatawpa River will be below mile 7; about 55 percent of the time, below mile 11; about 85 percent of the time, below mile 12.5; and more than 99 percent of the time, below mile 16.

QUALITY OF INTRUDED WATER

The downstream flow of fresh-water erodes the salt-water wedge and increases the dissolved-solids content of the water from the fresh-water reach to the Gulf. Consequently, the quality of water in the zone of salt-water intrusion varies between that found in the fresh-water reaches of the streams and that found in Mississippi Sound. The variation in specific conductance, a measure of the dissolved-solids content, with depth and distance below the salt front is shown graphically in plate 8. A segment of the thalweg of the streambed also is shown (pl. 8); the effect of the ridge (discussed on p. 77) at mile 13.2 is quite apparent.

Quality conditions that exist in the fresh-water reaches of the streams were described in a previous section. Analyses of samples collected from Mississippi Sound (table 18) show the dissolved-solids content of water to be variable and lower than the dissolved-solids content of ocean water. Undiluted ocean water contains about 35,000 ppm of dissolved solids, including about 19,000 ppm of chloride. The analyses of Mississippi Sound waters show a dissolved-solids content ranging from 19,900 to 27,100 ppm and a chloride content ranging from 10,600 to 14,900 ppm.

Maximum concentrations of dissolved solids and the principal constituents occurring in the zone of salt-water intrusion in the Pascagoula River basin (table 18) were within the range of concentrations observed in Mississippi Sound. The ratio of magnesium to calcium in the intruded water is about the same as that observed in Mississippi Sound; this similarity indicates that decreases in concentrations in the intruded water result from dilution of the salt water by fresh water. A partial listing of the analyses of samples from the zone of salt-water intrusion is shown in table 18.

TABLE 18.—*Chemical analyses, in parts per million, of water from Mississippi Sound near Horn Island and from the zone of salt-water intrusion, Pascagoula River basin, Miss.*

Date of collection	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids calculated from determined constituents	Hardness as $CaCO_3$		Specific conductance (micromhos at 25° C)	pH	Color	Density (gr per ml)
											Calcium, magnesium	Noncarbonate				
Mississippi Sound near Horn Island																
Sept. 4, 1959	0.00	269	801	5,790	354	100	0	2,020	10,600	19,900	3,960	3,880	29,700	6.9	6	1.012
Nov. 12, 1959	.00	338	1,020	8,140	429	118	0	2,190	14,700	26,900	5,040	4,940	39,200	7.2	5	1.018
Jan. 22, 1960	.00	316	898	7,640	421	108	0	2,180	13,400	24,900	4,480	4,390	34,200	6.5	9	1.016
Aug. 7, 1960	.00	355	1,010	8,060	430	124	0	2,260	14,900	27,100	5,040	4,940	39,800	7.2	5	1.018
Zone of salt-water intrusion, Pascagoula River basin																
Sept. 18, 1958	--------	21	55	386		18	--------	104	705	1,280	278	264	2,480	6.6	--------	--------
	--------	32	81	595		26	--------	156	1,080	1,960	413	392	3,550	6.7	--------	--------
	--------	54	129	1,010		30	--------	264	1,820	3,290	665	640	5,820	6.8	--------	--------
Aug. 26, 1958	--------	56	167	1,250		29	--------	335	2,250	4,070	826	802	7,080	6.6	--------	--------
Nov. 6, 1958	--------	83	231	1,770		31	--------	524	3,150	5,770	1,160	1,130	9,860	7.2	--------	--------
Aug. 26, 1958	--------	94	300	2,160		44	--------	517	3,960	7,050	1,470	1,430	11,900	7.1	--------	1.002
	--------	121	381	2,830		53	--------	695	5,140	9,190	1,870	1,820	14,800	6.7	--------	1.004
	--------	155	452	3,350		60	--------	793	6,140	10,900	2,240	2,200	17,300	6.8	--------	1.005
Nov. 14, 1958	--------	212	643	4,470		81	--------	1,330	8,580	15,600	3,170	3,110	21,900	7.6	--------	1.009
	--------	222	673	5,060		83	--------	1,430	9,060	16,500	3,320	3,250	24,600	7.3	--------	1.010
Nov. 6, 1958	--------	281	843	6,200		103	--------	1,700	11,200	20,300	4,170	4,080	28,800	7.9	--------	1.013
	--------	327	975	7,170		112	--------	1,770	13,100	23,400	4,820	4,730	33,200	8.0	--------	1.016

GROUND WATER

Fresh water is available to a depth of 1,600 feet or more in the Hattiesburg and Pascagoula Formations, but 70 percent of the groundwater supply in George and Jackson Counties is derived from aquifers in the Graham Ferry and Citronelle Formations at depths less than 400 feet. In earlier years the cities and industries dependent on wells drew their supplies from aquifers 800 to 1,100 feet in depth. Where geological conditions are favorable for development of the shallow aquifers, deep wells have been replaced by wells in the Graham Ferry Formation because of the lower mineralization of the water and more economical well construction.

Two generalities concerning the occurrence of aquifers in the area are that the formations of the Miocene Series (Hattiesburg and Pascagoula Formations) are more sandy in the western and northern parts of the area than they are in southeastern Jackson County, and the aquifers of the Pliocene Series (Graham Ferry and Citronelle) and the Pleistocene terrace deposits are thickest along the Pascagoula River valley.

A summary of the geologic and hydrologic properties of the formations yielding fresh water in the project area is presented in table 19.

CATAHOULA SANDSTONE

The Catahoula Sandstone of Miocene(?) age probably contains fresh water in the northern part of George County. The formation underlies the Hattiesburg Formation and overlies the Chickasawhay Limestone of late Oligocene age. The contact of the Catahoula with the overlying Hattiesburg Formation is difficult to determine and, according to McGlothlin (1944, p. 61), criteria are not established for designating the Catahoula-Hattiesburg contact in the subsurface of Mississippi. Beds known as the *Heterostegina* zone form the basal unit of the Catahoula and occur at a depth that ranges from about 1,300 feet in northern George County to about 4,300 feet on Horn Island. Age of the *Heterostegina* zone is controversial; some investigators consider the beds to be Miocene, others Oligocene.

Figure 23 is a structure map drawn on the top of the zone (often called *Heterostegina* Limestone). Thickness of the Catahoula Sandstone, including the *Heterostegina* zone, is probably between 300 and 500 feet.

No water wells have been completed in the Cathoula Sandstone in the study area owing to the availability of shallower aquifers. In counties to the north, wells in the Catahoula are capable of producing as much as 1,000 gpm each. Wells 1,200 to 1,500 feet deep would be required to reach the Catahoula Sandstone in George County.

TABLE 19.—*Geologic formations and their water-bearing properties*

System	Series	Formation	Thickness (feet)	Lithology and stratigraphy	Hydrology
Quaternary	Recent	Alluvium	20-80+	Clay, silt, sand, and fine gravel. Contains carbonaceous and woody material in lower end of Pascagoula River valley.	Contains a large supply of water in the valley that is probably salty as far north as salt water penetrates up the river. North of the river junction (mile 17.7), fresh water having a low dissolved-solids content available.
	Pleistocene	Terrace deposits (including the Pamlico Sand)	0-100	Sand and clay grading downward into coarse sand and fine gravel in extensive deposits underlying the terrace from Wade to Escatawpa. Comprised of fossiliferous beds, more carbonaceous material, and less sand near the coast.	Contain a large supply of fresh water having a low dissolved-solids content. Near the coast at shallow depths, the water is subject to salt-water encroachment.
Tertiary	Pliocene	Citronelle	0-100+	Sand and gravel, buff to brick-red in the uplands, gray in southern Jackson County. Attains its greatest thickness in northeastern George County and in Bayou Casotte area.	Maintains high base flows of streams. Supplies most rural wells in uplands of George County. In Bayou Casotte contains an aquifer having large unused volume of water in storage subject to salt-water encroachment from the Pascagoula River if overpumped.
		Graham Ferry	0-200	Gray, carbonaceous, and fossiliferous clay and sand, in places coarse but usually fine to medium. Lithology distinct from the Citronelle Formation in southern Jackson County.	Supplies 60 percent of the municipal and industrial ground-water supply in Jackson County. A large unused supply west of Pascagoula River where the aquifer is more than 100 feet thick. Soft sodium bicarbonate type of water.
	Miocene	Pascagoula	250-1000+	Gray-green and blue-green clay, shale, and sand. Sand is lenticular, fine to very coarse. Fossiliferous *Rangia johnsoni*, clam characteristic of the Pascagoula Formation, identified in several wells.	Comprises five aquifers along the coast and many sand beds of local extent. The base of fresh water in Jackson County is in the lower part of the formation. Where thickness is substantial, transmissibility is high. Soft, sodium bicarbonate type of water, usually having higher chloride content than Graham Ferry Formation.
		Hattiesburg	850+	Gray and green shale and sand similar to Pascagoula Formation.	Contains supplies of fresh water of undetermined quantity in George County Supplies town of Lucedale. Probably salty in southern Jackson County.
	Miocene(?)	Catahoula Sandstone	300+	Sand, shale, and sandstone.	Probably contains fresh water in northern George County. Unused.

HATTIESBURG FORMATION

Outcrops of the Hattiesburg Formation are unknown in George County. The formation is the oldest in George and Jackson Counties which contains aquifers developed for a water supply, and the 1,000-foot city wells in Lucedale (C15 and C17) are the only known wells completed in it. S. M. Herrick examined sample cuttings from well

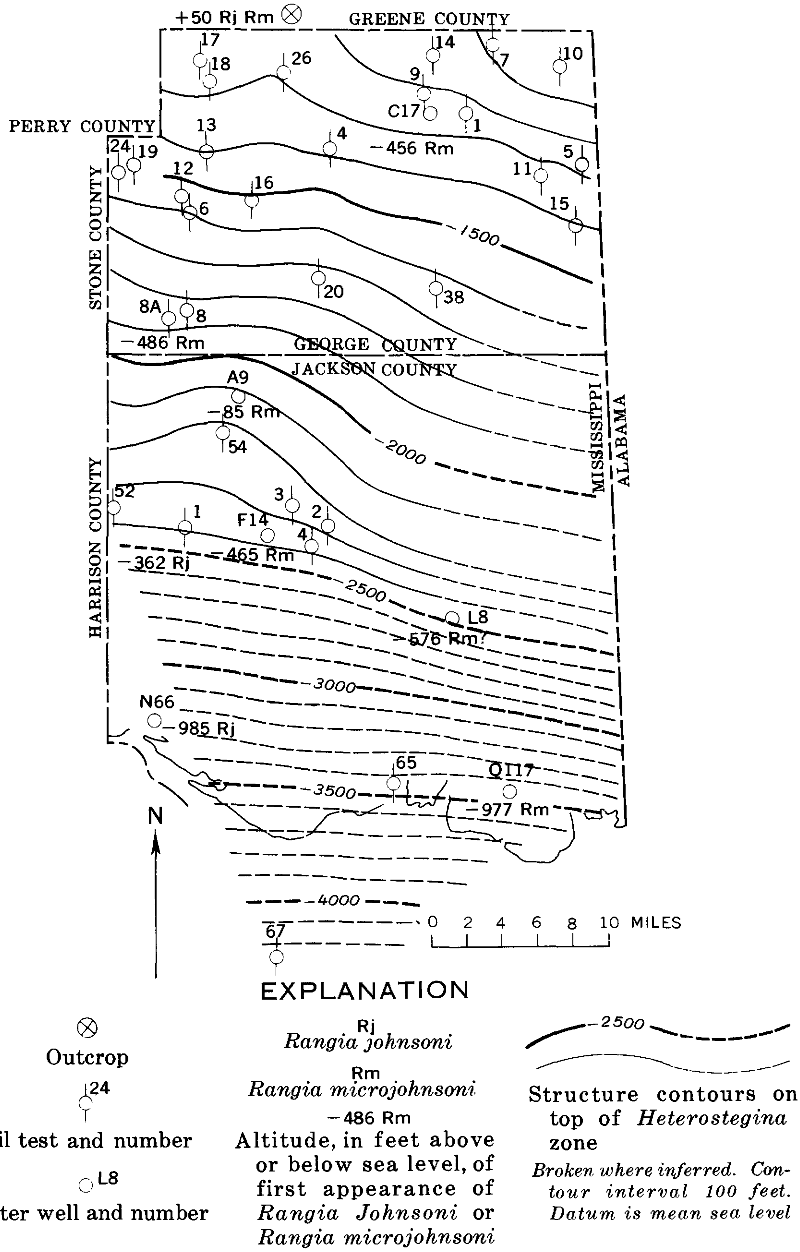

FIGURE 23.—Map of George and Jackson Counties showing configuration of the top of the *Heterostegina* zone. See list of oil tests on facing page.

C17 but did not find *Amphistegina* sp., guide fossil of the Hattiesburg, although the well was drilled several hundred feet into the formation. The contact between the Hattiesburg and the Pascagoula Formations is assumed to be at a depth of about 250 feet in United Gas Public Service-Williams Unit 1 oil test (pl. 9). A paleontological report from oil company files showed *Amphistegina* sp. in the first sample examined at 251 to 279 feet, which probably is near the top of the Hattiesburg Formation. Base of the formation is probably near the base of the sand at 1,080 feet in the Williams Unit well. If so, the Hattiesburg is about 800 feet thick at this location.

In another test, Ohio Oil-L. N. Dantzler Lumber 2, (fig. 23), Herrick found *Rangia microjohnsoni* at a depth of 570 feet; therefore the Pascagoula Formation extends at least to that depth. He did not find *Amphistegina* sp. The top of the Hattiesburg Formation is believed to be at some depth below the massive sand at 1,000 feet in Ohio Oil-Dantzler 1 (pl. 2 and fig. 23). Sand considered to be Hattiesburg contains fresh water at depths of 1,200 and 1,400 feet, and the base of the Hattiesburg in the Dantzler 2 well probably is at about 1,700 feet, 200 feet above the occurrence of *Archaias* sp., which has been found to occur with *Heterostegina* (Akers and Drooger, 1957, p. 666). The formation is between 800 and 1,000 feet thick at this location.

In the Humble Oil & Refining-Dantzler B-1 test (fig. 23), in northwestern Jackson County, Herrick identified *Rangia johnsoni* in sample

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Oil tests (fig. 23)

George County:
1. United Gas P. S.-Luce Packing Co. 1
4. Hassie Hunt Trustee-McLain 1
5. I. P. Larue-Stanford-Crow Drilling-Mrs. Florence Boss et al 1
6. I. P. Larue-Stanford-Crow Drilling-A. F. Dantzler et al 1
7. United Gas P. S.-Williams Unit 1
8. The Ohio Oil-L. N. Dantzler 1
8A. The Ohio Oil-L. N. Dantzler 2
9. Central Oil-Luce Packing Co. 1
10. Southern Production-Crow Drilling-Hibernia Bank and Trust 1
11. I. P. Larue-Stanford-Crow Drilling-K. W. Stringfellow 1
12. H. H. Duck-A. F. Dantzler 1
13. Crow Drilling-S. P. Borden-B. E. Green 1
14. Sinclair Oil & Gas-Luce Packing Co. 1
15. Sadler Oil-Hibernia Bank and Trust 1
16. R. G. Copeland et al-Pascagoula Hardware and Lumber Co. 1
17. Ryan & Anderson-J. J. Newman Lumber Co. 1 and 2
18. Sunnyland Contracting-U. S. A. 1
19. Crew Drilling-S. P. Borden-A. S. Dantzler 1
20. Gulf Refining-Pascagoula Hardware Co. 2
24. Gulf Refining-L. N. Dantzler 8
26. Central Oil-Zach Brooks Drilling-B. E. Green 1
38. Viking Oil-Hibernia Bank and Trust 1

Jackson County:
1. Humble Oil & Refining-Dantzler Lumber Co. B-1
2. J. R. Brown-Crow Drilling-International Paper Co. 1
3. J. R. Brown-Crow Drilling-International Paper Co. 2
4. Southeastern Drilling-J. R. Brown-C. L. Dees 1
52. Weston Drilling-U. S. A. J-1
54. Gulf Refining-Dantzler Lumber Co. 1
65. Gulf Refining-Dantzler Lumber Co. 5
67. C. A. Floto-State of Mississippi 1

cuttings from several places between 470 and 1,630 feet, and *Amphistegina* sp. at 2,368 feet, probably near the base of the Hattiesburg. The Hattiesburg probably begins above 1,600 feet and extends to almost 2,300 feet. A paleontological report by B. L. Smith (oral communication, 1961) shows that *Sorites* sp. occurs at a depth of 2,490 feet in this well. Akers and Drooger (1957, p. 666) and Puri (1953, p. 45) stated that *Sorites* sp. is found with *Archaias* sp. Thickness, of the Hattiesburg probably is at least 800 feet.

South of the Humble-Dantzler test the Hattiesburg is too deep to be considered as a source of fresh water. The complete thickness of the formation has not been prospected as a source of water, although the Lucedale wells probably are completed in the lower part of the formation.

Water from George County well C15 (table 21) is a sodium-bicarbonate type and similar to water in the Pascagoula Formation. Yields of wells C15 and C17 are reported to be about 500 gpm. Comparison of the logs of the wells with electrical logs of oil tests in other parts of George County indicates that water wells having similar yields can be made in the Hattiesburg Formation in other parts of the county and that a substantial supply of water is available from this source to meet future demands.

PASCAGOULA FORMATION

STRATIGRAPHY

The Pascagoula Formation was first named Pascagoula Clay by McGee (1891) because clay was so often found beneath the overlying gravel of the Citronelle Formation. In many places the contact with overlying terrace deposits or sand and gravel of the Citronelle is marked by the presence of green, dark blue, or gray clay beds of the Pascagoula. Occasionally sand of the Pascagoula, usually gray or dark blue and silty, occur below the contact. In the subsurface, several hundred feet of fine to coarse sand occurs in the section in lenses that cannot be traced far.

Brown and others (1944, p. 142–143), by interpreting the log of the Sea Coast Oil Hibbler 1 test well, in northwest Moss Point, placed the base of the Pascagoula at 1,800 feet and assigned 1,400 feet of sand and clay to the formation. In the Humble-Dantzler well, Brown placed the base of the Pascagoula at a depth of 1,600 feet, although he does not show in the log the presence of *Amphistegina*. Herrick found *Amphistegina* at 2,368 feet and placed the base of the Pascagoula Formation at 2,338 feet. The total thickness thus represented of more than 2,000 feet for the formation seems excessive. With the exception of the city wells (C15 and 17) at Lucedale in George County and an abandoned 1,800-foot well that produced hot salt water in Moss Point, all wells drilled below the Citronelle or Graham Ferry Formations are completed in the Pascagoula Formation.

No attempt has been made to divide the Pascagoula Formation because of the lenticularity of the deposits. Brown's interpretation (Brown and others, 1944) of the top of the formation and the one presented herein are in general agreement. However, the 500-foot sand at Ocean Springs, which Brown considered basal Graham Ferry, is probably in the Pascagoula Formation. The Pascagoula Formation dips to the south at about 40 feet per mile. *Rangia johnsoni* was found in well Q117 at Bayou Casotte at a depth of 990 feet and in well N66 at Ocean Springs at 995 feet. The finding of *Rangia johnsoni* in these wells indicates that the beds do not dip appreciably to the west and that the strike of the Pascagoula Formation is almost east-west, and the correlation of the 500-foot sand at Gautier and Ocean Springs further substantiates the east-west strike.

In the vicinity of Pascagoula, a pronounced change in lithology usually is apparent at the base of the sand of the Graham Ferry Formation, where hard green shale 200 to 300 feet thick underlies the sand. Several sands are fairly continuous in small areas. Probably the most extensive sand units are those at 500- and 800- foot depths at Ocean Springs. The 500-foot sand at Ocean Springs can be traced as far east as the western part of Pascagoula, where three flowing wells were completed in the unit. These are the only known flowing wells in Pascagoula in 1961; other wells, both deeper and shallower, ceased to flow before 1958. The sand has not been recognized in wells farther east, although sandy zones noted at approximately the 500-foot depth are probably equivalent.

The 500-foot sand consists of fine to coarse grains of quartz and granules of black polished chert and has a gray appearance owing to the large percentage of dark minerals. Granules of chert and quartz are more abundant near Ocean Springs than at Gautier. In Gautier and western Pascagoula, about 30 to 40 feet of sand in this interval was correlated with the sand farther west on the basis of lithology, stratigraphic position, water levels, and chemical composition of the water. At Ocean Springs, the 500-foot sand may vary in short distances from more than 100 feet of coarse sand to an equal thickness of sandy shale containing a few thin lenses of coarse sand.

The sand occurring at 800 feet at Ocean Springs is not as persistent as the 500-foot sand (pl. 10). Lithologically, the sands are similar. The 500- and 800-foot sands are distinguished from each other by the chemical character of their contained water. The 800-foot aquifer is not as extensively used as the shallower aquifer.

At Pascagoula and Gautier, sands occur at depths of 700 to 900 feet; they are probably equivalent to the 800-foot sand at Ocean

Springs, even though considerable difference exists in the quality of the water in the two areas and the chloride content is much higher at Pascagoula.

A sand occurring at a depth of 800 feet underlies Moss Point, but it apparently changes to a shaly section in the surrounding areas. Because of the dip of the beds, this sand is not considered equivalent to the 800-foot sand in Pascagoula.

In a small area in the eastern part of Pascagoula a bed of fine-grained sand occurs at depths ranging from 600 to 650 feet. It is similar to other sands of the Pascagoula Formation; but because of its lesser thickness and fine texture, it is not capable of yields as large as those of the 800-foot sand. As other wells are drilled, its areal extent will be better known.

Aquifers at depths of more than 1,000 feet have been utilized very little in George and Jackson Counties. Test wells have been drilled and a few water wells completed in sand 1,000 or more feet deep in the vicinity of Pascagoula. Owing to the lenticularity of these aquifers and to the higher chloride content usually prevailing in water from the deeper sand, development has been slight. In the Bayou Casotte area, three test wells drilled to depths of 1,000 to 1,100 feet failed to penetrate an aquifer. However, sufficient sand for the development of domestic or small industrial water supplies usually can be found, and a few wells have been drilled through as much as 80 feet of sand at depths exceeding 1,200 feet (Q34, K37, fig. 2). The mineral content of the water in well K37, on Bluff Creek, is exceptionally low for the Pascagoula area, and the chloride content is lower than that found in shallower wells. Most of the older wells, completed at depths of more than 1,000 feet, produced water having more than 500 ppm of chloride. Only two of these older wells are in use in 1961.

HYDROLOGY

The formations that show the greatest amount of areal decline in water level are usually the most heavily used. The deeper sands are pumped more heavily in the western part of Jackson County, but most of the ground water in the project area is derived from the Graham Ferry Formation at a depth less than 400 feet. Comparison of water-level measurements made in 1958–61 with the earliest measurements available for the 500- and 800-foot sands shows declines of 50 and 75 feet, respectively. In many places away from the centers of pumping, flowing wells still exist after 75 years of use. The artesian pressure of the 800-foot sand at Pascagoula and Moss Point has decreased about 75 feet since 1897; pumpage has increased from a few hundred gallons per day to 3 mgd between 1897 and 1958, and 10 percent of the available pressure has been used. If pumpage remains constant, water levels will become nearly stabilized, but increased pumpage will cause an additional decline in water levels.

The declines in water level are not only dependent on the amount of water pumped but are also affected by the transmissibility and storage coefficient of the aquifer. Three pumping tests on sands of the Pascagoula Formation in Jackson County indicated that transmissibilities range from 25,000 to 60,000 gpd per ft (fig. 24 and table 20). It is estimated that transmissibilities will equal 60,000 gpd per ft for the 500- and 800-foot sands at Ocean Springs.

Water levels in the 500-foot sand at Ocean Springs declined at the moderate rate of about 1 foot per year since 1919. Measurements made in 1919, 1939, and 1958 do not indicate an increased rate of decline in the past 20 years. Water levels are 10 feet lower in the center of Ocean Springs than in the area east of town (pl. 5; fig. 25). The contour map shows that ground water is moving from the outcrop area in northern Jackson County toward Ocean Springs and Gautier. The natural discharge area of the aquifer lies at some distance offshore. The use of water from this aquifer has not been large enough to cause wells to stop flowing except in the immediate vicinity of Ocean Springs. The contours in Ocean Springs show the effect of municipal pumpage and withdrawals in the Biloxi area to the west.

Where the piezometric surface of an aquifer (fig. 39) stands above the ground surface, a flowing well can be obtained. The map outlining areas where flowing wells can be constructed was based on locations of the deepest known wells in the two counties yielding fresh water (pl. 10). The piezometric surface slopes toward the coast, and the water in the deeper aquifers normally will stand under natural conditions at a higher level than the water in the shallower aquifers. The use of the aquifers along the coast has so altered the natural condition that the water in the 500-foot sand at Pascagoula, for example, stands at a little higher level than the water in the 800-foot sand.

Because of the lower chloride content of waer from wells in western Jackson County, more wells exceeding 1,000 feet in depth are in use in the vicinity of Ocean Springs and LaRue community than in the remainder of the area. Electrical logs of oil tests drilled in the northern parts of Jackson and George Counties show the presence of several thick, sand beds in the Pascagoula Formation. Sample cuttings from deep wells show that the sands in the northern area are generally very coarse and that each supply well should be capable of yielding several hundred gallons per minute. However, information on deep borings is lacking in much of Jackson County, and continuity of the deeper sands is not well known.

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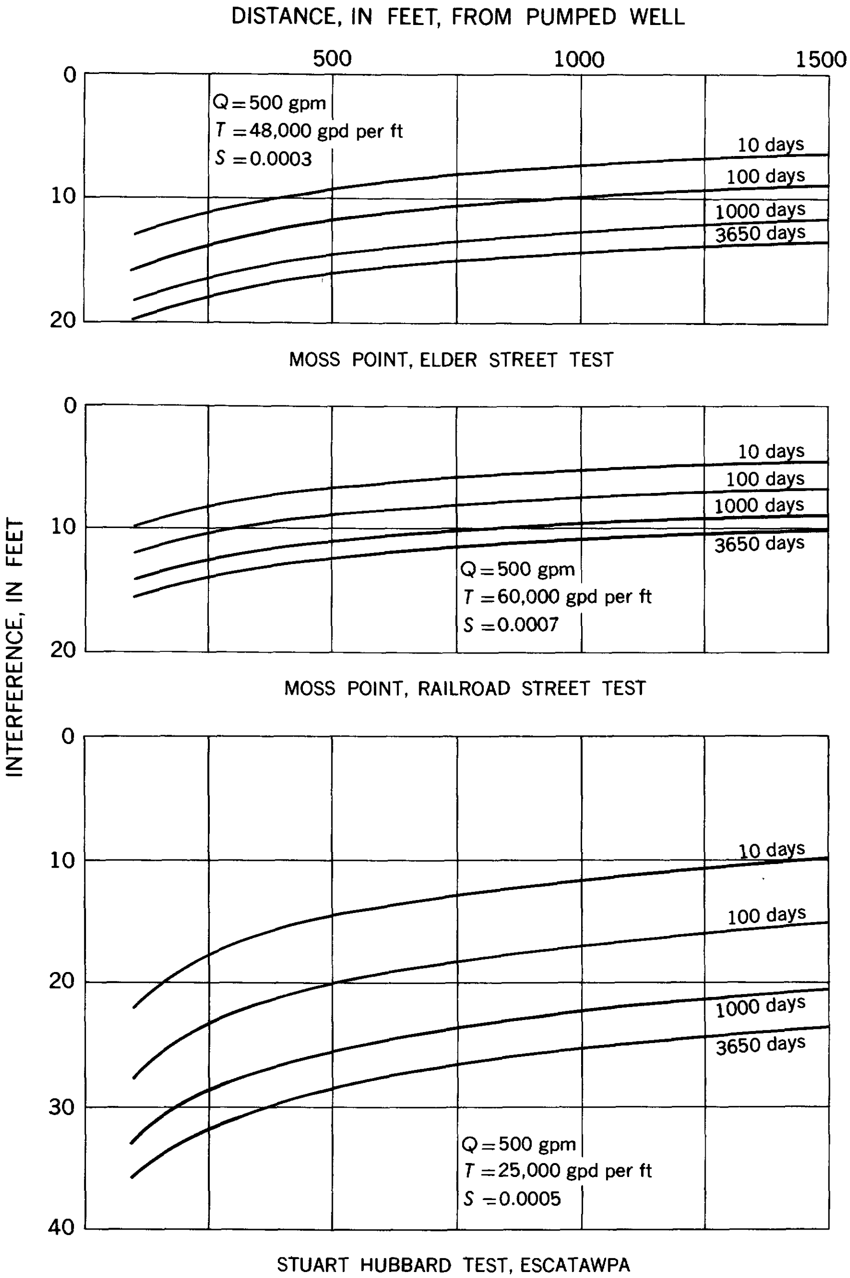

FIGURE 24.—Yield-drawdown relationship in aquifers of the Pascagoula Formation.

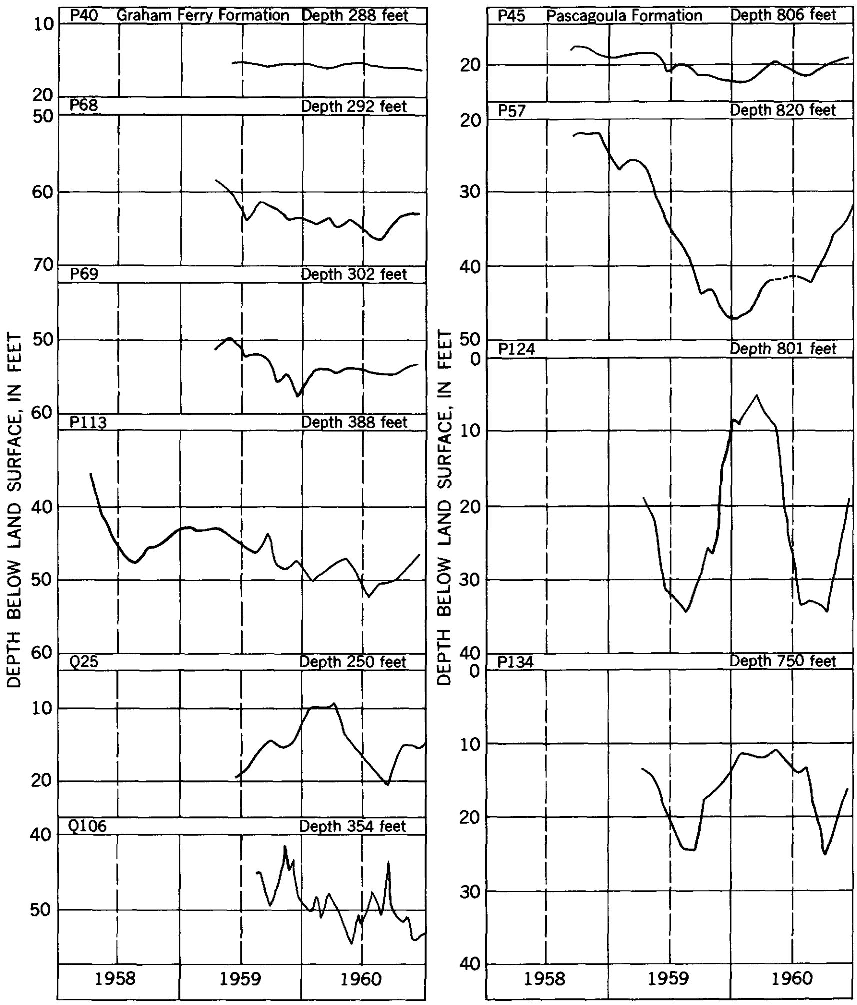

FIGURE 25.—Hydrographs of wells in the Pascagoula and Graham Ferry Formations.

CHEMICAL QUALITY

Water from the three principal water-bearing units of the Pascagoula Formation is soft and is usually colored in varying degrees. Basically, it is of the sodium bicarbonate type, having considerable quantities of chloride in water from the 800- and the 1,200-foot sands. Locally, the percentage of chloride may be sufficient to change the classification of the water to a sodium chloride type. The dissolved-solids content of water from this formation is variable; generally, it increases with depth and with distance from the outcrop area.

TABLE 20.—*Pumping test data for aquifers in vicinity of Pascagoula, Miss.*

[See figures 24, 27, and 30 for time-distance-drawdown relationships]

Owner	Formation	Thickness of sand (ft)	Coefficient of transmissibility (gpd per ft)	Coefficient of permeability (gpd per sq ft)	Coefficient of storage	Specific capacity (gpm per ft of drawdown)	Specific capacity of typical wells (gpm per ft of drawdown)	Typical yields (gpm)	Remarks
Coastal Chemical Co	Graham Ferry.	60	23,000	380	0.0002	13	7–16	300–500	Average of two tests.
H. K. Porter Co	do	50	14,000	280	.002	2	7–16	300–500	Erratic development of aquifer in this area. Sand at pumped well poorly developed.
Quaker Oats Co	do	100	54,000	540	.0005	------	7–16	300–500	
City of Moss Point:									
Elder Street	Pascagoula	56	48,000	860	.0003	13	10–20	500	
Railroad Street	do	80	60,000	750	.0007	18	10–20	500	
Stuart Hubbard	do	------	25,000	------	.0005	10	------	------	Flowing wells.
County Board of Supervisors	Citronelle	80	45,000	560	.0006	11	------	100–500	Average values of transmissibility and storage from four observation wells.

The observed maximum and minimum concentrations of the predominant constituents and dissolved solids are shown in the following table.

Chemical analyses, in parts per million, of water from the Pascagoula Formation

Constituent	Concentration	
	Maximum	Minimum
Sodium (Na)	619	16
Alkalinity (HCO_3, CO_3)	760	16
Chloride (Cl)	756	2
Dissolved solids	1,640	112

The individual concentrations of calcium, magnesium, and sulfate seldom exceeded 10 ppm. Calcium and magnesium usually were less than 5 ppm. The fluoride content of 1.9 and 2.4 ppm in wells P21 and Q34 exceeded the upper limit of 1.5 ppm for potable waters recommended by the U.S. Public Health Service. The results of analyses of water from wells in George and Jackson Counties are shown in tables 21 and 22. A few of these analyses are shown graphically in plates 9 and 10. These figures also illustrate the variability of chloride in the area. The higher concentrations of chloride, and an equivalent quantity of sodium, are presumed to be a result of incomplete flushing of sea water that was trapped in the Pascagoula sediments when they were deposited. The high sodium bicarbonate content probably results from a series of reactions involving calcium carbonate, base-exchange minerals, and carbonaceous material. Foster (1950) states that only in a formation containing these three materials, and, usually, only at some depth in the formation, may water of a high sodium bicarbonate content be expected. Conversely, the occurrence of such water may be taken as indicative of the presence of these three materials in a formation.

In the Ocean Springs area the chloride content of water from the 500-foot sand usually was less than 20 ppm. The chloride content of water from the 800-foot sand ranged from 34 to 151 ppm, and in water from the 1,200-foot sand it ranged from 340 to 762 ppm.

The difference in chloride content in waters from the 800- and 1,200 foot sands in the Pascagoula-Moss Point area is not as distinct as that found in the Ocean Springs area. In the Pascagoula-Moss Point area the chloride content of water from the 800-foot sand ranged from 57 to 300 ppm, and from the 1,200-foot sand it ranged from 175 to 545 ppm. Considerable overlapping occurs in the maximum values for chloride in the 800-foot sand and in the minimum values for chloride in the 1,200-foot sand in this area, and chloride values that approach the maximum of 300 ppm are found at various depths within the 800-foot sand unit. Such factors as environment of deposition, continuity of the aquifer, permeability, and distance to the outcrop are complexly related, and together they explain the variation in chemical quality of the water.

An increase in chloride content of water from a coastal aquifer usually is considered indicative of salt-water intrusion. Two wells (P124 and P134) were sampled periodically to monitor changes in the chloride content of water from the Pascagoula Formation. Although these analyses (see table 22) show a variation in chloride content, they do not indicate salt-water intrusion in the aquifer.

The sands of the Pascagoula Formation at various depths in the Pascagoula-Moss Point area are lenticular. An examination of sample cuttings and the results of pumping tests indicate that the permeability of the sands varies from low to moderately high. These characteristics affect the flushing of salt water from the aquifers because low permeabilities hinder the free movement of water. The variability of chloride with depth and the lack of distinction in chloride content between the 800- and 1200-foot sands in the area probably are a result of different rates of flushing of salt water from the sands. On the other hand, the 500- and 800-foot sands in the Ocean Springs area, although somewhat lenticular, are more continuous as a whole, and their flushing is therby facilitated to a greater degree than in the Pascagoula area. The generally lower chloride content of water in the Ocean Springs area in the 500-, 800-, and 1,200-foot sands contrasts with the higher chloride content in the aquifers at those depths in the Pascagoula area.

The Pascagoula Formation crops out in a large part of the upland surface west of Pascagoula River, and natural recharge to the sandy aquifers in the outcrop is direct. East of the river, where much of the upland surface is covered by a thick mantle of the Citronelle and terrace deposits, water available for recharge must pass through the thick surficial deposits before reaching the underlying Pascagoula Formation (pls. 3, 9). Rate and distance of movement of water through the aquifers to the coast are important factors in the mineralization of the water.

The depositional environment of the sand and surrounding clay beds, whether in a marine, brackish-water, or fresh-water environment, would influence the type of water available today. More thorough flushing would be needed to obtain potable water supplies from marine deposits than from continental deposits.

According to electrical logs of oil tests drilled in west-central Jackson County, the base of fresh-water sands is at depths ranging from 1,500 to 1,800 feet. The log of the C. A. Floto State of Mississippi 1 test drilled on Horn Island shows the presence of moderately fresh water at a depth of 1,500 feet. In Moss Point, a well drilled 1,807 feet deep was sampled in 1956 and yielded water having a chloride content of 1,560 ppm. In Pascagoula, water containing 550 ppm of chloride was obtained at a depth of 1,600 feet. The deepest well south of the mainland (O47) for which an analysis is available is 1,140 feet deep and yields water having a chloride content of 135 ppm. The combination of electrical logs and water analyses for deep wells indicates that the lower limit of occurrence of fresh water ranges from a depth of 1,200 feet at the coast to 1,600 feet in central Jackson County. From the coast to Horn Island, the lower limit of occurrence of fresh water is almost level.

GRAHAM FERRY FORMATION

STRATIGRAPHY

The Graham Ferry Formation contains the aquifer most widely used and generally most consistently present in the vicinity of Pascagoula. The formation was named and described by Brown and others (1944) from exposures at a power-line crossing south of Graham Ferry near the center of the eastern half of sec. 38, T. 5 S., R. 7 W. The contact between the Graham Ferry and the Pascagoula is not visible at this locality. The Graham Ferry outcrop lies in the northwestern part of Jackson County, west of Pascagoula River and south of Red Creek. Remnants of the formation may be exposed in stream valleys east of the river, but they have not been recognized. Typical gray clay and silty sand beds are exposed along the road cuts and creeks north of Vancleave. The 400-foot sand developed in Pascagoula and Bayou Casotte is equivalent to the sandy beds at Graham Ferry.

The base of the 400-foot sand at Pascagoula was considered by Brown to be the base of the Graham Ferry Formation and in contact with the top of the Pascagoula Formation of Miocene age. However, about 500 feet of clay and sand below the 400-foot sand may belong to the Pliocene instead of the Miocene Series. According to Akers and Drooger (1957, p. 667) "* * * the suggested Miocene-Pliocene boundary in the Gulf Coast is in accordance with usage of oil companies which follow Ellisor (1940) in recognizing the *Rangia microjohnsoni* zone as uppermost Miocene." However, until additional information is available, Brown's interpretation of the boundary in the vicinity of Pascagoula is accepted in this study.

The apparent dip of beds of the Graham Ferry is southward at the rate of 19 feet per mile, as determined from seven measured sections extending for 3 miles north and south of Graham Ferry on the west bank of Pascagoula River. The contact between a 3-foot bed of gray clay overlying a bed of light gray fossiliferous sand is the horizon on which the calculation of dip is based. Even though this fossiliferous bed was not traced in the subsurface, projection of the dip southeast to Pascagoula indicates a correlation of the sand exposed in the bluff (see measured section, p. 13) with the 400-foot sand at Pascagoula. Similarly, the sand and overlying clay in the measured section on the river, when projected west to the geologic section (pl. 2), correlates with the sand and overlying clay occurring in the wells along the cross section. Even though the strata are faulted in the vicinity of Graham Ferry, the displacement is small and of minor consequence in the correlation.

The relation of the Graham Ferry to the underlying Pascagoula Formation is obscure, and a definite contact between the formations in the outcrop area has not been observed. The base of the sand can be traced in well logs from Gautier to Vancleave. Correlation of the sand beds west of the river with those east of the river is based on tracing the water levels from the drawdown cone in Pascagoula to Gautier, on correlation of electrical logs, and on chemical characteristics of the water. The correlation is shown in a geologic section (pl. 2) extending from the vicinity of Vancleave to Gautier and thence along sections (pls. 10, 12) to Pascagoula and Bayou Casotte.

Brown correlated the 400-foot sand at Pascagoula with sand occurring at a depth of 500 to 600 feet at Ocean Springs. An alternative explanation based on correlation of electrical logs, sample studies, and water levels in numerous wells indicates that the sand in the Graham Ferry Formation fills a broad trough at Pascagoula and rises somewhat to the west (pls. 10, 13).

The chief reason for changing Brown's correlation of the 400-foot sand at Pascagoula with the 500-foot sand at Ocean Springs is the difference in water levels in the two aquifers in the vicinity of Gautier (pls. 4, 5). Pumpage from the Graham Ferry Formation in Pascagoula has created a drawdown cone that is reflected as far as Gautier. The water level in the Graham Ferry stands 10 to 20 feet below the water level in the 500-foot sand in Gautier. Comparison of the two piezometric maps shows that the difference in water levels in the two aquifers decreases toward Vancleave as the effect of the pumpage at Pascagoula decreases.

The 400-foot sand usually is gray and similar in many respects to sand in the Pascagoula Formation, but it contrasts markedly with the overlying sand of the Citronelle Formation and terrace deposits. The gray color is caused by an abundance of magnetite and other dark heavy accessory minerals, which occur in large concentrations in some wells and in smaller quantities in others. The sand in the bluffs along Pascagoula River similarly contains an abundance of dark mineral grains that give the outcrop a characteristic gray color. The pronounced variation in mineral content of the sand that occurs within very short distances is suggestive of beach deposits. The variation in amount of sand, percentage of heavy mineral constituents, and interbedding with marine clay and carbonaceous beds clearly indicate estuarine and near-shore environments of deposition for the sediments. The sand is well sorted and fine- to medium-grained. The lower 10 to 20 feet is coarse-grained in the vicinity of Gautier and contains granules of polished chert and well-rounded quartz. The difference in transmissibility that occurs in Bayou Casotte and in the city of Pascagoula is evidence of the textural variation.

A dense gray carbonaceous clay bed 20 to 40 feet thick separates the 400-foot sand from the overlying coarse sand and gravel of the Citronelle Formation. The sand thickens gradually at the expense of the overlying clay from Vancleave to Pascagoula where the sand is as much as 110 feet thick. The thickness of the sand increases from Ocean Springs to Pascagoula and then decreases somewhat to the east. In the Bayou Casotte area the sand ranges from 40 to 80 feet thick and in places is divided into two beds separated by a shaly unit from 20 to 40 feet thick. Where the aquifer is shaly, it can be traced by the presence of thin sandy layers that correlate with the thicker sands. The sand can be traced as far north as Escatawpa on the east side of the river where it wedges out beneath the coarse alluvial and terrace deposits in the Pascagoula River valley and the broad terrace. The sand is virtually absent in places along U.S. Highway 90 (pl. 10) where equivalent beds of sandy clay 50 to 75 feet thick are present.

HYDROLOGY

Because 60 percent (6.6 mgd) of all ground water used in the Pascagoula-Moss Point area is pumped from the Graham Ferry Formation, water levels in this aquifer have declined considerably. Since 1939, most of the city supply has been pumped from this formation. Municipal pumpage from the Graham Ferry amounted to 1.9 mgd in 1958. Pumpage data for earlier years are not available. In the Bayou Casotte industrial area, the average daily pumpage according to records and estimates is 2.2 mgd. The remaining 2.5 mgd is used in other industries and in private water systems supplying residential subdivisions.

The earliest recorded water-level measurements were made in 1939 when three city wells were drilled along Communy Street and water levels stood from 4 to 8 feet below land surface. The first industrial wells were drilled in 1936, and two others were added in the area prior to drilling of the city wells. Since that time, many domestic wells, 3 additional municipal wells, and about 20 industrial wells have been constructed in various parts of the area.

During the period 1939–60, the water level has declined in downtown Pascagoula at the rate of 1.7 feet per year. The hydrographs (fig. 25) compare water-level declines in several parts of the area. Wells P68,

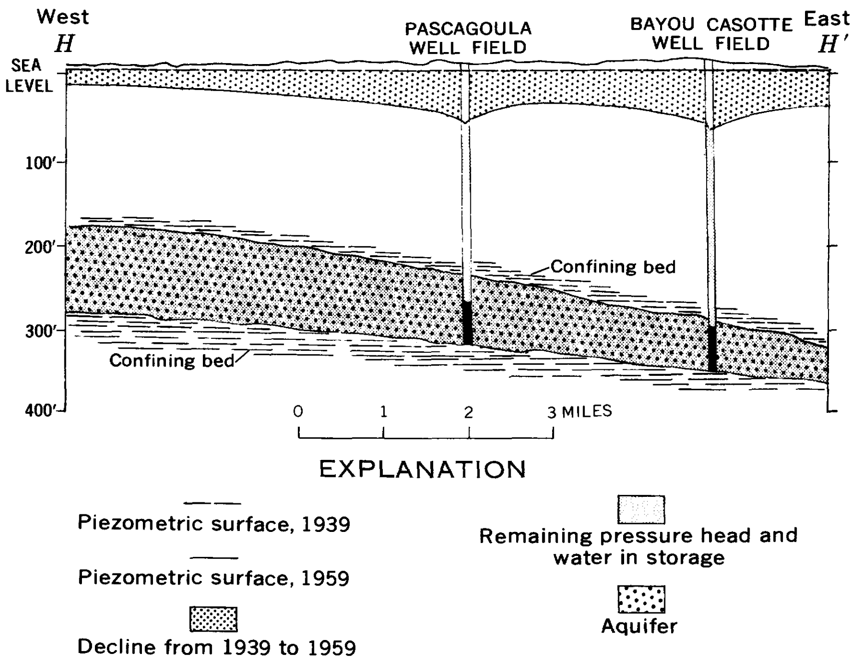

FIGURE 26.—Section *H-H'* across City of Pascagoula and Bayou Casotte industrial area showing profile of piezometric surface in 1959-60. See plate 4 for location of section.

P69, and P113 are city wells in operation. The rate of decline in P68 and P69 is about 2 feet per year, whereas the decline in P113 is 1.5 feet per year in 1961. The water level in well P123, one of three wells in the Graham Ferry at the Communy Street well field, declined at the rate of 1.7 feet per year.

In May 1957, the static water level of the Graham Ferry Formation at Bayou Casotte stood 11 feet below land surface, approximately the same as the water level of the overlying Citronelle Formation in 1961. Since 1957–58, when seven industrial wells were constructed in the Graham Ferry, the static water level has fallen 39 feet, while the water level of the Citronelle Formation has remained the same (fig. 26). Prior to 1957, domestic wells in the area completed in the Graham Ferry were equipped with suction pumps that are capable of operating efficiently when the static water level is less than 21 feet below the surface. An increase in industrial pumpage has necessitated the installation of jet pumps capable of lifting water from greater depths.

Early in 1961, water levels in the Bayou Casotte area had begun to stabilize under the draft (fig. 25, Q106). The annual decline in water levels will diminish in the future until an additional draft is imposed on the formation through construction of new wells or pumpage is increased from operating wells. The rate of decline will increase in proportion to the increased draft.

The results of three pumping tests in the Bayou Casotte area and one in the western part of the city show considerable range in the transmissibility of the Graham Ferry Formation (table 30). The transmissibility determined in the test in Pascagoula is 54,000 gpd per ft. The average for the tests in Bayou Casotte is about 23,000 gpd per ft. The coefficients of storage determined from three of the tests were of the same magnitude and averaged about 0.0003. Due to the lower transmissibility, greater drawdowns can be expected in Bayou Casotte than in the city. Figure 27 is a graph comparing the amount of interference that can be expected between two wells in the Graham Ferry Formation having the coefficients determined in the two areas. Electrical and drillers' logs show considerable variation in total thickness of sand in the formation; for this reason, the transmissibility will vary from place to place. The short period of pumping in Bayou Casotte has resulted in a decline in water levels that equals the decline recorded in the city over a much longer period of time. This decline is due to the concentration and amount of pumping and the lower transmissibility.

Records and estimates indicate that about 1,500 gpm (2.2 mgd) was pumped on the average day in 1959 and 1960 from the Graham Ferry Formation at Bayou Casotte. By using coefficients of transmissibility and storage determined from the test at the Quaker Oats Co. plant (table 20), the effect on the city wells was calculated with the Theis equation for a period of 1 year of steady operation and a distance of 4 miles between the center of pumping at Bayou Casotte and city well P113. The interference amounted to 10 feet. However, there has not been that large a decline in water levels in any of the city wells in 1959 and 1960.

A shaly zone which would form a partial barrier to free movement of ground water may exist in the aquifer near the ground-water divide between the municipal and the Bayou Casotte well fields. The inference may be drawn that recharge has developed either (1) from within the area, through contribution of water from overlying and underlying beds caused by reduction in pressure in the aquifer, or (2) from movement of water into the area at a more rapid rate owing to a hydraulic connection with the Citronelle Formation in the vicinity of the Escatawpa River (pl. 10; fig. 28). The recharge probably is due to a combination of these causes.

The Graham Ferry Formation is recharged in the uplands west of Pascagoula River where it is exposed in the hills north of Vancleave. Here the formation is overlain in places by the Citronelle Formation, which discharges water to the streams and permits some water to

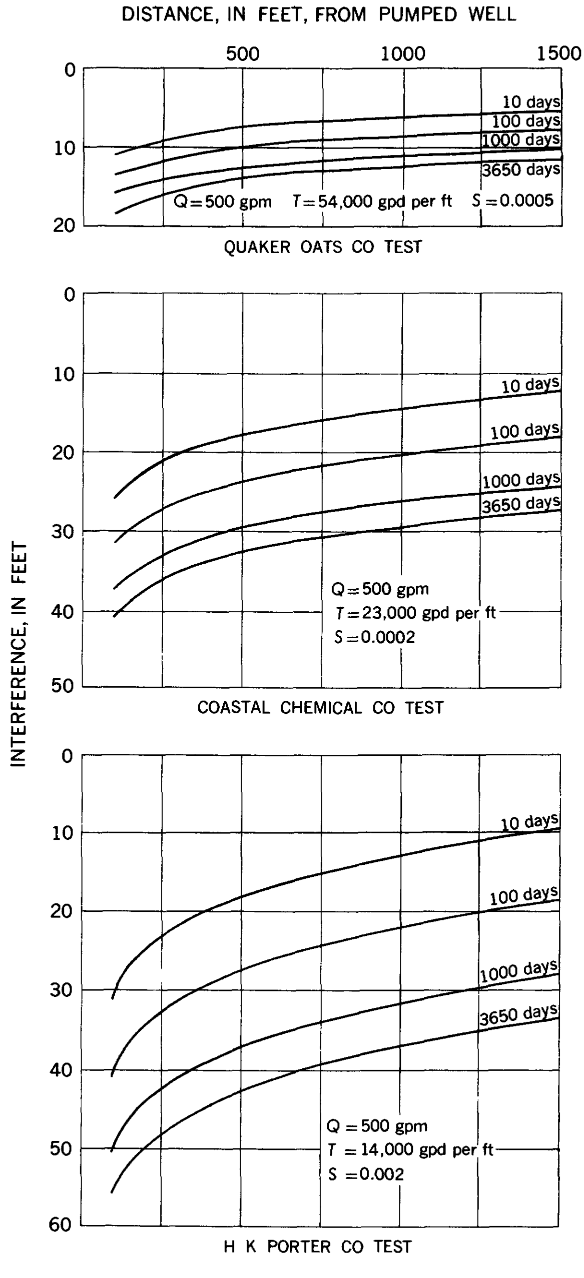

Figure 27.—Yield-drawdown relationship of the Graham Ferry Formation.

infiltrate the Graham Ferry beneath it. Recharge also occurs indirectly through the alluvium, terrace deposits, and Citronelle Formation on the broad terrace north of Escatawpa River. Because the recharge area is not far distant, a perennial supply of water is available to replace much of the water used near the coast. The piezometric map (pl. 4) indicates the direction of movement of ground water under confined conditions into the drawdown cone. Lower mineralization of the water to the west and northwest indicates a source of recharge in that direction.

Because of the proximity of the recharge area, an amount of water equal to that pumped in 1959–60 from this formation in the Pascagoula area can be developed without seriously impairing the quality of the water. Deeper pump settings will be required as pumpage increases.

The piezometric map (pl. 4) shows the form of the water surface and the elevation at which water stood in wells in the winter of 1959–1960. Pumping has created drawdown cones; the depth of the cone depends on the rate and duration of pumping, transmissibility of the aquifer, and location of centers of pumping. Three cones exist in the area: Kreole, Pascagoula, and Bayou Casotte. From the area of the cones to Escatawpa, the piezometric surface rises until it coincides approximately with the piezometric surface in the overlying Citronelle. Ground water moves into the area of heavy pumpage from the north and northwest. West of Pascagoula River the influence of pumping in Pascagoula is reflected in the water levels, which are somewhat lower than in the overlying and underlying aquifers.

Summarizing, the rate of decline apparently is not much different early in 1961 from what it has been for the long period, although the amount of water pumped in 1961 is greater. This stability means that if use had not increased, the rate of decline during the past 3 years would have been less. It follows also that as demand continues to increase, water levels in the area will decline at about the same rate unless the demand is sharply accelerated.

Although localities exist where little sand is present in the Graham Ferry, as in the northern part of Bayou Casotte industrial area, the sand can be traced to the east. The sand is thick in the western part of Pascagoula and Gautier. These are areas for additional development of water supplies from the aquifer. Although pumping tests have not been made west of the river, the transmissibility probably is about the same as that determined in Pascagoula. Additional pumpage in the Gautier area will decrease the quantity of water moving into Pascagoula and will lower water levels in the city.

Figure 26 shows the relationship between depth of the aquifer and available pressure head remaining for additional development. Profile of the piezometric surface was taken from the piezometric map (pl. 4), but the thickness and uniformity of the aquifer are generalized between the drawdown cones. If the use of water from the aquifer is doubled or tripled, certain wells should be monitored to detect the presence and source of any possible increase in chloride content. The natural recharge can be supplemented by reinjection of water.

CHEMICAL QUALITY

Water from the Graham Ferry Formation is of a sodium bicarbonate type and has a relatively high percentage of chloride in some places. The water is soft (hardness ranged from 7 to 52 ppm in samples analyzed) and slightly colored. The iron content usually is less than 0.5 ppm; however, water from three wells in the Moss Point area had an iron content ranging from 1.2 to 2.6 ppm. The dissolved-solids content of the water generally increases in a southeasterly direction. Observed maximum and minimum concentrations of the predominant constituents and the dissolved solids in water samples analyzed are summarized in the following table.

Chemical analyses, in parts per million, of water from the Graham Ferry Formation

Constituent	Concentration	
	Maximum	Minimum
Sodium (Na)	272	55
Alkalinity (HCO_3+CO_3)	576	144
Chloride (Cl)	205	12
Dissolved solids	766	226

Results of analyses of water from the Graham Ferry Formation are shown in table 22. The chemical character of the water is similar to that of water from the Pascagoula Formation; this similarity indicates that the individual chemical characteristics of the water probably are a result of the same type of environmental conditions. For the most part the higher concentration of chloride in the Pascagoula area is a result of incomplete flushing of the sea water that was trapped in the sediments at the time of their deposition. The high sodium bicarbonate content of water is a result of the same series of reactions, involving calcium carbonate, base-exchange minerals, and carbonaceous material, that produce the high sodium bicarbonate water in the Pascagoula Formation.

Analyses of water from wells west of Pascagoula River show that a marked decrease in chloride content occurs in the direction of

Ocean Springs and Vancleave (pl. 12). This decrease may be due to the nearby source of recharge in the uplands north of Vancleave. The piezometric map (pl. 4) shows that ground water is moving southeastward from the Vancleave area toward Pascagoula and that the chloride content increases in the same direction.

Four wells (P68, Q100, Q101, and Q111) were sampled periodically to monitor the chloride content of water in the Graham Ferry Formation. The variation in chloride (see table 22) did not indicate any salt-water intrusion in the aquifer. The analyses are indicative of the magnitude of variation of chloride content in water from this formation.

CITRONELLE FORMATION AND TERRACE DEPOSITS

STRATIGRAPHY

The Citronelle Formation and terrace deposits are considered together as a hydrologic unit, although the Citronelle is an older deposit and underlies the terrace deposits along the coast. The Citronelle Formation is extensive; it blankets the uplands in the northern part of Jackson County and a large part of George County. The areal extent of the Citronelle and terrace deposits is shown on the geologic map (pl. 1). West of Pascagoula River the Citronelle has been more deeply eroded and is less extensive than in the area east of the river. From the outcrop the formation dips beneath the surface south of Big Point where it is overlain by a progressively thickening section of alluvial and marine terrace deposits at the coast line. The base of the formation drops 350 feet from Lucedale to Bayou Casotte at an average dip of 8 feet per mile south (pl. 6). The contact with underlying formations is unconformable, irregular, and marked in many places by a distinct change in color and material. The locations and altitudes of a few contacts are shown in plate 6.

The contact between the Citronelle Formation and the underlying Pascagoula or Graham Ferry Formation is marked usually by coarse sand and gravel underlain by purple weathered clay. Layers of crossbedded sand alternating with beds of clay balls occur in many places in the lower part of the Citronelle. Petrified wood is common in many exposures. Gravel is irregularly distributed, but generally more conspicuous in the lower part of the formation and in the terrace deposits bordering the river. In the subsurface near the coast, the base of the Citronelle was traced in sample cuttings by the first appearance of gray carbonaceous or pale green clay of the underlying Graham Ferry. Electrical logs of water wells usually show a distinct change in character of the resistivity curve at the contact.

The formation increases in thickness from zero, where it is completely eroded away on the upland slopes, to more than 100 feet near the coast. Near Lucedale, the formation is as much as 80 feet thick. As much as 100 feet of coarse sand occurs in one unbroken unit at Bayou Casotte. Elsewhere the unit may consist of lenses of coarse sand separated by carbonaceous or fossiliferous clay and sandy clay.

East of Pascagoula River a practically continuous blanket of sand, comprising the Citronelle Formation and terrace deposits, covers the surface from the northern edge of George County to Pascagoula. The blanket thins southward to Harleston, where there is only about 20 feet of sand, and thickens again farther south. On the terrace west of Hurley, sand and gravel deposits similar in content, texture, and lithology to the Citronelle reach 100 feet in thickness. These are mapped as terrace deposits at the surface, but the lower part of the sand and gravel unit south of Big Point may be Citronelle inasmuch as it continues uninterrupted into the coarse sand at the coast. The Citronelle apparently continues beneath the alluvial fill of the Pascagoula River and thins west of Gautier.

The Citronelle is thicker and more uniform in texture near the coast in the vicinity of the Pascagoula River valley, and it thins both east and west of the valley (pl. 10). In Bayou Casotte the sand is massive but thins to some extent northward toward Kreole. Logs of wells north of Escatawpa River show an abundance of coarse sand equal in thickness to the Citronelle farther south. On the broad terrace partly occupied by Black Creek Swamp, sand and gravel is uniformly distributed; it increases in thickness from 60 feet below the escarpment west of Hurley to about 80 feet near the Pascagoula River west of Wade.

HYDROLOGY

The source of the water in the Citronelle Formation and the associated terrace deposits is precipitation on the area. As noted earlier, the belt of highest rainfall, which extends across George County, coincides with the greatest upland accumulation of deposits of the Citronelle. Although only a very small percent of the total precipitation percolates to the water table, the volume is considered large because of the extensive area involved and the permeable nature of the material. In the higher parts of the area, as much as 40 feet of saturated sand and gravel exists above the top of the Miocene formations under water-table conditions. Water moves laterally in all directions from the underground reservoir to the tributary streams of Pascagoula and Escatawpa Rivers. Because of the relatively slow movement through the Citronelle and terrace deposits, a large volume of water is discharged fairly evenly by the numerous contact springs to the streams throughout the year.

From Lucedale to the coast the water table conforms to the land surface (pl. 6). In the uplands, where the land surface is from 250 to 300 feet above sea level, the water table stands as much as 60 feet below the surface. Water-table conditions generally exist at least as far south as Wade and Hurley. In the broad flat area south of Wade, the water table stands within a few feet of the surface. The presence of clay beds in the lowlands causes semiartesian conditions. At the coast line, where artesian conditions exist and the aquifer is buried beneath 50 to 100 feet of clay, silt, and fine sand, the piezometric surface stands from 3 to 15 feet below land surface, or very nearly at sea level. Plate 14 shows variations in the saturated thickness of the Citronelle Formation and terrace deposits east of the Pascagoula River.

Many domestic wells derive water from the Citronelle and terrace deposits. A few industrial wells and one municipal well are completed in the Citronelle Formation at depths of 150 feet along the north side of Escatawpa River and in Moss Point. Hydrographs of two wells in the Citronelle Formation are presented in figure 28. In the Escatawpa area some logs show the presence of sand and gravel to a depth of 230 feet, considerably below the depth to which the Citro-

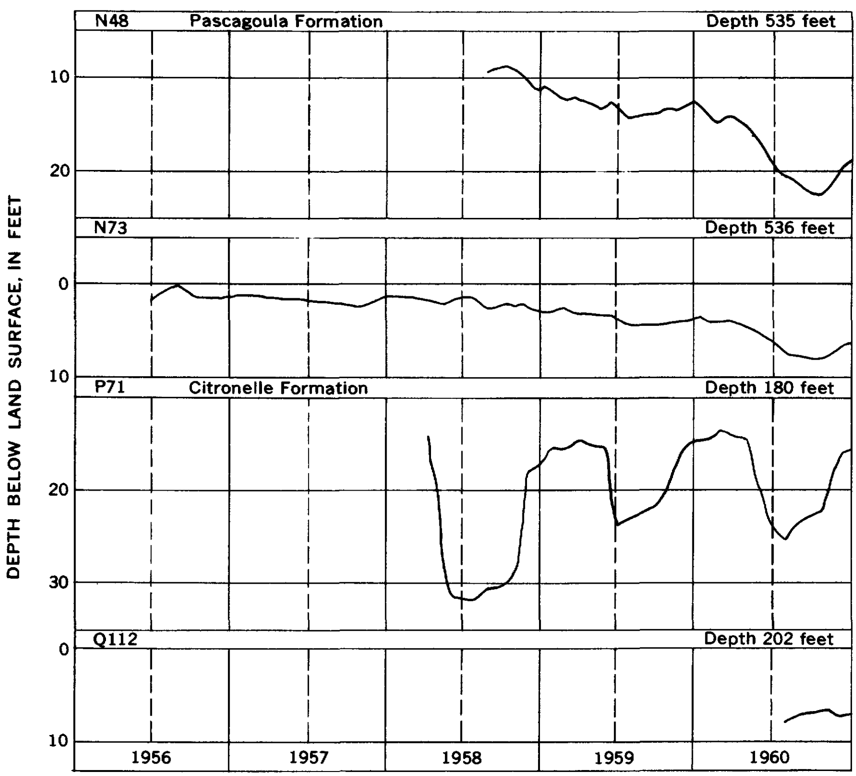

FIGURE 28.—Hydrographs of wells in the Pascagoula and Citronelle Formations.

nelle should extend. The clay bed normally present between the Graham Ferry and Citronelle apparently is absent in places, and the water from the deeper aquifer at 230 feet is similar in chemical quality to that from 150 feet. The iron content, particularly is unusually high for a well completed in the Graham Ferry. Altitudes of water levels in these wells were used on the water-level contour map of the Citronelle Formation and terrace deposits, and they indicate a draw-down cone in the center of the Escatawpa River industrial area. These water levels fit the piezometric map of the Graham Ferry Formation equally well.

In the uplands, ground water is discharged from the Citronelle at its contact with the underlying clay beds of the Pascagoula and Graham Ferry Formations. The discharge area of the Citronelle Formation farther south is in the alluvial valley of Pascagoula River and south of the coast line beyond Horn Island. Movement of water through the formation in the vicinity of Escatawpa and Pascagoula is relatively slow because the water surface is nearly level. The quantity of water passing through the aquifer toward the gulf and the river is directly proportional to the hydraulic gradient. It is estimated that 3 to 5 mgd of water is discharging across the 10-foot contour to the Pascagoula River and the gulf. Increasing the hydraulic gradient by increasing the draft on the aquifer will speed the southerly flow of water. Only a small part of the water that normally discharges into the gulf is intercepted by wells.

A pumping test was made on the aquifer at Bayou Casotte to determine the coefficients of transmissibility and storage and the differences in chloride content of the water. Plate 15, in addition to being a geologic section, shows the differences in chloride content of the water and variations in thickness of the aquifer. The test was laid out along a north-south line 5,900 feet long (fig. 29) and was run continuously for 21 days. The transmissibility of the aquifer was determined for each of the wells by using the Theis nonequilibrium method and the Thiem equilibrium method. The values were nearly uniform for all the wells except for a lower value of transmissibility at the north well (O–1), which is indicative of an increasing clay content in the formation in that direction. This increase had been noted earlier in wells drilled in the vicinity of U.S. Highway 90. The application of the test results to future ground-water development in the Bayou Casotte industrial area is discussed under "Potential Development" pages. The yield-drawdown relationship determined from the pumping test is shown in figure 30.

CHEMICAL QUALITY

The chemical character of water from the Citronelle Formation and from the terrace deposits is similar. In the upland areas the

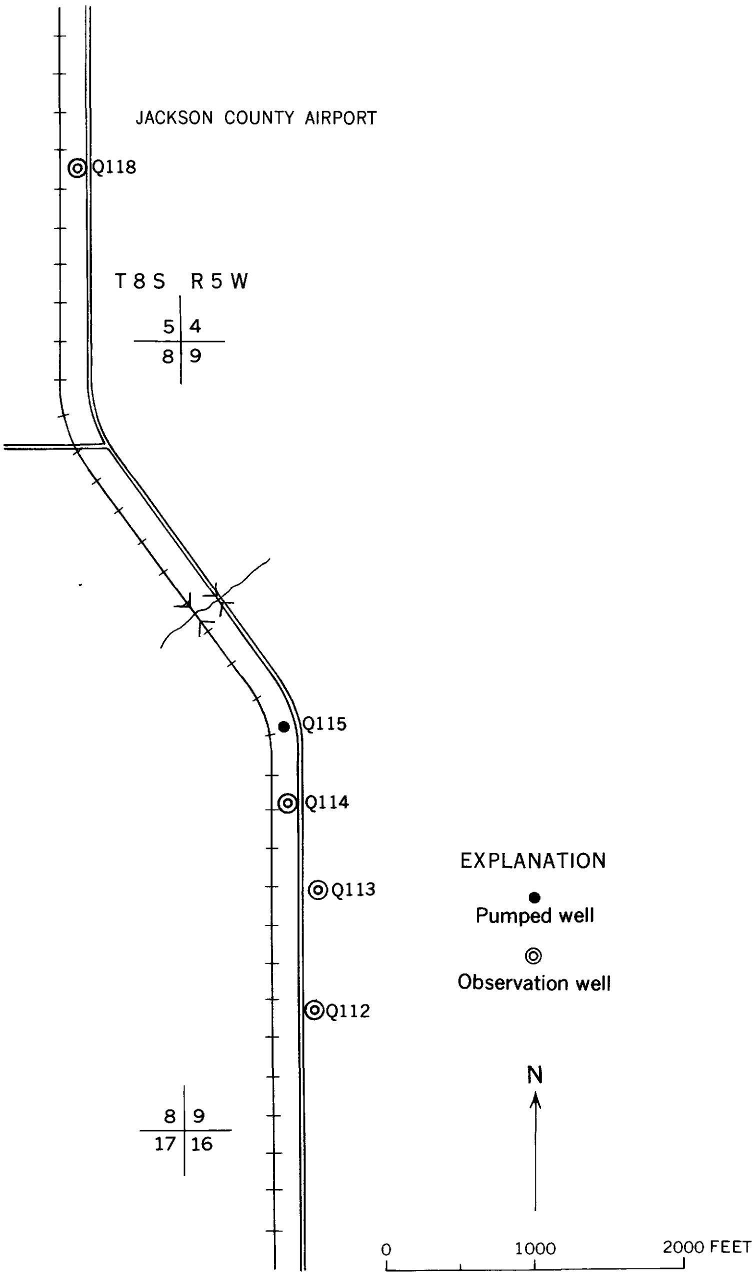

FIGURE 29.—Layout of pumping test in Bayou Casotte area.

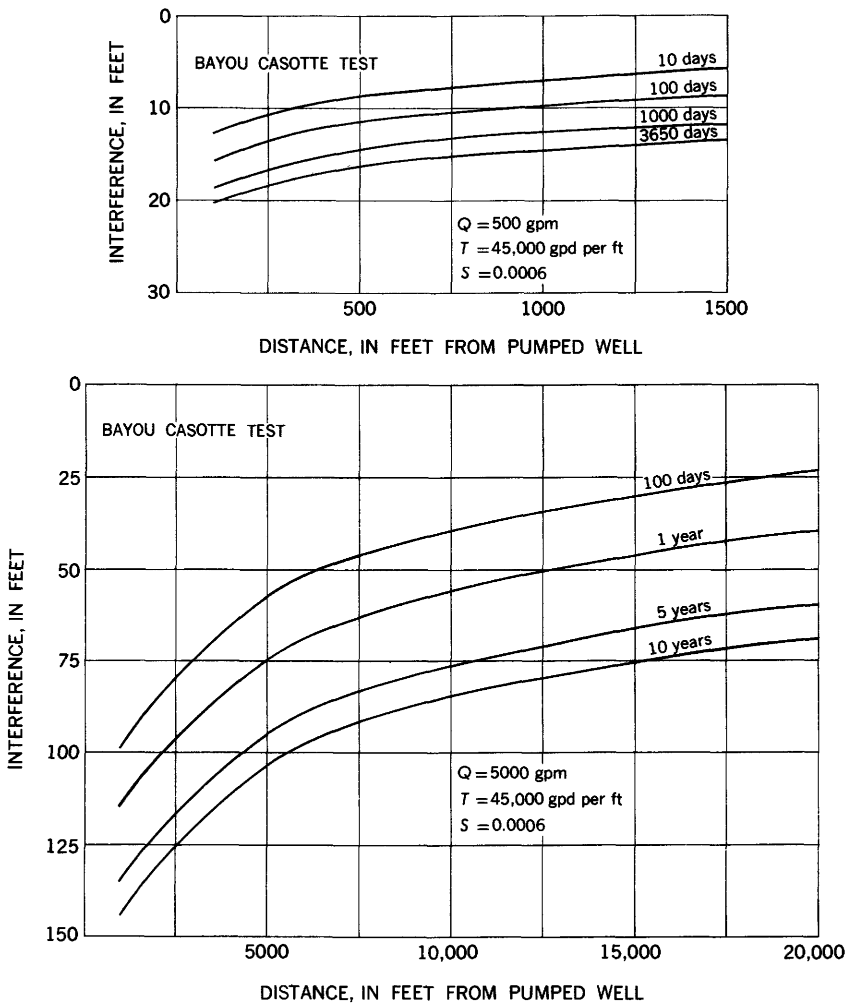

FIGURE 30.—Yield-drawdown relationship of the Citronelle Formation.

water is essentially of a calcium bicarbonate type and has a low dissolved-solids content. The dissolved-solids content increases coastward, and along the coast is considerably higher than in the upland areas. This increase results primarily from increases in the concentration of sodium, bicarbonate, and chloride. A gradual increase in chloride content from 38 ppm in well Q119 to 185 ppm in well Q104 is shown, on the geologic section (pl. 15), to extend south through Bayou Casotte. The same southward trend of increasing chloride content exists in Pascagoula, although it is not as well defined. The increase of sodium is greater than the increase of calcium and magnesium; however, in local areas, calcium and magnesium may be present in considerable quantities.

The iron content and the hardness of water from these deposits usually are higher than those found in water from the Pascagoula and Graham Ferry Formations. In water from the Citronelle Formation and terrace deposits, hardness and iron values as much as 200 and 7.5 ppm, respectively were observed. Analyses of water from these deposits are shown in tables 21 and 22. A few analyses are shown graphically on plate 10.

Danger of salt-water encroachment exists in the Citronelle Formation and the terrace deposits along the lower reaches of Pascagoula and Escatawpa Rivers. No definite salt-water encroachment as a direct result of pumping was recognized in 1960.

Where these deposits are adjacent to and have a hydraulic connection with the salt-water reaches of the rivers, saline water from the rivers diffuses into them and contaminates the fresh ground water. The salinity of water in the aquifer varies with discharge of water from the aquifer and the salinity of water in the rivers. The landward limit of the zone of diffusion moves back and forth in response to variations in river stage relative to the altitude of the water table.

Along the coast, water from wells completed in the Citronelle Formation at depths from 72 to 156 feet contain 190 to 230 ppm of chloride, whereas, in the center of Pascagoula wells ranging in depth from 110 to 180 feet in the same formation contain from 31 to 170 ppm of chloride. The contrast in the chloride content of the water obtained in Pascagoula with that obtained in the sands at various depths in the Pascagoula River Valley is shown by the analyses for wells P70 and P78; the salt-water fresh-water contact is between these two wells. On the west bank of the Pascagoula River, well P78, completed at a depth of 88 feet, had a chloride content of 12,100 ppm. One-half mile east of the river, well P70 had a chloride content that ranged from 30 to 38 ppm. Samples of water taken at intervals since 1958 from well P70 indicate a possible slow increase in chloride content. However, continued monitoring will be necessary to establish existence of a trend.

Figure 31 is a generalized sketch showing ground-water conditions in an aquifer that is connected with a stream carrying saline water. Part *A* of this figure shows that variations of chloride content in water from wells depends on the location and depth of the screen with respect to the zone of diffusion. Well P78 (pl. 1 and table 22) evidently is screened in salt water, and well P70 is in fresh water. The analyses for well P34 (table 22) indicate that this well is screened in the fringe area of the zone of diffusion. Any changes in the salt content of water in the aquifer likely will depend on changes in the salt content of the surface water and the amount of pumpage from the sands.

Part *B* of figure 31 shows the condition that would exist if pumpage from the aquifer were sufficient to extend the cone of depression to the salt-water zone. To avoid this eventuality, any large-scale development of this aquifer will require careful control.

ALLUVIUM

The extent of the alluvial deposits of the river valleys is shown on the geologic map (pl. 1); the thickness in the Pascagoula River valley is shown in the geologic sections (pls. 3, 12, and 16). The deposits extend for short distances up tributary streams and decrease rapidly in thickness above the mouths of the streams.

Along section *G–G′* (pl. 3) the alluvial deposits range from 50 feet thick on the west side of the valley to 30 feet thick on the east side. Along section *F–F′* from Vancleave to the Escatawpa River no data were available on the depth of the alluvium. The deposits under-

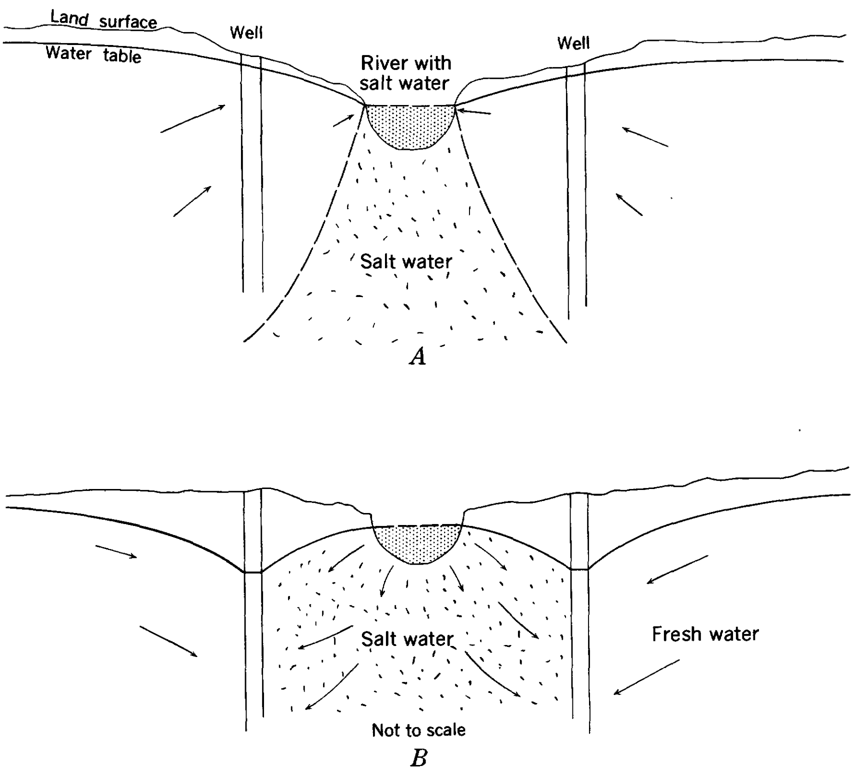

FIGURE 31.—Ground-water conditions in an aquifer cut by a stream carrying saline water. *A*, water flow before pumping; *B*, during pumping. A cone of depression is formed around each well; this cone depresses the water table and causes lateral encroachment of salt water into the wells.

lying the terrace extend to a depth of about 100 feet. If the bottom of the Pascagoula valley coincides with the base of the terrace deposits, as it is shown on the geologic section, the deposits would be about 80 feet thick. The Citronelle Formation, present in the lower reaches of Pascagoula River, probably wedges out beneath the alluvial deposits at some point upstream from U.S. Highway 90. Because no distinct boundary was determined between the alluvial deposits and the Citronelle Formation, the materials were mapped as undivided (pls. 10, 12).

Samples of water for chemical analysis were obtained from wells along the valley adjacent to the river flood plain. However, the deposits in which these wells are completed, formerly thought to be alluvial deposits, are here considered to be terrace deposits. The only distinction between the alluvial and terrace deposits is that of position, the lithology being similar. Inasmuch as the water table slopes toward the valley from the adjacent terrace (pl. 6), the quality of water in the alluvial deposits should be similar in character to that in the terraces. Where salt water is present in the river, a zone of salt water will exist beneath the river. The distance upstream that salt water occurs in the alluvial deposits will be determined by the extent of salt-water penetration up the river.

POTENTIAL DEVELOPMENT

SURFACE WATER

Large quantities of surface water of good quality are available in the Pascagoula area. Use of water from the Escatawpa River system in 1958 was about 130 mgd, of which 80 mgd were removed from the drainage basin and transported to Mobile, Ala., for municipal and industrial uses. In the lower reach of the river, about 50 mgd were withdrawn for industrial use. The water returned to the stream is high in organic content; however, the return water is added to the river at a location downstream from the withdrawal point and in a reach that is penetrated frequently by salt water. The water resources of the other streams are largely undeveloped.

QUANTITY

ESCATAWPA RIVER

Consumptive withdrawals from Escatawpa River would require some type of storage facility to assure the availability of water during periods of low flow. It is presumed that withdrawals from the river would be transported to the Bayou Casotte industrial area and not returned to the river; in effect, the withdrawals would be a consumptive use. The 1956 Mississippi water law prohibits withdrawals for consumptive use when the flow of a stream is less than the average minimum. If a reservoir is to supply a continuous withdrawal of 100 mgd, the storage must be sufficient to provide for the withdrawal and to maintain the average minimum flow in the river. Computations using data for the station Escatawpa River near Hurley, not allowing for evaporation and seepage losses, indicate a storage of about 25,000 acre-feet of water would be necessary to meet these requirements during an extended period of low flow having a 50-year recurrence interval.

If a reservoir is operated to maintain the average minimum flow of 128 cfs (83 mgd) during periods of extreme low flow, the outflow from the reservoir would be greater than the natural flow of the Escatawpa River would have been. The flows of Big, Jackson, and Franklin Creeks also augment the natural flow of Escatawpa River downstream from the Hurley gage by nearly 100 percent. During the drought of 1954, the flow of Escatawpa River near Wilmer, Ala., was 30 percent less than the average minimum. It is probable that this condition also existed in the lower reaches of Escatawpa River. If a reservoir is capable of maintaining the average minimum flow during such periods of low flow, the extent of salt water penetration in Escatawpa River would be less than that experienced during 1954. Therefore, a reservoir on Escatawpa River operated as suggested would be beneficial to existing (1961) industrial users and would assure an additional water supply of 100 mgd for the area.

The drainage area of Escatawpa River near Hurley (at Brown's bridge) is 639 square miles, about 75 percent of which lies within Alabama. However, during periods of low flow about 50 percent of the flow at Hurley is derived from the drainage area within Mississippi. During periods of flood runoff the streamflow yields of segments of the basin are more or less proportional to the drainage area. A water compact between Mississippi and Alabama will be necessary to assure an orderly and equitable development of the water resources in the Escatawpa River basin.

PASCAGOULA RIVER

The Pascagoula River is a potential source for a large water supply. At Graham Ferry the minimum flow of the river during a drought having a 50-year recurrence interval would probably exceed 1,000 cfs. However, to satisfy legal requirements, consumptive withdrawals (based again on the assumption that the water would be transported to the Bayou Casotte industrial area) cannot be made during periods when streamflow is less than the average minimum flow. The average minimum flow at Graham Ferry was estimated to be 1,360 cfs. On the basis of frequency data shown in table 9, the annual 7-day minimum flow at this location will be less than 1,360 cfs on the average of once in 8 years; and the annual 30-day minimum, once in 16 years.

Some type of storage facility would be required to assure a continuous supply of water during periods of low flow, when legal restrictions would prevent withdrawals for consumptive use. Withdrawals made in the vicinity of Graham Ferry or Cumbest Bluff would require an off-channel storage of about 30,000 acre feet, not allowing for evaporation and seepage losses, to maintain a continuous supply of 155 cfs (100 mgd) during an extended period of low flow having a recurrence interval of 50-years. When the flow of Pascagoula River exceeds the average minimum, withdrawals can be made as low as mile 20 with assurance that salt water would not penetrate to that location except as the result of hurricane tides.

An amendment to the water law is being considered by the 1962 Mississippi Legislature. The proposed amendment provides that the Board of Water Commissioners may authorize an industrial use of water when the streamflow is less than the average minimum. If the amendment becomes part of the water law, the Pascagoula River at Cumbest Bluff or Graham Ferry could be made available as a continuous source for an industrial water supply of 100 mgd, and the only storage needed would be a small amount to assure a continuous water supply during operational emergencies.

An engineering firm suggested in a preliminary report for industrial water supply that Black Creek Swamp be used for off-channel storage of Pascagoula River water. The water would be transported from the swamp to the Bayou Casotte area by means of open channels, pipe lines, and an inverted siphon to cross Escatawpa River. The general topography of Black Creek Swamp is such that levees would be required on the west side and on the north and south ends of the swamp to form a reservoir. Swamp deposits, several feet thick, overlie a strata of sand. If the stored water is in contact with the sand, seepage will occur; however, in time, sediment will partially seal the underlying sand.

TRIBUTARY STREAMS

Many tributary streams in the area are potential sources for a water supply. Big, Jackson, and Franklin Creeks, tributaries to Escatawpa River, have high base flows and water of good quality. Big Creek, near its mouth, has a dependable flow of about 50 cfs (32 mgd). This figure is based on the streamflow of Big Creek basin below the reservoir. However, most of this drainage area is in Alabama where water-supply developments can be made without compliance with Mississippi water law. Most of Jackson and Franklin Creek drainage basins are also in Alabama. Water rights to 3 cfs (2 mgd) from Franklin Creek have been granted by the Mississippi Board of Water Commissioners.

Big Cedar, Indian, White, and Big Creeks, tributaries to Pascagoula River from the east, are potential sources of dependable water supplies. A dependable supply of about 25 cfs (16 mgd), without storage, can be obtained from Big Cedar Creek near its mouth.

Big Black and Red Creeks, tributaries to the Pascagoula from the west, are potential sources for fairly large supplies. During periods of low flow, Big Black Creek at State Highway 57 has a dependable flow of about 70 cfs (45 mgd), about the same as Escatawpa River near Hurley. Red Creek at Vestry has a dependable discharge of about 50 cfs (32 mgd). Bluff Creek near Vancleave has a dependable flow of about 3 cfs (2 mgd).

Any of these tributary streams could be developed to the extent of the dependable flow of the stream if the use was largely nonconsumptive and the quality of the return water not greatly impaired.

QUALITY

Quality of water is an important factor in consideration of a potential water supply. In general, most industries require clear water that has a low and fairly uniform dissolved-solids content and hardness (American Water Works Association, Inc., 1950). Under natural conditions, surface waters in the area above the zones of salt-water intrusion are low in dissolved solids, and the chemical constituents remain fairly constant at all rates of streamflow. The dissolved-solids content of water in Pascagoula River and Red Creek is increased at times by addition to the streams of oil-field brine, which causes a wide variation in the day-to-day quality. Off-channel storage of Pascagoula River or Red Creek water would tend to even out the daily variations in quality.

As a result of drainage from swampy areas, waters in most of the tributary streams have high color and, in some instances, a low pH value. In order for most of these waters to meet the general requirements for industrial-process water, treatment would be necessary to remove color and suspended materials and to adjust the pH.

If any of the tributary streams in the area were impounded in a reservoir, the effect of storage probably would be minor. Impoundment probably would affect the organic material and the temperature of the water more than the concentrations of the major chemical constituents. The larger particles of organic material would tend to settle from the upper stratum and accumulate in the deeper parts of the reservoir. Decomposition of the material might cause increases in concentrations of some of the minor constituents in the deeper parts of the reservoir. Impoundment would tend to make the water temperature more uniform.

GROUND WATER

PASCAGOULA-MOSS POINT AREA

Most of the water pumped from wells in this area is derived from the Graham Ferry Formation from depths less than 400 feet. The remainder of the ground-water supply is derived from the Citronelle Formation at depths of 200 feet or less and from the Pascagoula Formation at depths of 650 feet and 800 to 900 feet. These zones seem to be more consistent than others in their development. Owing to the lenticularity of the sands of the Pascagoula, it is difficult or impossible to predict their presence over broad areas. The 800-foot sand at Pascagoula is shaly east of the city and in the Kreole area, and the probability of developing a large water supply from the aquifer is not promising in that area. The 800-foot aquifers at Moss Point and at Pascagoula are made up of lenses. Where these aquifers are present the transmissibility is high and yields of 500 to 1,000 gpm can be expected. The 1958 yield of 3 mgd can be doubled by lowering the water level from the 1958–1960 level of 20 feet to 100 feet below the surface. In earlier years the yields of flowing wells were 300 to 500 gpm and the waste was considerable. Widespread lowering of the piezometric surface will prevent this continued waste of water.

Most test holes drilled in the area have stopped at depths of 1,000 to 1,100 feet. Fresh water can be obtained to a depth of 1,600 feet, although the water is moderately mineralized (550 ppm chloride). Wells have been successfully completed at depths of 1,300 to 1,400 feet at Orange Grove School east of Kreole and north of Gautier, and the water is satisfactory for many uses. The areal extent and depth of the sands should be located by test drilling. Sufficient information is lacking to delineate areas where the sands may occur.

The 650-foot sand, which supplies water to the subdivisions in the eastern part of Pascagoula, is limited in its development to about 1 square mile. It is a fine-grained sand that yields from 50 to 100 gpm and cannot be expected to yield large supplies of water.

The most promising aquifers for future development are the Graham Ferry and Citronelle Formations. Although the industrial development in 1957–58 has caused the water level in the Graham Ferry Formation to decline in the area of concentrated pumping, the rate of decline will diminish. Additional pumping demands will accelerate the lowering of the peizometric surface.

New developments can be made on the flanks of the drawdown cone east of the industrial sites. In the north end of the Bayou Casotte industrial area the sand of the Graham Ferry is thin and shaly. Additional test drilling in this area may prove that the shaly zone is not extensive. Although this sand is apparently shaly along a line drawn between wells P142 and Q117, wells completed in it northeast of Pascagoula along U.S. Highway 90, in Kreole, and in Orange Grove indicate that the shaly area is not extensive.

Additional development of water from the aquifer, preferably located away from centers of pumpage, is feasible. It is estimated that 3 mgd of water is flowing across the zero contour line from the north into the drawdown cone encompassing the Bayou Casotte-Pascagoula area to replace a part of the water pumped in that area. An increase in the draft on the aquifer will lower water levels and cause a steepening of the hydraulic gradient with a proportional increase in the flow of water into the drawdown cone. The contribution of ground water from the northwest to the drawdown cone is larger than that from the east, owing to the higher transmissibility of the aquifer in the western part of Pascagoula.

Serious salt-water encroachment is not likely to develop in the Graham Ferry Formation because of the overlying clay aquiclude that is present in most of the area. The chloride content of the water has not increased since 1939 when the municipal wells were constructed on Communy Street.

The aquifer in the Citronelle Formation has a moderately high transmissibility in the Bayou Casotte area, which makes it an important source of water for future development. A draft of 5,000 gpm (7 mgd) eventually would cause considerable lowering of the piezometric surface (fig. 30). Injection of water into the formation would prevent excessive lowering of the piezometric surface and the eventual salt contamination of water supplies. The movement of water in the Citronelle Formation is very slow in the vicinity of Pascagoula owing to the small hydraulic gradient. If a well field were established having a production rate of 5,000 gpm, the piezometric surface would be lowered in accordance with the graph, figure 30. To determine the velocity at which water would move in the aquifer and the lapse of time before saline water would contaminate wells in Pascagoula, it is necessary to know the permeability, porosity, and hydraulic gradient of the aquifer.

The following formula may be used in estimating the velocity of ground water moving through the aquifer:

$$V=\frac{PI}{p}$$

where

V=average velocity in feet per day,

P=permeability in cubic feet per day per square foot,

I=hydraulic gradient expressed as a decimal fraction,

p=porosity expressed as a decimal fraction.

The permeability of the aquifer, determined from the pumping test, is 450 gpd per sq ft or 450/7.5=60 cu ft per day per sq ft. The average hydraulic gradient between points 1,000 and 20,000 feet from the center of the well field is 77/19,000=0.004 (fig. 30). The porosity of the water-bearing material is unknown, but a value of 0.30 is assumed to be reasonable. Substituting the values on the above formula the velocity may be obtained:

$$V=\frac{60\times 0.004}{0.30}=0.8 \text{ foot per day}$$

If the physical characteristics of the aquifer are uniform, saline water beneath the Pascagoula River would move toward the center of pumping at the rate of 1 mile in 18 years.

The quality of water in the Pascagoula and Graham Ferry Formations is similar. Water from both formations is of a sodium bicarbonate type, soft, slightly colored, and low in iron content. The chloride and dissolved-solids content of water in the Pascagoula Formation are higher and more variable than that in the Graham Ferry Formation. The low iron content and the softness of the water, together with the even temperature of this water, are desirable features for an industrial supply, but the color may be undesirable in some manufacturing processes.

Water from the Citronelle Formation usually has a lower dissolved-solids content than water from the deeper formations. The iron content and hardness are higher than in the deeper formations. Locally, the water may be very hard. Water from this formation probably would require treatment for hardness and iron before it would be suitable for most industrial processing. Although the chloride content of the water is low to moderate, the opportunity is present for saline water to encroach from the lower reaches of the Pascagoula and Escatawpa Rivers, where the quality of water in this aquifer is affected by the diffusion of saline water from the streams into the sand. Water of higher mineralization also may move up the dip.

OCEAN SPRINGS-GAUTIER AREA

The Graham Ferry and Citronelle Formations and the 800- and 500-foot sands in the Pascagoula Formation are the four chief aquifers in the Ocean Springs-Gautier area. Only the 500-foot sand is used to any great extent. The other aquifers are used for domestic supplies and for a few small industrial supplies.

The average decline in water level in wells completed in the sands of the Pascagoula at 800- to 900-foot depth is 1 foot per year for the 70 years, 1891 to 1960. The average decline in water level in the 500-foot sand is 0.8 foot per year; this decline is based on measurements made as early as 1885 and at various times from then until 1961.

Although 70 percent of the water for municipal use is pumped from the 500-foot sand, the water level has declined at a slower rate than in the 800-foot sand. Both sands are excellent aquifers containing water of low mineral content. If the use of water from the aquifers continues at the present rate, water levels will decline at a progressively slower rate.

More than 230 wells are flowing in Jackson County. It is estimated that 3 mgd of ground water is going to waste. This waste is equal to one-third of the total ground water pumped in Jackson and George Counties for municipal and industrial uses. Because of the decline in pressure, the high flows that were reported in the early 1900's have diminished considerably; this decline aids in the conservation of the remaining supply. The area in which a flowing well can be drilled today is about the same as it was in 1940 (Brown and others, 1944, pl. 2) because deeper aquifers in the Pascagoula Formation sustain little draft compared with the 500- and 800-foot sands. In some areas it is impossible to obtain a flowing well in the 500- and 800-foot sands, but it is possible to obtain a flowing well at depths of 1,000 to 1,600 feet almost anywhere in the artesian area (pl. 11).

The Graham Ferry Formation is little used west of Pascagoula and is available for additional development in the area between Gautier and Fontainebleau. Although the piezometric surface reflects the influence of pumpage in Pascagoula, it is generally not more than 15 feet below sea level in Gautier and gradually rises to sea level 1½ miles to the northwest. The aquifer is more than 100 feet thick in places, and its transmissibility is probably as high as it is in the western part of Pascagoula. Additional pumping from this aquifer in the Gautier area would cause water levels in the western part of Pascagoula to decline.

The Citronelle Formation is subject to salt-water encroachment in this area as it is in Pascagoula. The Citronelle consists of lenses of sand separated by clay and is not as thick and consistent as it is in Bayou Casotte. However, it should be possible to develop supplies of several hundred gallons per minute.

Little is known about the sands of the Pascagoula Formation below the 800-foot sand. About a dozen wells have been drilled to depths of around 1,200 feet in the Ocean Springs area. Comparison of sample, electrical, and drillers' logs from the area suggest that the sands should be capable of yields of several hundred gallons per minute per well. The water is more mineralized than that in the shallower aquifers.

WADE-ESCATAWPA AREA

A large ground-water supply is available on the terrace extending from Wade to Escatawpa. Here the Graham Ferry Formation wedges out beneath the overlying gravelly deposits and is considered unimportant as a source of water except for domestic supplies. Sand in the underlying Pascagoula Formation, as elsewhere, is medium to coarse and lenticular, and wells are completed at depths ranging from 250 to 1,200 feet. The north-south cross section (pl. 9) does not reveal a consistent aquifer in the Pascagoula, although many sand deposits of small extent exist. The best section known is east of Wade in well C16 where 150 feet of sand and fine gravel occurs in two lenses about midway in the Pascagoula Formation. Doubtless other lenses similar to these occur in which wells yielding 1,000 gpm can be made.

The chief aquifer of the area is the terrace deposits that extend from the surface to a depth ranging from 60 to 100 feet. It is estimated that about 1 million acre-feet of water is in storage in the aquifer and that, under existing conditions, ground water is discharging from the aquifer toward Mississippi Sound and Pascagoula River at the rate of 3 to 5 mgd. Sand occurs at or near the surface of the ground, and the water table stands from 4 to 15 feet below land surface. The saturated thickness of the aquifer ranges from 60 feet near Wade to 100 feet at Escatawpa and averages about 80 feet.

Because a large part of the terrace lies north of the Pascagoula River division at mile 17.7, the opportunity for salt-water encroachment in the aquifer is remote. Wells capable of yielding from 200 to 500 gpm can be drilled in many parts of the area. A development of several million gallons a day would lower the water table and increase the hydraulic gradient and the flow of water to the center of pumping.

Should large supplies of water be developed in the future, the aquifer can be recharged through spreading pits or wells. Several sources of water, including precipitation on the area and diversion from Big Cedar Creek, are available for artificially recharging the aquifer. In many recharging operations, spreading pits of varying size, number, and depth are used as a means of inducing infiltration, the type of pit depending mostly on the geological nature of the surface and the aquifer and depth to water.

THE UPLANDS

The hills of George and northern Jackson Counties compose the uplands, which are covered in large part by the Citronelle Formation. The Citronelle is the primary aquifer of the area because it serves as the reservoir that sustains the base flow of the streams. The chief artesian aquifers in the area are the lenticular sands in the Pascagoula and Hattiesburg Formations. Most of the wells have been drilled for domestic and farm supplies and are usually less than 100 feet deep. Wells of greater depth are rare in most of the area. North of Ocean Springs a dozen wells have been drilled to depths as much as 1,400 feet to obtain artesian water. The municipal wells at Lucedale are

1,000 feet deep. Examination of sample cuttings and electrical logs reveals that throughout the area one or more sands capable of yields of several hundred gallons per minute per well are generally present.

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TABLES 21 AND 22

TABLE 21.—*Chemical analyses, in parts per million, of water from wells in George County, Miss.*

Well	Water bearing unit (Pl. 1)	Depth (feet)	Date of collection	Temperature (° F)	Silica (SiO_2)	Total Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180° C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25° C)	pH	Color
A1	Tp	335	8-24-41	71							245	39	2	63	1.2			12	0			
A2	Qt	23	8-28-41	68							10	0	1	5	0	0		15				
B1	Tp	525	4-20-59	72	5.1	0.08	1.4	0.1	105	1.3	226	16	6.4	7.0	.3	1.0	281	4	0	395	8.7	25
B3	Tp	185	4-20-59	68	7.7	.33	1.6	.6	66	1.3	144	0	2.2	21	.4	.6	221	6	0	288	7.4	15
B9	Tp	260	8-28-41	68							241	16	1	67	.9			15	0			
C15	Th?	1,012	12-16-58		8.9	.10	.8	.1	56	2.0	114	0	8.4	18	.1	.2	186	2	0	236	6.9	7
C16	Tc	20	8- 7-19		13	.05	.6	.6	18 (Na+K)		17	13	1.9	4.5			58	4	0			
C21	Tc	32	8-28-41								18	0	1	4	0	6.5		30				
C24	Tc	20	8-28-41								2	0	1	10	0	13		23				
D13	Tp		8-28-41								16	0	10	2	.1	0		18				
F14	Tc	63	4-22-59	70	2.3	.46	1.2	.4	2.2	.2	5	0	.8	3.5	.0	.6	26	4	0	29	5.4	1
F15	Tp	190	8-28-41	69							216	40	5	14	.7			18				
F17	Tp	153	8-28-41	69							280	14	1	67	1.3	0		27				
H4	Tp	145	8-28-41	70							91	0	7	2	.2	0		12				
J2	Tp	476	? -59				2.5	.9						15				10		571		
J4	Tp	104	8-28-41	67							137	24	7	5	.5	0		21				
J5	Tp	93	8-28-41	69							140	21	9	4	.7	0		18				
J6	Tp	145	8-28-41	69							172	18	8	4	.6	0		12				
J7	Tp	140	8-28-41	69							132	10	10	4	.5	0		14				
J15	Tp	120?	8-28-41								136	11	9	5	.6	1.2		21				
J17	Tp	185	8-28-41								132	21	12	3	.4			14				
K2	Tp	93	4-22-59	69	18	.45	7.2	1.5	16	2.5	64	0	6.2	3.2	.0	.3	112	24	0	114	7.6	2
K2	Tp	93	8-28-41	69							66	0	4	3	.2	0		36				
M2	TC?	75	8-28-41								27	0	1	3	0	2.7		34				

TABLE 22.—*Chemical analyses, in parts per million, of water from wells in Jackson County, Miss.*

Well	Water bearing unit (Pl. 1)	Depth (feet)	Date of collection	Temperature (° F)	Silica (SiO_2)	Total Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color
B3	Tp	1,128	6-15-59	72	3.8	0.04	1.8	0.2	106	1.8	236	16	6.6	6.2	0.5	2.1	297	6	0	426	8.8	20
D33	Tp	424	12-17-58	73	4.1	.07	1.0	.0	169	.8	410	6	2.6	20	.7	.1	442	2	0	658	8.3	30
E1	Tp	230	12-7-59	70	17	.18	1.9	.3	44	2.7	118	0	6.4	2.5	.2	.6	158	6	0	194	7.4	5
E6	Tp	286	1-21-60	66	--	--	1.2	.1	--	--	--	--	--	6.0	--	--	--	--	--	139	--	--
G11	Tp	258	8-8-60	72	6.4	--	3.3	.4	132	2.4	346	0	1.4	13	.3	.5	380	10	0	576	8.2	40
G12	Tp	810	9-13-60	74	2.5	--	2.9	.0	146	2.9	382	0	1.6	12	.8	.3	400	7	0	579	7.9	25
J37	Tp	965	6-27-39	--	--	--	--	--	--	--	230	21	6.0	23	.1	--	--	9	--	--	--	--
K23	Tp	326	12-11-58	68	4.6	.26	1.2	.1	131	.7	320	0	3.6	18	.6	.4	347	4	0	512	8.2	25
K37	Tp	1,352	--	--	8.6	--	1.8	.0	189	3.2	314	0	.6	120	.4	.6	538	4	0	852	7.8	30
K41	Tp	800	12-11-58	76	6.1	.07	2.5	.1	180	1.8	280	0	2.6	123	.4	.1	500	6	0	794	8.2	25
L22	Qt	52	9-4-59	71	--	3.7	1.0	.4	--	--	--	--	1.6	4.5	--	--	--	--	--	27	--	--
L22	Qt	52	10-8-59	71	--	--	.7	1.2	--	--	--	--	--	5.5	--	--	--	--	--	59	--	--
L22	Qt	52	11-5-59	71	--	--	1.3	.4	--	--	--	--	--	4.8	--	--	--	--	--	32	--	--
L22	Qt	52	12-3-59	67	--	--	.6	.9	--	--	--	--	--	8.5	--	--	--	--	--	33	--	--
L22	Qt	52	1-7-60	67	--	--	1.3	.2	--	--	--	--	--	7.5	--	--	--	--	--	26	--	--
L22	Qt	52	2-11-60	68	--	--	.6	.6	--	--	--	--	--	7.5	--	--	--	--	--	27	--	--
L22	Qt	52	3-17-60	69	--	--	1.0	.5	--	--	--	--	--	5.0	--	--	--	--	--	30	--	--
L22	Qt	52	4-7-60	72	--	--	1.0	.4	--	--	--	--	--	5.5	--	--	--	--	--	31	--	--
L22	Qt	52	5-5-60	68	--	--	1.0	1.2	--	--	--	--	--	9.0	--	--	--	--	--	53	--	--
L22	Qt	52	6-13-60	69	--	--	.7	.9	--	--	--	--	--	9.0	--	--	--	--	--	33	--	--
L22	Qt	52	7-13-60	69	--	--	.6	.7	--	--	--	--	--	7.0	--	--	--	--	--	25	--	--
L22	Qt	52	8-24-60	71	--	--	.5	.7	--	--	--	--	--	6.5	--	--	--	--	--	42	--	--
L22	Qt	52	10-24-60	71	--	--	.6	.6	--	--	--	--	--	5.5	--	--	--	--	--	27	--	--
L22	Qt	52	11-29-60	67	--	--	.9	.4	--	--	--	--	--	5.5	--	--	--	--	--	24	--	--
L28	Tp	660	11-5-59	77	7.7	.15	1.8	.4	259	5.4	576	24	.0	48	1.4	.8	684	6	0	1,040	8.6	140
L29	Qt	61	9-4-59	69	--	2.7	3.1	.8	--	--	--	--	.0	6.5	--	--	--	--	--	57	--	--
L29	Qt	61	10-8-59	70	--	--	2.4	1.5	--	--	--	--	--	7.0	--	--	--	--	--	91	--	--
L29	Qt	61	11-5-59	69	--	--	2.8	1.5	--	--	--	--	--	7.2	--	--	--	--	--	88	--	--
L29	Qt	61	12-3-59	68	--	--	2.7	1.2	--	--	--	--	--	9.0	--	--	--	--	--	61	--	--
L29	Qt	61	4-7-60	67	--	--	3.0	1.3	--	--	--	--	--	8.2	--	--	--	--	--	93	--	--
L29	Qt	61	5-5-60	68	--	--	1.6	2.3	--	--	--	--	--	7.0	--	--	--	--	--	67	--	--
L29	Qt	61	6-13-60	--	--	--	2.4	1.3	--	--	--	--	--	7.2	--	--	--	--	--	65	--	--
L29	Qt	61	7-13-60	69	--	--	2.4	1.4	--	--	--	--	--	10	--	--	--	--	--	61	--	--
L29	Qt	61	8-24-60	70	--	--	2.4	1.7	--	--	--	--	--	8.5	--	--	--	--	--	92	--	--
L29	Qt	61	9-16-60	69	--	--	2.1	1.5	--	--	--	--	--	8.0	--	--	--	--	--	60	--	--

TABLE 22.—*Chemical analyses, in parts per million, of water from wells in Jackson County, Miss.*—Continued

Well	Water bearing unit (Pl. 1)	Depth (feet)	Date of collection	Temperature (° F)	Silica (SiO_2)	Total Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color
L29	Qt	61	10-24-60	--	--	--	2.1	1.5	--	--	--	--	--	7.0	--	--	--	--	--	55	--	--
L29	Qt	61	11-29-60	68	--	--	2.4	1.4	--	--	--	--	--	8.5	--	--	--	--	--	59	--	--
M5	Tp	787	8- 8-60	76	6.8	--	1.4	.1	261	4.4	408	0	0.2	175	0.7	0.9	720	4	0	1,140	8.1	40
M9	Tp	684	9- 4-59	--	8.0	0.64	1.1	.4	202	2.4	462	24	2.0	18	1.0	1.0	480	4	0	771	8.7	60
M13	Tp	808	12-11-58	77	4.2	.26	1.9	.0	278	1.7	636	8	1.8	59	.6	.2	727	4	0	1,090	8.4	90
M25	Tp	352	7- 8-60	--	6.2	--	3.3	.4	319	5.0	584	0	.0	170	1.4	.6	905	10	0	1,400	8.2	110
N22	Tp	859	6-27-39	--	--	--	--	--	--	--	227	19	2	96	0	--	--	14	--	--	--	--
N32	Tp	316	12- 7-59	70	8.7	.40	.9	.9	84	1.6	200	12	1.8	4.0	.8	1.4	257	6	0	353	8.4	140
N42	Tp	1,224	6-27-39	87	--	--	--	--	--	--	289	16	1	418	.1	--	--	30	--	--	--	--
N43	Tp	940	6-27-39	--	--	--	--	--	--	--	204	22	3	58	.2	--	--	6	--	--	--	--
N44	Tp	1,290	9- -42	--	--	--	--	--	--	--	272	28	1	342	--	--	890	42	--	--	8.6	--
N48	Tp	535	9- 7-19	--	32	.04	.6	.4	105		102	77	10	8.0	--	.3	294	3	--	--	--	--
N49	Tp	1,290	6-27-39	--	--	--	--	--	--	--	301	16	1	762	0	--	--	52	--	--	--	--
N49	Tp	1,290	9- 7-19	--	42	--	12	.6	619		312	30	4.3	756	--	--	1,640	32	--	--	--	--
N59	Tp	875	9- 7-19	--	36	.05	2.0	1.6	181		213	47	3.2	109	--	--	493	12	--	--	--	--
N63	Tp	640	9- 7-19	--	28	.02	1.3	1.1	115		185	53	8.7	6.7	--	.9	311	8	--	--	--	--
N68	Tp	545	9- 7-19	--	34	.04	1.5	1.0	111		156	65	9.5	7.7	--	--	312	8	--	--	--	--
N83	Tp	940	12-12-58	80	5.7	.10	1.1	.0	126	1.0	244	14	4.8	37	.5	.2	328	2	0	551	8.7	20
O8	Tg	217	12-11-58	59	19	.20	6.0	1.0	55	2.8	144	0	3.4	16	.2	.2	226	19	0	256	7.0	18
O13	Tp	964	5-14-59	77	6.9	.26	1.8	.2	287	3.4	462	28	2.2	150	1.3	.9	772	6	0	1,210	8.7	100
O20	Tp	735	2-15-60	77	20	.45	1.6	.1	216	5.2	318	12	.6	151	.8	.8	628	4	0	984	8.5	70
O21	Tg	230	2-15-60	67	--	--	7.6	1.7	--	--	--	--	--	12	--	--	--	--	--	125	--	--
O22	Tp	700	6-27-39	--	--	--	--	--	--	--	293	22	2	40	.1	--	--	4	--	--	--	--
O38	Tp	630	12-12-58	--	3.1	.08	.9	.1	126	.8	250	8	8.2	34	.4	.2	338	2	0	541	8.4	20
O40	Tp	568	5-14-59	75	6.3	.15	.5	.1	111	1.6	250	12	7.2	8.0	.6	.3	312	2	0	439	8.8	20
O47	Tp	1,140	1-22-60	85	6.8	.00	3.1	.0	195	4.7	300	0	.4	135	.7	.7	542	8	0	889	8.1	32
O48	Tp?	819	7- ?-44	--	21	.01	1.0	.4	127		209	28	4.8	40	.4	.0	322	4	0	--	9.0	--
O49	Tp?	836	7- ?-44	--	20	.03	1.8	.3	183		213	37	1.9	116	.6	.0	463	6	0	--	9.2	--
P14	Tp	328	12-11-58	--	4.0	.18	1.6	.1	148	1.7	300	0	2.0	57	.6	.4	405	4	0	626	8.2	28
P21	Tp	1,220	5-12-59	80	5.5	.30	2.6	.3	421	4.7	536	20	.2	312	1.9	1.2	1,120	8	0	1,790	8.5	100
P23	Qt	40	9- 4-59	72	--	.70	8.0	3.2	--	--	--	--	21	14	--	--	--	--	--	179	--	--
P23	Qt	40	10- 8-59	76	--	--	6.8	4.3	--	--	--	--	--	16	--	--	--	--	--	178	--	--
P23	Qt	40	11- ?-59	--	--	--	5.8	3.0	--	--	--	--	--	9.5	--	--	--	--	--	129	--	--
P23	Qt	40	12- 3-59	62	--	--	5.9	2.7	--	--	--	--	--	13	--	--	--	--	--	168	--	--
P23	Qt	40	1- 7-60	--	--	--	4.7	2.5	--	--	--	--	--	9.5	--	--	--	--	--	126	--	--
P23	Qt	40	2-11-60	60	--	--	4.5	2.8	--	--	--	--	--	9.0	--	--	--	--	--	113	--	--
P23	Qt	40	3-17-60	59	--	--	5.4	2.5	--	--	--	--	--	6.5	--	--	--	--	--	111	--	--

P23	Qt	40	4- 7-60	72			5.9	2.2						5.5						129		
P23	Qt	40	5- 5-60	69			5.2	3.1						8.5						113		
P23	Qt	40	6-13-60				7.9	3.0						15						189		
P23	Qt	40	7-13-60				7.2	2.6						19						164		
P23	Qt	40	8-24-60				4.8	2.6						10						127		
P23	Qt	40	9-16-60				5.6	2.3						9.0						121		
P23	Qt	40	10-24-60				5.4	2.0						8.0						111		
P23	Qt	40	11-29-60	69			4.6	2.3						9.0						113		
P34	Qt	35	9- ?-59	75		.15	4.1	5.8					15	60						379		
P34	Qt	35	10- 8-59	76			3.3	7.7						68						366		
P34	Qt	35	11- 5-59	75			3.2	5.7						60						362		
P34	Qt	35	12- 3-59	70			3.8	6.0						63						389		
P34	Qt	35	1- 7-60	68			3.7	6.0						62						367		
P34	Qt	35	2-11-60	61			3.4	5.5						58						348		
P34	Qt	35	3-17-60	65			2.9	5.7						53						331		
P34	Qt	35	4- 7-60	67			3.7	4.9						52						323		
P34	Qt	35	5- 5-60	67			3.6	5.4						53						349		
P34	Qt	35	6-13-60	69			3.3	5.8						54						351		
P34	Qt	35	7-13-60	71			3.6	5.8						56						363		
P34	Qt	35	8-24-60	72			3.5	4.9						52						327		
P34	Qt	35	9-16-60	76			3.5	5.3						50						316		
P34	Qt	35	10-24-60	73			3.0	4.7						48						316		
P34	Qt	35	11-29-60	71			3.0	5.2						52						329		
P41	Tg	207	5-12-60	73	13	.35	8.6	5.0	189	7.5	244	0	.0	190	.6	2.2	637	42	0	1,020	7.3	15
P44	Tp	793	9- 6-19		25	.04	2.4	.9	209		285	22	2.4	135			537	10				
P45	Tp	806	9- 6-19		41	.05	2.8	.9	226		268	50	1.8	138		1.3	601	11				
P48	Tp	1,100	6-27-39	84							445	23	2.0	292	1.3			12	0			
P54	Tp	829	11-14-58	80	6.0	.15	2.9	.1	257	2.3	346	0	.8	200	.7	.2	686	8	0	1,120	8.2	40
P55	Tp	840	9- 6-19		37	.04	3.0	.8	241		256	65	1.0	147		.3	627	11				
P57	Tp	820	6-27-39	78							285	25	1.0	135	.2			9	0			
P59	Tc	90	5-12-60	70			1.0	.6						7.5						67		
P62	Tg	326	5-14-59	73	11	.18	2.0	1.1	178	4.0	324	0	1.0	95	1.2	1.5	516	10	0	801	8.0	35
P67	Tg	300	4-15-60	72			5.6	.9						137						896		
P68	Tg	292	9- ?-59	73		.29	6.4	1.0					.0	150						942		
P68	Tg	292	10 -8-59	72			5.1	5.5						150						961		
P68	Tg	292	11- 5-59	72			4.4	3.6						150						943		
P68	Tg	292	12- 3-59	71			5.2	2.3						155						951		
P68	Tg	292	1- 7-60	71			8.5	3.8						152						997		
P68	Tg	292	3-17-60	73			5.6	2.1						148						931		
P68	Tg	292	4- 7-60	71			6.3	3.1						152						968		
P68	Tg	292	5- 5-60	72			5.2	3.8						150						961		
P68	Tg	292	6-13-60	72			4.4	2.2						148						949		
P68	Tg	292	7-13-60	72			4.7	2.6						152						943		
P68	Tg	292	8-24-60	72			3.6	2.9						150						934		
P68	Tg	292	9-19-60	72			3.3	2.9						155						941		
P68	Tg	292	10-24-60	72			3.8	3.2						155						941		
P68	Tg	292	11-29-60	72			3.3	3.4						155						956		
P70	Tc	180	9- 4-59	67		5.2	17	6.4					.0	30						299		

TABLE 22.—*Chemical analyses, in parts per million, of water from wells in Jackson County, Miss.*—Continued

Well	Water bearing unit (Pl. 1)	Depth (feet)	Date of collection	Temperature (° F)	Silica (SiO_2)	Total Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color
P70	Tc	180	10- 8-59	72			17	8.8						33						307		
P70	Tc	180	11- 5-59	72			19	7.8						32						339		
P70	Tc	180	5- 5-60	72			18	6.7						35						321		
P70	Tc	180	7- 7-60	72			17	7.0						34						304		
P70	Tc	180	9- 1-60				17	6.5						32						295		
P70	Tc	180	9-16-60	71			17	6.5						34						298		
P70	Tc	180	10-25-60	71			17	6.4						34						294		
P70	Tc	180	11-29-60	71			17	6.7						38						308		
P72	Tg	336	6- 9-58	73	52		3.2	1.5	200	3.6	309	0	2.3	138	.8	1.4	536	14	0	929	7.7	0
P74	Tp	550	6-27-39								297	25	2	71	.3			6				
P78	Tc?	88	6-14-60		9.3	.04	355	880	6,430	434	128	0	2,050	12,100	1.1		25,400	4,500	4,400	34,900	6.8	10
P78	Tc?	88	10-25-60	71			329	864						11,800						32,300		
P82	Tc	157	6-24-60	73	16	3.1	179	96	581	35	102	0	36	1,420	.2	5.7	3,140	842	758	4,800	6.3	5
P82	Tg	304	6-23-60		5.0	.33	5.1	.1	135	4.4	276	0	1.6	62	.2	1.6	415	13	0	529	8.2	6
P83	Qt	66	4-15-60	67			13	2.9						14						167		
P84	Tp	600	6-15-59	76	3.1	.00	.9	.1	221	2.0	344	22	.4	122	.9	.5	589	2	0	945	8.7	45
P88	Tc	136	4-15-60				20	7.0						16						310		
P94	Tp	758	4-29-60	75	22	.07	2.1	.8	192	4.5	296	12	.0	120	1.1	1.1	588	8	0	960	8.6	40
P99	Tc	147	4-29-60	75			13	4.6						22						363		
P102	Tg	262	12-11-58	67	14	.51	14	4.0	86	4.2	236	0	3.0	33	.5	.4	343	52	0	448	7.5	18
P108	Tp	785	5-14-59	74	7.4	.33	3.5	.8	334	4.9	368	12	.2	300	.9	.7	932	12	0	1,500	8.6	50
P109	Tp	875	9- 6-19		38	.04	4.7	2.1	2	64	276	34	.7	205			683	20				
P111	Tp	1,600?	6-27-39	89							380	11	1	550	1.3			21				
P112	Tp	800	6-27-39	79							348	19	1	282	.6			10				
P120	Qt	89	6-17-60	72			24	11						62						460		
P123	Tg	340	5-13-59	73	13	.12	2.9	.8	211	3.3	308	0	.6	155	.8	1.6	602	10	0	957	7.9	30
P124	Tp	801	5-12-59	80	9.0	.16	3.1	.3	306	4.6	352	0	1.4	275	1.1	.4	867	8	0	1,410	8.1	50
P124	Tp	801		79		.07	3.1	.1					.0	275				10		1,420		
P124	Tp	801	10- 8-59	79			7.8	2.8						278						1,430		
P124	Tp	801	11-20-59	77			6.2	.7						275						1,350		
P124	Tp	801	12- 3-59	78			13	3.3						275						1,450		
P124	Tp	801	7- 7-60	80			4.0	.5						270						1,450		
P124	Tp	801	8-24-60	80			4.3	.4						270						1,380		
P124	Tp	801	9-16-60	80			4.4	1.4						275						1,430		
P124	Tp	801	10-24-60	79			4.1	.2						280						1,420		
P124	Tp	801	11-29-60	79			3.7	.5						278						1,420		
P125	Tc	179	4-15-60	71	9.5	1.6	17	9.8	90	6.0	188	0	.0	91	.2	1.2	341	83	0	582	7.8	10
P126	Tc	170	5- 6-60	72	12	2.0	17	11	149	9.6	238	0	.0	160	.5	1.0	540	88	0	915	7.2	5

P127	Tc	157	5- 6-60	71			15	9.9						170						902		
P128	Tc	110	5- 6-60				27	11						104						637		
P129	Qt	80	10-13-60	73			29	13						122						650		
P130	Tc	200	4-13-60	72	14	1.5	29	29	290	15	236	0	24	435	.6	2.0	1,040	192	0	1,810	7.3	15
P130	Tc	200	4-15-60	74	14	1.0	26	30	284	14	256	0	18	415	.6	.6	1,020	188	0	1,780	7.5	10
P131 [1]	Tp	812	?- -59		32		2.8		218		177	0	24	226			1,140	7	0		7.6	25
P132	Tg	294	7- 7-60		11	.48	4.7	1.2	222	4.8	576	0	.0	18	.4	.5	620	16	0	1,030	8.0	40
P133	Qt	77	5-10-60	70	16	.22	6.5	1.9	216	16	288	10	.0	190	.8	3.2	683	24	0	1,150	8.5	30
P134	Tp	750	5-13-59	77	12	.19	2.8	.2	281	4.7	336	0	1.0	240	.7	11	798	8	0	1,260	8.2	45
P134	Tp	750	1- 7-60	81			6.6	.4						230						1,250		
P134	Tp	750	2-11-60	80			3.6	.9						230						1,240		
P134	Tp	750	3-21-60				5.1	1.0						230						1,290		
P134	Tp	750	4- 7-60	81			2.9	.7						228						1,240		
P134	Tp	750	5-10-60	81			5.1	1.4						230						1,260		
P134	Tp	750	6-13-60	81			3.6	.8						225						1,260		
P136	Qt	72	6-12-60				15	6.5						190						997		
P138	Tp	750	6-27-39								322	15	1	435	.7			15				
P139	Tc	195	5-12-60	69			8.1	7.5						68						506		
P141	Tc	106	10-10-60	73			25	8.4						29						314		
P142	Tp	654	7-15-60	79	6.4	.07	2.4	.1	272	1.7	338	0	.0	235	.4	1.3	770	6	0	1,190	8.1	35
P143	Tc	190	6-25-60	72			6.7	5.7						77						577		
Q3	Qt	60	1- 4-59	74			4.0	4.2						28						246		
Q15	Tg	250	5-12-60	71	15	2.6	8.6	4.4	130	5.1	312	0	1.8	50	.8	1.5	445	40	0	797	8.2	45
Q18	Tg	250	5-12-60	71	16	2.3	7.1	4.7	130	5.3	312	0	.0	55	.9	.5	423	37	0	639	7.9	25
Q26	Tg	240	5-18-60	73	16	1.2	7.9	3.0	162	5.8	352	0	.0	72	.9	1.6	494	32	0	753	7.9	40
Q30	Tg	255	5-11-60	72	8.4	.11	3.6	1.1	213	5.8	412	0	.0	105	1.1	2.8	614	14	0	942	8.2	60
Q31	Tg	231	5-11-60	70			2.1	2.2						115						965		
Q32	Tg	241	12-11-58	70	4.7	.18	2.7	.6	248	2.2	448	0	1.0	126	1.1	.2	657	9	0	1,040	8.2	70
Q34	Tp	1,253	5-12-59	79	5.6	.40	2.7	.1	401	5.0	744	8	1.4	175	2.7	1.5	1,050	7	0	1,600	8.4	135
Q35	Qt	15	10- 4-59	76			5.1	21						285						1,040		
Q36	Tg	221	8-24-60	72			1.6	1.4						115						962		
Q38	Qt	30	11- 4-59	72			3.8	6.3						39						261		
Q39	Qt	55		73			.6	2.6						28						113		
Q40	Tg	279	5-11-60	71			2.9	1.8						205						1,270		
Q42	Tp	415	5-12-59	70	5.1	.55	1.9	.4	300	3.8	434	22	1.6	192	1.3	.7	825	6	0	1,320	8.6	75
Q44	Tg	292	7- 8-60	73	6.6	1.0	3.4	.7	272	4.8	422	0	.0	190	1.1	.5	766	12	0	1,230	8.1	90
Q45	Tc	143	7-10-60	72	5.6	2.8	5.3	2.6	94	3.5	158	0	.0	70	.0	.7	293	24	0	452	7.6	50
Q46	Qt	21	?- -59	72			3.2	4.8						66						244		
Q48	Tg	264	5-11-60				4.3	4.3						135						1,020		
Q51	Tg	297	5-12-60	72			3.4	2.3						135						1,020		
Q53	Tg	248	5-11-60	71			1.8	1.9						46						537		
Q55	Tp	1,020	5- 6-39								344	12		500		.0	1,250					
Q59	Tg	272	5-12-60	71			5.9	4.1						125						909		
Q60	Tg	310	5-12-60	72			2.9	1.1						62						944		
Q61	Qt	80	?- -59	72			33	7.9						18						261		
Q62	Tg	320	4-15-60	74			2.5	1.4						96						908		

[1] Analysis by Gulf Engineering Co.

TABLE 22.—*Chemical analyses, in parts per million, of water from wells in Jackson County, Miss.*—Continued

Well	Water bearing unit (Pl. 1)	Depth (feet)	Date of collection	Temperature (° F)	Silica (SiO_2)	Total Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color
Q68	Tp	654	12-12-58	--	6.8	0.15	2.7	0.2	324	2.4	360	0	4.6	285	0.9	0.4	863	8	0	1,400	8.0	28
Q76	Tg	273	5-11-60	71	--	--	3.1	4.5	--	--	--	--	--	120	--	--	--	--	--	902	--	--
Q77	Tc	193	?- -59	72	--	--	5.2	4.1	--	--	--	--	--	26	--	--	--	--	--	290	--	--
Q78	Qt	64	11- 4-59	72	--	--	47	18	--	--	--	--	--	23	--	--	--	--	--	411	--	--
Q79	Qt	87	?- -59	73	--	--	42	22	--	--	--	--	--	19	--	--	--	--	--	403	--	--
Q80	Qt	81	?- -59	72	--	--	39	27	--	--	--	--	--	20	--	--	--	--	--	449	--	--
Q81	Tc	120	4-15-60	73	--	--	27	15	--	--	--	--	--	51	--	--	--	--	--	430	--	--
Q87	Tc	218	9- 4-59	--	--	3.5	11	7.1	--	--	--	--	.8	106	--	--	--	--	--	643	--	--
Q87	Tc	218	10- 8-59	74	--	--	9.8	8.9	--	--	--	--	--	110	--	--	--	--	--	640	--	--
Q87	Tc	218	11- 5-59	72	--	--	11	8.9	--	--	--	--	--	112	--	--	--	--	--	640	--	--
Q87	Tc	218	12- 3-59	71	--	--	11	7.9	--	--	--	--	--	109	--	--	--	--	--	655	--	--
Q87	Tc	218	1- 7-60	72	--	--	11	8.5	--	--	--	--	--	110	--	--	--	--	--	658	--	--
Q87	Tc	218	2-11-60	71	--	--	9.7	7.7	--	--	--	--	--	106	--	--	--	--	--	641	--	--
Q87	Tc	218	3-17-60	72	--	--	10	6.2	--	--	--	--	--	106	--	--	--	--	--	629	--	--
Q87	Tc	218	4- 7-60	72	--	--	11	7.6	--	--	--	--	--	108	--	--	--	--	--	651	--	--
Q87	Tc	218	5-11-60	--	--	--	10	7.6	--	--	--	--	--	106	--	--	--	--	--	616	--	--
Q87	Tc	218	6-13-60	--	--	--	8.7	8.0	--	--	--	--	--	105	--	--	--	--	--	638	--	--
Q87	Tc	218	7- 7-60	72	--	--	9.2	7.3	--	--	--	--	--	106	--	--	--	--	--	625	--	--
Q87	Tc	218	8-24-60	72	--	--	9.3	7.6	--	--	--	--	--	109	--	--	--	--	--	652	--	--
Q87	Tc	218	9-16-60	--	--	--	9.4	7.5	--	--	--	--	--	112	--	--	--	--	--	642	--	--
Q87	Tc	218	10-24-60	72	--	--	10	7.2	--	--	--	--	--	110	--	--	--	--	--	628	--	--
Q87	Tc	218	11-29-60	72	--	--	10	7.7	--	--	--	--	--	110	--	--	--	--	--	615	--	--
Q88	Tc	138	?- -59	--	--	--	16	13	--	--	--	--	--	150	--	--	--	--	--	849	--	--
Q89	Tg	294	5-11-60	72	--	--	6.4	3.7	--	--	--	--	--	110	--	--	--	--	--	855	--	--
Q90	Qt	88	7- 7-60	74	--	--	34	29	--	--	--	--	--	12	--	--	--	--	--	461	--	--
Q92	Tg	308	5-12-59	75	6.0	.27	6.7	3.0	185	6.4	318	0	1.6	118	1.1	2.5	532	29	0	867	8.0	25
Q94	Tg	336	5-13-59	74	5.6	.17	2.5	1.0	170	3.9	310	12	.8	82	.8	.4	485	10	0	770	8.6	40
Q95	Tc	156	4-15-60	--	8.4	1.3	12	8.8	173	9.0	232	0	2.6	195	.7	2.8	546	66	0	1,000	7.3	15
Q97	Tc	135	4-15-60	70	8.9	7.6	28	22	160	12	248	0	2.2	230	.6	2.6	644	160	0	1,120	7.0	15
Q98	Tc	180	5-12-60	65	--	--	25	21	--	--	--	--	--	130	--	--	--	--	--	707	--	--
Q100	Tg	350	9-13-58	--	5.3	.24	3.8	.3	228	3.0	348	0	.8	155	1.4	.6	605	10	0	979	8.1	55
Q100	Tg	350	9- 3-59	76	--	.11	4.1	.6	--	--	--	--	.0	155	--	--	--	--	--	1,020	--	--

Q100	Tg	350	12- 3-59	74	----	----	6.6	2.0	----	----	----	----	----	160	----	----	----	----	----	1,070	----	----
Q100	Tg	350	2-11-60	76	----	----	4.6	2.2	----	----	----	----	----	175	----	----	----	----	----	1,080	----	----
Q100	Tg	350	6-13-60	75	----	----	4.8	1.4	----	----	----	----	----	162	----	----	----	----	----	1,030	----	----
Q100	Tg	350	7- 7-60	76	----	----	4.6	1.6	----	----	----	----	----	162	----	----	----	----	----	1,040	----	----
Q100	Tg	350	8-24-60	76	----	----	4.8	1.4	----	----	----	----	----	165	----	----	----	----	----	1,010	----	----
Q101	Tg	374	10- 8-59	76	----	----	5.9	2.4	----	----	----	----	----	165	----	----	----	----	----	1,060	----	----
Q101	Tg	374	1- 7-60	75	----	----	6.5	1.6	----	----	----	----	----	162	----	----	----	----	----	1,050	----	----
Q101	Tg	374	3-17-60	77	----	----	5.4	1.2	----	----	----	----	----	160	----	----	----	----	----	1,030	----	----
Q101	Tg	374	4- 7-60	75	----	----	7.2	2.1	----	----	----	----	----	160	----	----	----	----	----	1,020	----	----
Q101	Tg	374	5- 5-60	----	----	----	6.8	1.2	----	----	----	----	----	158	----	----	----	----	----	1,040	----	----
Q101	Tg	374	9-19-60	75	----	----	5.2	2.0	----	----	----	----	----	165	----	----	----	----	----	1,030	----	----
Q101	Tg	374	10-24-60	75	----	----	3.7	1.5	----	----	----	----	----	165	----	----	----	----	----	1,020	----	----
Q101	Tg	374	11-29-60	74	----	----	4.0	1.2	----	----	----	----	----	170	----	----	----	----	----	1,020	----	----
Q104	Tc	151	11-25-59	71	8.2	3.6	22	12	138	14	200	0	1.4	185	.1	3.1	524	104	0	879	7.9	13
Q104	Tc	151	11-25-59	71	----	----	20	14	----	----	----	----	----	175	----	----	----	----	----	901	----	----
Q104	Tc	151	11-25-59	71	----	----	19	15	----	----	----	----	----	180	----	----	----	----	----	912	----	----
Q105	Tp	840	8- 7-59	77	7.7	----	2.7	.2	305	5.2	364	0	.2	260	1.0	1.6	834	8	0	1,390	7.8	45
Q106	Tc	142	8- 3-59	72	5.9	2.3	22	15	119	14	218	0	.2	152	.2	.5	479	116	0	836	7.1	7
Q106	Tc	207	8- 3-59	77	5.1	3.0	17	11	116	8.4	192	0	.2	138	.2	.4	446	88	0	743	7.0	7
Q106	Tg	350	8- 5-59	77	9.1	.29	4.8	1.6	215	6.5	352	0	.6	145	1.4	1.9	615	18	0	994	7.5	40
Q110	Tg	361	9- 3-59	76	----	.11	2.7	2.1	----	----	----	----	.0	145	----	----	----	----	----	1,010	----	----
Q111	Tg	357	11- 9-58	74	7.8	.26	4.0	1.3	207	3.7	352	0	.4	128	1.2	.5	582	16	0	1,000	8.1	45
Q111	Tg	357	10- 8-59	75	----	----	4.4	5.2	----	----	----	----	----	148	----	----	----	----	----	1,010	----	----
Q111	Tg	357	12- 3-59	75	----	----	4.9	2.2	----	----	----	----	----	150	----	----	----	----	----	1,040	----	----
Q111	Tg	357	1- 7-60	74	----	----	3.1	2.1	----	----	----	----	----	152	----	----	----	----	----	1,040	----	----
Q111	Tg	357	2-11-60	75	----	----	3.6	2.0	----	----	----	----	----	152	----	----	----	----	----	1,040	----	----
Q111	Tg	357	3-23-60	75	----	----	4.2	1.9	----	----	----	----	----	150	----	----	----	----	----	1,040	----	----
Q111	Tg	357	4- 7-60	75	----	----	5.2	2.1	----	----	----	----	----	145	----	----	----	----	----	1,010	----	----
Q111	Tg	357	5- 5-60	74	----	----	3.6	2.8	----	----	----	----	----	150	----	----	----	----	----	1,020	----	----
Q111	Tg	357	6-13-60	74	----	----	5.0	2.4	----	----	----	----	----	150	----	----	----	----	----	1,030	----	----
Q111	Tg	357	7- 7-60	75	----	----	3.5	2.0	----	----	----	----	----	145	----	----	----	----	----	1,020	----	----
Q111	Tg	357	8-24-60	75	----	----	4.2	2.3	----	----	----	----	----	150	----	----	----	----	----	1,010	----	----
Q111	Tg	357	9-19-60	75	----	----	3.9	1.7	----	----	----	----	----	145	----	----	----	----	----	1,010	----	----
Q111	Tg	357	10-24-60	75	----	----	3.2	2.0	----	----	----	----	----	150	----	----	----	----	----	997	----	----
Q111	Tg	357	11-29-60	74	----	----	3.6	1.8	----	----	----	----	----	145	----	----	----	----	----	1,000	----	----
Q112	Tc	202	4-22-60	72	10	4.8	13	9.7	82	10	148	0	.0	99	.2	3.0	346	72	0	571	8.2	25
Q113	Tc	211	4-20-60	73	9.1	3.9	13	9.9	80	9.8	152	0	.8	92	.1	2.9	334	73	0	549	7.6	15
Q114	Tc	218	5- 4-60	72	9.1	7.5	13	9.0	83	9.8	156	0	4.8	92	.2	3.0	370	70	0	554	8.2	15
Q115	Tc	197	5- 6-60	72	9.1	----	13	9.8	75	9.5	156	0	.0	83	.2	3.2	315	73	0	520	7.4	40
Q115	Tc	197	6-21-60	72	9.3	.84	16	12	75	11	162	0	16	87	.1	.5	340	90	0	658	8.0	40
Q116	Tc	194	12- 2-59	71	11	1.6	9.5	3.2	76	7.5	164	0	.6	54	.2	1.5	269	36	0	435	6.8	23
Q118	Tc	206	5- 3-60	72	10	.29	14	5.9	65	4.3	154	0	.4	56	.0	1.5	260	60	0	412	7.3	6
Q119	Tc	157	11-20-59	71	11	2.3	12	6.8	45	4.1	128	0	.0	38	.1	1.0	204	58	0	320	7.9	18

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