HYDROGEOLOGY OF THE MISSISSIPPI RIVER ALLUVIAL AQUIFER IN NORTHWESTERN MISSISSIPPI

J. Kerry Arthur
U.S. Geological Survey, Pearl, Mississippi

INTRODUCTION

The Mississippi River alluvial aquifer is part of the large aquifer system that underlies the Mississippi River alluvial plain in parts of six States in the Mississippi embayment. In northwestern Mississippi, the Mississippi alluvial plain is a lens shaped area that includes all or part of 19 counties covering about 7,000 square miles (fig. 1). Locally this area **is** known as the Delta. The Delta extends from the Mississippi-Tennessee border at Memphis, Tennessee, about 200 miles southward to Vicksburg, Mississippi. At the widest point, about midway between Memphis and Vicksburg. the Delta is about 70 miles wide. The western extent of the Delta is the Mississippi River, and the eastern extent is the loess-capped Bluff Hills. The Delta land surface has very little relief, and slopes gently at about 0.5 foot per mile from about 200 feet above sea level at the northern end near Memphis to about 80 feet above sea level near Vicksburg. The Bluff Hills escarpment provides an abrupt transition in topography from the alluvial plain by rising 100 to 200 feet above the alluvial plain. The Yazoo-Yalobusha-Tallahatchie-Yocona-Coldwater River system drains the eastern part of the Delta and a large upland area to the east of the alluvial plain. The Sunflower-Bogue Phalia River system drains most of the central and western part of the alluvial plain outside of the Mississippi River levee system. All the water drained by the Sunflower-Bogue Phalia River system originates within the Delta and flows into the Yazoo River just north of Vicksburg. The Delta has many oxbow lakes that store large quantities of water, but the largest of these crescent-shaped lakes are old meanders of the Mississippi River. Five of the largest lakes are Horn Lake in De Soto County, Moon Lake in Coahoma County, Lake Bolivar in Bolivar County, Lake Washington in Washington County, and Eagle Lake in Warren County (fig. 1).

The climate in the Delta is humid subtropical. Average annual temperature ranges from 62 degrees Fahrenheit near Memphis to 66 degrees Fahrenheit near Vicksburg (Krinitzsky and Wire 1964). Average annual precipitation in the Delta **is** about 52 inches with very little spatial variation. Most of the precipitation, about 62 percent, occurs in the winter and spring. The fall season has the least precipitation comprising about 17 percent of the annual total.

The alluvial aquifer is the most heavily pumped aquifer in Mississippi and supplies most of the water used for agriculture and industry in the Delta. Only the city of Vicksburg and the Eagle Lake Water Association **use** water from the alluvial aquifer as a drinking water source. Vicksburg's annual water use is **less** than 1 percent of the annual total pumpage from the alluvial aquifer. Most of the pumpage from the alluvial aquifer is for agriculture. The Delta is the economic center for agriculture in Mississippi, producing about all of the rice grown in the State, about 96 percent of the catfish, about 79 percent of the soybeans, and 72 percent of the cotton. Water for catfish and rice production accounts for most of the agricultural ground-water demand in the Delta. More than half of the catfish pond acreage in the Delta is in Humphreys, Sunflower, and Leflore Counties. Farms in Bolivar, Sunflower, and Washington Counties produce more than half of the rice produced in the Delta. Irrigation of cotton, soybeans, and corn during periods of deficient rainfall also contributes to the agricultural demand for water from the alluvial aquifer.

Since fall 1980, personnel from the U.S. Geological Survey (USGS), the Mississippi Department of Environmental Quality, Office of Land and Water Resources (OLWR), and the Yazoo Mississippi Delta Joint Water Management District (YMD) have made water-level measurements at more than 300 observation wells in the alluvial aquifer during the spring and fall of each year except in 1987 and 1988 when only fall measurements were made. The water-level measurements were valuable in helping to conceptualize the regional flow characteristics of the alluvial aquifer.

From 1995 to 2000 the USGS, in cooperation with the OLWR, conducted a study to better understand the hydrogeology of the alluvial aquifer flow system in northwestern Mississippi and to construct a computer model of the flow system. Hydrologic information and field assistance for the study were provided by the OLWR, the YMD, and the Natural Resources Conservation Service. This paper presents a regional overview of the hydrogeology of the alluvial aquifer as determined by data review and by field investigations.

HYDROGEOLOGY OF THE MISSISSIPPI RIVER ALLUVIAL AQUIFER

The Mississippi River alluvial aquifer flow system is a dynamic, rapidly responding flow system. The flow system is probably the most complex of the major aquifers in Mississippi with regard to changes in recharge and natural discharge as a result of fluctuations in hydrologic and climatic conditions. The aquifer is recharged by water from the Mississippi River and rivers within the Delta during periods of high river stages; by natural and man-made lakes, both inside and outside the Mississippi River levee system; by aquifers and sediments abutting the eastern edge of the alluvial plain; by rainfall that does not run off, evaporate, or transpire; and by water in aquifers directly underlying the alluvial aquifer. The aquifer discharges water to the Mississippi River and to streams within the Delta during periods of low river stages; to lakes during the summer and fall when lake levels are low; to aquifers underlying the alluvial aquifer when heads in the alluvial aquifer are greater than heads in the underlying aquifer; and to pumpage for agricultural, industrial, and municipal uses. The components of recharge and discharge vary greatly in time and space depending upon the local depositional environment and climatic and economic conditions not only within the Delta but also outside the Delta area.

The alluvial aquifer consists of sand and gravel deposits of Quaternary age. The alluvial sediments were deposited in an entrenchment into Tertiary-age rocks in the Mississippi River Valley. Pleistocene glaciation caused a lowering of sea level and increased stream gradients, which resulted in incisement of the Mississippi River Valley as water from the melting glaciers rushed toward the Gulf of Mexico. The valley in places was eroded more than 100 feet deeper than the present surface of the alluvial plain (Krinitzsky and Wire 1964). As sea level rose, stream gradients decreased and the entrenched valley was filled with sediment. Since the initial formation of the alluvial plain, the deposition of eroded Coastal Plain deposits and the continued erosion and deposition of materials by the Mississippi River and other streams within the alluvial plain has resulted in a diverse sequence of deposits forming the alluvial plain.

Geology

The Mississippi River alluvium was deposited on an erosional Tertiary-age surface having a system of north-south valleys (Fisk 1944). The thickness of the alluvium in Mississippi averages about 135 feet. Throughout most of the Delta, the thickness ranges from 120 to 160 feet (fig. 2). The coarsest sediments, consisting mostly of gravel and coarse sand, generally occur at or near the base of the alluvium and tend to be thicker where the alluvium is thickest. The finer clay, silt, and sand sediments generally occur in the upper part of the alluvium, but these sediments can occur to varying degrees throughout the entire thickness of the alluvium. The sand and gravel that form the alluvial aquifer average about 110 feet in thickness. The aquifer is generally thickest in the central part of the alluvial plain and thinnest adjacent to the Bluff Hills and in west-central Washington County (Arthur and Strom 1996).

The various combinations of clay, silt, and fine sand that occur near the surface of the alluvial plain make up a low permeability topstratum (Fisk 1944). The topstratum consists of alternating interbedded silty sand and silty clay of natural levees along stream channels and sand bars. The topstratum also consists of clay plugs, which were formed by the deposition of fine-grained relatively impermeable sediments in abandoned river channels and sloughs. The topstratum, which is referred to in this paper as the upper confining unit, overlies the alluvial aquifer throughout most of the Delta. Where present, the upper confining unit ranges from about 10 to about 50 feet thick and averages about 25 feet in thickness.

The geologic units of Tertiary age that underlie the alluvial aquifer are, from oldest to youngest the Zilpha Clay, Sparta Sand, Cook Mountain Formation, Cockfield Formation, Yazoo Clay, and the Forest Hill Formation (fig. 3). These units dip about 15 to 40 feet per mile to the west in the northern part of the Delta and to the southwest in the southern part of the Delta toward the axis of the Mississippi River embayment trough. The axis of the embayment approximately parallels the Mississippi River. A geologic section (Jennings 2001) showing the relation of these units to each other and to the overlying alluvial aquifer are presented in figure 4. The sediments of these units in contact with the alluvial aquifer consist of unconsolidated sand, silt, and clay beds of varying thickness. The Zilpha Clay and Yazoo Clay are low permeability marine clays. The Cook Mountain Formation is mostly clay but has substantial sand thickness in the northern half of the Delta. The Cockfield Formation and the Sparta Sand are mostly sand with clay beds separating individual sand beds. The sand beds within the Cockfield and Sparta form two of the major drinking-water aquifers in the State. In areas where sand beds of the Cockfield Formation or Sparta Sand are in contact with the alluvial aquifer, hydraulic connection will exist between the alluvial aquifer and the deeper aquifer. The Forest Hill Formation underlies the alluvial aquifer in a small area (about 3 square miles) in Warren County at the edge of the Bluff Hills. The Forest Hill Formation consists mostly of sand and clay and is a minor aquifer in Mississippi.

Aquifer Flow Boundaries

The alluvial aquifer in the Delta functions as an independent flow system from the alluvial aquifer west of the Mississippi River in Arkansas and Louisiana. Stresses applied to the alluvial aquifer on the western side of the river have no effect on the alluvial aquifer in the Mississippi Delta. Because of the great depth of the Mississippi River, the river channel vertically penetrates most of the thickness of the alluvium adjacent to the river, and as a result the river serves as a lateral hydraulic boundary. The stage of the Mississippi River can vary as much as 50 feet from extreme flood to severe drought conditions. The wide range of stage in the Mississippi River causes the river to function as a variable-head hydraulic boundary. Because of the large water-level change in the river, the river functions as both a recharge source and discharge area for the alluvial aquifer. When the Mississippi River is at a high stage, water flows from the river into the aquifer; conversely, when the river is at a low stage, water flows from the aquifer to the river. The alluvial aquifer water levels adjacent to the river are buffered within the range of river-stage change. The aquifer is recharged and drained locally by the Mississippi River on a seasonal basis, and as a result, the net long-term contribution to ground water from the river is probably small compared to the recharge to the aquifer from other sources.

The eastern flow boundary of the alluvial aquifer is the lateral contact where the sand and gravel of the alluvial aquifer abut the non-alluvial sediments near the western edge of the loess-capped Bluff Hills. The western edge of the Bluff Hills generally marks the eastern extent of the Mississippi River alluvial plain and approximately the eastern extent of the alluvial aquifer. The floor of the Mississippi River valley is incised into the underlying Tertiary-age deposits along the eastern edge of the Delta (fig. 2). In this area, along the lateral contact between the alluvial aquifer and the Cockfield and Sparta aquifers, the water levels in the Cockfield and Sparta aquifers are higher than the water level in the alluvial aquifer. As a result, the potential exists for water to move laterally into the alluvial aquifer from the water-bearing units underlying the Bluff Hills. This potential for water to move into the alluvial aquifer in this area and the presence of lower specific conductance water in the alluvial aquifer adjacent to this area indicates that the eastern boundary probably is a major recharge source for the alluvial aquifer.

The upper boundary of the alluvial aquifer is the contact between the topstratum and the sediments of the alluvial aquifer. The topstratum consists of interbedded clay, silt, and sand and is present at some thickness over most of the Delta. A detailed description of the topstratum (upper confining unit) is given in Arthur (1994). Where present, the topstratum impedes vertical recharge to the alluvial aquifer from precipitation and from surface-water bodies (rivers, lakes, ponds, and agricultural applications). About 20 inches of the annual precipitation in the Delta is runoff leaving about 32 inches for evaporation, transpiration by vegetation, and replenishment of the ground-water reservoir. Krinitzsky and Wire (1964) estimated that only about 5 percent of the total rainfall (about 2 1/2 inches per year) replenishes the alluvial aquifer. Sumner and Wasson (1990) estimated that from April 1981 to April 1983 about 0.5 inch of precipitation per year recharged the alluvial aquifer. Little is known about the magnitude of recharge from precipitation in the Delta, but it is probably highly variable in space and time. Boswell, Cushman, and Hosman (1968) reported that infiltration of precipitation is probably a major source of recharge to the alluvial aquifer. Water from surface-water bodies such as rivers and lakes recharges the alluvial aquifer when the water level in the surface-water body is greater than the water level in the alluvial aquifer. The amount of recharge is dependent upon the magnitude of the water-level difference, the thickness and hydraulic conductivity of the bed sediments, and the degree of incisement of the surface-water channel into the topstratum. Recharge to the alluvial aquifer at the upper boundary from precipitation and surface-water bodies is probably a major component of the recharge to the aquifer, but the magnitude of the recharge probably can vary over a large range depending upon hydrologic and climatic conditions.

The lower flow boundary of the alluvial aquifer is the contact between the alluvial aquifer and the underlying Tertiary age deposits (predominantly the Sparta Sand and Cockfield Formation) (fig. 3). In these areas, flow between the alluvial aquifer and the two underlying aquifers is probable. The area where flow upward into the alluvial aquifer is most likely is near the eastern edge of the Delta. The area for flow downward from the alluvial aquifer is most likely in the western part of Delta where the Cockfield Formation underlies the alluvial aquifer and heads in the Cockfield aquifer are lower than the heads in the alluvial aquifer. In areas where the Yazoo Clay, Zilpha Clay, and Cook Mountain Formation underlie the alluvial aquifer, the low permeability characteristics of these deposits impede vertical flow. In recent times, net recharge to the alluvial aquifer at the lower boundary is probably small, but recharge could be important locally where the alluvium is in direct contact with the underlying water-bearing sand beds, and where the water level in the alluvial aquifer is lower than the water level in the underlying aquifer. Sumner and Wasson (1990), in their modeling analysis, assumed that flow interaction between the underlying Tertiary aquifers and the alluvial aquifer was negligible and simulated the lower boundary as a no-flow boundary. Before extensive development of the Cockfield and Sparta aquifers, water levels in the two aquifers in the Delta were substantially greater than the water levels in the alluvial aquifer, and recharge from the underlying aquifers was probably greater. Probable evidence of predevelopment upward flow from the Cockfield aquifer is the greater concentration of dissolved solids in the alluvial water in the southwestern part of the Delta.

Aquifer Characteristics

The alluvial aquifer is capable of storing and yielding large quantities of water in most locations in the Delta. The thickness of the sand and gravel in the alluvial aquifer averages about 110 feet. Wells pumping more than 2,000 gallons per minute from the alluvial aquifer are common in the Delta.

Few aquifer tests are available for the alluvial aquifer in northwestern Mississippi to provide information on the aquifer characteristics that indicate the capacity of an aquifer to store and transmit water. Slack and Darden (1991) reported the results of six aquifer tests for the alluvial aquifer in the Mississippi Delta. Three tests were made in Warren County, two in Washington County, and one in Coahoma County. The storage coefficients for the aquifer tests ranged from 0.0003 to 0.016. Krinitzsky and Wire (1964) reported a specific yield of 0.15 in Tallahatchie County. West of the Mississippi River in Arkansas, the specific yield of the alluvial aquifer is reported to range from 0.27 to 0.38 based on laboratory tests of repacked samples (Krinitzsky and Wire 1964). The range of transmissivity from the six tests in Mississippi is from 12,000 to 51,000 feet squared per day, and the range of hydraulic conductivity is from 130 to 400 feet per day. Krinitzsky and Wire (1964) reported a hydraulic conductivity of over

1,100 feet per day for alluvial aquifer material in Arkansas.

Water-Level Measurements, Potentiometric Surfaces, and Direction of Flow

Prior to extensive development of the alluvial aquifer as a source of water for agriculture and industry, water levels in the aquifer were within 10 to 20 feet of land surface over most of the Delta (Brown 1947). Wells near the Mississippi River when the river is at high stage and some wells adjacent to the Bluff Hills were reported to flow indicating the aquifer in these locations was under confined conditions. After development of the aquifer (mainly for agriculture), water levels have declined to as much as 45 feet below land surface in localized areas in the central part of the Delta. Outside the heavy use area in the central part of the Delta, water levels in the aquifer average less than 25 feet below land surface, and some wells adjacent to the Mississippi River levee system flow when the Mississippi River is at high stage.

To supplement the spring and fall water-level measurements made by YMD at more than 300 observation wells, the OLWR began in 1992 making monthly water-level measurements at selected observation wells during the fall and winter seasons along three west-to-east sections across the Delta. Water-level measurements indicate that water levels in the alluvial aquifer fluctuate seasonally with the highest water levels occurring during the early spring and the lowest water levels occurring during early fall. Since 1980, the average water level during the fall in the Delta is about 3.7 feet lower than the preceding average water level in the spring. During the winter, water levels recover and the spring water levels average about 3.5 feet higher than the preceding fall water level, resulting in about an average decline of less than 0.2 foot per year since 1980. The range of the seasonal fluctuation in water levels is between about 1.0 and 5.5 feet depending on the amount and distribution of rainfall and pumpage.

In the summer of 1988, rainfall was below average, and pumpage for agriculture was greater than normal. As a result, the fall 1988 average water level in the alluvial aquifer was the lowest on record (average 24.6 feet below land surface) until fall 1999 when the record average low water level was equaled. Water levels recovered substantially by spring 1989; however, during the spring of 1989 water levels (average 19.9 feet below land surface) were still below the typical spring levels. During the spring and summer of 1989, precipitation was above average and pumpage for agriculture was less than normal. As a result of the wet spring and summer and reduced pumpage during the 1989 growing season, the fall 1989 water levels (average 21.6 feet below land surface) were about equal to fall levels prior to the drought during summer 1988.

Since fall 1980, the regional potentiometric surface of the alluvial aquifer in the Delta was lowest in fall 1988 (fig. 5) and fall 1999 and the highest in spring 1984 (fig. 5). Since fall 1980, the regional potentiometric surface has fluctuated seasonally, but the regional potentiometric surface has declined only about 2 to 3 feet. Locally the potentiometric surface has declined greater than 30 feet in the central part of the Delta near the Sunflower-Leflore County line and as much as 15 feet in central Humphreys County.

Historically, the regional potentiometric surface of the alluvial aquifer has sloped from north to south, from the west, and from the east toward the Sunflower River, which flows from north to south in the central part of the Delta. The shape of the potentiometric surface indicates that the regional flow direction in the aquifer is composed of two components--a north-to-south axial flow reflecting the north-to-south slope of the alluvial plain and a periphery-to-interior lateral flow due to the influence of the high altitude recharge source to the east and the Mississippi River to the west. The shape of the potentiometric surface indicates that the Sunflower and Yazoo Rivers are regional drains for the alluvial aquifer during low river stages. Although the alluvial plain has very little topographic relief, the land-surface slope is reflected in the regional potentiometric surface of the aquifer. East of the Delta, the water levels in the water-bearing units underlying the Bluff Hills are generally equal yo or greater than the altitude of the surface of the Mississippi River alluvial plain. Flow from this area is reflected in an east-to-west slope of the potentiometric surface toward the central part of the Delta. Flow from the western edge of the Delta is influenced by the Mississippi River.

During the 3 to 4 months of the year when the Mississippi River typically is at a stage higher than the potentiometric surface of the alluvial aquifer adjacent to the river, flow direction is eastward from the river. When the river is at low stage, the flow in the aquifer adjacent to the river is westward toward the river. In most areas along the river, an equilibrium water level in the aquifer is established about 3 to 6 miles east of the river. From this area, the potentiometric surface generally slopes to the southeast toward the central part of the Delta.

Natural discharge from the alluvial aquifer provides water to internal streams and lakes in the Delta when the stages of the streams and lakes are below the level of the potentiometric surface of the aquifer; conversely, during the periods when the internal streams have sufficient runoff to produce high stream stages, flow is reversed locally and water flows from the streams into the aquifer. The magnitude of the flow between the aquifer and the internal surface-water bodies is determined by the extent of incisement of the surface-water body channel into the upper confining unit (topstratum), the head difference between the aquifer and the surface water, and the duration of the head difference. Due to the shorter duration of the high stages in the unregulated internal streams and shallower incisement of the channel into the alluvium as compared to the Mississippi River, the internal streams at high stages have less effect on the regional flow pattern in the alluvial aquifer than does the Mississippi River. On a local scale, the internal water bodies are probably major recharge sources in the Delta, especially the surface-water bodies near the large drawdown areas in the central part of the Delta.

Recharge from precipitation probably has little effect on the present regional flow direction. Recharge from precipitation can vary significantly in space and time due to the variations in permeability of the topstratum and rainfall patterns; but on a regional, long-term basis, areal recharge is believed to be relatively uniform if climatic conditions stay similar to current conditions. Water that enters the alluvial aquifer from underlying water-bearing units (Cockfield Formation and Sparta Sand), or water that flows from the alluvial aquifer into these units may locally have some impact on flow direction and shape of the potentiometric surface in areas where the alluvial aquifer has good hydraulic connection with the underlying water-bearing units.

Water Volume

The sand and gravel deposits of the alluvial aquifer have the capacity to store an enormous volume of water. Assuming the aquifer has an average specific yield of 0.32 and ignoring the water stored as the result of compaction of water and the expansion of the aquifer with increasing head, the aquifer in the Delta has the capacity to store an average of about 21,570 acre-feet of water per square mile. Based on twice yearly water-level measurements made since fall 1980, the least volume of water stored in the alluvial aquifer was estimated to have occurred during fall 1999 with an average of about 20,690 acre-feet per square mile. Generally, areas in the Delta with the greatest volume of water are those where the sand and gravel beds are thickest. Most counties in the Delta have the large volumes of alluvial water, but an exception is west-central Washington County where the sand and gravel beds are less than 50 feet thick. Bolivar and Sharkey Counties have the greatest average thickness of sand and gravel in the Delta and, consequently, have the largest volume of water per square mile of surface area. The greatest average total volume of water in the aquifer since fall 1980 was estimated to be about 21,290 acre-feet per square mile during spring 1984. On a regional basis, only a small volume of water has been depleted from the alluvial aquifer. Since fall 1980 the amount of water stored in the aquifer has ranged from about 96 percent to about 99 percent of the aquifer's unconfined capacity even though localized areas in the central part of the Delta have experienced drawdowns greater than 30 feet. If all the water in the alluvial aquifer were placed on the land surface it would create a lake about 32 feet deep over the entire Mississippi Delta. This volume of water would be about 420 times the volume of water in the Ross Barnett Reservoir at Jackson.

The volume of water in the alluvial aquifer fluctuates yearly and seasonally. The volume of water in the aquifer increases from fall to spring and generally decreases from spring to fall. The magnitude of the volume change depends upon the amount of natural recharge and discharge from the aquifer and the magnitude of pumpage. Most of the natural discharge and pumpage from the aquifer occurs during the summer and early fall, whereas most of the recharge occurs from late fall through spring. The volume of water in the alluvial aquifer fluctuates the greatest within about 3 to 6 miles of the Mississippi River because of the typically large seasonal stage changes in the Mississippi River. From 1988 to 1996 the average monthly stage of the Mississippi River at Vicksburg ranged from 46.3 to 91.9 feet above sea level. During periods of low stage of the Mississippi River, water drains locally from the alluvial aquifer into the river; and conversely, when the stage in the river is high, water flows from the river into the aquifer. Based on water-level measurements made during fall and spring from 1980 to 1999, assuming a specific yield of 0.32, and that the aquifer is under unconfined conditions, the estimated average rate of gain of water to the alluvial aquifer in the Delta from fall to spring is about 1,500 million gallons per day (201 million cubic feet per day). The least gain of water from fall to spring since fall 1980 was about 380 million gallons per day (51 million cubic feet per day) from fall 1985 to spring 1986. From November 1985 through April 1986, only 13.22 inches of precipitation was recorded at Stoneville, as compared to the long-term average of 30.40 inches for the same 6-month period. The average rainfall at Stoneville for this period since 1981 is 29.41 inches. The greatest gain of water from fall to spring since 1981 was about 2,200 million gallons per day (294 million cubic feet per day) from fall 1988 to spring 1989. This recovery occurred after the severe drought in summer of 1988. Every year since 1980 the volume of water in the alluvial aquifer has decreased from spring to fall, except during 1989 when 35.96 inches of rainfall was recorded at Stoneville from May through October. The long-term average rainfall for this 6-month period at Stoneville is 21.29 inches. The estimated average loss of water from the alluvial aquifer from spring to fall since 1980 is about 1,800 million gallons per day (241 million cubic feet per day). The greatest loss of water from spring to fall since 1980 from the aquifer was about 3,200 million gallons per day (428 million cubic feet per day) in 1999.

Water Quality

The quality of water in the alluvial aquifer in the Delta is generally well suited for irrigation, but less suited for municipal use and some industrial uses. Most of the industrial use is for cooling water since the supply is plentiful and the water temperature is stable at about the average annual air temperature (62 to 66 degrees Fahrenheit). The water is commonly a hard, calcium bicarbonate type, and usually contains appreciable amounts of manganese, and dissolved iron concentrations are usually greater than 3.0 milligrams per liter making the water less desirable for municipal use. Dissolved solids concentrations in 68 water samples from the aquifer ranged from 153 to 751 milligrams per liter (Dalsin 1978). Along the eastern edge of the alluvial plain adjacent to the Bluff Hills, the quality of alluvial water is probably better suited for municipal use than water from other areas of the Delta.

Specific conductance measurements were made during August 1992 and August 1998 on water samples collected from about 300 irrigation wells pumping from the alluvial aquifer in the Delta. The specific conductance studies were made to determine an estimate of the areal distribution of dissolved solids in the aquifer and to help determine the sources and possible relative magnitudes of recharge to the aquifer. The results of the 1992 and 1998 specific conductance studies indicate that the specific conductance of water in the alluvial aquifer increases from east to west with the largest values (between 1,400 and 1,600 microsiemens per centimeter) occurring in west-central and south-central Washington County (fig. 6). In parts of these areas the alluvial aquifer water may have dissolved solids concentrations greater than the desired level for some crops. The smallest values measured were between 200 and 400 microsiemens per centimeter; these were mostly in areas adjacent to the Bluff Hills along the eastern edge of the Delta. All irrigation wells sampled were outside the Mississippi River levee system, so no information is available for water directly adjacent to the river; therefore, within about 2 miles of the river, most water samples had a specific conductance value between 600 and 800 microsiemens per centimeter. Over most of the Delta the specific conductance of water from the alluvial aquifer ranged between 400 and 800 microsiemens per centimeter.

Water in streams at high stages in the Delta and in streams flowing into the Delta from the Bluff Hills naturally contains low concentrations of dissolved solids (specific conductance less than 200 microsiemens per centimeter). Water in the Mississippi River at high stages typically has a specific conductance of less than 300 microsiemens per centimeter. Most water samples collected from the Sparta and Cockfield aquifers near the edge of the Bluff Hills have specific conductance values of less than 300 microsiemens per centimeter. In the southwestern part of the Delta, the dissolved solids concentrations in the Cockfield and Sparta aquifers are greater, and specific conductance values as much as 3,000 microsiemens per centimeter have been measured in Washington County in water samples from wells screened in the Cockfield aquifer.

The greater specific conductance water in the alluvial aquifer in the west-central part of the Delta may be the result of upward movement of water from the Cockfield aquifer during predevelopment time. Prior to extensive development of the aquifers in the Mississippi embayment, the Mississippi River alluvial plain was a regional, downdip discharge area for the Sparta and Cockfield aquifers. The predevelopment potentiometric surfaces of the Sparta and Cockfield aquifers in the Delta were substantially higher than the potentiometric surface of the alluvial aquifer. In areas where the underlying aquifers were in contact with the alluvial aquifer, water flowed upward from the Sparta and Cockfield aquifers into the alluvial aquifer. As pumpage increased in the Sparta and Cockfield aquifers, the potentiometric surfaces of the two aquifers declined, and the rate of discharge into the alluvial aquifer decreased to the point where the net regional discharge to the alluvial aquifer in the Delta probably is very small. It is also possible that the higher specific conductance water was more extensive in the Delta during predevelopment time than during the 1992 and 1998 study periods. As a result of decreasing recharge to the alluvial aquifer from the underlying aquifers and increasing recharge of lower specific conductance water, the average specific conductance of water in the higher specific conductance areas of the Delta may be decreasing. The two maps shown in figure 6 represent only snapshots in time, but they indicate that the average specific conductance of alluvial water in Washington County may be decreasing. Additional specific conductance studies are needed to verify this interpretation.

The influence of Mississippi River water on the specific conductance of the water in the alluvial aquifer appears to be small, but immediately adjacent to the river, water in the aquifer is probably more reflective of the quality of the water in the river at high stage. The results of the specific conductance studies give support to the assumption that long-term net recharge from the Mississippi River to the alluvial aquifer is probably small (Boswell, Cushman, and Hosman 1968); however, the possibility exists that water from the Mississippi River is influenced by geochemical processes as the water moves through the aquifer, resulting in increased dissolved solids concentrations.

The areal distribution of specific conductance indicates that the water with a low concentration of dissolved solids that flows into the alluvial aquifer along the eastern edge of the alluvial plain has a substantial influence on the quality of water in the aquifer. The areal distribution of specific conductance also indicates that recharge at the eastern edge of the Delta is a major source of water for the alluvial aquifer (fig 6).

Pumpage

Pumpage from the alluvial aquifer for irrigation began on a small scale in the Delta in about 1910 when a few large-capacity wells were installed to provide water for rice production. Interest in rice production soon declined because of an unfavorable market, and from 1912 until 1948 few irrigation wells were drilled in the Delta. In 1950 a favorable rice market returned, and rice acreage increased substantially with most of the acreage located adjacent to streams and lakes to facilitate surface-water usage. The drought during 1951-54 reduced surface-water availability and forced many rice growers to drill wells to save their crops. From 1950 to 1954 the number of large-capacity alluvial wells in the Delta increased from 35 to 480 (Harvey 1956). Few new large-capacity wells were installed in the aquifer until the early 1970's when rice and catfish production increased significantly. More than 12,000 alluvial aquifer wells are permitted in the Mississippi Delta (J. H. Hoffmann, OLWR, oral commun., 1999).

Most of the current pumpage from the alluvial aquifer is for agriculture and is concentrated in the central part of the Delta. Most of the agricultural pumpage is for rice and catfish production. Prior to 1948 less than 5,000 acres of rice were planted annually in the Delta. By 1954 rice acreage had increased to 79,000 acres and pumpage from the alluvial aquifer was estimated by Harvey (1956) to be 334,000 acre-feet (298 million gallons per day). Rice acreage averaged about 55,000 acres until 1973. Since 1973 rice acreage has increased and fluctuated widely with the maximum annual acreage planted being greater than 300,000 acres. Catfish pond acreage has increased from about 18,000 acres in 1977 to more than 100,000 acres in 1998. In 1983 pumpage from the alluvial aquifer was estimated to be 1,100 million gallons per day (Sumner and Wasson 1990). Water application rates for rice and for maintaining water levels in catfish ponds can vary widely depending on rainfall during the rice growing season and water management of the catfish ponds. Sumner and Wasson (1990) reported water application rates between 3.3 and 4.2 feet per year for rice and 5.1 and 7.3 feet per year for catfish production. Currently application rates for rice and catfish production are probably less than the rates reported by Sumner and Wasson because Delta farmers have made a concerted effort to incorporate the most up-to-date farm research and technology to conserve water.

A major need in the Delta is to establish a Delta-wide program to estimate ground-water pumpage at permitted wells completed in the alluvial aquifer. In addition to estimating withdrawals at individual large-capacity wells, an understanding of the actual net removal of water from the aquifer is necessary to determine the true stress on the aquifer system. Prior studies such as the Mississippi Delta Management Systems Evaluation Areas (MSEA) project have quantified irrigation runoff from various farm management practices. Some of the excess irrigation runoff water probably is returned to the alluvial aquifer as the water flows through small channels toward larger surface-water bodies. As a result, the current estimated pumpage at individual irrigation wells is probably an overestimate of the net removal of water from the alluvial aquifer. Heimes et al. (1987) indicated that from 28 to 76 percent of the irrigation pumpage from the High Plains aquifer in three counties in Nebraska was resupplied to that aquifer. Although the soil characteristics in Nebraska are different from the characteristics of Delta soils, the possibility of agricultural pumpage water being resupplied to the alluvial aquifer needs to be considered.

SUMMARY

The Mississippi River alluvial aquifer underlies a 7,000-square-mile area of the Mississippi River alluvial plain in northwestern Mississippi locally known as the Delta. Farming and farm-related businesses are the major sources of income in the Delta. The Delta is a lens-shaped area with little topographic relief that slopes about 0.5 foot per mile from the Mississippi-Tennessee border to near Vicksburg, Mississippi. The climate in the Delta is humid subtropical and precipitation averages about 52 inches annually. The alluvial aquifer is the most heavily pumped aquifer in Mississippi and supplies most of the water used for agriculture and industry in the Delta. In order to better understand the hydrogeology of the alluvial aquifer, the U.S. Geological Survey, in cooperation with the Mississippi Department of Environmental Quality, Office of Land and Water Resources, began a study in 1995 to investigate the alluvial aquifer in the Mississippi Delta.

Results of the study indicated that the alluvial aquifer flow system is dynamic and complex in regard to changes in recharge and natural discharge in response to fluctuations in hydrologic and climatic conditions. The aquifer is recharged by the Mississippi River and by internal rivers and lakes, by precipitation, by underlying aquifers, and by laterally adjacent aquifers underlying the Bluff Hills. The alluvial aquifer discharges water to the Mississippi River and internal rivers and lakes when their stages fall below the water level in the alluvial aquifer.

The alluvial aquifer is of Quaternary age and consists of sand and gravel deposits of the Mississippi River alluvium. The average

thickness of the alluvium in the Delta is 135 feet. The various combinations of clays, silts, and fine sands that occur near the surface of the alluvial plain make up a low permeability topstratum. The topstratum averages about 25 feet in thickness and overlies most of the Delta. The sand and gravel of the alluvium that make up the alluvial aquifer averages about 110 feet in thickness. Tertiary age deposits underlie the alluvial aquifer and dip to the west and southwest toward the axis of the Mississippi embayment. The Cockfield and Sparta aquifers underlie the alluvial aquifer and are two major aquifers in Mississippi.

The Mississippi River and the Bluff Hills are the lateral flow boundaries of the alluvial aquifer. The topstratum and the deposits that separate the alluvial aquifer from the underlying water-bearing units are the top and bottom flow boundaries of the alluvial aquifer. Hydraulic conductivity of the alluvial aquifer ranges from 130 to 400 feet per day, and storage coefficients range from 0.0003 to 0.016. Specific yield ranges from 0.27 to 0.38. Prior to development, water levels in the alluvial aquifer were between 10 and 20 feet below land surface. During fall 1999, the average water level in the aquifer was about 24.6 feet below land surface. During fall 1999, the alluvial aquifer had the least volume of water since fall 1980 with an average of about 20,690 acre-feet per square mile. The water in the alluvial aquifer is generally well suited for irrigation, but less suited for municipal use and some industrial uses. The water is commonly hard, calcium bicarbonate type with appreciable amounts of manganese and dissolved iron.

Pumpage from the alluvial aquifer for irrigation began on a small scale in the Delta about 1910 when a few large-capacity wells were installed to provide water for rice production. From 1950 to 1954 the number of large-capacity alluvial wells in the Delta increased from 35 to 480. More than 12,000 alluvial aquifer wells are permitted in the Mississippi Delta.

SELECTED REFERENCES

Arthur, J.K. 1994. Thickness of the upper and lower confining units of the Mississippi River alluvial aquifer in northwestern Mississippi. U.S. Geological Survey Water- Resources Investigations Report 94-4172, 1 sheet.

Arthur, J.K., and Strom, E.W. 1996. Thickness of the Mississippi River alluvium and thickness of the coarse sand and gravel in the Mississippi River alluvium in northwestern Mississippi. U.S. Geological Survey Water-Resources Investigations Report 96-4305, 1 sheet.

Boswell, E.H., Cushing, E.M., and Hosman, R.L. 1968. Quaternary aquifers in the Mississippi Embayment, *with a discussion of* Quality of the water, by H.G. Jeffery. U.S. Geological Survey Professional Paper 448-E, 15 p.

Brown, G.F. 1947. Geology and artesian water of the alluvial plain in northwestern Mississippi. Mississippi Geological Survey Bulletin 65, 424 p.

Dalsin, G.J. 1978. The Mississippi River valley alluvial aquifer in Mississippi. U.S. Geological Survey Water-Resources Investigations Report 78-106, 1 sheet.

Fenneman, N.M. 1938. Physiography of the eastern United States. McGraw-Hill, 714 p.

Fisk, H.N., 1944, Geological investigation of the alluvial valley of the lower Mississippi River. U.S. Department of Army, Mississippi River Commission, 78 p.

Harvey, E.J. 1956. Records of wells in the alluvium in northwestern Mississippi. U.S. Geological Survey Bulletin 56-1, 130 p.

Heath, R.C. 1983. Basic ground-water hydrology U.S. Geological Survey Water-Supply Paper 2220, 24 p.

Heimes, F.J., Ferrigno, C.F., Gutentag, E.D., Luckey, R.R. Stephens, D.M. 1987. Comparison of irrigation pumpage with change in ground-water storage in the High Plains aquifer in Chase, Dundy, and Perkins Counties, Nebraska, 1975-83. U.S. Geological Survey Water-Resources Investigations Report 87-4044, 34 p.

Jennings, S.P. 2001. Preliminary report on the hydrogeology of the Tertiary aquifers in the Alluivial Plain region of northwestern Mississippi--subcrop geologic map and cross sections. Mississippi Department of

Environmental Quality, Office of Land and Water Resources Open-File Report OLWR 01-1-1, 3 sheets.

Krinitzsky, E.L., and Wire, J.C. 1964. Ground water in the alluvium of the lower Mississippi valley (upper and central areas). U.S. Army Corps of Engineers Waterways Experiment Station, TR3-658, v. 1 and 2, 400 p.

Slack, L.J., and Darden, Daphne. 1991. Summary of aquifer tests in Mississippi, June 1942 through May 1988. U.S. Geological Survey Water-Resources Investigations Report 90-4155, 40 p.

Sumner, D.M., and Wasson, B.E. 1990. Geohydrology and simulated effects of large ground-water withdrawals on the Mississippi River alluvial aquifer in northwestern Mississippi. U.S. Geological Survey Water-Supply Paper 2292, 60 p.

Wasson, B.E. 1980. Sources for water supplies in Mississippi. Mississippi Research and Development Center Bulletin, 112 p.

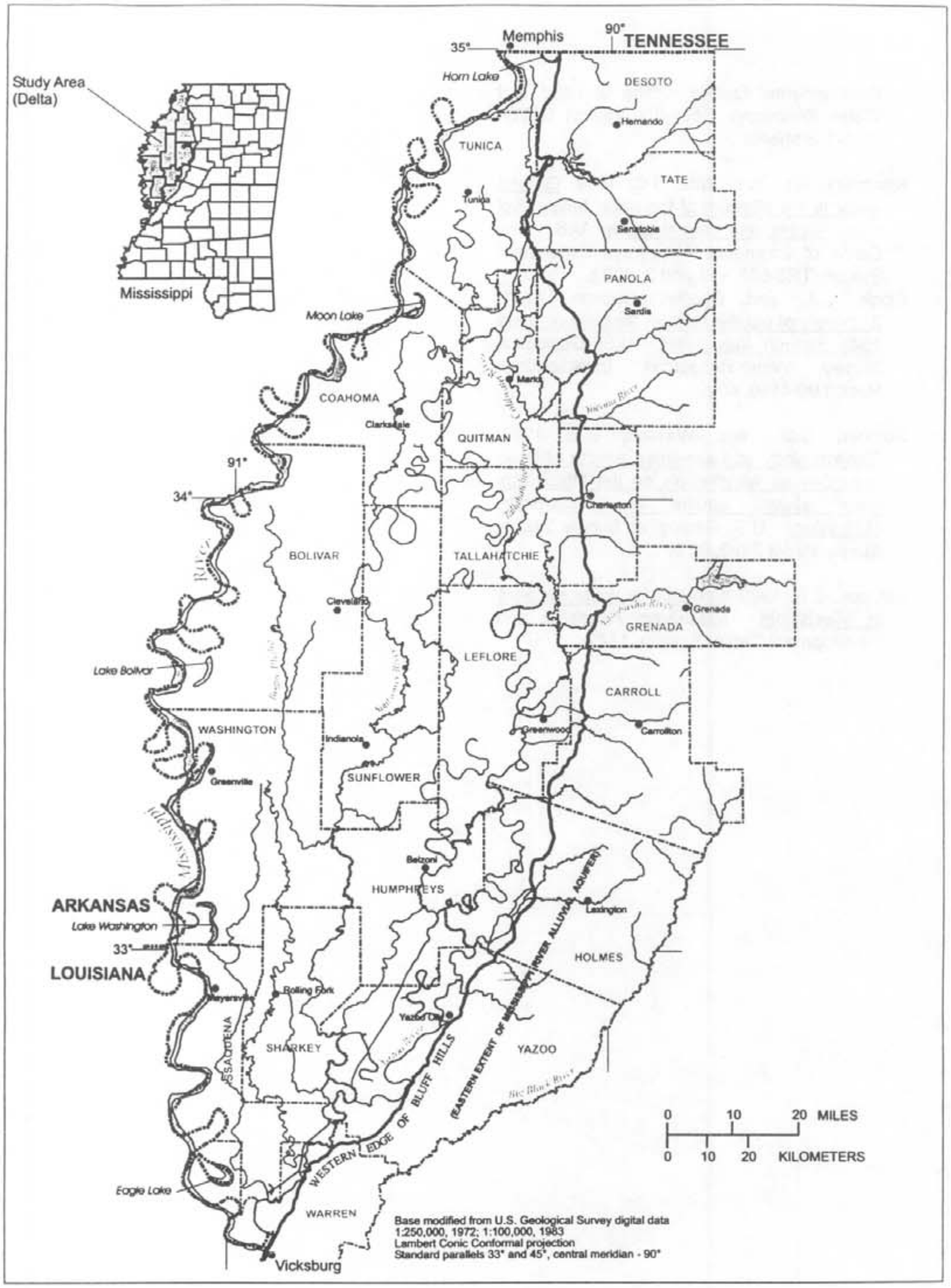


Figure 1. Location of study area, northwestern Mississippi.

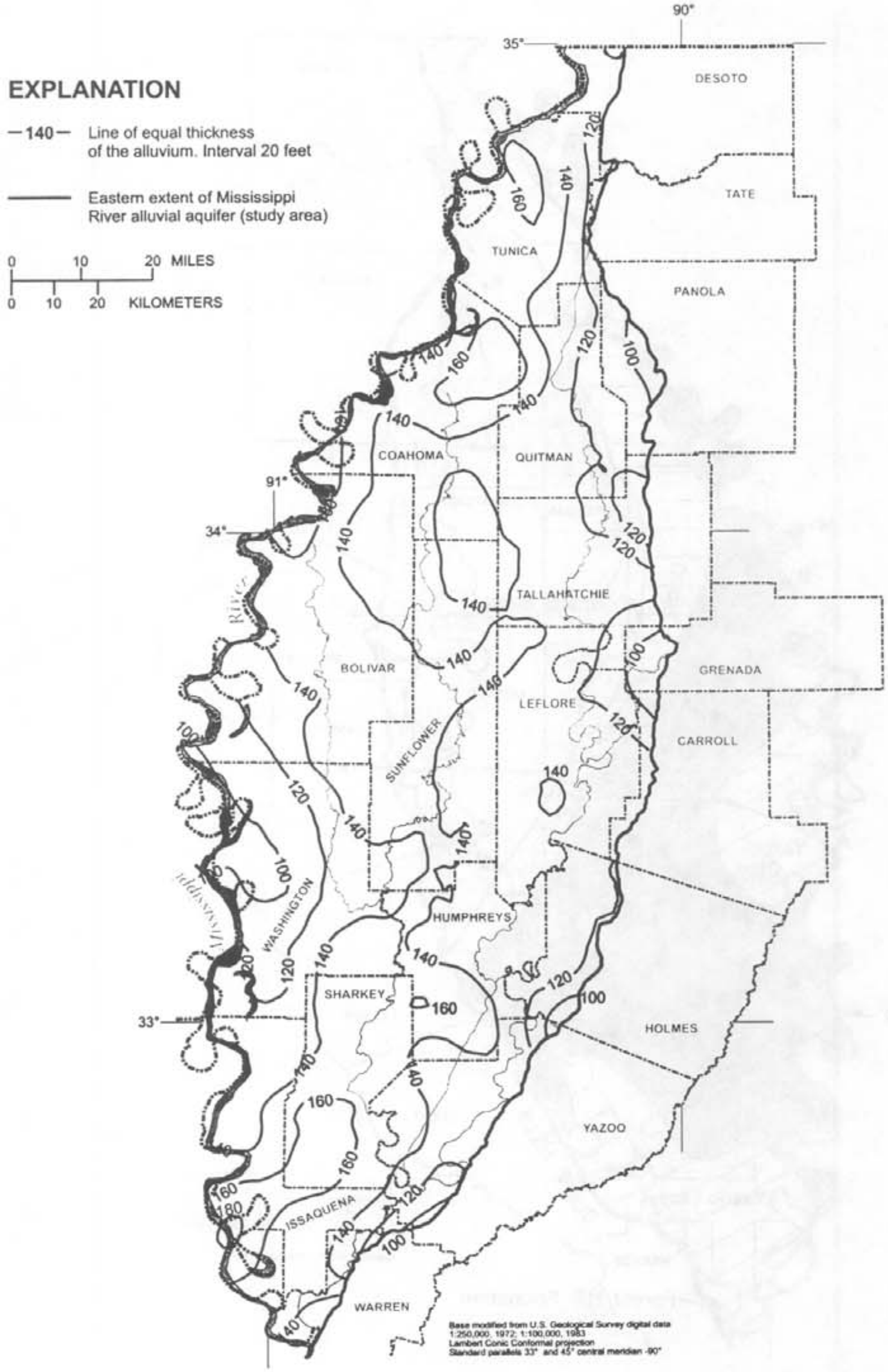


Figure 2. Generalized thickness of the Mississippi River alluvium.

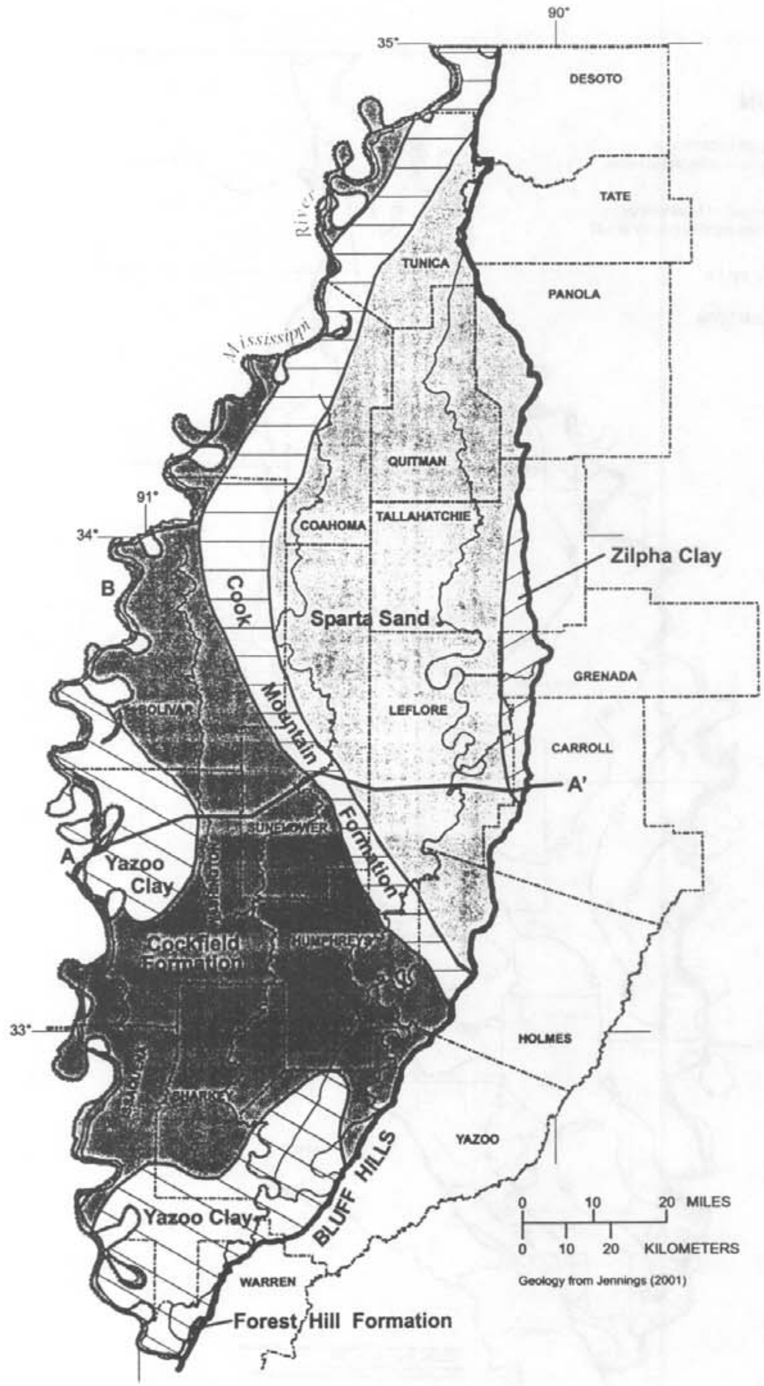


Figure 3. Geologic units underlying the Mississippi River alluvial aquifer.

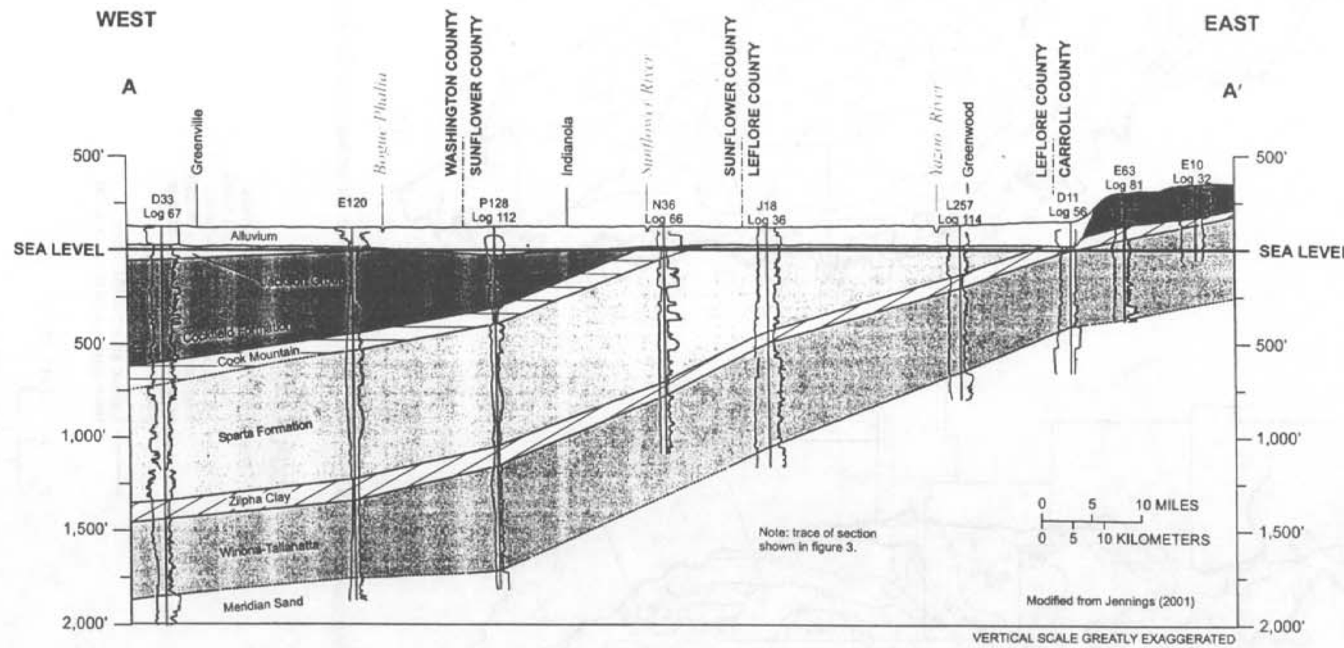
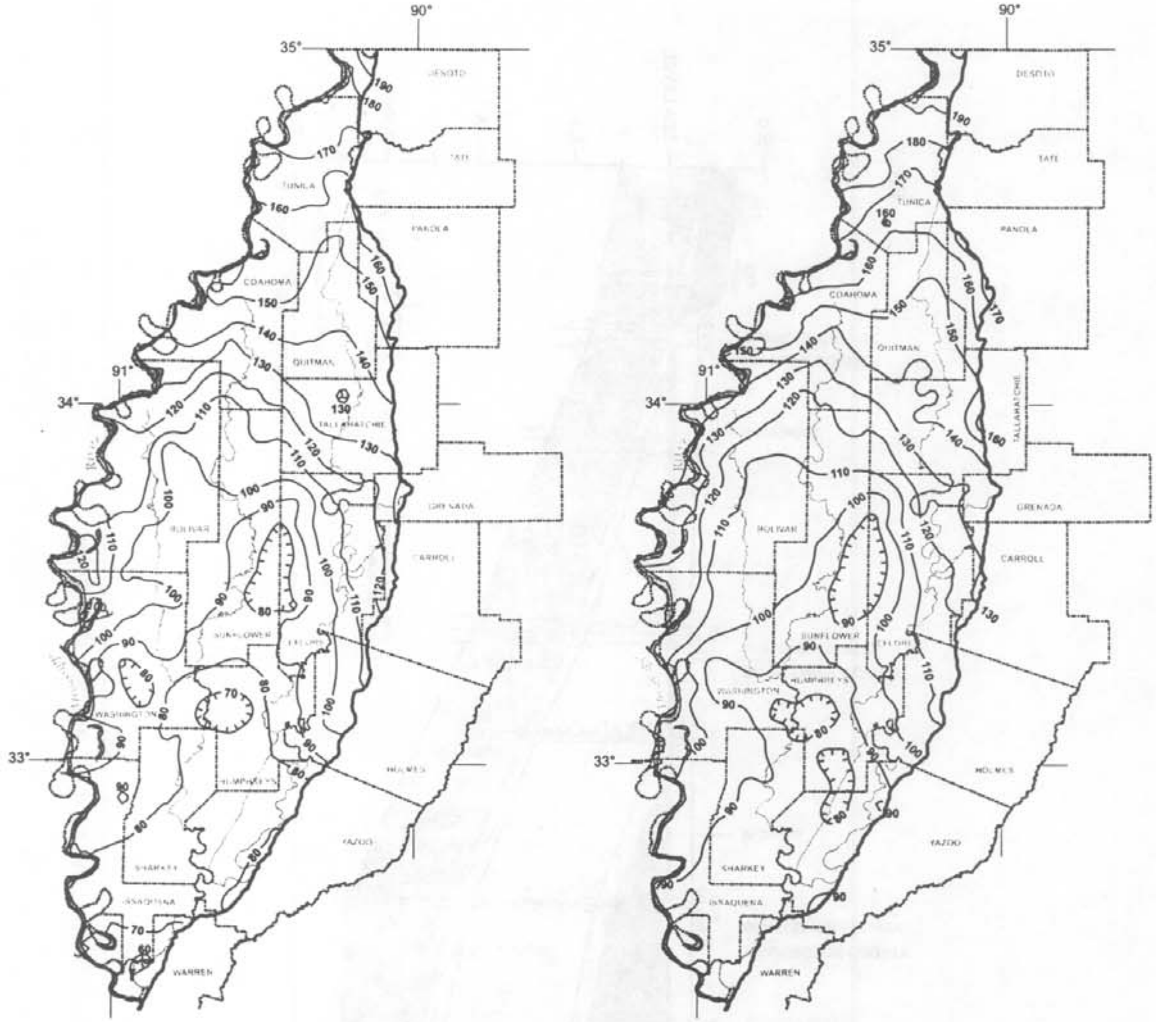


Figure 4. Geologic section A-A' from west to east across the Delta.



a. Lowest Potentiometric Surface (fall 1988)

b. Highest Potentiometric Surface (spring 1984)

EXPLANATION

— 80 ⊤⊤ Potentiometric contour – Shows altitude at which water level would have stood in tightly cased wells. Interval 10 feet. Hachures indicate water-level depression. Datum is sea level

—— Eastern extent of Mississippi River alluvial aquifer (study area)

0 10 20 MILES

0 10 20 KILOMETERS

Figure 5. Lowest (a) and highest (b) potentiometric surfaces of the Mississippi River alluvial aquifer since 1980.

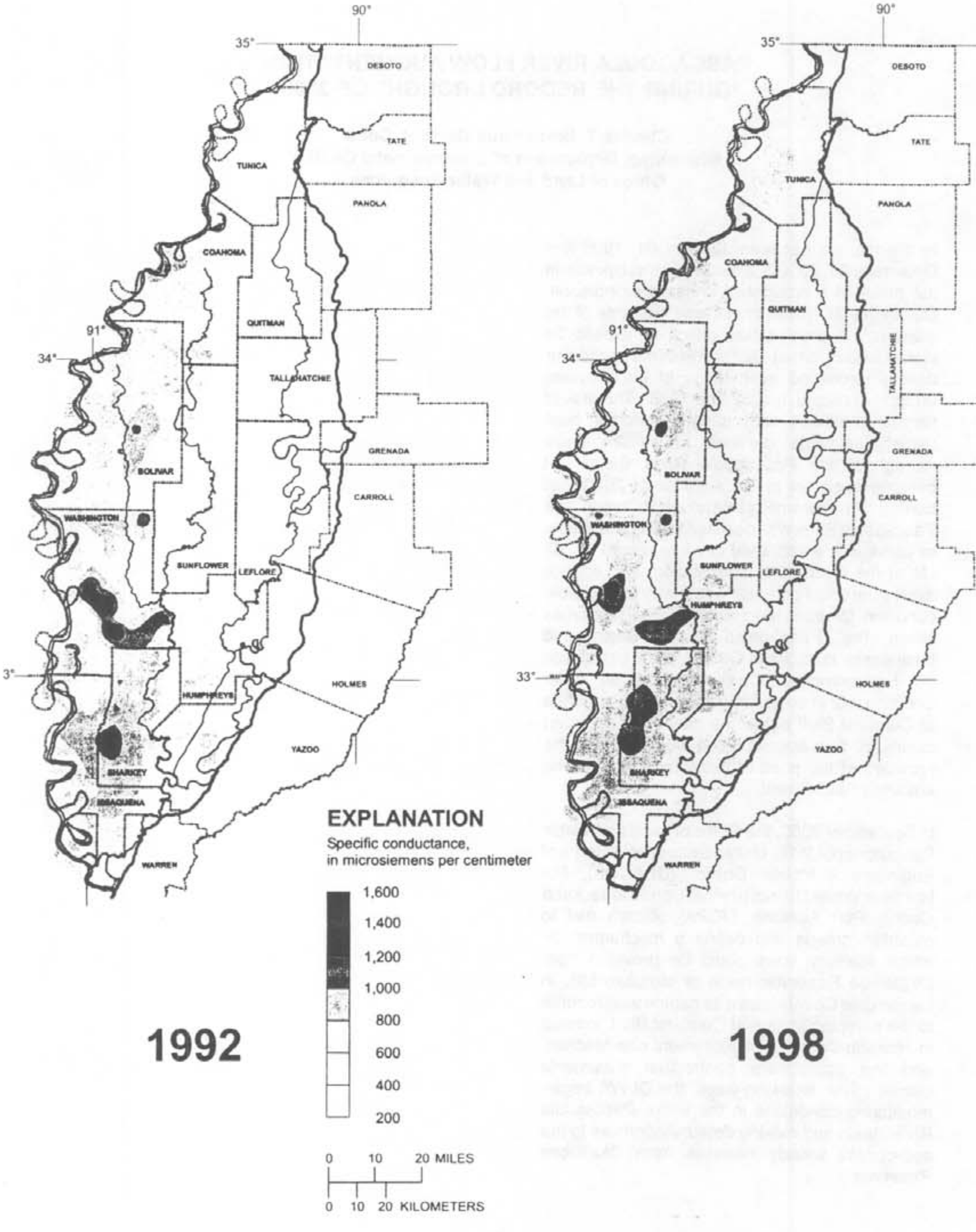


Figure 6. Specific conductance of water in the Mississippi River alluvial aquifer in 1992 and 1998.