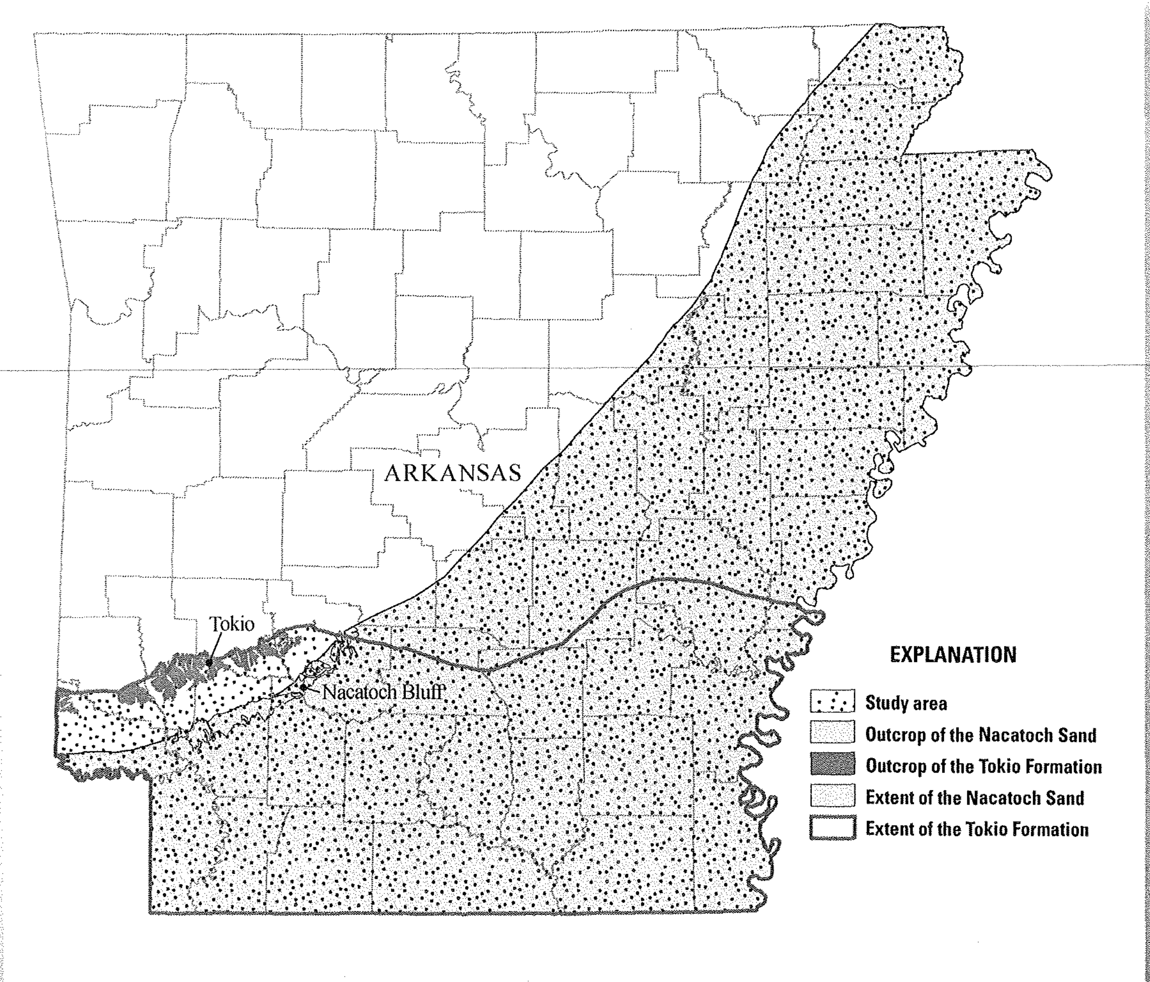
Groundwater Resources Program

Characterization of the Structure, Clean-Sand Percentage, Dissolved-Solids Concentrations, and Estimated Quantity of Groundwater in the Upper Cretaceous Nacatoch Sand and Tokio Formation, Arkansas



Scientific Investigations Report 2014–5068

U.S. Department of the Interior
U.S. Geological Survey

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By Jonathan A. Gillip

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
foot per day (ft/d)	0.3048	meter per day (m/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Characterization of the Structure, Clean-Sand Percentage, Dissolved-Solids Concentrations, and Estimated Quantity of Groundwater in the Upper Cretaceous Nacatoch Sand and Tokio Formation, Arkansas

By Jonathan A. Gillip

Abstract

The West Gulf Coastal Plain, Mississippi embayment, and underlying Cretaceous aquifers are rich in water resources; however, large parts of the aquifers are largely unusable because of large concentrations of dissolved solids. Cretaceous aquifers are known to have large concentrations of salinity in some parts of Arkansas. The Nacatoch Sand and the Tokio Formation of Upper Cretaceous age were chosen for investigation because these aquifers produce groundwater to wells near their outcrops and have large salinity concentrations away from their outcrop areas. Previous investigations have indicated that dissolved-solids concentrations of groundwater within the Nacatoch Sand, 2–20 miles downdip from the outcrop, render the groundwater as unusable for purposes requiring freshwater. Groundwater within the Tokio Formation also exhibits large concentrations of dissolved solids downdip. Water-quality data showing elevated dissolved-solids concentrations are limited for these Cretaceous aquifers because other shallower aquifers are used for water supply. Although not suitable for many uses, large, unused amounts of saline groundwater are present in these aquifers. Historical borehole geophysical logs were used to determine the geologic and hydrogeologic properties of these Cretaceous aquifers, as well as the quality of the groundwater within the aquifers. Based on the interpretation of borehole geophysical logs, in Arkansas, the altitude of the top of the Nacatoch Sand ranges from more than 200 to less than -4,000 feet; the structural high occurs in the outcrop area and the structural low occurs in southeastern Arkansas near the Desha Basin structural feature. The thickness of the Nacatoch Sand ranges from 0 to over 550 feet. The minimum thickness occurs where the formation pinches out in the outcrop area, and the maximum thickness occurs in the southwestern corner of Arkansas. Other areas of large thickness include the area of the Desha Basin structural feature in southeastern Arkansas and in an area on the border of Cross and St. Francis Counties in eastern Arkansas. The clean-sand percentage of the total Nacatoch Sand thickness ranges from less than 20 percent to more than 60 percent and generally decreases downdip. The Nacatoch Sand contains more than 120.5 million acre-feet of water with a dissolved-solids concentration between 1,000 and 10,000 milligrams per liter (mg/L), more than 57.5 million acre-feet of water with a dissolved-solids concentration between 10,000 and 35,000 mg/L, and more than 122.5 million acre-feet of water with a dissolved-solids concentration more than 35,000 mg/L. The altitude of the top of the Tokio Formation, in Arkansas, ranges from more than 200 feet to less than -4,400 feet; the structural high occurs in the outcrop area and the structural low occurs in southeastern Arkansas near the Desha Basin structural feature. The thickness of the Tokio Formation, in Arkansas, ranges from 0 to over 400 feet. The minimum thickness occurs where the formation pinches out in the outcrop area, and the maximum thickness occurs in the southwestern corner of Arkansas. The clean-sand percentage of the total Tokio Formation thickness ranges from less than 20 percent to more than 60 percent and generally decreases away from the outcrop area. The Tokio Formation contains more than 2.5 million acre-feet of water with a dissolved-solids concentration between 1,000 and 10,000 mg/L, more than 12.5 million acre-feet of water with a dissolved-solids concentration between 10,000 and 35,000 mg/L, and nearly 43.5 million acre-feet of water with a dissolved-solids concentration more than 35,000 mg/L.

Introduction

The West Gulf Coastal Plain, Mississippi embayment, and underlying Cretaceous groundwater systems are rich in water resources; however, large areas of aquifers in this system are largely unusable because of elevated total dissolved-solids concentrations. Cretaceous aquifers are known to have large dissolved-solids concentrations away from their outcrop areas. A dissolved-solids concentration more than 1,000 milligrams per liter (mg/L) may require treatment for applications that require freshwater, and a dissolved-solids concentration of 10,000 mg/L is considered to be the upper limit for treatment to produce freshwater (U.S. Environmental Protection Agency, 1984). The total dissolved-solids concentration of the groundwater within the Nacatoch Sand is considered to render the groundwater as unusable 2–20 miles (mi) downdip from the outcrop area, with reported total dissolved-solids concentrations as large as 6,500 mg/L (Boswell and others, 1965). The Tokio Formation is largely undeveloped as a source of groundwater in the outcrop area in southwestern Arkansas; however, the dissolved-solids concentration may be as high as 2,500 mg/L near the outcrop area (Boswell and others, 1965). In these areas of poor water quality, other shallow aquifers are used for water supply, and because of other readily available sources of water, limited water-quality data are available for deeper aquifers that do not yield freshwater. Because of the lack of data, further characterization of the quality and quantity of waters in the Cretaceous Nacatoch Sand and Tokio Formation is needed to evaluate their potential use, particularly as fresh groundwater in those aquifers is depleted, or purposes that do not require freshwater emerge.

The study described in this report was conducted as a pilot study through the U.S. Geological Survey (USGS) Groundwater Resources Program as one of the Challenge Area Studies investigating Saline Groundwater Resources. Results of the study will help the USGS address the goals of the SECURE Water Act, Section 9507 (2009), to describe significant brackish aquifers located throughout the United States.

Purpose and Scope

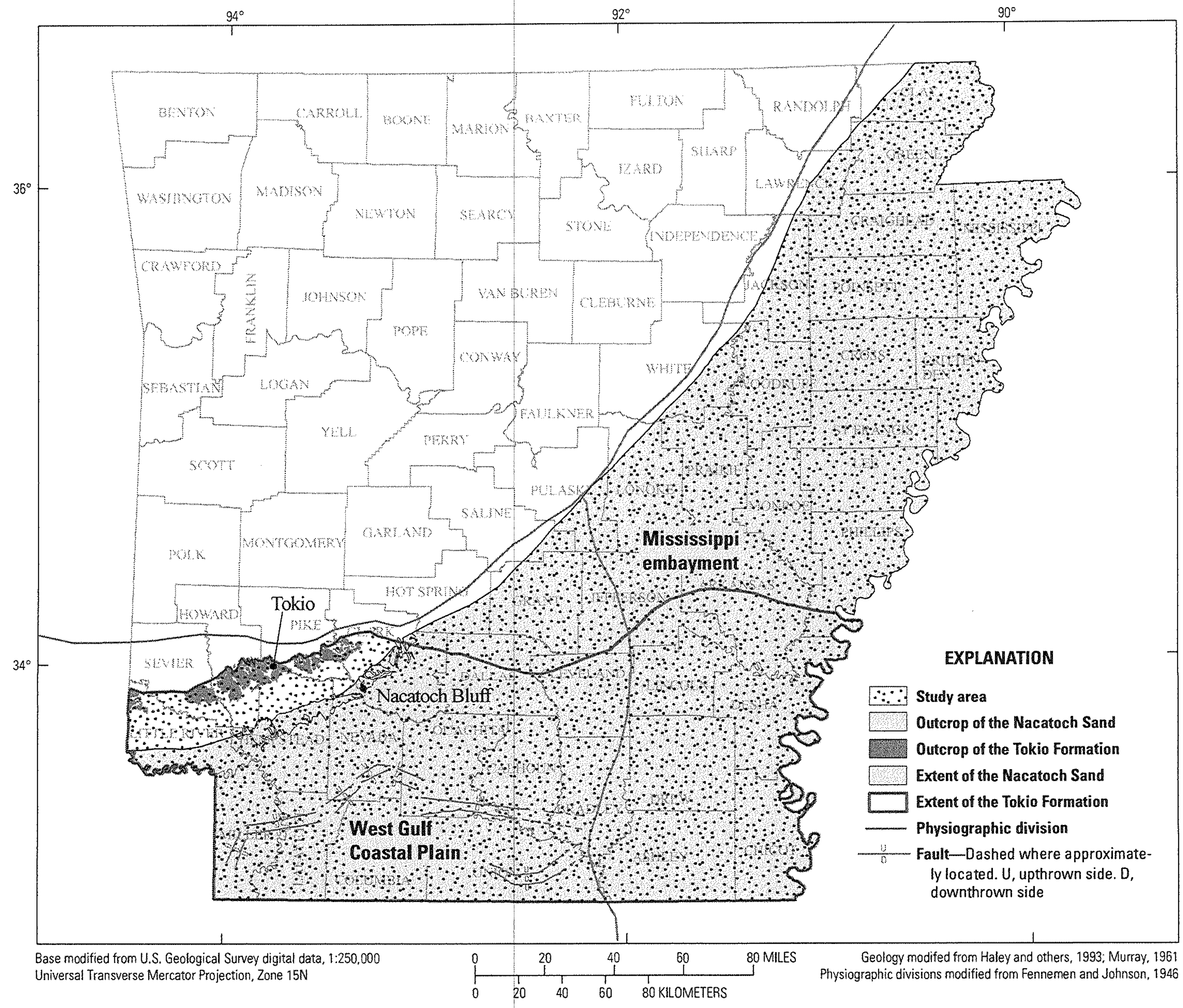
The purpose of this report is to determine the quality and quantity of saline groundwater available in the Cretaceous Nacatoch Sand and Tokio Formation of the West Gulf Coastal Plain and Mississippi embayment in the State of Arkansas (fig. 1). This study summarizes the geologic, geohydrologic, and water-quality data available from the aquifers and documents the geologic structure, thickness, clean-sand percentage of the total formation thickness, and dissolved-solids concentrations as interpreted from borehole geophysical logs. The Nacatoch Sand and Tokio Formation were chosen because they are the principal aquifers of the Upper Cretaceous in Arkansas. The scope of this report is focused within the boundaries of the State of Arkansas, although data in northern Louisiana were considered. Aquifers of similar age located within the Mississippi embayment east of the Mississippi River are not discussed because they are of a different sediment provenance and are disconnected from their counterparts in Arkansas by the axis of the Mississippi embayment. The scope of the investigation is limited to the formations within the Cretaceous system that are currently used for groundwater withdrawal and could potentially provide large amounts of groundwater for withdrawal.

Previous Investigations

Groundwater is an important natural resource throughout the Mississippi embayment. The Cretaceous aquifers in Arkansas have a long history of use, mainly near their outcrop areas. The general geology, hydrology, water quality, water use, and water levels have been the subject of previous investigations, some of which are described in this section. While most of the available information is from near the outcrop area, this information provides valuable information about the aquifer that may apply beyond the outcrop area.

General Geologic Setting

The Mississippi embayment and West Gulf Coastal Plain are underlain by Mesozoic and Cenozoic sedimentary deposits (table 1) (McFarland, 2004). These sedimentary deposits represent the cyclic invasions of transgressing and regressing seas through the Mesozoic and Cenozoic eras that followed the last covering of the continent by shallow seas and extended in an unbroken belt from Central America to New England (Manger, 1983; Arthur and Taylor, 1998). The eastern border of Arkansas is the Mississippi River, which falls roughly along the axis of the Mississippi embayment, a south-plunging, asymmetrical syncline with the dip of the beds being steeper on the west side. The Mississippi embayment is a result of downwarping and rifting related to the Ouachita orogeny, which formed a deep basin for subsequent sedimentation (Hosman, 1996). The Mississippi embayment represents an extension of the Gulf Coastal Plain into the continental interior; as a result, saltwater seas extended much further inland than would have otherwise been possible (Manger, 1983). Downwarping and downfaulting proceeded further as a response to the weight of sediment accumulation (Hosman, 1996). Whereas the oldest sediments exposed at the surface in the Mississippi embayment and Gulf Coastal Plain are Cretaceous in age, Jurassic-aged sediments have been encountered in the subsurface (Manger, 1983; Clark and Hart, 2009; Clark and others, 2011). These strata of Mesozoic and Cenozoic ages rest on a prominent erosional surface developed on the underlying Paleozoic rocks throughout the area (Manger, 1983). The Cretaceous sedimentary deposits exposed in the Gulf Coastal Plain of southwestern Arkansas represent shallow, marginal, and often restricted marine environments (McFarland, 2004). Toward the axis of the Mississippi embayment, these deposits were covered by Cenozoic deposits consisting of Tertiary marginal-marine and continental deposits of Tertiary age with a veneer of terrace and alluvial deposits of Quaternary age. The veneer of Quaternary terrace and alluvial deposits dominate eastern and northeastern Arkansas with minor exposures of Tertiary units (Hosman and others, 1968; Hosman, 1982; Manger, 1983; Hosman, 1996; McFarland, 2004; Clark and others, 2011). The Cenozoic deposits constitute the main water-bearing units of importance within the Mississippi embayment (Clark and others, 2011).



Base modified from U.S. Geological Survey digital data, 1:250,000
Universal Transverse Mercator Projection, Zone 15N

Geology modifed from Haley and others, 1993; Murray, 1961
Physiographic divisions modified from Fennemen and Johnson, 1946

Figure 1. Study area and location of Nacatoch Sand and Tokio Formation.

Table 1. Stratigraphic-column and correlated hydrogeologic units of the Mississippi embayment and Gulf Coastal Plain Regions, Arkansas.

[Modified from Counts, 1957; Hosman and others, 1968; Payne, 1972; Petersen and others, 1985; Hart and Clark, 2008; Hart and others, 2008]

Time-stratigraphic unit			Group	Formation		Regional geohydrologic unit
Era	System	Series				
Cenozoic	Quaternary	Holocene		Alluvium		Mississippi River Valley alluvial aquifer[1] Ouachita-Saline River alluvial aquifer[2] Red River alluvial aquifer[2]
		Pleistocene		Terrace deposits		
	Tertiary	Eocene	Jackson	Jackson Group		Vicksburg-Jackson confining unit[1]
			Claiborne	Cockfield Formation		Upper Claiborne aquifer[1]
				Cook Mountain Formation		Middle Claiborne confining unit
				Sparta Sand	Memphis Sand[3]	Middle Claiborne aquifer[1]
				Cane River Formation		Lower Claiborne[1]
				Carrizo Sand		Lower Claiborne confining unit[1]
			Wilcox	Undifferentiated		Middle - Lower Wilcox aquifers[1]
		Paleocene	Midway	Porters Creek Clay Clayton Formation		Midway confining unit[1]
Mesozoic	Cretaceous	Upper-Cretaceous		Arkadelphia Marl		
				Nacatoch Sand		McNary - Nacatoch aquifer[2]
				Saratoga Chalk Marlbrook Marl Annona Chalk Ozan Formation		
				Brownstone Marl Tokio Formation Woodbine Formation		Tokio-Woodbine aquifer[2]
		Lower-Cretaceous		Kiamichi Shale Goodland Limestone		
			Trinity	Paluxy Sand DeQueen Limestone Holly Creek Formation Dierks Limestone Delight Sand Pike Gravel		Trinity aquifer[2]

[1] Modified from Hart and others, 2008.

[2] Modified from Renken, 1998.

[3] North of 35°N Latitude, the Sparta Sand, Cane River Formation, and Carrizo Sand are undifferentiated and referred to regionally as the Memphis Sand (Counts, 1957; Hosman and others, 1968; Payne, 1972; Petersen and others, 1985; Hart and others, 2008).

Nacatoch Sand

Geology

In Arkansas, the Nacatoch Sand is an Upper Cretaceous-age formation of interbedded lithologies, predominated by generally unconsolidated sands with local lenses and beds of fossiliferous sandy limestone (Counts and others, 1955; Plebuch and Hines, 1969). The Nacatoch Sand is named after its type exposure at Nacatoch Bluff in Clark County, Ark., where about 50 feet (ft) of the upper Nacatoch Formation crop out (fig. 1). Veatch (1906) defined the Nacatoch Sand as the beds lying between the Marlbrook Marl and the Arkadelphia Marl, including the Saratoga Chalk (table 1). Stephenson (1927) and Dane (1929) separated the Saratoga Chalk from the Nacatoch Sand, establishing the essentials of the definition of the formation used today. Weeks (1938) applied the name Nacatoch Formation, but the Lexicon of Geological Names of the United States uses the name Nacatoch Sand (Wilmarth, 1936).

Considerable sea transgressions and regressions occurred after the Lower Cretaceous. While the Lower Cretaceous deposition in Arkansas occurred mainly in near-shore environments, transgression resulted in finer-grained, more carboniferous rocks, particularly marls and chalks, being deposited during the Upper Cretaceous (Veatch, 1906). Sediment provenance was apparently to the east and north, with the sand found in Miller and Lafayette Counties likely being derived from the north (Dollof and others, 1967). The sediments of both formations suggest they were deposited in a shallow near shore marine environment. Dane (1929) noted that the lithologic variability and sedimentary structure such as crossbedding within the Nacatoch Sand represent changing conditions characteristic of a near shore, shallow-water environment with variation in sand content representing switching input from multiple sediment sources.

The Nacatoch Sand includes three distinct lithologic units: a lower unit comprising interbedded clays, marls, and sands with irregular concretionary beds and lenses of calcareous, fossiliferous, and slightly glauconitic sand; a middle unit comprising a fossiliferous, dark-green, glauconitic sand that weathers to a lighter green; and an upper unit that is the principal water-bearing unit, which consists of unconsolidated, crossbedded, gray, fine-grained quartz. The sands in the Nacatoch Sand are generally unconsolidated. In southwestern Arkansas, the Nacatoch Sand unconformably overlies the Saratoga Chalk, Marlbrook Marl, and Ozan Formation (table 1). The Nacatoch Sand is overlain unconformably by the Arkadelphia Marl where the Nacatoch Sand serves as an aquifer in southwest Arkansas. Formation thickness ranges from 150 to nearly 600 ft (Veatch, 1906; Boswell and others, 1965; Zachry and others 1986). The Nacatoch Sand generally has a larger percentage of sand to the west and north, with the exception of an anomalously high sand content in the area of the eastern border of Union County (Dollof and others, 1967).

The Nacatoch Sand outcrops in southwestern Arkansas along a belt 3–8 mi wide that extends from central Clark County southwestward to the west edge of Hempstead County (fig. 1). In Little River County, the Nacatoch Sand is covered by Quaternary alluvial and terrace deposits (Counts and others, 1955). In southwestern Arkansas, the Nacatoch Sand dips south and southeast at a rate of about 30 feet per mile (ft/mi) (Veatch, 1906; Boswell and others, 1965; Ludwig, 1973). Spooner (1935) noted structural control on Nacatoch Sand lithology, with sand being abundant over structurally high areas, grading rapidly to finer sediment on the flanks of structural highs. The Nacatoch Sand is faulted downdip in Miller, Little River, Lafayette, Hempstead, Nevada, Ouachita, Calhoun, and Bradley Counties (fig. 1) (Petersen and others, 1985). The lower sand unit in the Nacatoch Sand is a petroleum producing formation in the Smackover Field (not shown on maps) of southern Arkansas (Weeks, 1938).

The Nacatoch Sand is also present in the subsurface across most of eastern and northeastern Arkansas; a formation thickness up to 380 ft has been documented (Caplan, 1954). In northeastern Arkansas, the formation comprises glauconitic sands interbedded with drab or gray laminated clays. Localized calcareous and fossiliferous layers occur in the formation. In much of northeastern Arkansas, the formation rests unconformably on Paleozoic rocks and is overlain by Quaternary alluvium (table 1). In White, Lonoke, and Pulaski Counties, however, the Nacatoch Sand rests unconformably on Paleozoic rocks and is overlain by Eocene strata, primarily of the Midway Group (table 1). The Nacatoch Sand strikes to the northeast roughly parallel to the trend of the Paleozoic rocks and the Fall Line and dips to the southeast (Stephenson and Crider, 1916; Petersen and others, 1985). Near southwestern Lawrence County, the Nacatoch Sand dips at about 40 ft/mi to the southeast. In this area, sand content increases downdip and makes up 40–60 percent of the formation in extreme southeastern Randolph and eastern Lawrence Counties (Lamonds and others, 1969).

Hydrologic Characteristics

Hydrologic data for the Nacatoch Sand are sparse; however, a limited amount of data is available. An aquifer test from a well in the Nacatoch Sand in Clark County, Ark., yielded a transmissivity value of 161 feet square per day (ft^2/d). The results of a test on a well in Hempstead County showed a transmissivity value of about 480 ft^2/d. Reported yields from wells in southwestern Arkansas were as large as 300 gallons per minute (gal/min) (Boswell and others, 1965; Ludwig, 1973). An aquifer test in Nevada County also resulted in a transmissivity value of about 480 ft^2/d (Ludwig, 1973). Most wells completed in the Nacatoch Sand are relatively small-yield wells. Throughout southwestern Arkansas, Counts and others (1955) reported well yields from 1 to greater than 300 gal/min. Wells in Hempstead and Nevada Counties can be expected to yield from 150 to 300 gal/min (Counts and others, 1955; Ludwig, 1973). Wells yielding from 200 to 500 gal/min could be developed in the Nacatoch Sand in Jackson County (Albin and others, 1967). Artesian conditions exist in southwestern and northeastern Arkansas (Renfroe, 1949; Counts and others, 1955; Ludwig, 1973). Zachry and others (1986) investigated the potential of injecting wastewaters into Cretaceous aquifers but concluded that while vertical movement upward into Tertiary sediments was unlikely, the variability of sand thickness and sand distribution prevented reliable prediction of lateral movement of water within the Nacatoch, Ozan, and Tokio Formations. The presence of artesian wells, along with the geologic character of overlying and underlying formations, indicate that the Nacatoch Sand is under confined conditions except near outcrop areas (Renfroe, 1949; Counts and others, 1955; Ludwig, 1973).

The Nacatoch aquifer is recharged directly from precipitation in the area where it outcrops in southwestern Arkansas and receives recharge through the alluvium and terrace deposits where it subcrops in northeastern Arkansas (Stephenson and Crider, 1916; Boswell and others, 1965; Petersen and others, 1985). In southwestern Arkansas, the regional direction of groundwater flow is to the southeast (Schrader and Blackstock, 2010). In northeastern Arkansas, groundwater flows to the southeast in the direction of the aquifer dip (Stephenson and Crider, 1916; Petersen and others, 1985; Schrader and Blackstock, 2010). The flow directions may be locally controlled by clay content and faulting (Boswell and Hosman, 1964).

Water-Quality Data

Counts and others (1955) proposed that because the Nacatoch Sand was a marine deposit, the original salt content had never been flushed completely from the formation, accounting for the larger salinity values in the downgradient and deeper parts of the aquifer (fig. 2) (Counts and others, 1955; Albin and others, 1967; Plebuch and Hines, 1969; Ludwig, 1973; Terry and others, 1986). Increases in total dissolved solids above 500 mg/L are attributed to larger concentrations of sodium and chloride, allowing dissolved solids to be used as a proxy for salinity (Boswell and others, 1965).

Chloride concentrations generally increase downgradient from the outcrop area in Hempstead and Nevada Counties; however, the salinity gradient is not as large, and concentrations are much smaller, than for sites in the western and eastern parts of the outcrop area (fig. 1). In contrast to western and eastern parts of the outcrop area, groundwater from wells in Hempstead and Nevada Counties have chloride concentrations that are below the secondary drinking water standard of 250 mg/L (U.S. Environmental Protection Agency, 1984) as far as 13 mi from the outcrop area. As such, good-quality, low-salinity groundwater can be extracted in a much broader area in these counties. Chloride concentrations sharply increased in a southeasterly direction for three wells in Miller County from 355 mg/L, 565 mg/L, and finally to 1,670 mg/L, all within a distance of 0.7 mi. In the eastern part of the outcrop area (Clark County), one well with a chloride concentration of 7,560 mg/L was less than 0.8 mi from the outcrop area and less than 1.5 mi from a well containing only 10 mg/L chloride (Plebuchand Hines, 1969). This indicates that the water quality of the formation does not change uniformly and may be affected by other factors (Counts and others, 1955; Albin and others, 1967; Plebuch and Hines, 1969; Ludwig, 1973; Terry and others, 1986, Timothy M. Kresse, U.S. Geological Survey, written commun., 2014).

Tokio Formation

Geology

The Tokio Formation of Upper Cretaceous age is a clastic formation primarily comprising sand and gravel units with interbedded clay and marl and ranging in thickness from 50 to greater than 400 ft (Weeks, 1938; Boswell and others, 1965; Ludwig, 1973). The formation is named for the type locality near Tokio in Hempstead County. The Tokio Formation initially was included with strata named as the Bingen Sand by Hill (1888). Stephenson (1927) divided the Bingen Sand into the Tokio Formation and the Woodbine Formation, discarding the term Bingen Sand.

The Tokio Formation unconformably overlies consolidated rocks of Mississippian and Pennsylvanian age in Clark and northeastern Nevada Counties (Plebuch and Hines, 1969); overlies the Trinity Group in Pike, Nevada, Miller, and most of Hempstead Counties (Petersen and others, 1985); and overlies the Woodbine Formation in Little River, Sevier, Howard, and northwestern Hempstead Counties (table 1) (Boswell and others, 1965). The Tokio Formation is overlain by the Brownstown Marl, although in an area of Union County, the Brownstone Marl is absent and the Tokio is overlain by the Ozan Formation (table 1) (Boswell and others, 1965; Zachry and others, 1986). The formation outcrops from Clark County southwestward to Sevier County and attains a maximum width of about 10 mi in Howard County (fig. 1) (Schrader and Blackstock, 2010). The Tokio Formation consists of discontinuous, interbedded gray clay and poorly sorted crossbedded sands, lignite, scattered carbonaceous materials, and in some areas, a prominent basal gravel. While the formation is generally unconsolidated, the basal gravel may locally be cemented by iron oxides and some beds of calcareous or ferruginous sandstone occur (Counts and others, 1955; Boswell and others, 1965; Dollof and others, 1967; Plebuch and Hines, 1969; Petersen and others, 1985).

In southern Sevier County and parts of Howard and Hempstead Counties, the Tokio Formation comprises three distinct aquifers, including a basal sand that grades to gravel to the east and two upper sands, which are separated by clay layers (Boswell and others, 1965). Toward the east, the clay layers separating the sands thin, and the sands merge into a massive sand, which is prevalent over most of Hempstead, southern Pike, and northern Nevada Counties. The formation dips at about 60 ft/mi to the southeast away from the outcrop area and ranges in thickness from 50 to more than 300 ft (Boswell and others, 1965), obtaining its maximum thickness in Miller County (Dollof and others, 1967). A fault

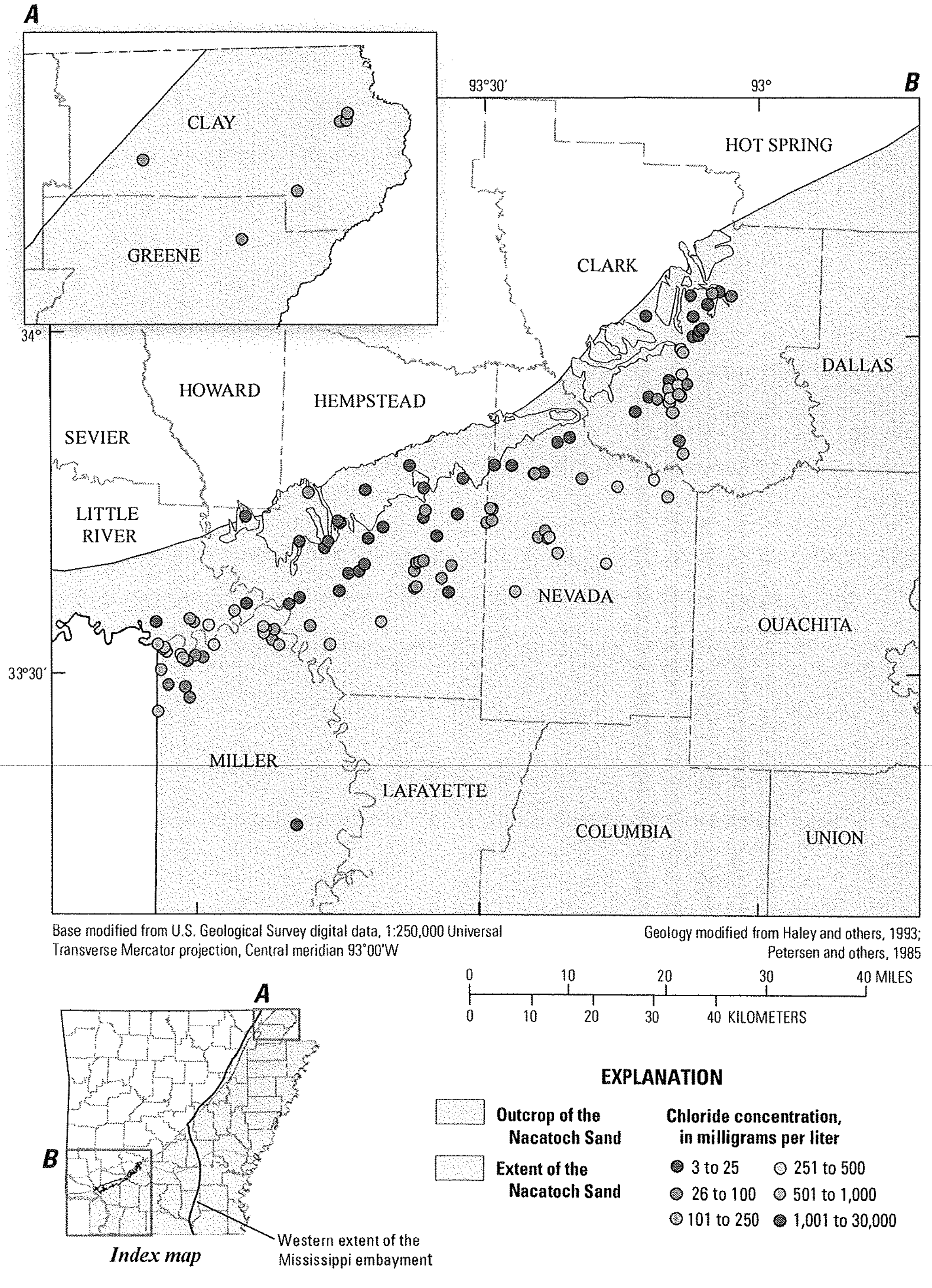


Figure 2. Spatial distribution of chloride for groundwater samples from wells completed in the Nacatoch Sand in Arkansas.

zone through the Tokio Formation occurs across Miller, Little River, Lafayette, Hempstead, Nevada, Ouachita, Calhoun, and Bradley Counties (fig. 1) (Petersen and others, 1985). Dane (1929) identified the Tokio Formation as a near shore marine deposit, as evidenced by sedimentary structures, fossils, and the presence of lignite. The basal gravel is interpreted as a beach deposit formed by a transgressing sea, with the gravel mainly being reworked from older Cretaceous formations (Dane, 1929).

Hydrologic Characteristics

Hydrologic data for the Tokio Formation are sparse; however, a limited amount of data is available from the outcrop area and nearby. Most wells constructed in the Tokio Formation are small-yield wells. A few wells completed in the Tokio Formation can produce from 150 to 300 gal/min. An aquifer test in southern Howard County resulted in a transmissivity of about 170 ft^2/d and a storage coefficient of 4.4×10^{-5} (Pugh, 2008). Results of a test using a municipal well in Hempstead County resulted in a transmissivity of about 600 ft^2/d (Boswell and others, 1965). Wells in central Hempstead County yield up to 300 gal/min (Counts and others, 1955). Wells in northwestern Little River County penetrated a 15- to 20-ft thick freshwater-bearing sand that produced yields of less than 10 gal/min (Ludwig, 1973). The Tokio Formation is the most important source of water from artesian wells in southwestern Arkansas, with artesian wells typically producing less than 20 gal/min under natural flowing conditions (Boswell and others, 1965). Artesian wells flowing as much as 90 gal/min occur in the bottom-land areas adjacent to streams (Counts and others, 1955). Schrader and Rodgers (2013) note artesian flow in the outcrop area in southeastern Pike, northeastern Hempstead, and northwestern Nevada Counties. The presence of artesian wells, along with the geologic character of overlying and underlying formations, indicates that the Tokio Formation is under confined conditions except near the outcrop area (Counts and others, 1955; Boswell and others, 1965; Ludwig, 1973).

The Tokio Formation receives direct recharge at its outcrop area and from the overlying alluvial deposits where it subcrops (Boswell and others, 1965). Potentiometric-surface maps show that the potentiometric-surface high for the Tokio Formation is within the outcrop area in northeastern Howard County (fig. 1), with groundwater flowing to the south and southeast from the outcrop area (Counts and others, 1955; Boswell and others, 1965; Plebuch and Hines, 1969; Petersen and others; 1985; Schrader, 1998, 1999,2007; Schrader and Scheiderer, 2004; Schrader and Blackstock, 2010; Schrader and Rodgers, 2013).

Water-Quality Data

Salinity content generally increases to the southeast in the downdip direction of groundwater flow (Counts and others, 1955; Plebuch and Hines, 1969; Ludwig, 1973), and chloride exhibits a positive, linear relation with specific conductance values greater than 1,000 microsiemens per centimeter at 25 degrees Celsius (μS/cm) (equating to dissolved-solids concentration of approximately 635 mg/L), indicating that chloride is dominant in the higher salinity groundwater (Boswell and others, 1965; Timothy M. Kresse, U.S. Geological Survey, written commun., 2014).

Chloride concentrations of groundwater from wells completed in the Tokio Formation ranged from 2.3 to 1,200 mg/L, with a median concentration of 11 mg/L (fig. 3), which could be derived naturally from evapotranspiration of infiltrating precipitation (Kresse and Fazio, 2002). The rate of increase in chloride concentrations is variable, with chloride concentrations exceeding 500 mg/L within 1 to 5 mi of the outcrop area in the western and eastern parts of the aquifer, and concentrations less than approximately 300 mg/L up to 20 mi from the outcrop area in the central part of the aquifer (fig. 3).

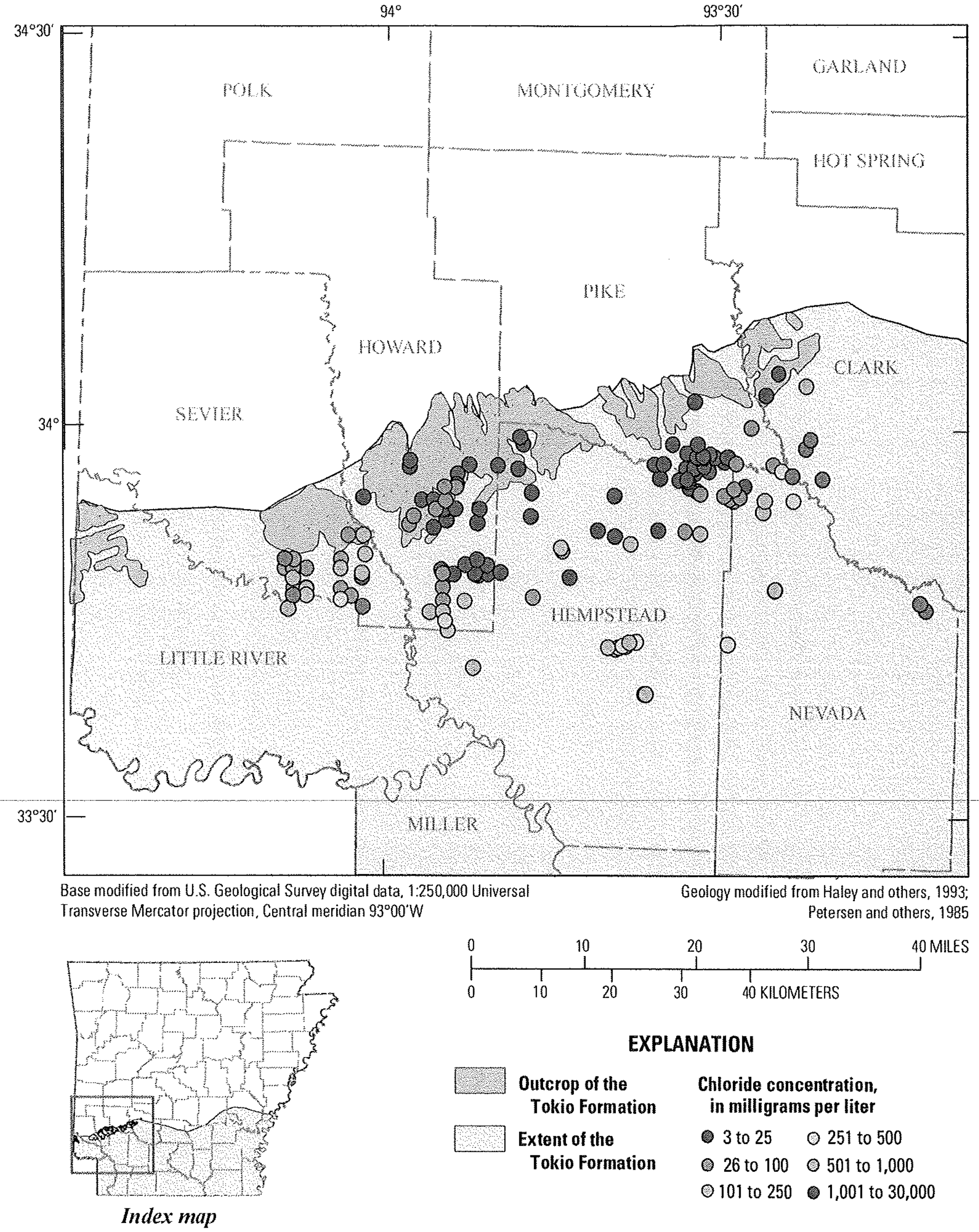
Methods

Lithologic Interpretation of Borehole Geophysical Logs

Lithologic interpretations of borehole geophysical logs presented in previous investigations (Boswell and others, 1965; Hosman and others, 1968; Hosman, 1982; Petersen and others, 1985) were honored or considered when making additional picks on logs not included in previous investigations. Because of the lithologic differences between the Nacatoch Sand and the Tokio Formation with overlying and underlying formations, contacts were interpreted from a variety of borehole geophysical logs including gamma, spontaneous potential (SP), and resistivity. An existing borehole geophysical log database of more than 2,600 wells in the Mississippi embayment (Hart and Clark, 2008) was queried to locate usable geophysical logs penetrating the Nacatoch Sand and Tokio Formation in Arkansas.

Clean-Sand Percentage Determined from Borehole Geophysical Logs

Detailed lithologic data of the Nacatoch Sand and the Tokio Formation are sparse, making the evaluation of the formations as aquifers difficult. In an effort to characterize variations in the lithology of the formations within the study area, a qualitative assessment was made from geophysical logs. Clean-sand percentage, as used in this report, refers to the percentage of the formations' total thickness that comprises clean sand with few silts and clays. The clean-sand thicknesses, as determined from geophysical logs, are used with the formation thicknesses to estimate what percentage of the total formation thickness comprises relatively clean sand and would



Base modified from U.S. Geological Survey digital data, 1:250,000 Universal Transverse Mercator projection, Central meridian 93°00′W

Geology modified from Haley and others, 1993; Petersen and others, 1985

Figure 3. Spatial distribution of chloride for groundwater samples from wells completed in the Tokio Formation in Arkansas.

likely be able to produce groundwater to a well completed in that part of the formation. Intervals with a large percentage of silt or clay combined with sand are less permeable than a clean sand and therefore would not produce as much water. Previous investigations (Clark and Hart, 2009; Clark and others, 2011) used the SP curve on borehole geophysical logs to estimate the percentage of a formation's thickness that is composed of clean sand for younger formations within the Mississippi embayment. The SP curve is a recording by depth of the difference between the electrical potential of a moveable electrode in the borehole and the electrical potential of a fixed surface electrode. The SP curve is more or less a straight line when measuring through shale to establish a shale baseline. In permeable formations, the SP curve deviates to the right or left of the shale baseline, with the direction of deviation determined by the chemical properties of the formation water and borehole fluid. The shale baseline and deviations are useful for basic lithologic interpretations and correlations between boreholes (Society of Petrophysicists and Well Log Analysts, 1975; Keys, 1988; Schlumberger, 1989). SP is measured in millivolts, but the numeric value of the SP curve cannot be used for lithologic determinations as it is affected by factors such as the lithologic properties of the geologic materials, water quality of the formation, and depth; however, where the SP curve deviates from the shale line, other borehole geophysical log parameters can be used to further characterize the geologic materials penetrated by the well. Increases in resistivity and separations of shallow and deep resistivity curves where the SP curve deviates from the shale baseline are indicative of intervals with larger values of porosity and permeability. The gamma radiation curve (gamma log) can be used to identify shale and clayey materials because they have a larger value of gamma radiation than sandy materials. By combining basic knowledge of the lithology of the formations being examined with information from the borehole geophysical log, it is possible to identify intervals that are likely composed of clean sand and are therefore more likely to be an effective aquifer (Society of Petrophysicists and Well Log Analysts, 1975; Keys, 1988; Schlumberger, 1989).

Determination of Dissolved-Solids Concentrations from Geophysical Logs

The dissolved-solids concentration is a measurement of the organic and inorganic substances dissolved within the liquid and is a good indicator of the overall quality of groundwater. Combined with existing water-quality data, dissolved solids can be used to estimate other characteristics, such as salinity, of the groundwater. The dissolved-solids limit for water use varies based on the constituents in the water, but several important thresholds have been established. A dissolved-solids concentration of 1,000 mg/L has been used to define the upper boundary for freshwater (Robinove and others, 1958; Winslow and others, 1968; Freeze and Cherry, 1979; U.S. Environmental Protection Agency, 1984; Reese, 1994; RosTek, 2003; Water-Quality Association, 2011). The transition from a dissolved-solids concentration less than 10,000 mg/L to more than 10,000 mg/L is particularly important for many reasons. The dissolved-solids concentration of 10,000 mg/L as the upper boundary for brackish water has been used in previous studies (Robinove and others, 1958; Winslow and others, 1968; Freeze and Cherry, 1979; Yobbi, 1996). The concentration of 10,000 mg/L defines the boundary where a simulation of groundwater flow must include differences in fluid density (Schnoebelen and others, 1995) and is the limit set by the U.S. Environmental Protection Agency (EPA) as the maximum dissolved-solids concentration for potentially potable water (U.S. Environmental Protection Agency, 1984). Another important dissolved-solids concentration threshold is 35,000 mg/L, the approximate average dissolved-solids concentration of seawater (Robinove and others, 1958; Winslow and others, 1968; Freeze and Cherry, 1979; Reese, 1994; Yobbi, 1996; RosTek, 2003; Water-Quality Association, 2011).

The petroleum industry has developed many methods to calculate the resistivity of formation water (R_w) from borehole geophysical logs, typically measured in ohm-meters (ohm-m). The R_w is influenced by the formation temperature, the concentration of dissolved ions, and the chemical composition of ions in the water. An estimate of dissolved solids is then made from the R_w value. Previous water-quality analyses from the Nacatoch Sand and Tokio Formation in Arkansas (Boswell and others, 1965; Timothy M. Kresse, U.S. Geological Survey, written commun., 2014) indicate that sodium and chloride are the dominate ions in water samples with elevated dissolved solids. The few available water-quality samples from the Nacatoch Sand and Tokio Formation in areas where the largest dissolved-solids concentrations were observed also show that the dominate ions present in the groundwater are sodium and chloride (U.S. Geological Survey, 2013); therefore, the calculated dissolved-solids values are an effective proxy for sodium chloride concentration.

Of the many methods available for interpretation, the energy industry standard "quick-look" method (also described as the ratio method) was used to calculate the resistivity of the formation water (Jorgensen, 1996). This method was selected because of the logs available for use in the study. The existing database of borehole geophysical wells contains many old electric logs that lack the information necessary for other methods of calculation. The ratio method calculates the R_w using the following equation (Jorgensen, 1996):

$$R_w = R_{mf}(R_o / R_{xo})$$

where

R_{mf} is the resistivity of the mud filtrate, in ohm-meters,
R_o is the observed resistivity, in ohm-meters, and
R_{xo} is the resistivity of the zone invaded by the mud filtrate, in ohm-meters.

The value of R_o is obtained from the long normal resistivity curve, where the spacing of the electrodes on the logging tool results in a resistivity reading from deeper in the formation, and the R_{xo} is taken from the short normal resistivity curve, where the spacing of the electrodes on the logging tool results in a resistivity measurement near the borehole in the zone where the mud filtrate has penetrated the formation. The R_{mf} is generally reported in the borehole geophysical log header; where it is not, then the R_{mf} can be calculated from the resistivity of the drilling mud (R_m), available in the borehole geophysical log header, using the following equation (Jorgensen, 1990):

$$R_{mf} \approx 0.75 R_m$$

Calculated values of R_w are dependent on the formation temperature (T_f). The corrected value can be calculated or established from industry standard nomographs (Schlumberger, 1986, 1989) or by calculation (Jorgensen, 1990, 1996). For this study, the temperature compensated R_w was calculated using the methods described in Jorgensen (1990, 1996). R_w can then be related to specific conductance (SC) and dissolved solids using the following equations described by Jorgensen (1996) and Hem (1985):

$$SC = 10{,}000 / R_w$$

and

$$Dissolved\ solids = (P)\ (SC)$$

where

P is a conversion constant plus a dimensional correlation factor in units of siemens per centimeter.

Combining the above equations yields the equation:

$$Dissolved\ solids \approx [P\ (10{,}000)]/R_w$$

The value of P typically ranges from 0.5 for saline water to 0.9 for alkaline water (Jorgensen, 1996). Comparing the dissolved solids to SC values from water-quality samples resulted in a P value of about 0.5 for samples taken from the saline part of the Nacatoch Sand and the Tokio Formation. The temperature at the sample interval was calculated by interpolating the value at the sample depth from the average annual air temperature at the surface (between 1901 and 2000) of 60.4 degrees Fahrenheit (National Oceanic and Atmospheric Administration, 2013) and the reported bottom hole temperature from the log. Where the bottom hole temperature was not reported on the log, the geothermal gradient established from a nearby log with a reported bottom hole temperature was used.

The reported dissolved-solids values are based on calculating the dissolved solids at five points throughout the clean-sand intervals of the formations. Values were calculated at 10, 30, 50, 70, and 90 percent of the formations' clean-sand interval and averaged. For example, if the sandy interval of the formation was 100 ft thick, values were calculated at 10, 30, 50, 70, and 90 ft from the top of the interval and averaged. Where multiple clean-sand intervals were present in the formation, separated by clayey intervals, the described calculation was applied for each interval, and the results were weighted by the thickness of the clean-sand intervals.

Estimation of Water Quantity Based on Clean-Sand Percentage

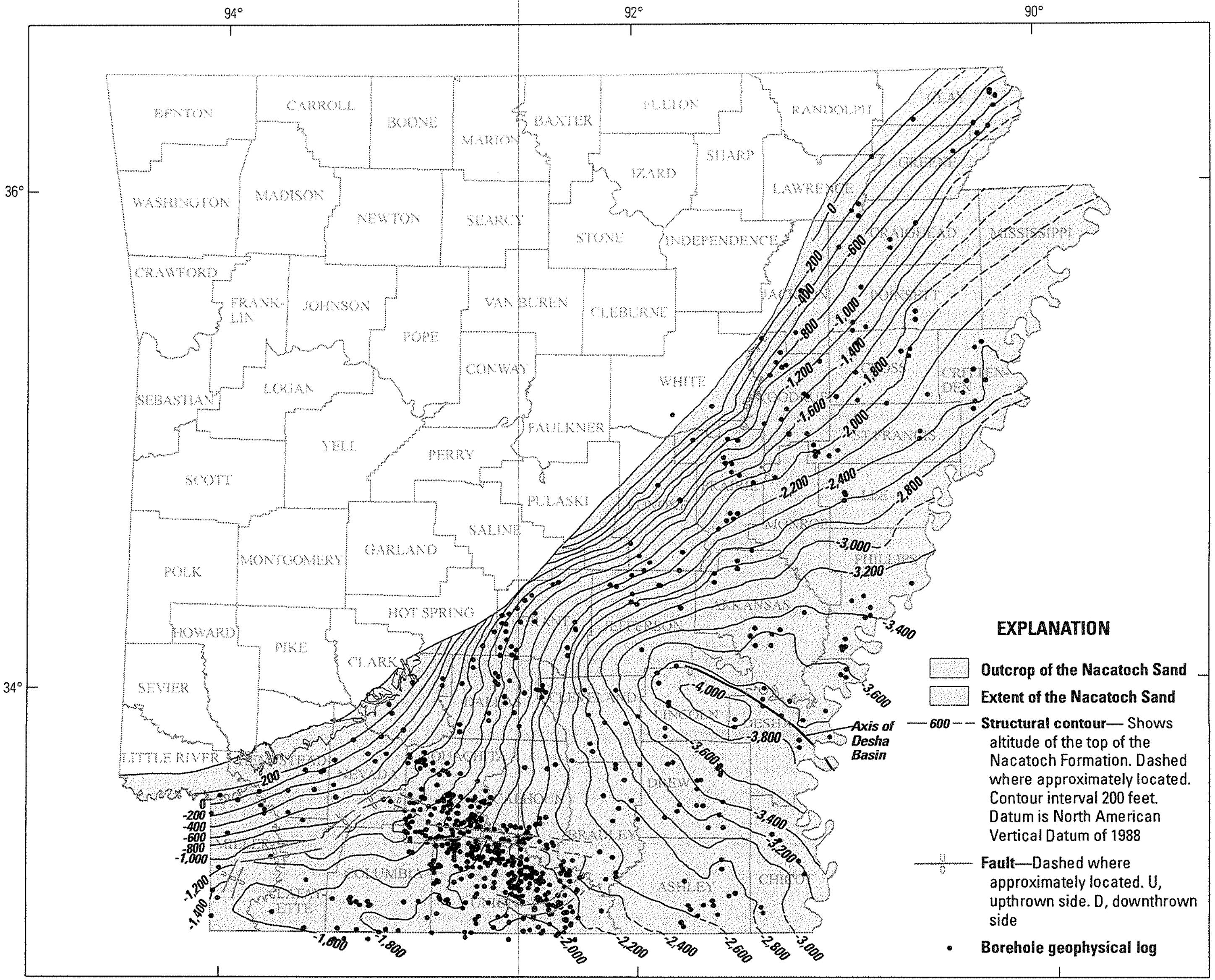
Once the thickness, clean-sand percentage, and dissolved-solids concentration of the water were evaluated, an estimation of the quantity of water in different dissolved solids ranges was made. This estimation was based on the thickness of clean sand, which is the clean-sand percentage multiplied by the formation thickness; an estimated porosity value; and the area of the aquifer within a dissolved-solids range. The values of clean-sand percentage and formation thickness were derived using a geostatistical process within ArcMap (Esri, 2014) to sample the values at the center of each cell of a 0.25-mi^2 grid, then averaging the sampled values within the area of the aquifer within the given dissolved solids range. A surface was created by applying linear kriging to the sampled data points (Esri, 2014). Because of irregular data distribution, a variable search radius was used. The surfaces were contoured within ArcMap; after the contours were created, manual adjustments were made where the contours did not honor data points. Since little porosity data were available, a porosity of 30 percent was used for the clean-sand intervals of the formations based on literature values for sand (Driscoll, 1986). The area was derived by clipping the aquifer extent polygon between dissolved-solids concentration lines and using the polygon properties feature within ArcMap to measure the area (Esri, 2014).

Altitude of the Tops and Thicknesses of the Nacatoch Sand and Tokio Formation

The top of the Nacatoch Sand was identified in 635 borehole geophysical logs, and, of those, the bottom of the Nacatoch Sand was identified in 417 borehole geophysical logs. The top of the Tokio Formation was identified in 437 borehole logs, and, of those, the bottom of the Tokio Formation was identified in 232 borehole geophysical logs. The thickness and structure of the formations established from borehole geophysical logs were found to be in close agreement with previously published investigations (Boswell and others, 1965; Petersen and others, 1985; Renken, 1998). Differences can be attributed to less data being considered in past studies.

The altitude of the top of the Nacatoch Sand ranges from more than 200 to less than -4,000 ft in relation to the North American Vertical Datum of 1988 (NAVD 88). The structural high occurs in the outcrop area, and the structural low occurs in southeastern Arkansas near the Desha Basin structural feature. The top of the Nacatoch Sand dips steeply from its extent along the western flank of the Mississippi embayment. In northern Arkansas, the dip decreases toward the axis of the Mississippi embayment. The structure of the Nacatoch Sand is interrupted by a faulted zone across southwestern Arkansas, and the dip of the Nacatoch Sand decreases dramatically south of the fault zone (fig. 4).

The altitude of the top of the Tokio Formation ranges from more than 200 to less than -4,400 ft in relation to NAVD 88. The structural high occurs in the outcrop area and



Base modified from U.S. Geological Survey digital data, 1:250,000
Universal Transverse Mercator Projection, Zone 15N

Geology modifed from Haley and others, 1993; Murray, 1961

Figure 4. Altitude of the top of the Nacatoch Sand.

the structural low occurs in southeastern Arkansas near the Desha Basin structural feature. The top of the Tokio Formation dips steeply from the outcrop area to the southeast. The structure of the Tokio Formation is interrupted by a faulted zone, which creates a graben structure, across southwestern Arkansas, and the dip of the Tokio Formation decreases dramatically south of the fault zone. The dip of the Tokio Formation decreases in southeastern Arkansas toward the axis of the Desha Basin structural feature (fig. 5).

Thickness and Clean-Sand Percentage of the Nacatoch Sand and the Tokio Formation

Maps were created to show the total thickness of the Nacatoch Sand and Tokio Formation and to show the percentages of the total thickness of the formations that are clean sand. Thickness and clean-sand percentages were calculated for 437 Nacatoch Sand logs and 232 Tokio Formation logs. The percentage of clean sand in the Nacatoch Sand ranges from 20 to more than 60 percent of the total formation thickness (fig. 6) and the Tokio Formation ranges in content of clean sand from less than 20 to over 60 percent of the total formation thickness (fig. 7).

The thickness of the Nacatoch Sand ranges from 0 to over 550 ft. The minimum thickness occurs where the formation pinches out in the outcrop area, and the maximum thickness occurs in the southwestern corner of Arkansas. Other areas of large thickness include the area near the Desha Basin structural feature in southeastern Arkansas and in an area on the border of Cross and St. Francis Counties in eastern Arkansas. The clean-sand percentage of the Nacatoch Sand generally decreases away from the outcrop. The highest clean-sand percentage occurs in an area of central Arkansas where the clean-sand percentage is more than 60 percent. Small areas of the Nacatoch Sand near the updip extent in northeastern Arkansas and in southwestern Arkansas contain clean sand in greater than 60 percent of the formation's thickness. Parts of the outcrop area contain between 40 and 60 percent clean sand, and the southwestern part of the outcrop area contains between 20 and 40 percent clean sand. The formation decreases to below 20 percent clean sand at approximately 20 to 50 mi from the outcrop area in southwestern Arkansas and in an area of southeastern Arkansas (fig. 6).

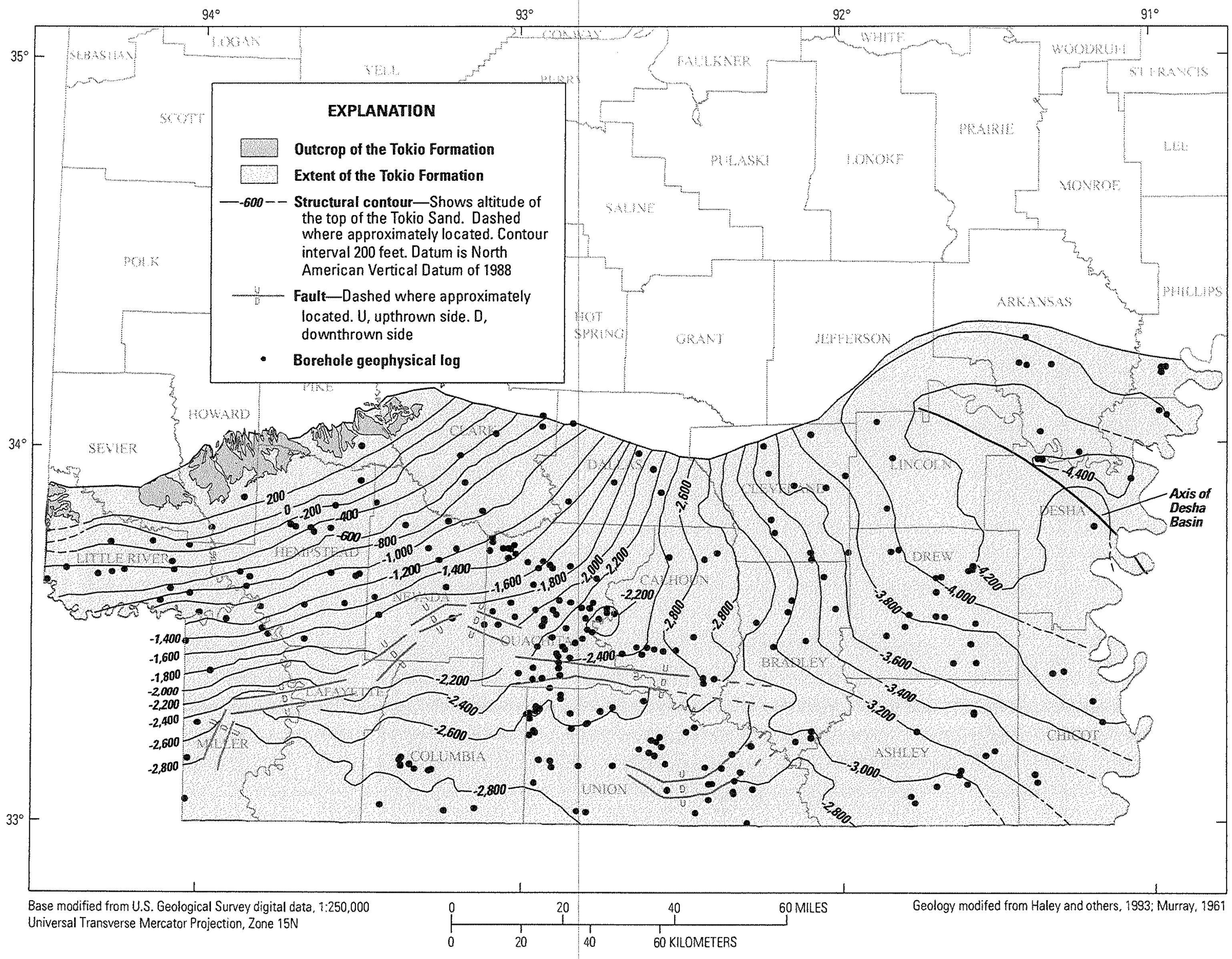
The thickness of the Tokio Formation ranges from 0 to over 400 ft (fig. 6). The minimum thickness occurs where the formation pinches out in the outcrop area, and the maximum thickness occurs in the southwestern corner of Arkansas. The clean-sand percentage of the Tokio Formation generally decreases away from the outcrop area. The Tokio Formation contains over 60 percent clean sand in areas in and near the outcrop. The Tokio Formation contains less than 40 percent clean sand in some areas of its outcrop and as far away as 40 mi downdip from the outcrop; an exception is a small area in Bradley County approximately 70 mi from the outcrop area, where the Tokio Formation also contains more than 40 percent clean sand. The Tokio Formation generally decreases in clean sand to less than 20 percent between approximately 6 and 40 mi downdip from the outcrop area (fig. 7).

Dissolved-Solids Concentrations in the Nacatoch Sand and Tokio Formation

Dissolved-solids concentrations of the formation waters were estimated from 416 Nacatoch Sand borehole geophysical logs and 211 Tokio Formation borehole geophysical logs, and the resulting dissolved-solids concentrations were used to create a map showing lines of equal dissolved-solids concentrations for the Nacatoch Sand and Tokio Formations (figs. 8 and 9, respectively). The dissolved-solids concentration boundaries for 1,000 and 10,000 mg/L developed for the Nacatoch Sand are comparable to the boundaries presented in Petersen and others (1985) and Renken (1998), and the dissolved-solids concentration boundary for 1,000 mg/L developed for the Tokio Formation is comparable to the boundary presented in Renken (1998). Minor differences can be attributed to less data being considered in previous studies.

The dissolved solids of the formation water of the Nacatoch Sand increased away from the outcrop area in southwest Arkansas. The dissolved solids reached 1,000 mg/L at a distance from approximately 1 to 17 mi from the outcrop area, 10,000 mg/L at a distance from approximately 15 to 25 mi away from the outcrop area, and 35,000 mg/L at a distance between approximately 25 and 50 mi from the outcrop area. The gradient of the dissolved-solids concentration is much more gradual in the northern part of Arkansas, with the dissolved solids of the formation water reaching 1,000 mg/L at a distance from approximately 45 to 75 mi south of the northern boundary of the State, 10,000 mg/L at a distance from approximately 100 to 135 mi south of the northern boundary of the State, and 35,000 mg/L at a distance from approximately 135 to 150 mi south of the northern boundary of the State. The dissolved solids of the formation water of the Nacatoch Formation exceeded 100,000 mg/L in a small area of southeastern Arkansas (fig. 8).

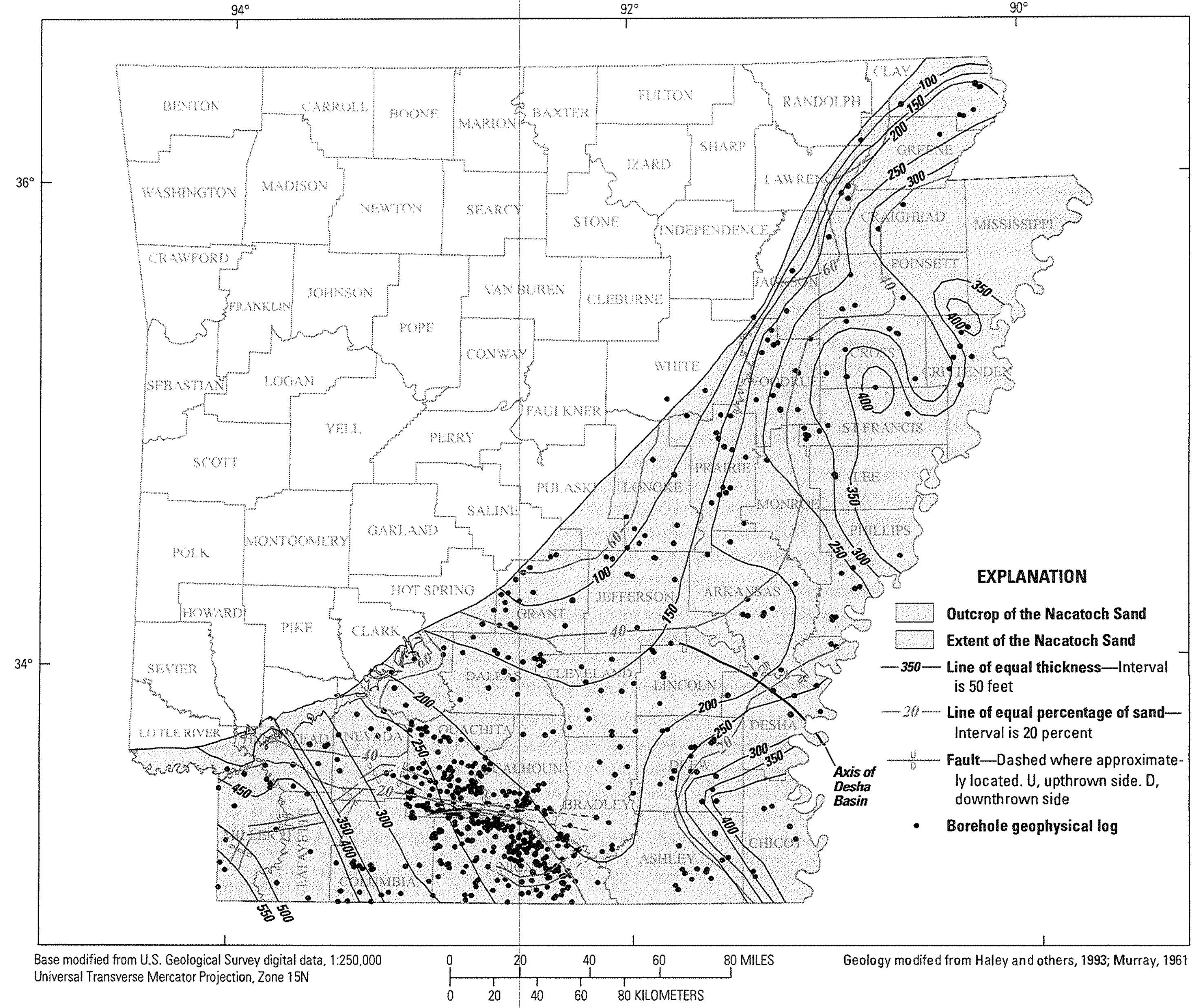
The dissolved solids of the formation water of the Tokio Formation increased away from the outcrop area in southwest Arkansas. The dissolved solids reached 1,000 mg/L at a distance from approximately 4 to 15 mi from the outcrop area, 10,000 mg/L at a distance from approximately 11 to 25 mi away from the outcrop area, and 35,000 mg/L at a distance between approximately 24 and 36 mi from the outcrop area. The dissolved solids of the formation water of the Tokio Formation exceeded 100,000 mg/L in all of southeastern Arkansas. The Tokio Formation is not present in the northern part of the State (fig. 9).



Base modified from U.S. Geological Survey digital data, 1:250,000
Universal Transverse Mercator Projection, Zone 15N

Geology modifed from Haley and others, 1993; Murray, 1961

Figure 5. Altitude of the top of the Tokio Formation.



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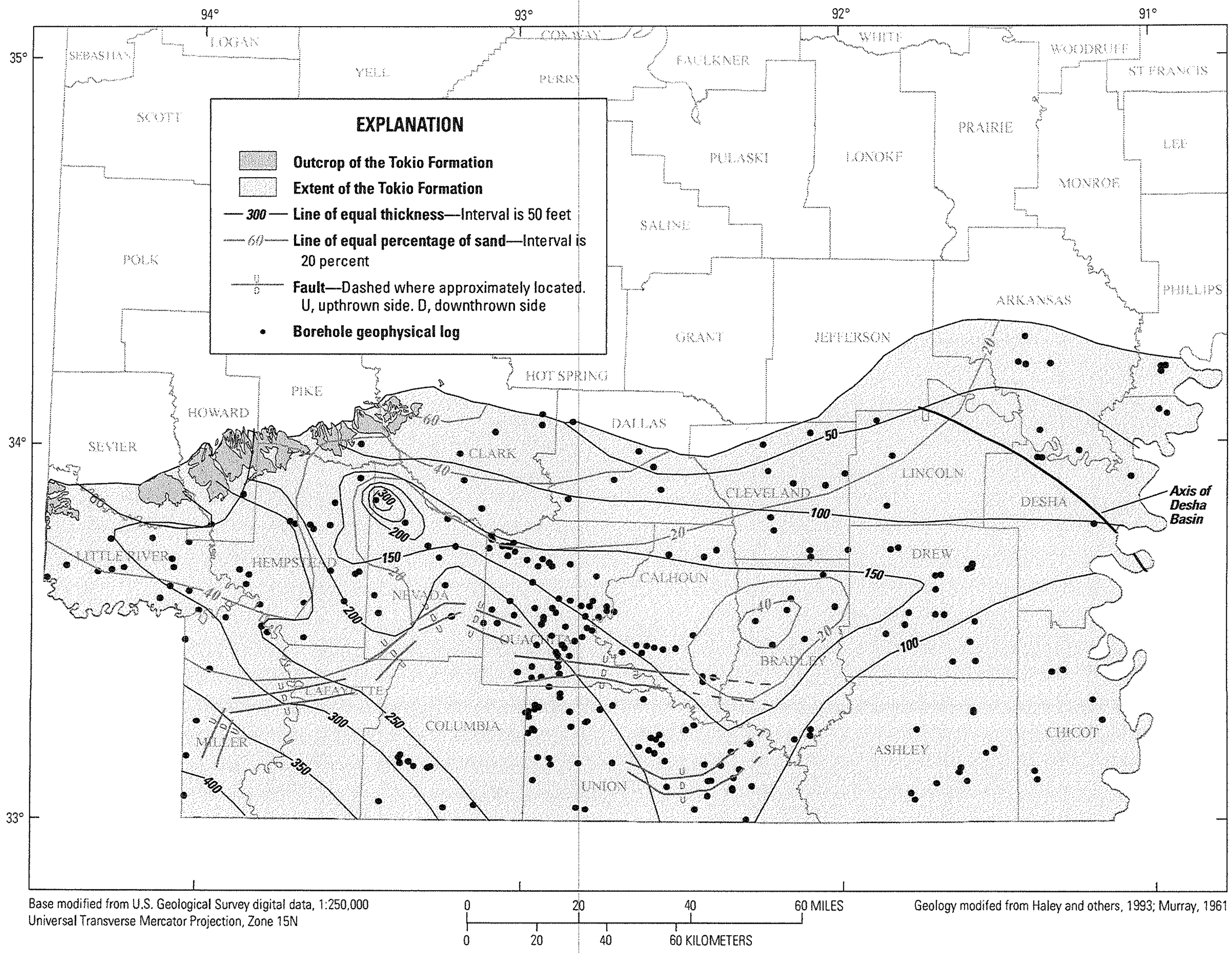
Geology modifed from Haley and others, 1993; Murray, 1961

Figure 6. Thickness and clean-sand percentage of the total formation thickness of the Nacatoch Sand.



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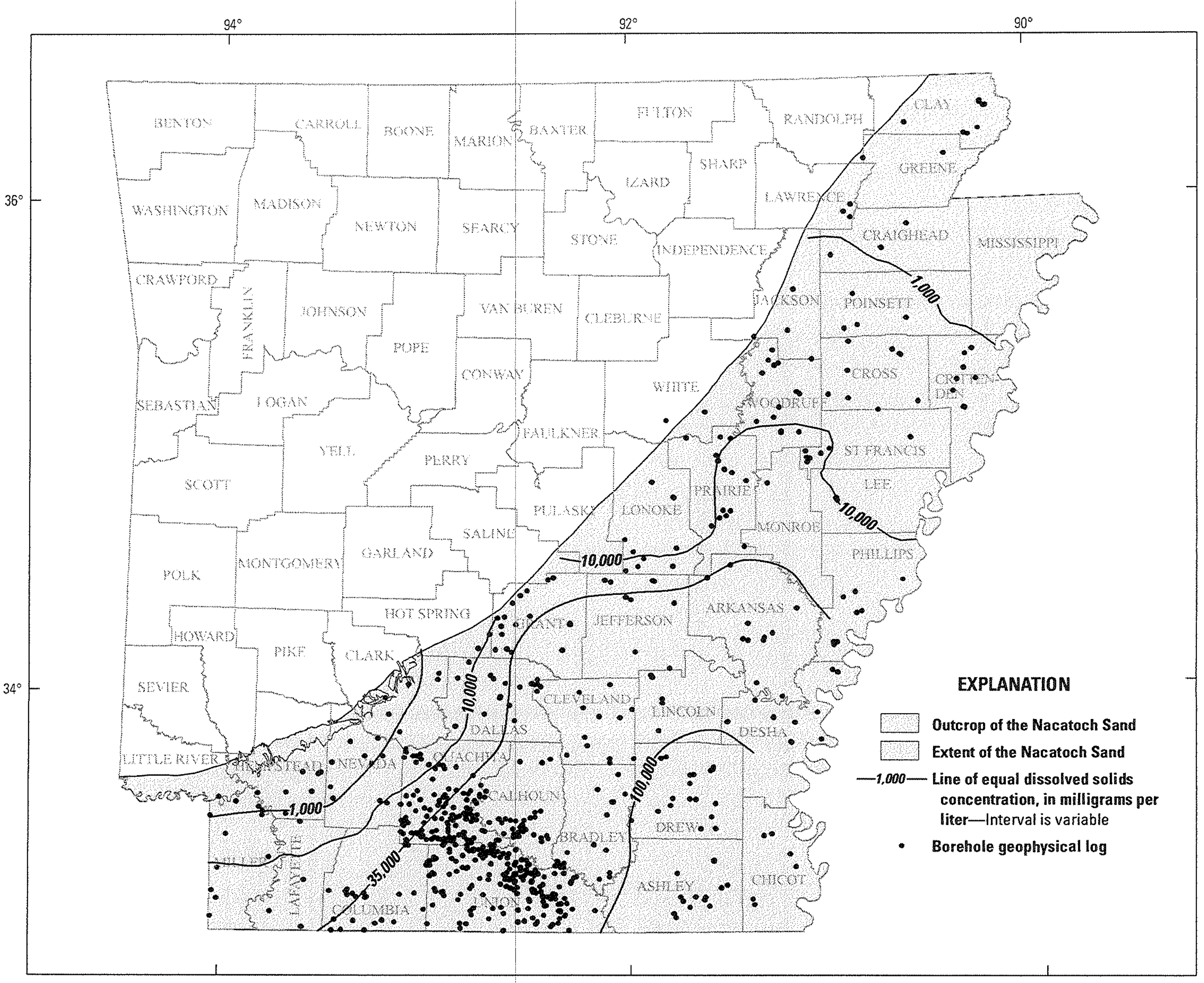
Geology modifed from Haley and others, 1993; Murray, 1961

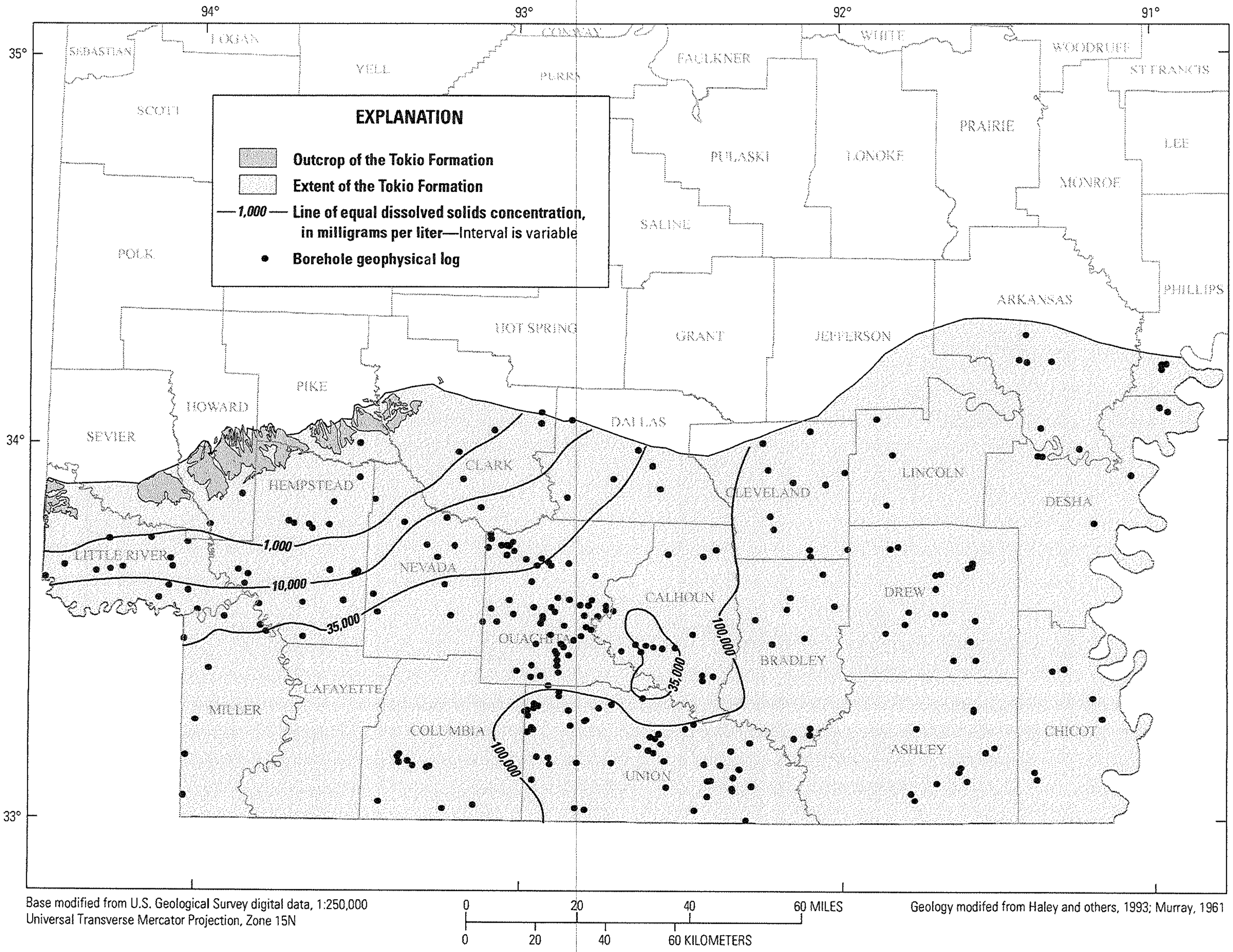
Figure 7. Thickness and clean-sand percentage of the total formation thickness of the Tokio Formation.



Base modified from U.S. Geological Survey digital data, 1:250,000
Universal Transverse Mercator Projection, Zone 15N

Geology modifed from Haley and others, 1993; Murray, 1961

Figure 8. Calculated dissolved-solids concentration of the groundwater of the Nacatoch Sand.



Base modified from U.S. Geological Survey digital data, 1:250,000
Universal Transverse Mercator Projection, Zone 15N

Geology modifed from Haley and others, 1993; Murray, 1961

Figure 9. Calculated dissolved-solids concentration of the groundwater of the Tokio Formation.

Estimated Quantity of Groundwater in the Nacatoch Sand and Tokio Formation

The estimation of water quantity of different salinity ranges is based on the thickness of the formation, the interpretation of clean-sand percentage of the total formation thickness, and the area where the salinity range was found to occur. A porosity of 30 percent was used for the clean-sand intervals of the formations based on literature values (Driscoll, 1986). This value is in the upper range of the porosity values attributed to sand and was used because the method used to determine clean-sand percentage would identify sand relatively free of finer grained sediments. The quantity of water was calculated for the areas where the groundwater dissolved-solids concentrations ranged from 1,000 to 10,000 mg/L, 10,000 to 35,000 mg/L, and over 35,000 mg/L for the Nacatoch Sand and the Tokio Formation (tables 2 and 3).

Based on the calculations, in Arkansas, the Nacatoch Sand contains more than 120.5 million acre-ft of water with a dissolved-solids concentration between 1,000 and 10,000 mg/L, more than 57.5 million acre-ft of water with a dissolved-solids concentration between 10,000 and 35,000 mg/L, and more than 122.5 million acre-ft of water with a dissolved-solids concentration more than 35,000 mg/L. The Tokio Formation, in Arkansas, contains more than 2.5 million acre-ft of water with a dissolved-solids concentration between 1,000 and 10,000 mg/L, more than 12.5 million acre-ft of water with a dissolved-solids concentration between 10,000 and 35,000 mg/L, and nearly 43.5 million acre-ft of water with a dissolved-solids concentration more than 35,000 mg/L. Because the Nacatoch Sand and Tokio Formation are under confined conditions, these values represent the amount of water present in the aquifers when they are fully saturated and may change with groundwater withdrawals.

Limitations

The methods used in this report are based on interpretation and, as such, the structure, water-quality, and quantity calculations presented are considered to be estimates. The top, thickness, clean-sand percentage of the total formation thickness, and dissolved-solids concentrations were calculated at points whose locations were determined by the U.S. Public Lands Survey System, resulting in an approximate location. Lithologic picks were based on best judgment by the author and the authors of previous investigations and are subject to interpretation. Additional interpolation of the data, whether by calculation or by using geostatistical methods to contour and sample data, potentially introduce additional error. The water volume was estimated based on a porosity value that falls within the range of published porosities of sand and is not an actual porosity value derived from the formations themselves. The hydraulic properties of the aquifers are not well known, so actual production from the aquifer is not known. The total volume of water available from the aquifer would be less than

Table 2. Estimated quantity of groundwater available from the Nacatoch Sand.

[mg/L, milligrams per liter; ft, feet]

Dissolved solids (mg/L)	Area (acres)	Average clean-sand thickness (ft)	Volume of saturated aquifer (acre-ft)	Porosity	Volume of water (acre-ft)
1,000 to 10,000	4,230,400	95	401,888,000	0.3	120,566,400
10,000 to 35,000	2,739,200	70	191,744,000	0.3	57,523,200
Over 35,000	6,291,200	65	408,928,000	0.3	122,678,400

Table 3. Estimated quantity of groundwater available from the Tokio Formation.

[mg/L, milligrams per liter; ft, feet]

Dissolved solids (mg/L)	Area (acres)	Average clean-sand thickness (ft)	Volume of saturated aquifer (acre-ft)	Porosity	Volume of water (acre-ft)
1,000 to 10,000	96,000	90	8,640,000	0.3	2,595,000
10,000 to 35,000	704,000	60	42,240,000	0.3	12,672,000
Over 35,000	4,140,800	35	144,928,000	0.3	43,478,400

the volume of water in the aquifer because of specific retention within the aquifer. The dissolved solids of the groundwater were estimated, but no analysis was made to determine the specific chemical composition of the water. Given these limitations, efforts were made to be conservative in calculating the quantity of groundwater present in the aquifers. Additional investigations could provide more information about the physical properties of the aquifer, the chemical character of the water, and the interaction of these aquifers with other aquifers.

Summary

The Nacatoch Sand and Tokio Formation are the principal water-bearing Late Cretaceous aquifers in Arkansas. Near its outcrop areas in southwestern Arkansas and in northeastern Arkansas, the Nacatoch Sand provides freshwater. The Tokio Formation provides freshwater near its outcrop area in southern Arkansas. Available water-chemistry data from both aquifers show that dissolved-solids concentrations are a close proxy to salinity. The dissolved-solids concentration of both aquifers increases dramatically downdip from the outcrop area and can exceed the dissolved-solids concentration of seawater. The dissolved-solids concentrations of formation water in each aquifer were calculated using the temperature-compensated ratio method. The thickness and structure of the formations were established from borehole geophysical logs and were found to be in close agreement with previously published structural maps for the formations. The clean-sand percentages of the Nacatoch Sand and the Tokio Formation were estimated by determining the thickness of relatively clean, porous sand based on borehole geophysical logs relative to the total thickness of the aquifers. The thickness and clean-sand percentage of the Nacatoch Sand and the Tokio Formation were used along with a literature value for porosity to calculate the volume of water that would be present in the formations in areas bracketed by important dissolved-solids concentrations.

The altitude of the top of the Nacatoch Sand ranges from more than 200 to less than -4,000 feet in relation to the North American Vertical Datum of 1988 (NAVD 88). The structural high occurs in the outcrop area, and the structural low occurs in southeastern Arkansas near the Desha Basin structural feature. The thickness of the Nacatoch Sand ranges from 0 to more than 550 feet. The minimum thickness occurs where the formation pinches out in the outcrop area, and the maximum thickness occurs in the southwestern corner of Arkansas. Other areas of large thickness include an area near the Desha Basin structural feature in southeastern Arkansas and in an area on the border of Cross and St. Francis Counties in eastern Arkansas. The clean-sand percentage of the total Nacatoch Sand thickness ranges from less than 20 percent to more than 60 percent and generally decreases downdip. Based on the calculations, in Arkansas, the Nacatoch Sand contains more than 120.5 million acre-feet of water with a dissolved-solids concentration between 1,000 and 10,000 milligrams per liter (mg/L), more than 57.5 million acre-feet of water with a dissolved solids concentration between 10,000 and 35,000 mg/L, and more than 122.5 million acre-feet of water with a dissolved-solids concentration more than 35,000 mg/L.

The altitude of the top of the Tokio Formation ranges from more than 200 to less than -4,400 feet in relation to the NAVD 88. The structural high occurs in the outcrop area and the structural low occurs in southeastern Arkansas near the Desha Basin structural feature. The thickness of the Tokio Formation, in Arkansas, ranges from 0 to more than 400 feet. The minimum thickness occurs where the formation pinches out in the outcrop area, and the maximum thickness occurs in the southwestern corner of Arkansas. The clean-sand percentage of the total Tokio Formation thickness ranges from less than 20 percent to more than 60 percent and generally decreases away from the outcrop area. The Tokio Formation contains more than 2.5 million acre-feet of water with a dissolved-solids concentration between 1,000 and 10,000 mg/L, more than 12.5 million acre-feet of water with a dissolved-solids concentration between 10,000 and 35,000 mg/L, and nearly 43.5 million acre-feet of water with a dissolved-solids concentration more than 35,000 mg/L.

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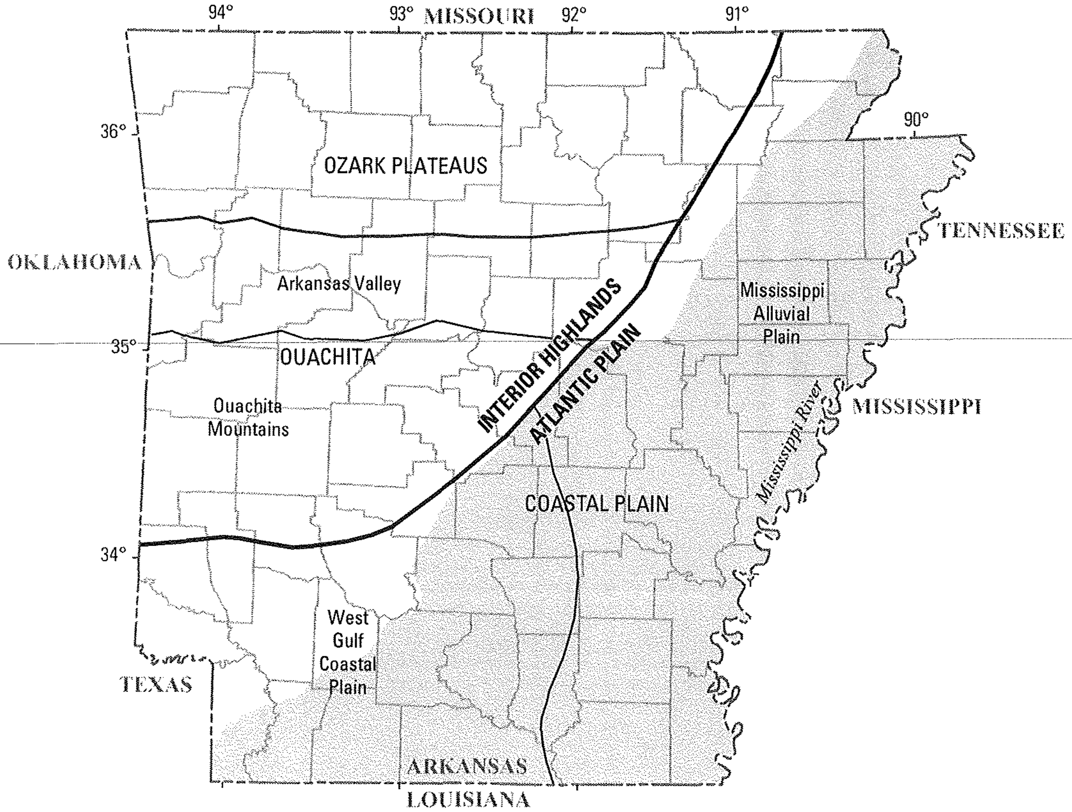
Water Levels and Water Quality in the Sparta-Memphis Aquifer (Middle Claiborne Aquifer) in Arkansas, Spring–Summer 2011



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