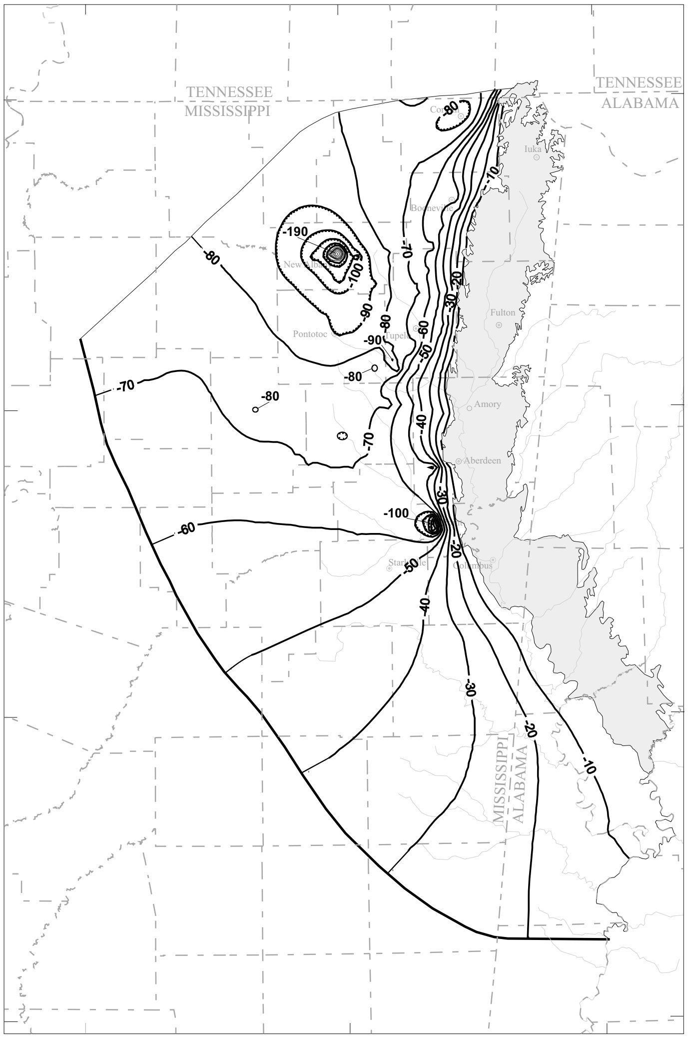
Prepared in cooperation with the
TENNESSEE VALLEY AUTHORITY

Simulation of Projected Water Demand and Ground-Water Levels in the Coffee Sand and Eutaw-McShan Aquifers in Union County, Mississippi, 2010 through 2050

Water-Resources Investigations Report 00-4268



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

Cover illustration: From figure 14, page 28.

Simulation of Projected Water Demand and Ground-Water Levels in the Coffee Sand and Eutaw-McShan Aquifers in Union County, Mississippi, 2010 through 2050

By Susan S. Hutson, Eric W. Strom, David E. Burt, *and* Michael J. Mallory

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 00-4268

Prepared in cooperation with the
TENNESSEE VALLEY AUTHORITY

Nashville, Tennessee
2000

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
640 Grassmere Park, Suite 100
Nashville, Tennessee 37211

Copies of this report may be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, Colorado 80225-0286

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
foot per minute (ft/min)	0.3048	meter per minute
mile (mi)	1.609	kilometer
square miles (mi^2)	640.0	acres
cubic foot (ft^3)	0.02832	cubic meter
gallon (gal)	0.0037854	cubic meter
gallon per day (gal/d)	0.0037854	cubic meter per day
million gallons (Mgal)	0.3785	cubic meter
million gallons per day (Mgal/d)	0.04381	cubic meter per second

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

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

$$°C = (°F-32)/1.8$$

Simulation of Projected Water Demand and Ground-Water Levels in the Coffee Sand and Eutaw-McShan Aquifers in Union County, Mississippi, 2010 through 2050

By Susan S. Hutson, Eric W. Strom, David E. Burt, *and* Michael J. Mallory

ABSTRACT

Ground water from the Eutaw-McShan and the Coffee Sand aquifers is the major source of supply for residential, commercial, and industrial purposes in Union County, Mississippi. Unbiased, scientifically sound data and assessments are needed to assist agencies in better understanding and managing available water resources as continuing development and growth places more stress on available resources. The U.S. Geological Survey, in cooperation with the Tennessee Valley Authority, conducted an investigation using water-demand and ground-water models to evaluate the effect of future water demand on ground-water levels.

Data collected for the 12 public-supply facilities and the self-supplied commercial and industrial facilities in Union County were used to construct water-demand models. The estimates of water demand to year 2050 were then input to a ground-water model based on the U.S. Geological Survey finite-difference computer code, MODFLOW.

Total ground-water withdrawals for Union County in 1998 were estimated as 2.85 million gallons per day (Mgal/d). Of that amount, municipal withdrawals were 2.55 Mgal/d with about 1.50 Mgal/d (59 percent) delivered to residential users. Nonmunicipal withdrawals were 0.296 Mgal/d. About 80 percent (2.27 Mgal/d) of the total ground-water withdrawal is produced from the Eutaw-McShan aquifer and about 13 percent (0.371 Mgal/d) from the Coffee Sand aquifer. Between normal- and high-growth conditions, total water demand could increase from 72 to 131 percent (2.9 Mgal/d in 1998 to 6.7 Mgal/d in year 2050) with municipal demand increasing from 77 to 146 percent (2.6 to 6.4 Mgal/d).

Increased pumping to meet the demand for water was simulated to determine the effect on water levels in the Coffee Sand and Eutaw-McShan aquifers. Under baseline-growth conditions, increased water use by year 2050 could result in an additional 65 feet of drawdown in the New Albany area below year 2000 water levels in the Coffee Sand aquifer and about 120 feet of maximum drawdown in the Eutaw-McShan aquifer. Under normal-growth conditions, increased water use could result in an additional 65 feet of drawdown in the New Albany area below year 2000 water levels in the Coffee Sand aquifer and about 135 feet of maximum drawdown in the Eutaw-McShan aquifer. Under high-growth conditions, increased water use could result in 75 feet of drawdown in the New Albany area below year 2000 water levels in the Coffee Sand aquifer and about 190 feet of maximum drawdown in the Eutaw-McShan aquifer. The resulting high-growth projected water level for the year 2050 at the center of the drawdown cone in the New Albany area is between 450 and 500 feet above the top of the Eutaw-McShan aquifer.

INTRODUCTION

Ground water from aquifers in formations of Cretaceous and Paleozoic age in northeastern

Mississippi counties supplies most of the water used for residential, commercial, and industrial purposes. Ground water is the sole source of water for residential, commercial, and industrial use in Union County, Mississippi. Through time, increased pumpage has resulted in large water-level declines at major pumping centers. In the late 1980's, water levels in the confined part of the Eutaw-McShan aquifer may have declined sufficiently to reach the upper part of the Eutaw Formation in the Tupelo, Mississippi area (Jennings and others, 1994). An investigation of aquifers in northeastern Mississippi was begun in 1990 to better understand the hydrogeology and the flow of water in and between the aquifers, and to provide information necessary for water managers to address ground-water resource problems. As part of the investigation, a model was developed in cooperation with the Office of Land and Water Resources (OLWR) of the Mississippi Department of Environmental Quality (DEQ) to simulate ground-water flow (Strom and Mallory, 1995). This model subsequently was refined to incorporate additional stratigraphic data collected by OLWR to simulate the Coffee Sand aquifer, to simulate additional aquifers in rocks of Paleozoic age, and to incorporate additional water-use data collected by OLWR's water-use program (Strom, 1998).

Accelerated growth in Union County, located in northeastern Mississippi, is reflected in the increased demand for water (Glenn Duckworth, Executive Director, Union County Development Association, oral commun., 1999). Population increased nearly 8 percent from 1990 (22,085 people) to 1998 (23,828 people). During the same period, employment increased nearly 17 percent (9,893 to 11,533 employees) and municipal water use increased nearly 39 percent [1.84 to 2.55 million gallons per day (Mgal/d)] (James H. Eblen, Ph.D., Economist, Economic Development, Tennessee Valley Authority, written commun., 1999; A.J. Warner, OLWR, written commun., 1999, respectively). About one-half of the increase (an increase of 19 percent) in water use occurred from 1995 (2.14 Mgal/d) to 1998 (2.55 Mgal/d). From 1990 to 1998, self-supplied commercial and industrial use declined 28 percent from 0.40 to 0.29 Mgal/d.

As the population continues to grow and the economy continues to expand, the need for additional ground water will increase. Long-term projections of water use are needed for water managers to determine whether the Eutaw-McShan and Coffee Sand aquifers can supply anticipated future water demand or whether alternative water sources should be considered. An investigation was completed in 1999, in cooperation with the Tennessee Valley Authority (TVA), to project water demand to the year 2050, and to determine the regional impact of increased local withdrawals on the Coffee Sand and Eutaw-McShan aquifer systems.

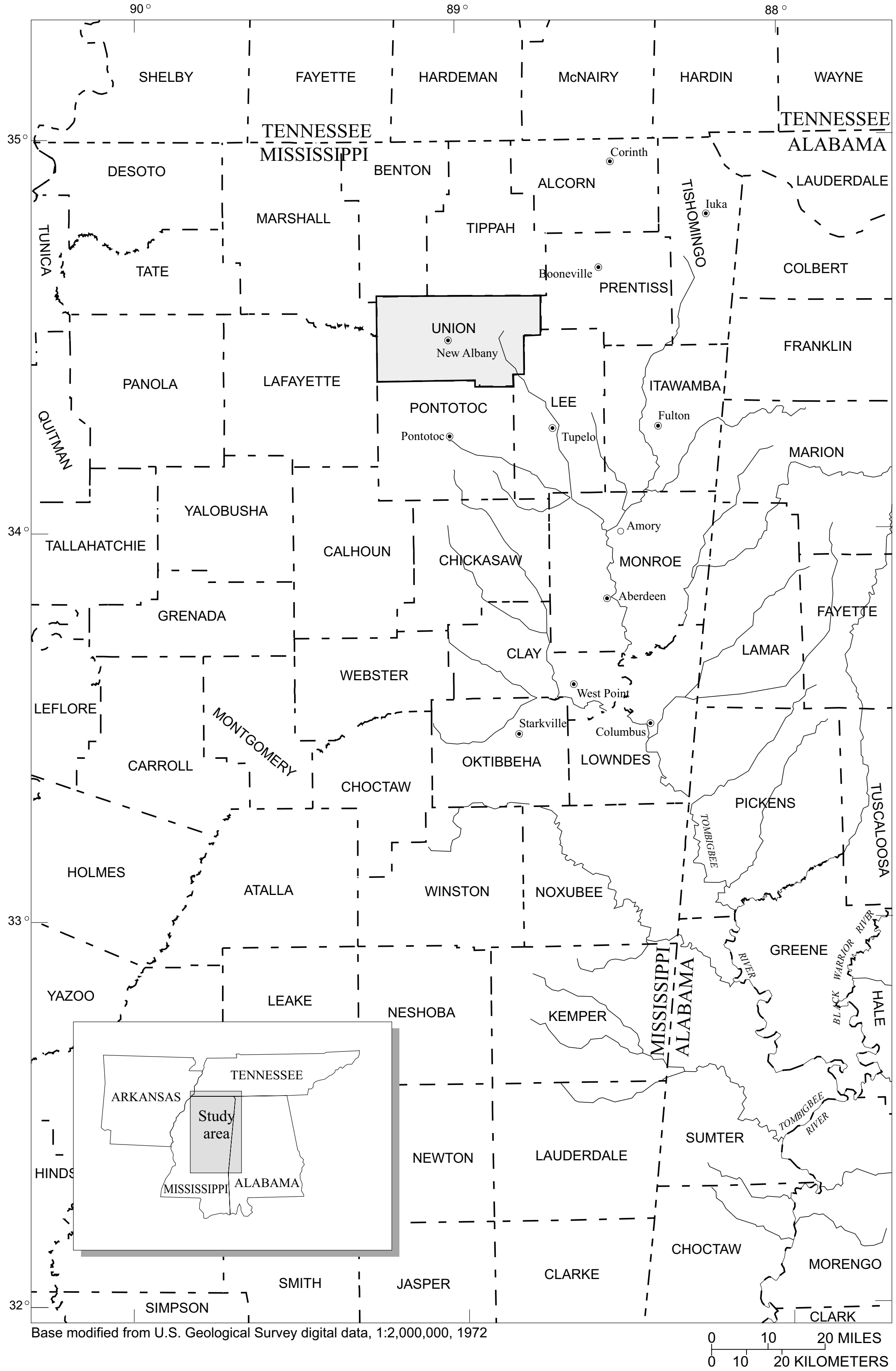
Purpose and Scope

This report provides estimates of water demand for Union County, Mississippi, to the year 2050 and describes the simulated ground-water drawdowns in the Coffee Sand and Eutaw-McShan aquifers in northeastern Mississippi from 2000 to 2050, which are a result of the projected increases in pumpage. Water-demand estimates are limited to municipal water (from a public-supply system) delivered to the residential, commercial, and industrial sectors (including conveyance losses in the distribution systems) and to nonmunicipal water (from a private well) for industrial and commercial use. Water withdrawn for domestic purposes from private wells was not investigated as part of the study.

Maps of projected water levels for the year 2000 (near current conditions) are presented, along with maps of subsequent projected water-level drawdowns for the year 2050 representing baseline-, normal-, and high-growth water-demand scenarios. The calibrated ground-water flow model (Strom, 1998) used in this investigation was applied over the entire area that was originally simulated (fig. 1) to account for boundary conditions and maintain calibration. Although the study area corresponds to the area of the calibrated ground-water flow model, the focus of the investigation is Union County, Mississippi, and discussions of the results are limited to Union County.

Approach

Water-use data were collected for each municipal and nonmunicipal facility in Union County for 1998. By applying regression analyses to the water-use data, an intercept and coefficients for a set of economic and climatic variables were determined. Future water demand was simulated using the Institute for Water Resources—Municipal and Industrial Needs (IWR-MAIN) system (Planning and Management Consultants, Ltd., 1999) with a linear-predictive format using the estimated model intercept and



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Figure 1. Location of the ground-water flow model area and Union County, Mississippi.

regression coefficients, and demographic, economic, and climatic data for 2010, 2020, 2030, 2040, and 2050. Water conservation was a part of the analysis. Nonresidential water use was simulated using a constant-rate model and with employment projections for the manufacturing and nonmanufacturing sectors. The water-demand model output was generated for normal- and high-growth scenarios.

The water-demand model output for the normal- and high-growth scenarios was used as input to the ground-water flow model to project water levels to the year 2050. Because the ground-water flow model originally simulated flow from 1900 to 1995, water-use data were added for 1996-2000 to start projection simulations at near-current conditions. This was accomplished by using 1996-1998 water-use data developed for the Coffee Sand and Eutaw-McShan aquifers for Union County and then increasing the 1998 Union County water-use data by 1.03 percent annually for 2 years to create the water-use data sets for the years 1999 and 2000. For areas outside of Union County and for two wells screened in the Gordo aquifer within Union County, the existing 1995 water-use data sets were increased 1.03 percent annually to create the 1996-2000 water-use data sets for all scenarios.

Stress periods representing each year from 2001 to 2050 were added to the model for the projection scenarios. For a baseline projection scenario, water use was increased by 1.03 percent each year from 2001 to 2050 for all wells simulated in the model. For the normal-growth water-use scenario, input from the water-use model representing normal growth was used for the Coffee Sand and Eutaw-McShan aquifers in Union County. In other areas, water use was increased by 1.03 percent each year from 2001 to 2050. For the high-growth water-use scenario, input from the water-use model representing high growth was used for the Coffee Sand and Eutaw-McShan aquifers in Union County. In other areas, water use was increased by 1.03 percent each year from 2001 to 2050.

In all of the scenarios simulated, one addition was made: pumpage from a likely mining operation in Choctaw County, Alabama, was added and simulated from 2001 to 2031 using withdrawal rates of 2 Mgal/d in the Coker aquifer and 4 Mgal/d in the massive sand aquifer. These rates were held constant for the projected 30 years of mining operations.

Hydrogeologic Setting

The study area for the ground-water flow model covers 34,960 square miles (mi^2), primarily in northeastern Mississippi, but includes parts of northwestern Alabama, southwestern Tennessee, and eastern Arkansas (fig. 1). The area includes the extent of the aquifers that are a source of freshwater in sediments and rocks of Cretaceous and Paleozoic age (excluding the Cretaceous Ripley aquifer) and adjacent areas that affect ground-water flow and availability of water in northeastern Mississippi (fig. 2). A detailed description of the hydrogeology of the study area may be found in Strom (1998). The focus of this investigation is limited to the Coffee Sand and Eutaw-McShan aquifers.

Coffee Sand Aquifer

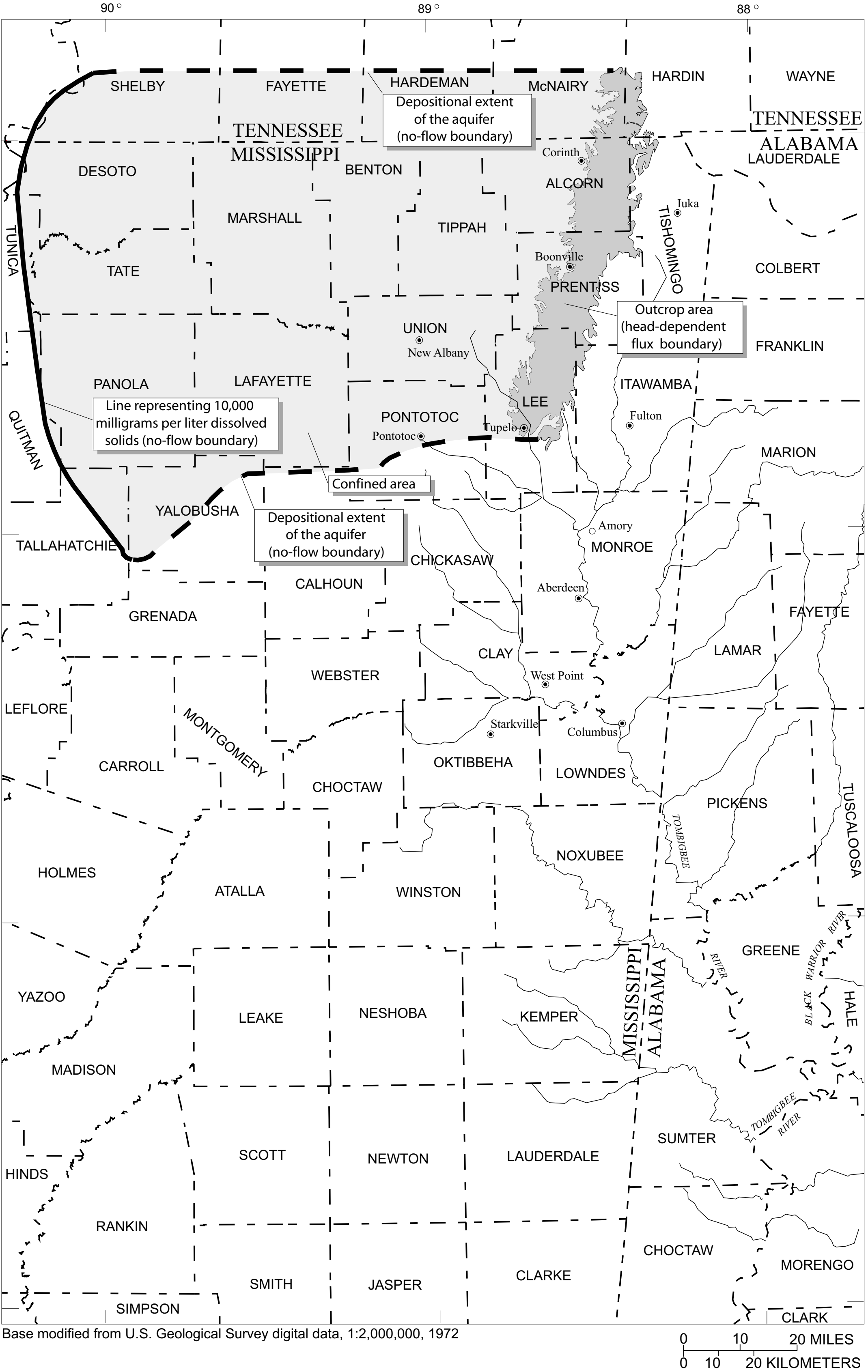
The Coffee Sand aquifer crops out predominantly in northeastern Mississippi and in central Tennessee (fig. 3). Although outcrops of the Coffee Sand occur as far north as southern Illinois, in Mississippi the unit appears to be continuous, extending northward to roughly an east-west line about 10 miles north of the Mississippi-Tennessee State line (E.F. Hollyday, U.S. Geological Survey, oral commun., 1997; W.S. Parks, U.S. Geological Survey, oral commun., 1997). To the west, in the downdip direction, the aquifer contains water with increasing dissolved-solids concentrations. To the south, the extent of the aquifer is limited by a facies change where the sand grades into chalk (Mellen, 1958). The aquifer dips about 35 feet per mile westward toward the axis of the Mississippi embayment (Boswell and others, 1965).

The Coffee Sand aquifer generally is composed of fine to medium quartz sand that is generally calcareous and glauconitic, with lenses of silt, sand, and clay (Boswell, 1963). Well-log data indicate the total sand thickness within the study area ranges from about 1 foot in the eastern part of the outcrop area to more than 200 feet in the downdip western part of the study area. Horizontal hydraulic conductivity values reported by Slack and Darden (1991) range from about 10 to 40 feet per day.

The Coffee Sand aquifer receives the majority of recharge from precipitation in the outcrop area. Water-level data indicate that discharge from the aquifer is to topographic lows in the outcrop area, to downdip areas of the Eutaw-McShan aquifer (Wasson, 1980a; Hoffmann and Hardin, 1994), and to wells screened in the Coffee Sand aquifer. The Coffee Sand

Erathem	System	Series	Group	Geologic unit	Principal aquifer or aquifer system		
Cenozoic	Tertiary	Eocene	Wilcox Group	Hatchetigbee Formation			
				Tuscahoma Formation	Lower Wilcox aquifer		
				Nanafalia Formation			
		Paleocene	Midway Group	Naheola Formation			
				Porters Creek Clay			
Mesozoic	Cretaceous	Upper Cretaceous	Selma Group	Prairie Bluff Chalk and Owl Creek Formation			
				Ripley Formation	Ripley aquifer		
				Demopolis Chalk			
				Coffee Sand Mooreville Chalk	Coffee Sand aquifer		Cretaceous-Paleozoic aquifer system
			Eutaw Group	Eutaw Formation Tombigbee Sand Member	Eutaw-McShan aquifer		
				McShan Formation			
			Tuscaloosa Group	Gordo Formation	Gordo aquifer	Tuscaloosa aquifer system	
				Coker Formation	Coker aquifer		
				Massive sand	Massive sand aquifer		
		Lower Cretaceous		Undifferentiated	Lower Cretaceous aquifer		
Paleozoic	Mississippian			Tuscumbia Formation Fort Payne Formation	Iowa aquifer	Paleozoic aquifer system	
	Devonian			Chattanooga Shale			
				Harriman Formation Flat Gap Limestone Ross Formation	Devonian aquifer		

Figure 2. Geologic units and principal aquifers in the study area. (Modified from Slack and Darden, 1991; Jennings, 1994.)



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Figure 3. Extent of the Coffee Sand aquifer, Mississippi and Tennessee.

aquifer is well confined from overlying aquifers by a thick sequence of chalk of the Demopolis Chalk formation (fig. 2).

Eutaw-McShan Aquifer

The Eutaw-McShan aquifer includes sediments of the Eutaw and McShan Formations. In Mississippi, these formations are considered to be a single aquifer because the sands are hydraulically connected; however, intervening beds of clay and silt may result in localized vertical head gradients.

The Eutaw-McShan aquifer crops out primarily in the northeastern part of Mississippi and northwestern part of Alabama within the study area (fig. 4). The northern and northwestern extent of the aquifer is the extent of the sediments. To the west, southwest, and south, in the downdip direction, the aquifer contains water with increasing dissolved-solids concentrations. The aquifer dips about 35 to 40 feet per mile westward toward the axis of the Mississippi embayment in the northern part and dips southwestward in the southern part.

The uppermost part of the Eutaw-McShan aquifer consists of the Tombigbee Sand Member, which is characterized by fine sand and silt that produces little water. The remainder of the Eutaw-McShan aquifer mainly consists of thin beds of fine- to medium-glauconitic sand (Boswell, 1963). Analysis of well-log data indicates the total sand thickness within the study area ranges from about 1 foot in the eastern part of the outcrop area to more than 300 feet in the southwestern and southern parts of the study area. An average horizontal hydraulic conductivity value of 12 feet per day, based on the results of 50 aquifer tests, was reported by Slack and Darden (1991).

The Eutaw-McShan aquifer receives recharge from precipitation in the outcrop area. Smaller amounts of recharge come from overlying and underlying aquifers (Mallory, 1993; Strom and Mallory, 1995). Water-level data indicate that discharge from the aquifer is to topographic lows in the outcrop area and to the Tombigbee and Black Warrior Rivers from upward leakage through units of the Selma Group (Wasson, 1980b; Gardner, 1981). The aquifer also may discharge water to the Gordo aquifer in parts of the updip area (J.H. Hoffmann, OLWR, oral commun., 1994) and to wells screened in the aquifer.

The Coffee Sand aquifer overlies the Eutaw-McShan aquifer, and is in turn overlain by the Ripley and lower Wilcox aquifers (fig. 2). The Eutaw-McShan aquifer is hydraulically separated from the Coffee Sand aquifer by the Mooreville Chalk south of an approximate east-west line at about the latitude of the Union and Pontotoc County boundary. North of this line, the Mooreville Chalk is absent, and the Eutaw-McShan aquifer is in contact with the Coffee Sand aquifer. Data indicate, however, that the Tombigbee Sand Member is very fine grained in this area and effectively acts as a confining unit, hydraulically separating the Eutaw-McShan and Coffee Sand aquifers (S.P. Jennings, Mississippi Office of Land and Water Resources, oral commun., 1994). The Eutaw-McShan aquifer is separated from the overlying Ripley and Lower Wilcox aquifers by thick sequences of clay and chalk in the Selma and Midway Groups (fig. 2).

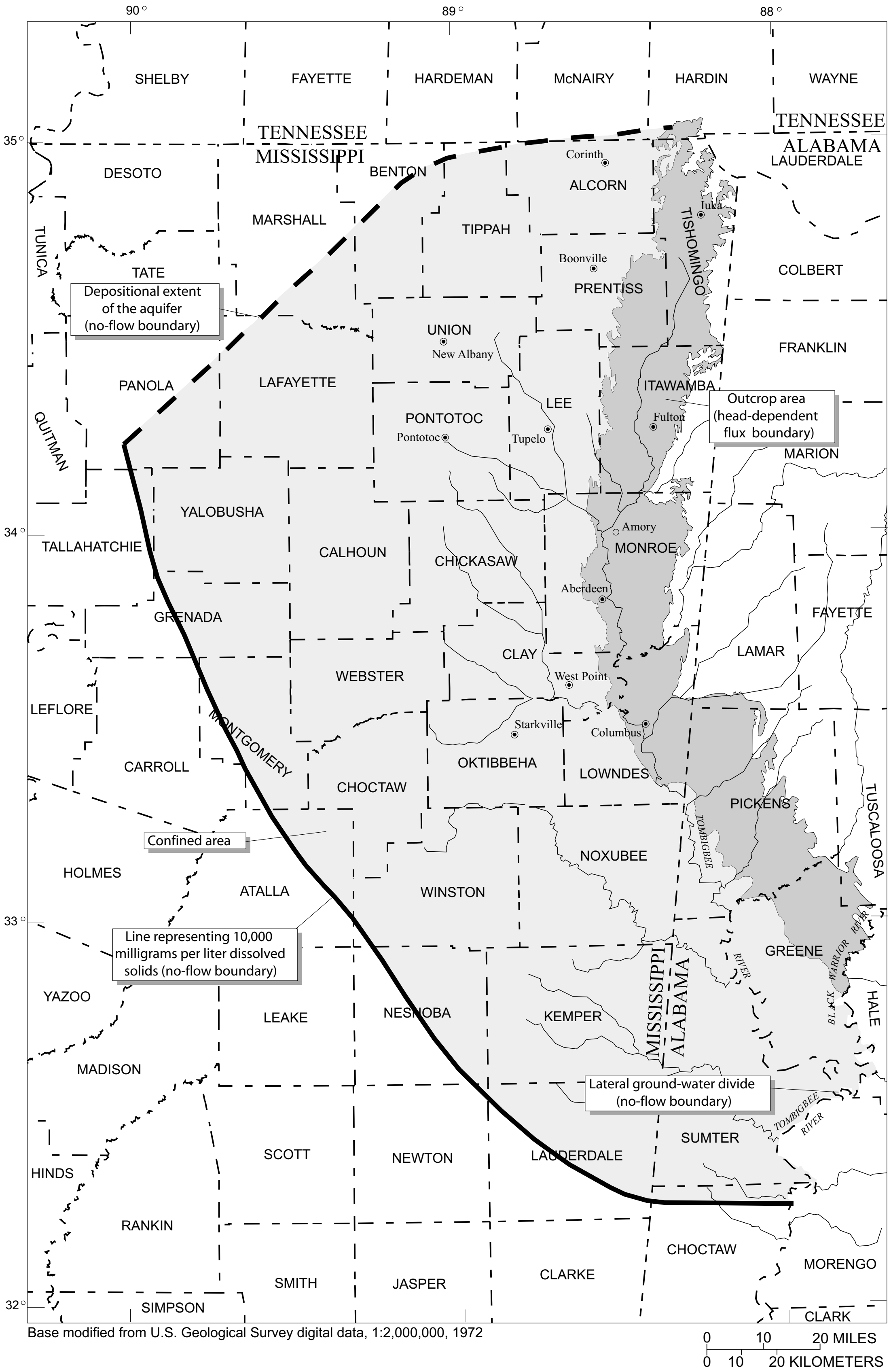
Shallow Aquifers

The lower Wilcox aquifer and the Ripley aquifer occur at land surface in Union County (Boswell, 1977 and 1978). The lower Wilcox aquifer is present in the western part of Union County, and the Ripley aquifer occurs in the eastern part of the county (fig. 5). The shallow aquifers provide water to private domestic wells. The Ripley aquifer consists of sands of the Ripley Formation and the McNairy Sand Member (Boswell, 1978). The shallow aquifers in Union County, the lower Wilcox and the Ripley aquifers, are separated from the underlying Eutaw-McShan aquifer by thick clay and chalk in the Selma and Midway Groups (fig. 2).

Water Use

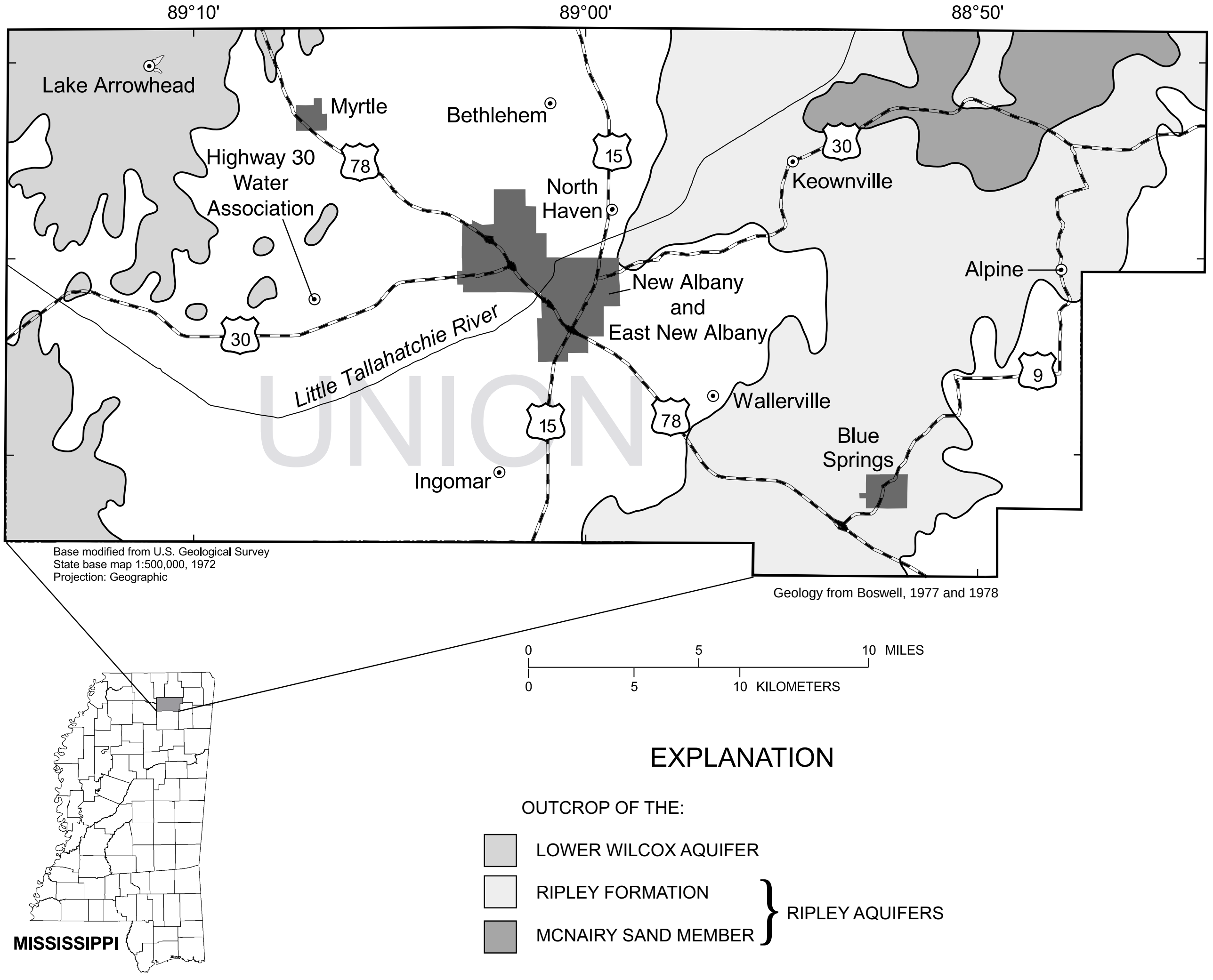
Municipal (public-supplied) and nonmunicipal (self-supplied commercial and industrial) water-use data were collected for 1998 for Union County. In addition to documenting the amount of water use by sector in Union County, the data were used as base-year data to calibrate the water-demand models. The ancillary information, such as number of wells and aquifer name, was used to prepare the water-use data input for the ground-water flow model. Conveyance losses and free water are referred to as public/unaccounted. For the purposes of this study, Union County is modeled as one water-service area (WSA), containing 12 public-supply systems (fig. 5). The self-supplied industrial and commercial facilities are modeled as one reporting unit, and the associated water use is included in the WSA total.

Municipal water withdrawals were either measured by meters at the wells (and the data provided by



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Figure 4. Extent of the Eutaw-McShan aquifer, Mississippi and Alabama.



Base modified from U.S. Geological Survey
State base map 1:500,000, 1972
Projection: Geographic

Geology from Boswell, 1977 and 1978

Figure 5. Pumping centers for public-supply systems and occurrences of shallow aquifers in Union County, Mississippi.

the public-supply system), estimated from usage metered at the connection (water sales and unaccounted for water), or estimated using an average household rate of use for the WSA and the number of connections. Nonmunicipal commercial and industrial rates of withdrawal were provided from internal reports by the facility. The public-supply systems provided billing records for 1998 for determining residential, commercial, and industrial water use and the public/unaccounted for water; the number of wells corresponding to each aquifer; price-rate structure; and number of connections. Municipal water withdrawals for Union County totaled 2.55 Mgal/d in 1998. The municipal water systems provided 1.50 Mgal/d (59 percent) for residential deliveries, 0.456 Mgal/d (18 percent) for commercial and industrial use, and 0.594 Mgal/d (23 percent) for public/unaccounted water.

Municipal and nonmunicipal water use for 1998 is summarized as follows:

- Total withdrawals were 2.85 Mgal/d (table 1).
- Municipal withdrawals (2.55 Mgal/d) were 90 percent of total withdrawals.
- Nonmunicipal withdrawals were 10 percent of the total withdrawals (0.296 Mgal/d).
- The main sources for water supply are the Eutaw-McShan and the Coffee Sand aquifers. About 80 percent of the water is from the Eutaw-McShan aquifer (2.27 Mgal/d); about 13 percent, from the Coffee Sand aquifer (0.371 Mgal/d); about 4 percent (0.129 Mgal/d), from the Gordo aquifer; and, the remaining 3 percent (0.082 Mgal/d) from the Ripley aquifer. About 93 percent of the municipal water is from the Eutaw-McShan and Coffee Sand aquifers (table 1).

SIMULATION OF PROJECTED WATER DEMAND

Water demand in the Union County WSA was simulated to year 2050 for two scenarios. The normal-growth scenario reflects normal historical growth for population, employment, and median household income for Union County. The high-growth scenario considers the recent period (1995 to 1998) of rapid growth for population, employment, and median household income for the WSA.

The Forecast Manager module of the IWR-MAIN software provides accounting and analysis tools for estimating future municipal and nonmunicipal water demand. The user's manual and suite description provide additional details for much of the discussion presented in this section of the report (Planning and Management Consultants, Ltd., 1999). The water-use forecasting algorithm of Forecast Manager is built to operate on data corresponding to the study area, water-use sectors and subsectors, months, and forecast years. The study area for the model is the Union County WSA. Forecasts were devised for the residential (single-family subsector) and nonresidential sectors (commercial and industrial subsectors) of municipal use and for the nonresidential sectors (commercial and industrial subsectors) of nonmunicipal use for years 2010, 2020, 2030, 2040, and 2050. The projection of residential water use to 2050 was simulated using a linear-predictive model with IWR-MAIN to incorporate demographic, socioeconomic, and climatic variables. The projection of non-residential water use to 2050 was simulated using a constant-rate model incorporating water use per employee and employment projections.

Residential Water Use

Residential water use for the Union County WSA was calculated using the number of households on public supply and the average per-household water use per day. Per-household water use is a function of demographic, socioeconomic, or climatic variables (Boland and others, 1984; Linaweaver, 1965; Maidment and others, 1985).

Residential water use for 2010, 2020, 2030, 2040, and 2050 was projected with a linear-predictive model using an estimated model intercept (inelastic demand) and linear coefficients for demographic, socioeconometric, and climatic factors. The factors commonly assumed to control daily household water use are monthly temperature and precipitation, marginal price, and median income. Daily per-household water use can therefore be expressed in the following form:

$$q = a + bt + cp + dm + ei, \qquad (1)$$

where, for each month and year,

q is the estimated rate of daily use per single-family household,

a is the inelastic demand, and

b, c, d, and e are linear coefficients of elasticity of per-household use for the factors t (temperature),

Table 1. Municipal and nonmunicipal facilities, source(s) of supply, and water use for the Union County, Mississippi, water-service area for 1998

[Figures may not add to totals because of independent rounding.]

Facility	Source(s) of supply Aquifer name	Withdrawals, in million gallons per day	Purchased water, in million gallons per day	Average monthly number of residential connections	Average gallons per household per day
Alpine Water Association	2 wells Eutaw-McShan	0.073	--	305	175
Bethlehem Water Association	New Albany Water System		0.06	259	211
Blue Springs Water Association	3 wells Eutaw-McShan Coffee Sand	.145 .054	--	497	246
East New Albany Water Association	1 well Eutaw-McShan New Albany Water System	.126	.06	434	236
Highway 30 Water Association	2 wells Eutaw-McShan	.127	--	456	180
Ingomar Water Association	2 wells Eutaw-McShan	.185	--	587	196
Keownville Water Association	3 wells Coffee Sand	.192	--	977	165
Lake Arrowhead Water Association	1 well Ripley	.007	--	35	193
Myrtle Water System	2 wells Ripley	.065	--	346	144
New Albany Water System	6 wells Eutaw-McShan	1.34	--	2,645	209
North Haven Water Association	1 well Coffee Sand	.081	--	332	171
Wallerville Water Association	3 wells Eutaw-McShan Gordo	.03 .129	--	717	194
Nonmunicipal industrial and commercial facilities	6 wells Eutaw-McShan Coffee Ripley	.242 .044 .01	--		
Totals Averages		2.85	.120	7,590	193

p (precipitation), m (marginal price), and i (median income).

Values for the inelastic demand and the coefficients of elasticity in equation (1) are developed or estimated prior to calculating projected water use. Based on regression analysis of monthly data, changes in temperature and precipitation may account for only 11 percent of the observed temporal variation in residential water use. Though climatic variables (temperature and precipitation) may change over the period of scenarios run, defining these changes was beyond the scope of this effort, and temperature and precipitation were held constant. Based on regression analysis of monthly variations in water use, the results validate residential water-use concepts and indicate that water use would increase with increasing temperature and decrease with increasing price.

Median household income is constant for each system for each month for 1998, but is likely to change from year to year in the future. Therefore, the coefficient of elasticity for median household income was determined from literature values (William Y. Davis, Planning and Management Consultants, Ltd., oral commun., 1999). The coefficient for median household income was calculated based on 1998 daily per-household water use and 1998 median household income. The coefficient is interpreted as an elasticity term and is determined as follows:

$$e = (q_{1998} * \beta_s)/X_{1998}, \qquad (2)$$

where,

e is the coefficient of the explanatory variable, median household income;

q is the estimated daily water use per household, 193 gallons per day (gal/d) in 1998;

β is 0.4, the literature value for elasticity of per-household water use for median household income; and

X is the median household income, in thousands of dollars. The value is 32.458 for 1998.

The elasticity (β) is a dimensionless measure of the relation between a percentage change in water use and a percentage change in median household income when other factors affecting demand remain unchanged (Boland and others, 1984). The literature value for β is 0.4 (Planning and Management Consultants, Ltd., 1995). The analysis assumes that for a 1-percent increase in median household income, water demand increases 0.4 percent.

For equation (1) inelastic water use is 58.1, water use associated with climatic factors is constant at 89, elasticity coefficient for marginal price is -15.7, and elasticity coefficient for median household income is 2.378. Per-household water use (q) is calculated as:

$$q = 58.1 + (89) – (15.7\ m) + (2.378\ i), \qquad (3)$$

where, m and i represent estimates of marginal price and median income.

Under the scenarios of normal- and high-economic growth in this study, climatic conditions are held constant and small adjustments are made to the marginal price. Extreme drought or larger changes to the marginal price can be used as alternative assumptions to develop alternate modeling scenarios. Marginal price is expected to change only slightly over the forecast years. The range of values for water use associated with marginal price is from -31 gal/d in 1998 to -42 gal/d in 2050. These negative numbers indicate a tendency for increases in marginal price to decrease water use. Median income is projected to change substantially over the forecast years and has the greatest influence on increasing water use per household for each forecast year. In the high-growth scenario, the component of water use associated with median income ranges from 77 gal/d in 1998 to 167 gal/d in 2050.

Total residential water use for years 2010, 2020, 2030, 2040, and 2050 is determined as follows:

$$Q_y = (q_y * h_y)/10^6, \qquad (4)$$

where,

Q_y is the total residential water use in year (y), in million gallons per day;

q_y is the per-household water use in year (y), as determined by equation 3; and

h_y is the number of households served by public supply in year (y).

Commercial and Industrial Water Use

Commercial and industrial water use projections to 2050 were determined using a constant-rate model based on the amount of water use per employee in each subsector and the projected number of employees to 2050. The base-year (1998) per-employee water-use rate was calculated from the base-year water use and the number of employees for the commercial and industrial subsectors (Planning and Management Consultants, Ltd., 1999). Future changes in water use per employee in the commercial and industrial subsectors are unknown. The water use per employee for 1998 remains constant for all of the forecast years for each subsector. The change in the number of employees (N) determines the change in the water-use forecast from year to year. Thus, the quantity of water use in a given subsector, month, and forecast year is calculated as:

$$Q_{s,\,m,y} = N_{s,\,m,y} * q_{s,m,y}, \qquad (5)$$

where,

Q is gallons per day used in subsector (s) in month (m) in year (y),

N is the number of employees in subsector (s) in month (m) in year (y), and

q is the average daily water-use rate per employee in subsector (s) in month (m) in base year for 1998.

With the constant-rate model, the change in employees (N) explains the change in the water-use forecast from year to year. For municipal use, the per-unit use rates in gallons per employee per day for the commercial and industrial subsectors are 58 and 19 gallons per employee per day (ged), respectively; for nonmunicipal use, 12 and 143 ged, respectively.

The results of the simulation for a high-growth scenario show that average demand could increase 131 percent from 2.9 Mgal/d in 1998 to 6.7 Mgal/d in 2050. Peak daily demand for municipal water was estimated as 1.65 times the average daily rate of use for both scenarios. The ratio 1.65 is the average peak demand ratio for public-supply systems using ground water in Mississippi (American Water Works Association, 1992).

Data Preparation/Model Input

Housing, employment, climatic, and economic data were prepared as input to the water-use models in IWR-MAIN. Several assumptions (about the character of the data for the base year and about the structure of socioeconomic conditions in future years) were necessary to model the Union County WSA. These assumptions are detailed within the respective data sections and in Appendix A. Data were prepared for the municipal (residential and nonresidential sectors) and nonmunicipal (nonresidential sectors) use for the base year 1998 and for future years 2010, 2020, 2030, 2040, and 2050.

Residential Data

Occupied housing units for the residential sector are counted as single-family households. Union County, in 1998, averaged 2.51 persons per household (U.S. Department of Commerce, 1992a). The number of households served by public supply for the forecast years (table 2) was estimated using projected

Table 2. Estimates of housing units for a normal- and a high-growth scenario, 1998 to 2050, in Union County, Mississippi

Socioeconomic variables	1998	2010	2020	2030	2040	2050
Normal-growth scenario						
Population[a]	23,828	26,139	27,599	29,369	30,950	32,557
Number of occupied-housing units[b]	9,493	10,414	10,996	11,701	12,331	12,971
Number of occupied-housing units served by a public supply	7,590	9,060	9,786	10,648	11,468	12,322
High-growth scenario						
Population[a]	23,828	27,932	31,332	34,732	38,132	41,532
Number of occupied-housing units	9,493	11,128	12,483	13,837	15,192	16,547
Number of occupied-housing units served by a public supply	7,590	9,904	11,359	12,869	14,432	16,050

[a] Data from Dr. James H. Eblen, Tennessee Valley Authority, Economic Development, written commun., 1999 (Appendix A).

[b] Data from U.S. Department of Commerce, 1992a.

population growth and assuming 2.51 persons per household. Population projections were derived by Dr. James H. Eblen (TVA, Economic Development, Technical Services, written commun., 1999). See Appendix A in this report for an explanation of the methodology and the projections for population for Union County, Mississippi. The number of occupied-housing units served by public supply was incrementally increased from 80 percent in 1998 to 95 percent of the total occupied-housing units in 2050 for the normal-growth scenario and to 97 percent for the high-growth scenario.

Other residential data are marginal price, median household income, temperature, precipitation, and water-conservation savings. The water and wastewater price-rate structures for each system were used to specify marginal price for the base and future years. An average marginal price of $1.97 for the systems was used for the base year. For those areas in the WSA most likely to acquire sewer lines by year 2050 (Glenn Duckworth, Executive Director, Union County Development Association, oral commun., 1999), marginal price was adjusted for future years, and a revised marginal price was input to the model. The model assumes that customers connected to public-supply systems with sewer capacity will use public wastewater treatment. For the purposes of this model, the dollars are expressed as 1998 constant dollars.

The only complete assessment of median household income in Mississippi occurs in each decennial census. For the base and forecast years, median household income was estimated using the methodology described in Appendix A. The dollars are expressed as 1998 constant dollars.

Public/unaccounted water use was estimated as a percentage of the total municipal use. For the base year of 1998, the public/unaccounted water use was about 23 percent, which reflects the average rate observed for the public-supply systems. For future years, the percentage remains constant through time at 15 percent, which is the water-industry average for Mississippi (American Water Works Association, 1992).

The average daily maximum temperature for each month and the total monthly precipitation for the base year 1998 and for the period 1956 to 1998 (table 3) were used as input for the forecast years.

Table 3. Average daily maximum temperature and total monthly precipitation data input to the residential water-demand model for the Union County, Mississippi, water-service area

[Precipitation data for New Albany, Mississippi, and temperature data for Benton County, Mississippi, from Dr. Charles L. Wax, State Climatologist, State of Mississippi, written commun., 1999]

	1998		Average, 1956 to 1998	
Month	Average maximum daily temperature, in degrees Fahrenheit	Total monthly precipitation, in inches	Average maximum daily temperature, in degrees Fahrenheit	Total monthly precipitation, in inches
January	53.5	5.46	50.6	6.75
February	57.1	5.09	56.0	5.18
March	62.3	3.48	65.0	7.57
April	73.4	7.30	71.3	3.25
May	84.6	2.82	81.4	7.50
June	91.3	2.05	87.9	8.82
July	91.8	7.13	91.2	2.92
August	90.8	2.21	90.5	1.71
September	91.6	0.95	85.0	2.83
October	79.1	1.58	75.5	4.72
November	66.6	2.59	63.4	1.76
December	54.5	8.63	54.4	4.78

Monthly data for years 1956 to 1998 at each of these stations were evaluated to define average climatological conditions for future years for residential water demand.

Water-conservation savings that would result from installing low-flow plumbing fixtures as required by the Federal Energy Conservation Act of 1992 were factored into the model. For this study, a conservative estimate of water savings was used to account for the uncertainties of the performance of the low-flow technology. Water use per household was reduced for all estimated new housing units that would be built from 1994 to 2050. The estimated savings are for one person per household instead of 2.51 persons per household. Estimated water savings of 14 gallons per unit per day were entered for 50 percent of the occupied households on public supply for the year 2010, for 75 percent of the occupied households on public supply in 2020, and for 100 percent of the occupied households on public supply for 2030 through 2050 (Planning and Management Consultants, Ltd., 1995; American Water Works Association, written commun., 1997). In the residential model, the estimated per-unit use is reduced by the given amount before the unit use is multiplied by the number of housing units (Planning and Management Consultants, Ltd., 1999).

Nonresidential Data

The constant-rate model projected municipal water use for the commercial (nonmanufacturing) and industrial (manufacturing) subsectors based on the estimated increases in employees. The employee counts (Appendix A) were multiplied by the corresponding unit-use coefficients of gallons per employee per day. The coefficients were derived from water-production records maintained by the public-supply systems and from employee counts reported to the Union County Development Association (Glenn Duckworth, Executive Director, written commun., 1999).

Nonresidential water usage for nonmunicipal water supplies, such as self-supplied industry, is held constant for the base and forecast years for the normal- and high-growth scenarios. This decision assumes that additional nonresidential water for new or expanding facilities would be provided by public-supply systems.

Projected Water Demand

The IWR-MAIN linear-predictive and constant-rate models applied to the Union County WSA were used to estimate water demand for years 2010, 2020, 2030, 2040, and 2050. The estimates for the municipal residential and nonresidential sectors and the nonmunicipal nonresidential sectors were aggregated to yield totals for the WSA for each year. The values are reported as two significant figures. Estimates for a normal-growth scenario from 1998 to year 2050 (table 4) show that:

- Simulated average total water demand could increase 72 percent,
- Municipal water demand could increase 77 percent,
- Residential water demand could increase 100 percent, and,
- Commercial and industrial water demand could increase 107 percent by 2050.

Estimates for a high-growth scenario show that average demand could increase 131 percent from 2.9 Mgal/d in 1998 to 6.7 Mgal/d in 2050. Peak daily demand for municipal water was estimated as 1.65 times the average daily rate of use for both scenarios. The ratio 1.65 is the average peak demand ratio for public-supply systems using ground water in Mississippi (American Water Works Association, 1992). Historical (1990, 1995, and 1998) and projected (2000, 2010, 2020, 2030, 2040, and 2050) water withdrawals for a normal- and a high-growth scenario for the municipal sector are shown in figure 6. An average annual increase of 1.03 percent was used to estimate baseline water use for areas outside of Union County.

Uncertainty in Predictions

The water-demand models were used primarily to test assumptions and the effects that various assumptions or changes would have on water use in the county rather than as a predictive tool to generate absolute values showing future water use. As with any model, the degree of uncertainty increases as the length of time of the projections increase. Projecting 50 years involves assuming many political, environmental, economic, and technical factors will not shift radically. If the assumptions are changed (for example, population decreases in the area) the water-demand results will change. The results depend on the validity of the assumptions.

Table 4. Projected water demand for the Union County, Mississippi, water-service area for 1998, 2010, 2020, 2030, 2040, and 2050, in million gallons per day

Sector	Historic water use	Projected water use					Percent change from 1998 to 2050
	1998	2010	2020	2030	2040	2050	
Normal-growth scenario							
Municipal water							
Residential	1.5	1.9	2.1	2.4	2.7	3.0	100
Commercial and industrial	0.46	0.56	0.62	0.73	0.84	0.95	107
Public/unaccounted	.60	.44	.49	.55	.62	.70	17
Subtotal municipal water	2.6	2.9	3.2	3.7	4.2	4.6	77
Peak daily demand[1]	*4.3*	*4.8*	*5.3*	*6.1*	*6.9*	*7.6*	*77*
Nonmunicipal water							
Commercial and industrial	.30	.30	.30	.30	.30	.30	0
Subtotal nonmunicipal water	.30	.30	.30	.30	.30	.30	0
Total water demand	2.9	3.2	3.5	4.0	4.5	5.0	72
High-growth scenario							
Municipal water							
Residential	1.5	2.1	2.6	3.0	3.6	4.2	180
Commercial and industrial	.46	.62	.78	.92	1.1	1.2	161
Public/unaccounted	.60	.49	.60	.70	.82	1.0	67
Subtotal municipal water	2.6	3.2	4.0	4.7	5.5	6.4	146
Peak daily demand[1]	*4.3*	*5.3*	*6.6*	*7.8*	*9.1*	*11*	*156*
Nonmunicipal water							
Commercial and industrial	.30	.30	.30	.30	.30	.30	0
Subtotal nonmunicipal water	.30	.30	.30	.30	.30	.30	0
Total water demand	2.9	3.5	4.3	5.0	5.8	6.7	131

[1] Peak daily demand is about 1.65 times the average daily use for public-supply systems using ground water in Mississippi (American Water Works Association, 1992).

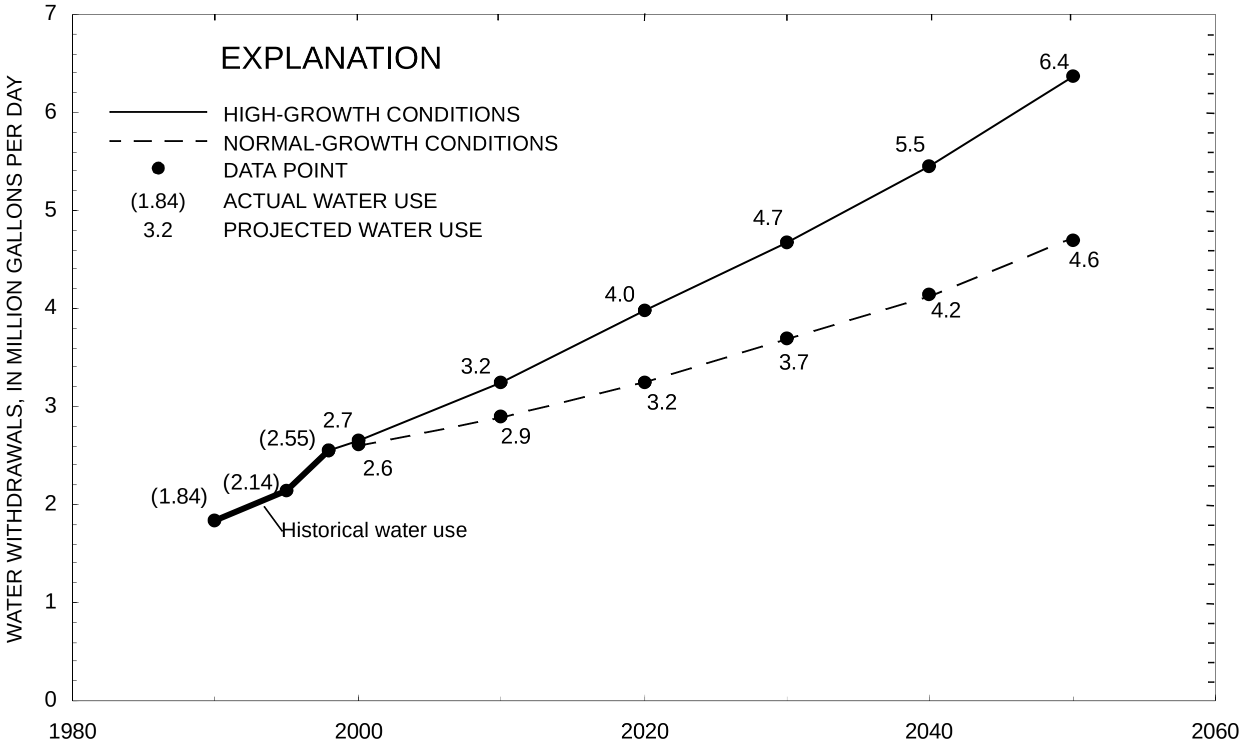


Figure 6. Municipal water withdrawals for 1990, 1995, and 1998 and estimates of future withdrawals for 2000, 2010, 2020, 2030, 2040, and 2050 for normal- and high-growth conditions for Union County, Mississippi.

The uncertainty in the forecast of water demand is embedded in the projections of values for population, employment, and median household income for normal- and high-growth scenarios (Appendix A) and assumptions about water conservation. Together, the normal- and high-growth projections provide a range within which growth can reasonably occur as summarized in table 5. Further, within the residential water-demand model, uncertainty is introduced in calculating the coefficient of elasticity for median household income. The elasticity used to calculate the coefficient is a literature value (0.4) rather than one determined by site-specific data.

SIMULATION OF PROJECTED GROUND-WATER LEVELS

A calibrated ground-water flow model was used to simulate projected water levels for the Cretaceous-Paleozoic aquifer system in northeastern Mississippi. A thorough description of model construction and boundary conditions is presented in Strom (1998); however, an abbreviated model description pertinent to the Coffee Sand and Eutaw-McShan aquifers is presented below.

Ground-Water Model Description

The ground-water model was constructed using the finite-difference computer code MODFLOW (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996). The model grid covered 34,960 mi^2 and was oriented north-south because no predominant axes of transmissivity for the aquifers were indicated by the data. A lateral anisotropy ratio of 1 was used in the simulations. Each grid layer consisted of 230 rows and 152 columns with each grid cell 1 mile square. The model was vertically discretized into 6 layers resulting in a total of 209,760 grid cells. Layers 1, 2, and 3 represented the Coffee Sand, Eutaw-McShan, and Gordo aquifers, respectively. The Coker and Iowa aquifers were represented by layer 4, and the massive sand and Devonian aquifers were represented by layer 5. Although the Coker and Iowa, and the massive sand and Devonian aquifers are not stratigraphically related, those aquifers can be simulated on shared

Table 5. Projected water demand for residential water use for scenarios of normal growth and high growth

[Normal- and high-growth projections include a reduction for water-conservation; Mgal/d, million gallons per day]

Year	Projected water demand	
	Normal growth, in Mgal/d	High growth, in Mgal/d
2010	2.1	2.4
2020	2.4	2.9
2030	2.7	3.4
2040	3.0	3.9
2050	3.4	4.6

layers because their boundaries do not areally coincide. The Lower Cretaceous aquifer was represented by layer 6.

Model boundaries determine where and how much water enters and leaves the model; therefore, the selection of appropriate boundaries for the aquifers is a major concern. The selection of model boundaries for the aquifers in this model was based on a conceptual interpretation of the flow system developed by using information reported by Boswell (1963, 1978); Boswell and others (1965); Cushing (1966); Hardeman (1966); Bicker (1969); Gandl (1982); Wasson (1986); Davis (1987); E.H. Boswell, J.F. Everett, D.L. Hardin, J.H. Hoffman, S.P. Jennings, P.A. Phillips (Mississippi Office of Land and Water Resources, oral commun., 1993); Jennings (1994); J.H. Hoffmann (Mississippi Office of Land and Water Resources, oral commun., 1997), and S.P. Jennings (Mississippi Office of Land and Water Resources, written commun., 1997).

The Coffee Sand aquifer is overlain by a thick, relatively impermeable sequence of units in the Selma Group; therefore, the area overlying the Coffee Sand aquifer was simulated as a no-flow boundary. Layer 1 represents the Coffee Sand aquifer in the northern part of the model, but also represents an upper constant-head boundary for the Eutaw-McShan aquifer (layer 2) in the southeastern part of the model area. The constant heads overlying the Eutaw-McShan in this region represent surficial water levels in the chalk and clay overlying the Eutaw-McShan aquifer. However, most of this potential water is hydraulically separated from the Eutaw-McShan by the clay and chalk confining unit that sharply thickens westward, limiting most vertical flow due to the low vertical hydraulic conductivity of the confining unit.

The downdip extent of freshwater (defined for the purposes of this study as a concentration of 10,000 milligrams per liter of dissolved solids) represents no-flow lateral boundaries for all of the aquifers because of the contrast in density across the freshwater-saltwater interface. Previous investigations (Mallory, 1993; Arthur, 1994; Strom and Mallory, 1995) have indicated that this contrast in density effectively eliminates horizontal movement. A no-flow boundary at this location assumes a stable downdip, freshwater-saltwater interface. For many of the aquifers, the region where the dissolved-solids concentrations are between 1,000 to 10,000 milligrams per liter is relatively small, which also implies there is little mixing of water and flow is parallel to the freshwater-saltwater interface. If flow were to occur across the interface in the downdip direction, flow would eventually move upward at some point to discharge; flow upward is unlikely, however, because the confining units above the Eutaw-McShan thicken to the southwest in the downdip direction to more than 1,500 feet near the freshwater-saltwater interface. Any substantial upward flow would be through secondary structural features, such as faults.

The northern or northwestern boundaries of the Coffee Sand and Eutaw-McShan aquifers represent the limits of the sediments and are simulated as no-flow boundaries (figs. 3 and 4, respectively). The southeastern boundary of the Eutaw-McShan is also simulated as a no-flow boundary. The southeastern boundary is at a lateral ground-water flow divide formed by the Tombigbee and Black Warrior Rivers. Water-level data indicate that these rivers, particularly near their confluence, are major discharge areas for the Eutaw-McShan aquifer, with lateral flow converging from both the east and the west captured by the river channels (Gardner, 1981). Consequently, no lateral flow is assumed to move beneath the Tombigbee and Black Warrior Rivers. Ground water in this area is discharged by upward leakance through the confining units.

An average of about 52 inches per year of precipitation falls on the aquifer outcrop areas in northeastern Mississippi (National Oceanic and Atmospheric Administration, 1981). Only a small fraction of this amount enters the ground-water flow system as recharge. Some of the water that enters the ground-water flow system travels only a short distance before being discharged locally into streams and other drains. The digital model does not simulate all the localized flow because of the 1-mile grid discretization. The model simulations represent the intermediate and regional scale flow system. The outcrop areas of the Coffee Sand and Eutaw-McShan aquifers were simulated with head-dependent flux boundaries. This was implemented using the river package in MODFLOW (Harbaugh and McDonald, 1996). The large base flows observed in even small streams in the outcrop area indicate that recharge from the precipitation-rich environment is more than sufficient to provide all the recharge that the aquifers can accept; however, much of the potential recharge is rejected by the aquifers and diverted into surface runoff due to the limited lateral transmissivities of the aquifers. The minimum land-surface altitude in each outcrop grid cell, which approximates stream base-flow water-level elevations, represents the river stages in the river package.

Projected Ground-Water Levels

Projection simulations were made using baseline-, normal-, and high-growth water-use demands. The simulated potentiometric surfaces of the Coffee Sand and Eutaw-McShan aquifers for year 2000 (figs. 7 and 8, respectively) serve as a reference for near-current conditions from which water-level changes are discussed.

Baseline Projections

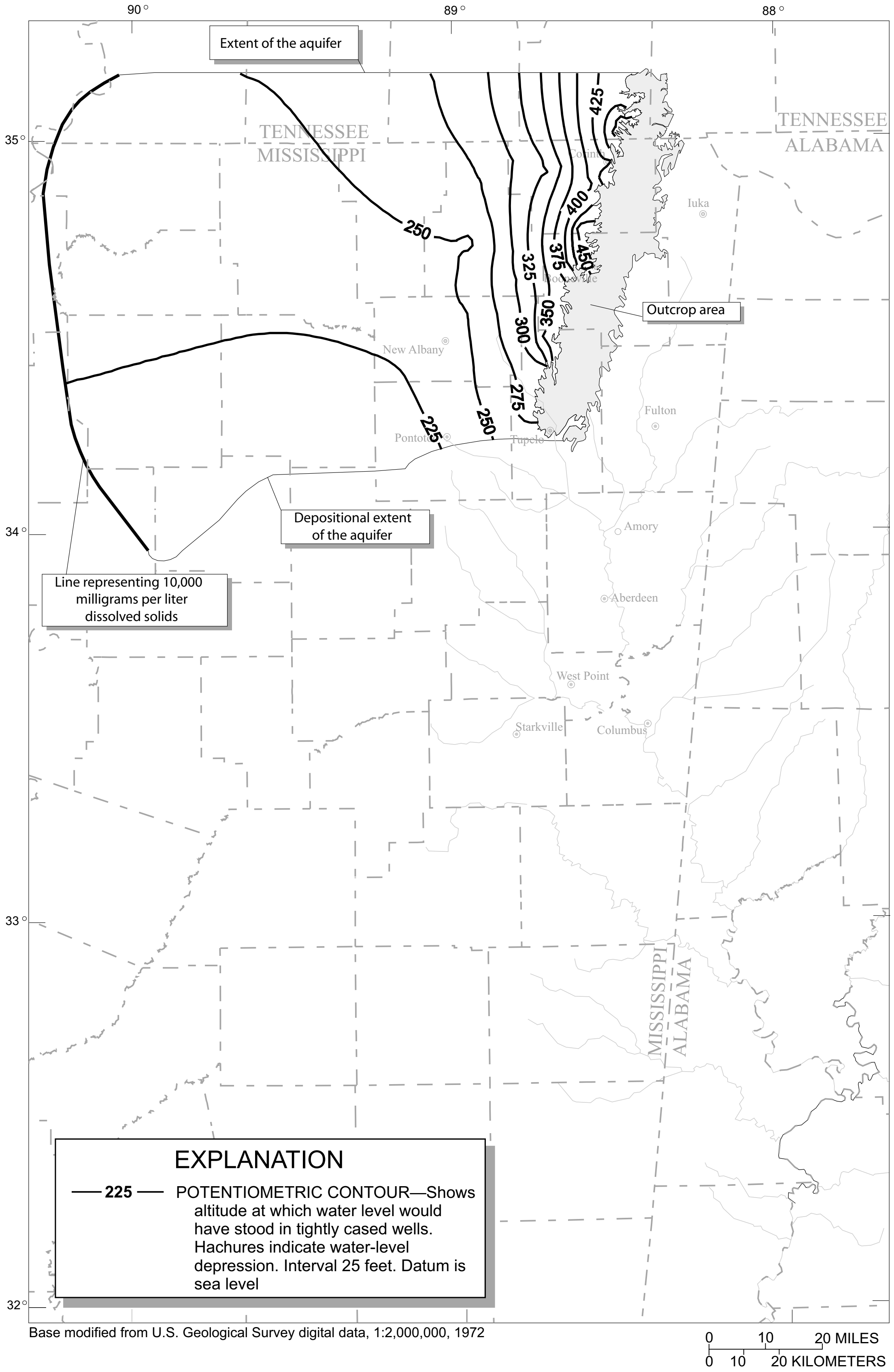
An annual increase of 1.03 percent in water use was used as the baseline projection simulations for the Coffee Sand and Eutaw-McShan aquifers for years 2000 to 2050 for all of the aquifers and areas in the model. For the Coffee Sand aquifer (fig. 9), this increase resulted in about 30 feet of additional water-level drawdown from simulated year 2000 water levels in the eastern part of Union County to a little more than 70 feet of drawdown in the western part of the county. In the New Albany area, simulated drawdowns in the Coffee Sand aquifer were about 65 feet below year 2000 water levels.

For the Eutaw-McShan aquifer, baseline projections (fig. 10) resulted in a cone of drawdown centered around the New Albany area of Union County. The cone shows drawdowns of about 80 feet from year 2000 water levels along its edges, with a maximum drawdown at the center of about 120 feet. The resulting projected water level for the year 2050 at the center of the drawdown cone in the New Albany area is between 500 and 550 feet above the top of the Eutaw-McShan aquifer.

Normal-Growth Projections

The normal-growth projection simulations for the Coffee Sand and Eutaw-McShan aquifers used output data from the Union County water-demand model for normal growth and an annual increase of 1.03 percent in water use for years 2001 to 2050 for other areas in the model. For the Coffee Sand aquifer (fig. 11), this increase resulted in about 30 feet of additional drawdown from simulated year 2000 water levels in the eastern part of Union County to a little more than 70 feet of drawdown in the western part of the county. In the New Albany area, simulated drawdowns in the Coffee Sand aquifer were about 65 feet below 2000 water levels.

For the Eutaw-McShan aquifer, normal-growth projections (fig. 12) resulted in a cone of drawdown centered around the New Albany area of Union County. The cone shows drawdowns of about 80 feet from 2000 water levels along its edges, with a maximum drawdown at its center of about 135 feet. The resulting projected water level for the year 2050 at the center of the drawdown cone in the New Albany area is between 500 and 550 feet above the top of the Eutaw-McShan aquifer.



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Figure 7. Simulated 2000 potentiometric surface of the Coffee Sand aquifer, Mississippi and Tennessee.

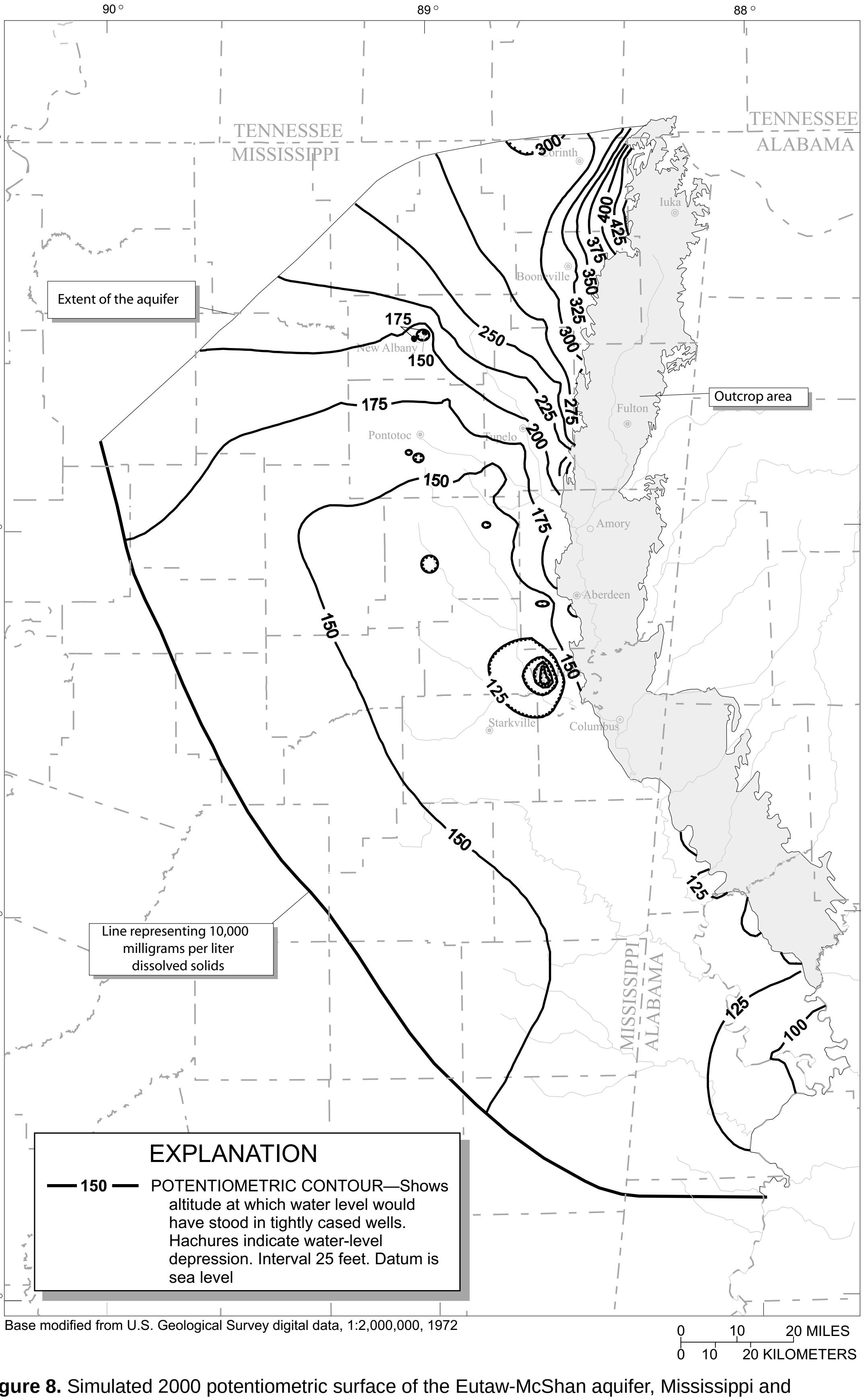
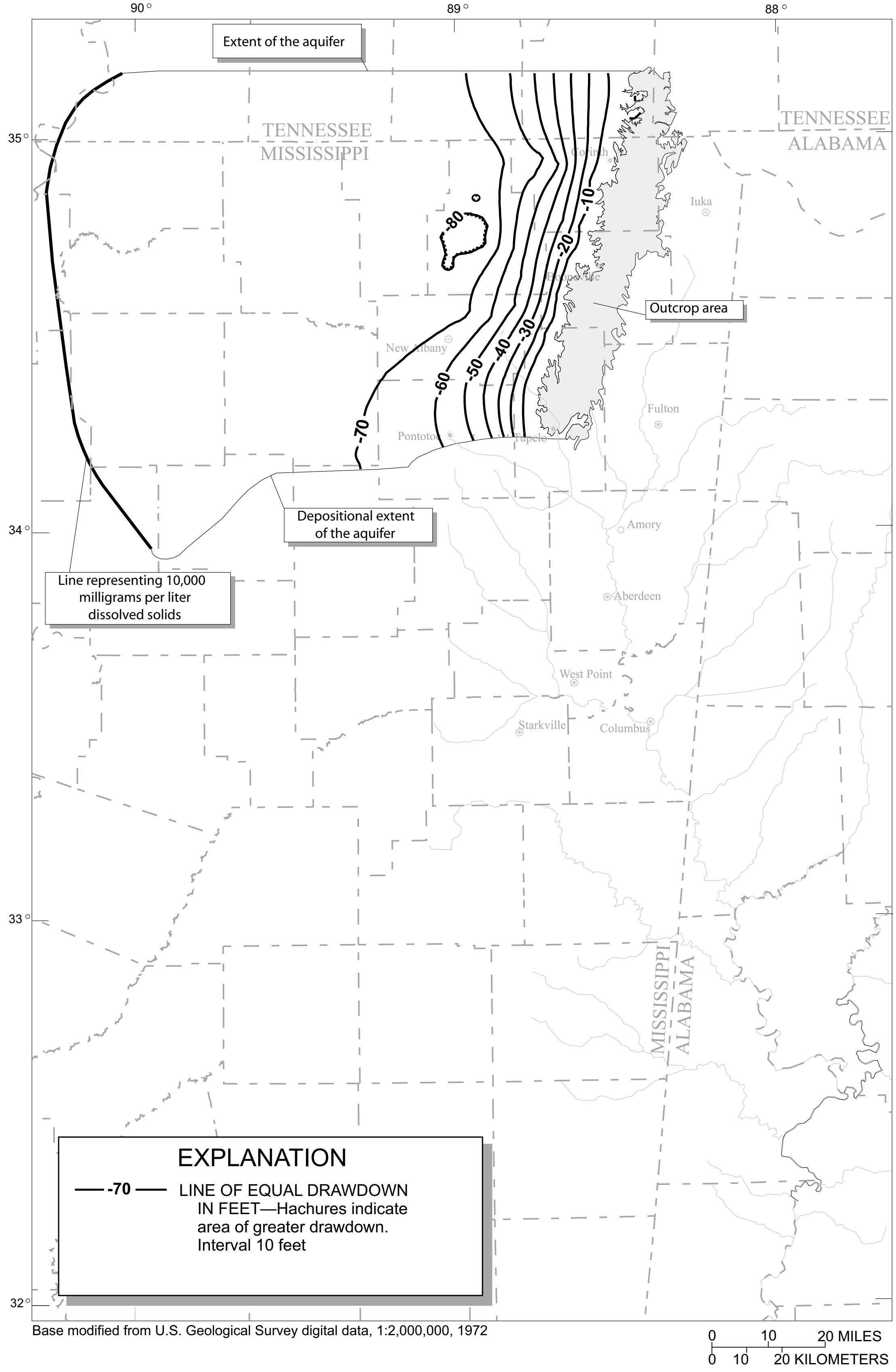
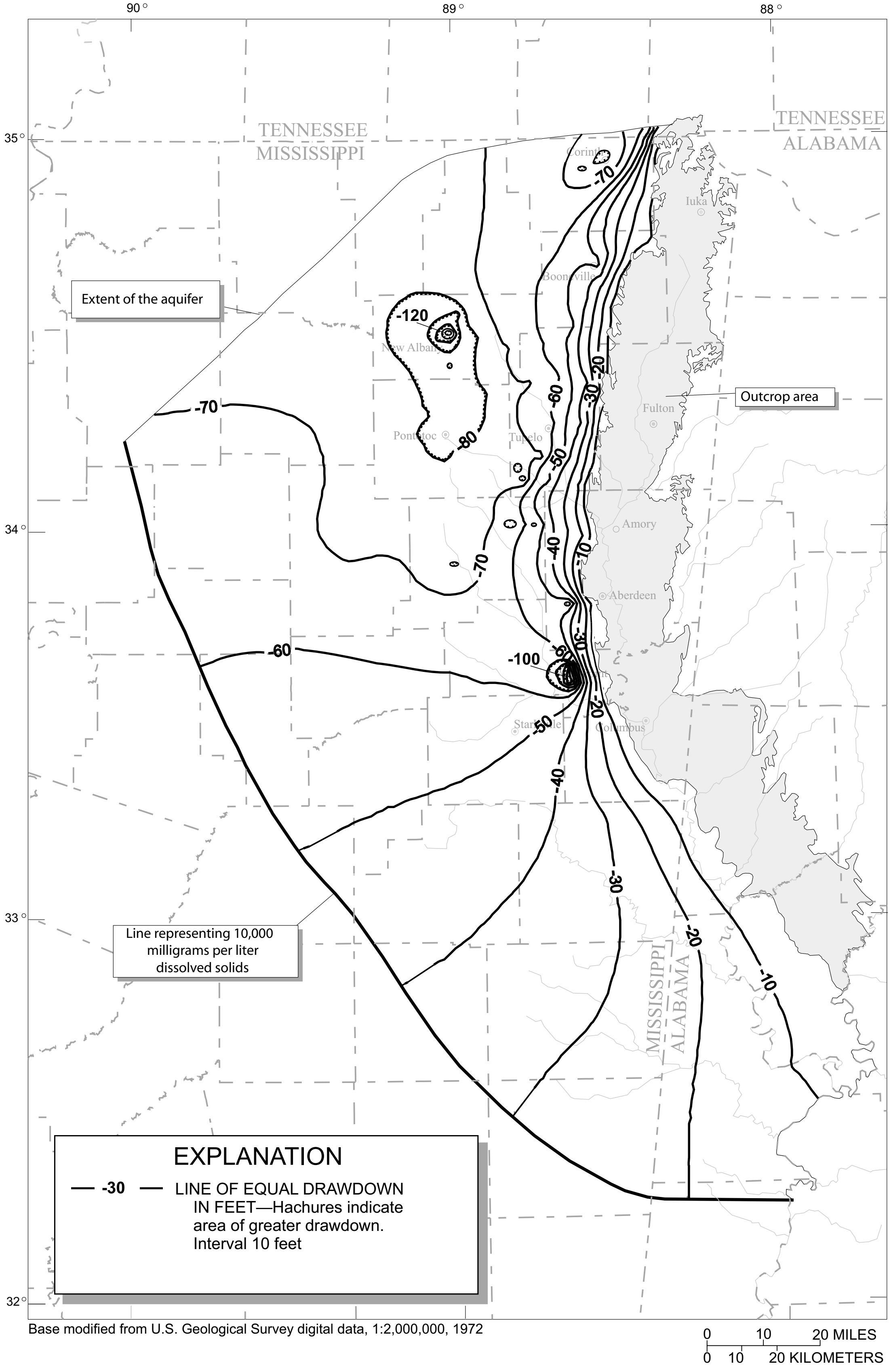


Figure 8. Simulated 2000 potentiometric surface of the Eutaw-McShan aquifer, Mississippi and Alabama.



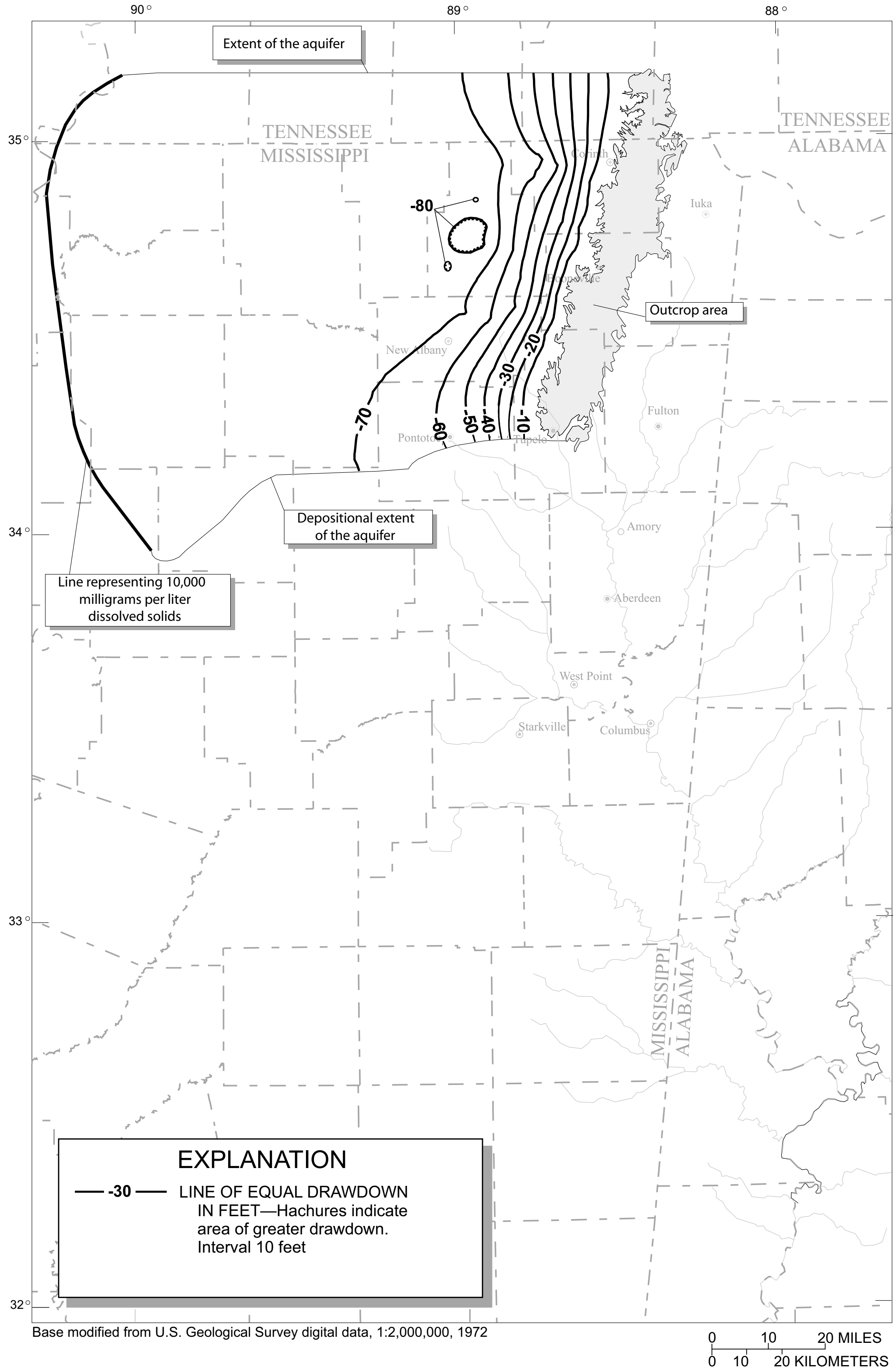
Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Figure 9. Simulated water-level drawdowns from 2000 to 2050 in the Coffee Sand aquifer, Mississippi and Tennessee, using an annual pumpage increase of 1.03 percent.



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Figure 10. Simulated water-level drawdowns from 2000 to 2050 in the Eutaw-McShan aquifer, Mississippi and Alabama, using an annual pumpage increase of 1.03 percent.



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Figure 11. Simulated water-level drawdowns from 2000 to 2050 in the Coffee Sand aquifer, Mississippi and Tennessee, using a normal-growth water-use projection for Union County and an annual pumpage increase of 1.03 percent in other areas.

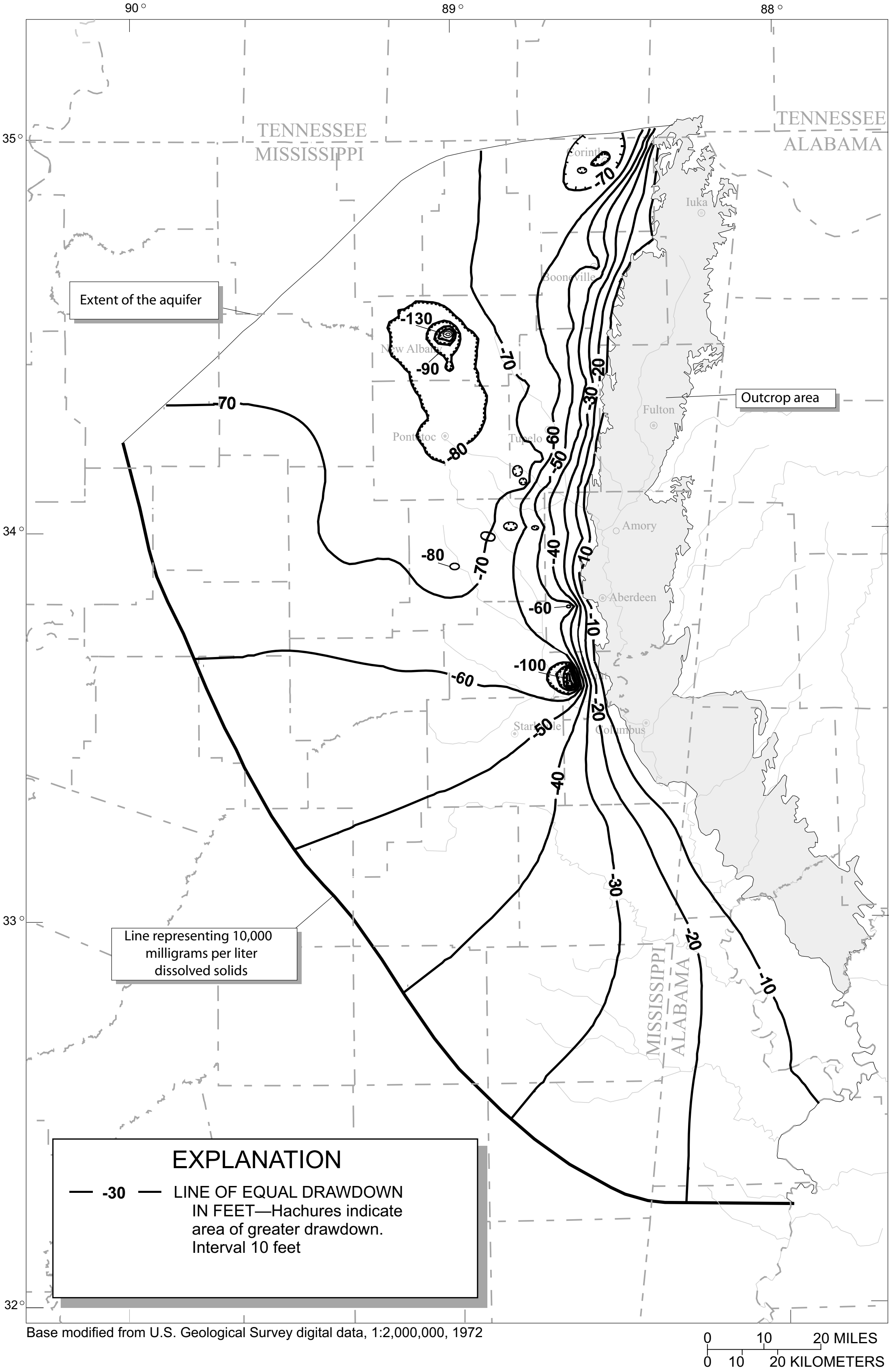


Figure 12. Simulated water-level drawdowns from 2000 to 2050 in the Eutaw-McShan aquifer, Mississippi and Alabama, using a normal-growth water-use projection for Union County and an annual pumpage increase of 1.03 percent in other areas.

High-Growth Projections

The high-growth projection simulations for the Coffee Sand and Eutaw-McShan aquifers used the output data from the Union County water-demand model for high growth and an annual increase of 1.03 percent in water use for years 2001 to 2050 for other areas in the model. For the Coffee Sand aquifer (fig. 13), this resulted in about 30 feet of additional drawdown from simulated year 2000 water levels in the eastern part of Union County to a little more than 80 feet of drawdown in the western part of the county. In the New Albany area, simulated drawdowns in the Coffee Sand aquifer were about 75 feet below year 2000 water levels.

For the Eutaw-McShan aquifer, high-growth projections (fig. 14) resulted in a cone of drawdown centered around the New Albany area of Union County. The cone shows drawdowns of about 90 feet from 2000 water levels along its edges, with a maximum drawdown at its center of about 190 feet. The resulting projected water level for the year 2050 at the center of the drawdown cone in the New Albany area is between 450 and 500 feet above the top of the Eutaw-McShan aquifer.

MODEL LIMITATIONS

The results of this investigation, to project future water demand in New Albany and to evaluate the response of the aquifers to increased pumping to meet that demand, are based on the IWR-MAIN and MODFLOW models. The results of both models depend on the data used to define model conditions and on the assumptions made to simulate actual conditions. As with any model, the degree of uncertainty increases the further out in time that projections are made. A projection of 52 years (1998-2050) assumes many political, environmental, economic, and technical factors will not shift radically.

IWR-MAIN is used primarily to test assumptions and the effect various assumptions or changes would have on water use in the WSA rather than as a predictive tool to generate absolute amounts in the future. This fact and basic assumptions about growth, land use, population, and technology determine the results. If the assumptions change (for example, if population decreases in the area), water-demand results will change. The accuracy of the results depends on the validity of the assumptions.

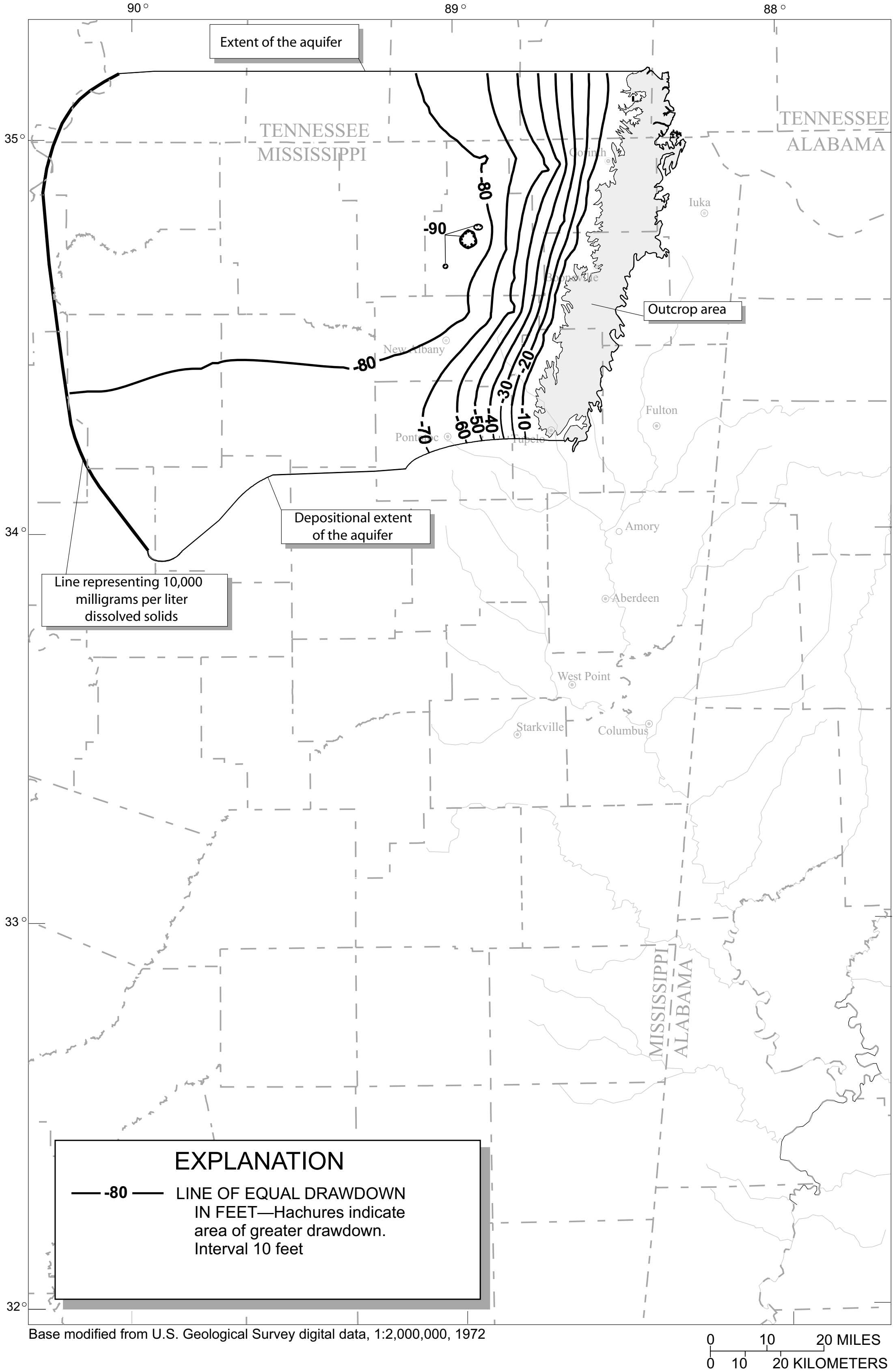
The accuracy of ground-water models is limited by the assumptions made in formulating the governing flow equations and in the assumptions made during model construction. Models are limited by cell size, number of layers, boundary conditions, time discretization, hydraulic values, accuracy of calibration, verification data, and parameter sensitivity. Models also are limited by the availability of data and the interpolations and extrapolations of available data in a model. The model may be calibrated and verified, but the calibrated parameter values may not be unique in satisfying a particular distribution of hydraulic head.

The model used in this study is suitable for analyzing ground-water flow on a regional scale. Site-specific analysis is limited by horizontal and vertical discretization of the model and the availability of site-specific data. The model calculates an average head for the entire cell area (1 square mile), which may not be a good approximation for the water level in an individual well. The transmissivity and other hydraulic data for an aquifer are assumed constant in each 1-mi^2 grid cell.

The ground-water flow model should not be used for analysis if large pumpages are placed near boundaries representing the outcrop area (a head-dependent flux boundary), near a ground-water flow divide (the Tombigbee River), or near the downdip limit of freshwater. The assumption of a fixed freshwater-saltwater interface boundary used in the downdip areas of the aquifers may not be valid if large-capacity pumping wells were placed nearby. The model is not designed to estimate movement of the freshwater-saltwater interface or to evaluate any change in water quality.

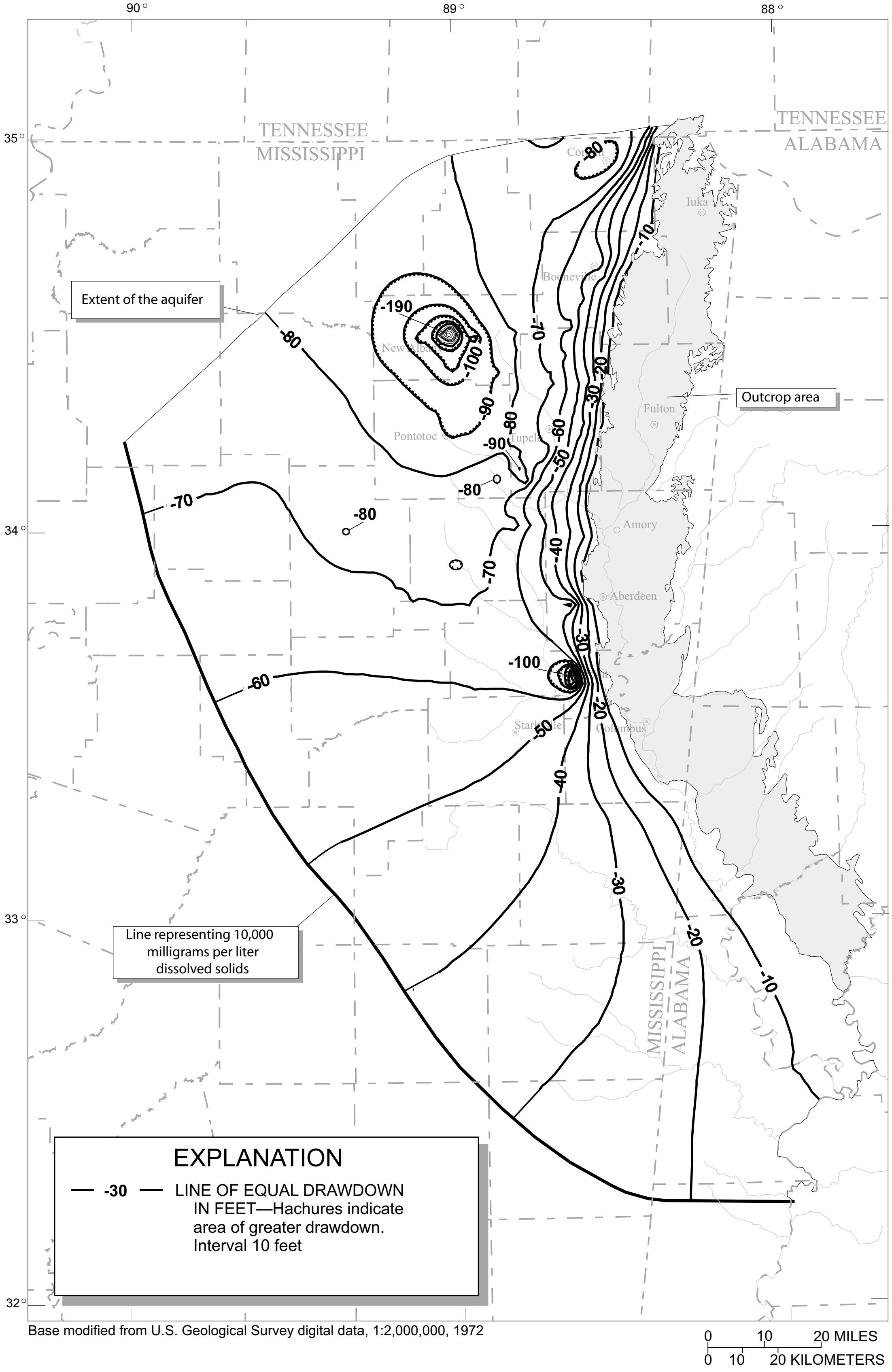
Sand and clay thickness maps used to develop the calibrated model are based on total thicknesses for the units derived from borehole-geophysical log analyses that were gridded to a 1-mi^2 grid. In some areas, sand and clay thicknesses for the aquifers vary greatly over short lateral distances, and thicknesses may actually vary substantially within a grid cell. In some areas, data points were widely spaced, and sand and clay thicknesses had to be extrapolated or interpolated over a broad area, possibly misrepresenting actual conditions where data were not available.

The best available historical pumpage estimates were used in the simulations (J.H. Hoffmann and A.J. Warner, Mississippi Office of Land and Water Resources, written commun., 1997); however, determining the exact values of historical pumpage for the



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Figure 13. Simulated water-level drawdowns from 2000 to 2050 in the Coffee Sand aquifer, Mississippi and Tennessee, using a high-growth water-use projection for Union County and an annual pumpage increase of 1.03 percent in other areas.



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Figure 14. Simulated water-level drawdowns from 2000 to 2050 in the Eutaw-McShan aquifer, Mississippi and Alabama, using a high-growth water-use projection for Union County and an annual pumpage increase of 1.03 percent in other areas.

aquifers is difficult. Reported pumpage values for recent years could not be verified for accuracy. If large inaccuracies in modeled pumpage exist, the model would not be considered properly calibrated.

Projected water withdrawals and the locations of these withdrawals may change over 50 years. Distributions will likely change to some degree; some large pumping centers may be added while others may cease pumping altogether. If large unforeseen changes in pumpage occur in the Union County area, the projections as simulated would be inaccurate. However, the farther away from Union County that such unforeseen changes occur, the less likely these changes will have a large affect on projections in Union County. Models are imperfect representations of a complex natural system; however, if used with caution and good judgment, they can be valuable tools.

SUMMARY

Ground water from the Eutaw-McShan and Coffee Sand aquifers, with lesser amounts withdrawn from the Gordo and Ripley aquifers, is the sole source of supply for residential, commercial, and industrial purposes in Union County, Mississippi. The recent accelerated rate of growth of the population and of the economy in Union County suggests that the need for additional ground water will increase in the future. Long-term projections are needed to determine if the aquifers can supply anticipated future municipal and nonmunicipal water demands for the water-service area to the year 2050.

Detailed water-use data and ancillary information for residential, commercial, and industrial sectors were collected for the 12 public-supply facilities and for the self-supplied commercial and industrial facilities in Union County for 1998. The data were used to document water use and to construct the linear-predictive and constant-rate models contained within Forecast Manager of the IWR-MAIN Water-Demand Management Suite software. Water demand to the year 2050 was estimated by relating water use to housing and employee counts, housing and employee types, median household income, marginal price of water, water-conservation practices, and long-term temperature and precipitation data.

In 1998, total ground-water withdrawals were estimated as 2.85 Mgal/d. Of that amount, municipal withdrawals were 2.55 Mgal/d. Residential deliveries from public-supply systems accounted for 59 percent (1.50 Mgal/d) of the municipal water; commercial and industrial, 18 percent (0.456 Mgal/d); and public/unaccounted water, about 23 percent (0.594 Mgal/d). Nonmunicipal withdrawals were 0.296 Mgal/d. About 80 percent (2.27 Mgal/d) of the water is pumped from the Eutaw-McShan aquifer; about 13 percent (0.371 Mgal/d) from the Coffee Sand aquifer; about 4 percent (0.129 Mgal/d) from the Gordo aquifer; and 3 percent (0.082 Mgal/d) from the Ripley aquifer.

Simulations of water demand were made using a normal- and a high-growth scenario. In a normal-growth scenario, total water demand would increase 72 percent from 2.9 Mgal/d in year 1998 to 5.0 Mgal/d in year 2050. Municipal demand would increase from 2.6 Mgal/d to 4.6 Mgal/d, or 77 percent. In a high growth-scenario, total water demand would increase 131 percent from 2.9 Mgal/d in year 1998 to 6.7 Mgal/d in year 2050. Municipal water demand would increase 146 percent during that same period. The rate of nonmunicipal use (0.30 Mgal/d) was held constant for the forecast years for both scenarios.

Simulations of projected ground-water levels were made using baseline-, normal-, and high-growth water demands. The ground-water model was constructed using the U.S. Geological Survey finite-difference computer code MODFLOW. The model had been previously calibrated as part of an earlier (1998) study of the aquifers comprising formations of Cretaceous and Paleozoic age in northeastern Mississippi. The calibrated ground-water flow model used in that investigation encompassed the entire area originally simulated to account for boundary conditions and to maintain calibration. Although the study area of the model corresponds to the area included in the ground-water flow model, the focus of this investigation was Union County.

An annual increase of 1.03 percent in water use was used for the baseline projection simulations for the Coffee Sand and Eutaw-McShan aquifers for years 2001 to 2050. In the New Albany area, simulated drawdowns in the Coffee Sand aquifer were about 65 feet below year 2000 water levels. At the center of a cone of depression in the New Albany area, simulated drawdowns in the Eutaw-McShan aquifer were about 120 feet for the year 2050. The resulting projected water level at the center of the drawdown cone in the New Albany area is between 500 and 550 feet above the top of the Eutaw-McShan aquifer.

The normal- and high-growth projection simulations for the Coffee Sand and Eutaw-McShan aquifers used the normal- and high-growth output data from the water-demand model for Union County, and an annual increase of 1.03 percent in water use for years 2001 to 2050 for other areas in the model. For normal-growth projections, simulated drawdowns in the Coffee Sand aquifer in the New Albany area were about 65 feet below year 2000 water levels. For high-growth projections, simulated drawdowns in the Coffee Sand aquifer were about 75 feet below year 2000 water levels.

For the Eutaw-McShan aquifer, normal-growth projections resulted in a cone of drawdown centered on the New Albany area of Union County. The cone shows a maximum drawdown at the center of about 135 feet. The resulting projected water level for the year 2050 at the center of the drawdown cone in the New Albany area is between 500 and 550 feet above the top of the Eutaw-McShan aquifer. For high-growth projections, the cone shows a maximum drawdown at the center of about 190 feet. The projected water level for the year 2050 at the center of the drawdown cone in the New Albany area is between 450 and 500 feet above the top of the Eutaw-McShan aquifer.

SELECTED REFERENCES

American Water Works Association, 1992, Water industry data base: utility profiles: Denver, American Water Works Association, 116 p.

Arthur, J.K., 1994, Generalized description and analysis of ground-water flow in the Cockfield and Sparta aquifers in Hinds, Madison, and Rankin Counties, Mississippi: U.S. Geological Survey Water-Resources Investigations Report 93-4143, 103 p.

Bicker, A.R., Jr., comp., 1969, Geologic map of Mississippi: Mississippi Geological Survey, 1 sheet.

Boland, J.J., Dziegiewlewski, B., Baumann, D.D., and Opitz, E.M., 1984, Influence of price and rate structures on municipal and industrial water use: Fort Belvoir, Virginia, U.S. Army Corps of Engineers Institute for Water Resources, Contract Report 84-c–2, 187 p.

Boswell, E.H., 1963, Cretaceous aquifers of northeastern Mississippi: Mississippi Board of Water Commissioners Bulletin 63-10, 202 p.

———1977, The Eutaw-McShan aquifer in Mississippi: U.S. Geological Survey Water-Resources Investigations Report 76-134, 2 sheets.

———1978, The Tuscaloosa aquifer system in Mississippi: U.S. Geological Survey Water-Resources Investigations Report 78-98, 3 sheets.

Boswell, E.H., Moore, G.K., MacCary, L.M., and others, 1965, Cretaceous aquifers in the Mississippi embayment *with discussions of* quality of the water by H.G. Jeffery: U.S. Geological Survey Professional Paper 448-C, 37 p.

Callahan, J.A., 1979, Public and industrial water supplies in northern Mississippi, 1975: Mississippi Board of Water Commissioners Bulletin 79-1, 79 p.

Crider, A.F., and Johnson, L.C., 1906, Summary of the underground-water resources of Mississippi: U.S. Geological Survey Water-Supply Paper 159, 86 p.

Cushing, E.M., 1966, Map showing altitude of the base of fresh water in coastal plain aquifers of the Mississippi embayment: U.S. Geological Survey Hydrologic Investigations Atlas HA-221, 1 sheet.

Cushing, E.M., Boswell, E.H., and Hosman, R.L., 1964, General geology of the Mississippi embayment: U.S. Geological Survey Professional Paper 448-B, 28 p.

Darden, D., 1984, Potentiometric map of the Gordo aquifer in northeastern Mississippi, November and December 1982: U.S. Geological Survey Water-Resources Investigations Report 83-4243, 1 sheet.

———1985, Potentiometric map of the Eutaw-McShan aquifer in northeastern Mississippi, fall 1982: U.S. Geological Survey Water-Resources Investigations Report 85-4042, 1 sheet.

Davis, M.E., 1987, Stratigraphic and hydrogeologic framework of the Alabama Coastal Plain: U.S. Geological Survey Water-Resources Investigations Report 87-4112, 39 p.

Domenico, P.A., and Schwartz, F.W., 1990, Physical and chemical hydrogeology: New York, John Wiley and Sons, 824 p.

Driscoll, F.G., 1989, Groundwater and wells: St. Paul, Johnson Filtration Systems, Inc., 1089 p.

Everett, J.F., and Jennings, S.P., 1994, Potentiometric map of the Eutaw-McShan aquifer in northeastern Mississippi fall and winter, 1992: Mississippi Department of Environmental Quality OLWR Hydrologic Map 93-3, 1 sheet.

Fenneman, N.M., 1938, Physiography of the Eastern United States: New York, McGraw-Hill, p. 67-83.

Gandl, L.A., 1982, Characterization of aquifers designated as potential drinking water sources in Mississippi: U.S. Geological Survey Open-File Report 81-550, 90 p.

Gardner, R.A., 1981, Model of the ground-water flow system of the Gordo and Eutaw aquifers in west-central Alabama: Geological Survey of Alabama Bulletin 118, 30 p.

Goldsmith, G.D.S., 1990, Potentiometric-surface map of the Gordo aquifer in northeastern Mississippi, August through December 1987: U.S. Geological Survey Water-Resources Investigations Report 89-4060, 1 sheet.

———1991, Potentiometric-surface map of the Eutaw-McShan aquifer in northeastern Mississippi, August through December 1987: U.S. Geological Survey Water-Resources Investigations Report 90-4157, 1 sheet.

Harbaugh, A.W., and McDonald, M.G., 1996, User’s documentation for MODFLOW-96, an update to the U.S. Geological Survey modular finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 96-485, 56 p.

Hardeman, W.D., 1966, Geologic map of Tennessee, west sheet: Tennessee Division of Geology, scale 1:250,000.

Hardin, D.L., and Everett, J.F., 1994, Potentiometric map of the Coker and massive sand aquifers in northeastern Mississippi, fall and winter 1992: Mississippi Department of Environmental Quality OLWR Hydrologic Map 93-5, 3 sheets.

Hoffmann, J.H., and Hardin, D.L., 1994, Potentiometric map of the Coffee Sand aquifer in northeastern Mississippi, fall and winter 1992: Mississippi Department of Environmental Quality OLWR Hydrologic Map 93-2, 1 sheet.

Jennings, S.P., 1994, Hydrogeology and aquifer potential of the Paleozoic rocks of northeastern Mississippi: Mississippi Department of Environmental Quality OLWR Hydrologic Investigations Report 94-1, 54 p.

———1996, Stratigraphic test hole drilling project in northeastern Mississippi—data and results: Mississippi Department of Environmental Quality OLWR Open-File Report 96-101, 27 p.

Jennings, S.P., and Phillips, P.A., 1994, Potentiometric map of the Paleozoic aquifer in northeastern Mississippi, fall and winter 1992: Mississippi Department of Environmental Quality OLWR Hydrologic Map 93-6, 1 sheet.

Jennings, S.P., Phillips, P.A., and Hoffmann, J.H., 1994, Water levels in the Eutaw-McShan and Gordo aquifers in the Tupelo, Mississippi area–May 1991, to October 1993: Mississippi Department of Environmental Quality OLWR Open-File Report 94-101, 13 p.

Kernodle, J.M., 1981, Two-dimensional ground-water flow model of the Cretaceous aquifer system of Lee County and vicinity, Mississippi: U.S. Geological Survey Water-Resources Investigations Report 81-70, 53 p.

Lang, J.W., and Boswell, E.H., 1960, Public and industrial water supplies in a part of northern Mississippi: Mississippi Geological Survey Bulletin 90, 104 p.

Linaweaver, F.P., Jr., 1965, Residential water use: The Johns Hopkins University for the Technical Studies Program of the Federal Housing Administration, 98 p.

Maidment, D.R., Miaou, S.P., Nvule, D.N., and Buchberger, S.G., 1985, Analysis of water use in nine cities: The University of Texas at Austin, Center for Research in Water Resources, 67 p.

Mallory, M.J., 1993, Hydrogeology of the southeastern coastal plain aquifer system in parts of eastern Mississippi and western Alabama: U.S. Geological Survey Professional Paper 1410-G, 57 p.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, chap. A1, book 6, 576 p.

Mellen, F.F., 1958, Cretaceous shelf sediments of Mississippi: Mississippi Geological Survey, Bulletin 85, 112 p.

Merrill, R.K., Gann, D.E., and Jennings, S.P., 1988, Tishomingo County geology and mineral resources: Mississippi Department of Natural Resources Bulletin 127, 178 p.

National Oceanic and Atmospheric Administration, 1981, Climatological data annual summary, Mississippi: v. 86, no. 13, p. 4-5.

Newcome, Roy, Jr., 1971, Results of aquifer tests in Mississippi: Mississippi Board of Water Commissioners Bulletin 71-2, 44 p.

Oakley, W.T., and Burt, D.E., 1992, Records of public-supply wells in Mississippi, 1991: U.S. Geological Survey Open-File Report 92-82, 110 p.

Phillips, P.A., and Hoffmann, J.H., 1994, Potentiometric map of the Gordo aquifer in northeastern Mississippi fall and winter, 1992: Mississippi Department of Environmental Quality OLWR Hydrologic Map 93-4, 1 sheet.

Planert, M., and Sparkes, A.K., 1985, Estimation of vertical hydraulic conductivity of the clay layer between the Eutaw and Gordo aquifers in the vicinity of Faunsdale, Marengo County, Alabama: U.S. Geological Survey Water-Resources Investigations Report 85-4083, 23 p.

Planning and Management Consultants, Ltd., 1995, IWR-MAIN water demand analysis software, version 6.1, user's manual and system description: Carbondale, Ill., Planning and Management Consultants, Ltd., 159 p.

———1999, IWR-MAIN water demand management suite, user's manual and system description, 85 p.

Poland, J.F., Lofgren, B.E., and Riley, F.S., 1972, Glossary of selected terms useful in studies of the mechanics of aquifer systems and land subsidence due to fluid withdrawal: U.S. Geological Survey Water-Supply Paper 2025, 9 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.

Stephenson, L.W., Logan, W.N., and Waring, G.A., 1928, The ground-water resources of Mississippi, *with discussions of* the chemical character of the waters by C.S. Howard: U.S. Geological Survey Water-Supply Paper 576, 515 p.

Strom, E.W., 1998, Hydrogeology and simulation of ground-water flow in the Cretaceous-Paleozoic aquifer system in northeastern Mississippi: U.S. Geological Survey Water-Resources Investigations Report 98-4171, 81 p.

Strom, E.W., and Mallory, M.J., 1995, Hydrogeology and simulation of ground-water flow in the Eutaw-McShan aquifer and in the Tuscaloosa aquifer system in northeastern Mississippi: U.S. Geological Survey Water-Resources Investigations Report 94-4223, 83 p.

U.S. Army Corps of Engineers, 1988, IWR-MAIN water use forecasting system, version 5.1: Fort Belvoir, Va., Water Resources Support Center, Institute for Water Resources, 324 p.

U.S. Department of Commerce, 1992a, 1990 Census of housing, general housing characteristics, Mississippi: U.S. Government Printing Office, 1990 CH-1-26, 236 p.

———1992b, 1990 Census of population and housing, summary social, economic, and housing characteristics, Mississippi: U.S. Government Printing Office, 1990 CPH-5-26, 198 p.

———1992c, 1990 Census of population, general population characteristics, Mississippi: U.S. Government Printing Office, 1990 CP–1–26, 327 p.

Wasson, B.E., 1979, Potentiometric map of the Paleozoic aquifer in northeastern Mississippi, October and November 1978: U.S. Geological Survey Open-File Report 79-71, 1 sheet, scale 1:500,000.

———1980a, Potentiometric map of the Coffee Sand aquifer in northeastern Mississippi, October and November 1978: U.S. Geological Survey Open-File Report 79-1587, 1 sheet.

———1980b, Potentiometric map of the Eutaw-McShan aquifer in northeastern Mississippi, September, October, and November 1978: U.S. Geological Survey Open-File Report 79-1584, 1 sheet.

———1980c, Potentiometric map of the Gordo aquifer in northeastern Mississippi, September, October, and November 1978: U.S. Geological Survey Open-File Report 79-1586, 1 sheet.

———1986, Sources for water supplies in Mississippi: Mississippi Research and Development Center Bulletin, 113 p.

Wasson, B.E., and Thomson, F.H., 1970, Water resources of Lee County, Mississippi: U.S. Geological Survey Water-Supply Paper 1899-B, 63 p.

APPENDIX A. Derivation and methodology of the projections for population, employment, and median household income for Union County, Mississippi

APPENDIX A. Derivation and methodology of the projections for population, employment, and median household income for Union County, Mississippi

Projections of population, employment, and median household income to the year 2050 were prepared for this study by Dr. James H. Eblen, Tennessee Valley Authority (written commun., 1999). The methodology and results were reviewed by Dr. Charles Campbell, Economist, Mississippi State University (written commun., 1999). The following counties are included in the Tennessee Valley Authority (TVA) area of northeastern Mississippi: Alcorn, Atalla, Benton, Calhoun, Chickasaw, Choctaw, Clay, Itawamba, Kemper, Lafayette, Leake, Lee, Lowndes, Marshall, Monroe, Neshoba, Noxubee, Oktibbeha, Panola, Pontotoc, Prentiss, Tallahatchie, Scott (south of Leake County), Tate, Tippah, Tishomingo, Union, Webster, Winston, and Yalobusha (fig. 1).

The economy of any small area, such as a county, depends on the economy of a larger area. Union County is a part of the economy of northeastern Mississippi and of the Nation. Therefore, forecasts and projections for these larger areas were utilized, to the extent available, to prepare the projections for Union County.

Specific forecasts and projections include TVA economic forecasts for northeastern Mississippi and corresponding national forecasts to the year 2021, along with U.S. Census Bureau projections of the population of the United States to 2050. The northeastern Mississippi forecasts were generated by TVA's Economic Forecasting system, whereas national forecasts are from Standard and Poor, Data Resources Incorporated (DRI). A linear-trend model was used to prepare the Union County projections. Trends were applied either to the data series itself or to a derived data series that shows the relation between the data series and a related series for northeastern Mississippi or for the Nation. The derived series are the "shares" referred to later in this Appendix.

A projection extends the past into the future and is an accurate predictor of the future only if the future events follow the pattern established by that segment of the past. The projections provide a range of values for population, employment, and income. The normal-growth projections in this study show what would happen if the growth pattern of the last two decades continues. For the high end, alternative projections were developed by various methodologies designed to capture the likely impacts of continued development at the higher rates seen during the last few years. Together, the normal- and high-growth projections provide a range within which growth can reasonably be expected to occur.

The normal-growth projections of population, total employment, and manufacturing employment growth for Union County since 1989 were calculated to 2021. The county shares of the northeastern Mississippi area are projected to continue to change at a reduced or dampened rate in the same direction as indicated by the trend since 1989. The dampening effect assumes that by 2021, the county will be growing at the same rate that northeastern Mississippi is growing. Projections were extended from 2021 to 2050 by extending the linear trend of the relation of each variable to changes in the population of the United States (table A1).

For normal-growth projections of median household income, a linear trend was used to calculate the United States median household income to 2050 by using data from 1979 to 1997. Then for Union County, the linear trend of median household income as a percentage of the national median household income was extended to 2010. From 2010 to 2050, the assumption was made that the median household income would increase at the national rate.

High-growth projections of population for Union County were calculated by a linear trend line from 1995. The decision to begin the historical period with 1995 assumed that the relatively high-growth rate from 1995 to 1998 would continue.

High-growth projections of total employment to the year 2021 for Union County were calculated similarly to the high-growth projections of population. These shares were then extended to 2050 by using the relation of total employment to the United States population. The employment projection for 1998 was adjusted to account for the recent job increases associated with a new major facility. A linear trend based on 1995 to 1998 employee counts was then used to project total employment to 2050. High-growth projections of manufacturing employment were determined by a linear extension for Union County trends. Nonmanufacturing employment is the difference between the total and the manufacturing employment (table A2).

High-growth projections of median household income were prepared by adjusting the normal-growth projections upward by the difference in the DRI control and high forecasts for the Nation. Ratios were held constant after 2021, the last year of the DRI forecast.

Table A1. Projections for population, employment, and median household income for a normal-growth scenario for Union County, Mississippi, to the year 2050

[--, no data; Input data to the Economic Forecasting system are from the files of the Tennessee Valley Authority, Economic Development, and are shown in **bold** type.]

Year	Population	Total employment	Manufacturing	Non-manufacturing	Median household income, in 1998 constant dollars
1979	--	--	--	--	**25,817**
1989	**22,194**	**9,669**	**3,705**	**5,964**	**27,773**
1990	**22,085**	**9,893**	**3,816**	**6,077**	Not available
1995	**22,841**	**11,051**	**4,254**	**6,797**	**29,980**
1996	**23,129**	**11,108**	**3,783**	**7,325**	**30,300**
1997	**23,568**	**11,342**	**3,686**	**7,656**	**31,228**
1998	**23,828**	**11,533**	**3,733**	**7,800**	32,458
2000	24,141	11,813	3,730	8,083	33,687
2010	26,139	13,529	4,075	9,454	42,714
2020	27,599	14,495	3,849	10,646	48,140
2030	29,369	16,388	3,782	12,607	53,566
2040	30,950	18,084	3,640	14,444	58,992
2050	32,557	19,898	3,456	16,442	64,417

Table A2. Projections for population, employment, and median household income for a high-growth scenario for Union County, Mississippi, to the year 2050

[--, no data; Input data to the Economic Forecasting system are from the files of the Tennessee Valley Authority, Economic Development, and are shown in **bold** type]

Year	Population	Total employment	Manufacturing	Non-manufacturing	Median household income, in 1998 constant dollars
1979	--	--	--	--	**25,817**
1989	**22,194**	**9,669**	**3,705**	**5,964**	**27,773**
1990	**22,085**	**9,893**	**3,816**	**6,077**	Not available
1995	**22,841**	**11,051**	**4,254**	**6,797**	**29,980**
1996	**23,129**	**11,108**	**3,783**	**7,325**	**30,300**
1997	**23,568**	**11,342**	**3,686**	**7,656**	**31,228**
1998	**23,828**	**11,884**	**3,830**	**8,054**	32,458
2000	24,532	12,303	3,836	8,467	34,176
2010	27,932	15,036	4,236	10,800	45,132
2020	31,332	17,769	4,041	13,727	52,609
2030	34,732	20,502	4,168	16,333	58,539
2040	38,132	23,235	4,256	18,978	64,468
2050	41,532	25,968	4,344	21,624	70,398