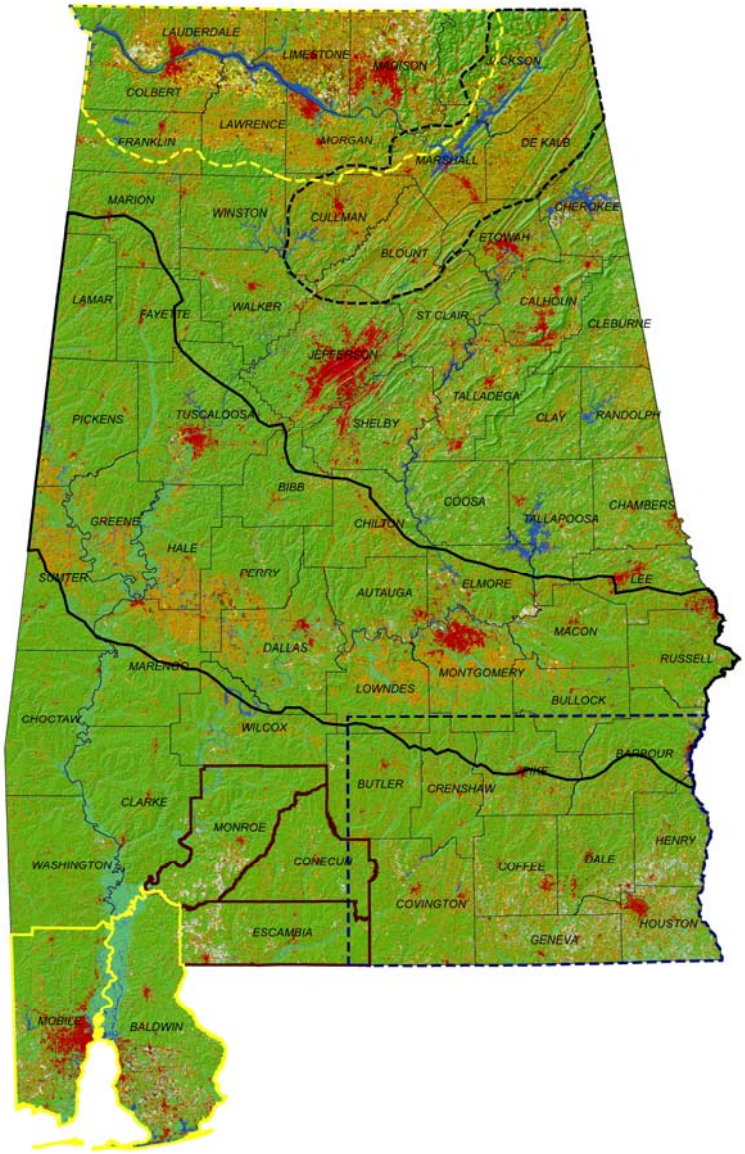
POTENTIAL FOR LARGE-SCALE IRRIGATION FROM GROUNDWATER SOURCES IN ALABAMA



GEOLOGICAL SURVEY OF ALABAMA

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GROUNDWATER ASSESSMENT PROGRAM

POTENTIAL FOR LARGE-SCALE IRRIGATION FROM GROUNDWATER SOURCES IN ALABAMA

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LIST OF ABBREVIATIONS

Advanced Wide Field Sensor	AWiFS
below land surface	bls
Cropland Data Layer	CDL
chloride	Cl
Common Land Unit	CLU
Farm Service Agency	FSA
feet	ft
feet below land surface	ft bls
feet per mile	ft/mi
gallons per minute	gpm
gallons per minute per foot	gpm/ft
horsepower	H.P.
land use/land cover	LULC
milligrams per liter	mg/L
million gallons per day	mgd
square miles	mi^2
Moderate Resolution Imaging Spectroradiometer	MODIS
mean sea level	msl
Mississippi State University Extension Service	MSUES
National Aeronautics and Space Administration	NASA
National Agricultural Statistics Service	NASS
National Elevation Dataset	NED
USGS National Land Cover Dataset	NLCD
Natural Resources Conservation Service	NRCS
pounds per square inch	psi
Safe Drinking Water Act	SDWA
State Soil Geographic	STATSGO
Source Water Assessment Area	SWAA
Source Water Assessment Program	SWAP
total dissolved solids	TDS
Tennessee River Valley Groundwater Irrigation Assessment Area	TRVGIAA
U.S. Department of Agriculture	USDA
U.S. Geological Survey	USGS

INTRODUCTION

The Alabama Irrigation Initiative is a cooperative effort involving Alabama universities and state and federal agencies to investigate the impact of irrigation on row crop agriculture and to determine potential irrigation water sources and impacts of large- scale water production for irrigation on water resources and the environment. Irrigation using groundwater resources, where available, is more reliable, less vulnerable to droughts, has fewer environmental impacts, and is more accessible for individual users compared to surface-water sourced irrigation systems. Groundwater occurs in most geological formations because nearly all rocks exhibit openings (pores or voids, or fractures) that allow infiltrating water to store and flow. However, adequate quantities for specific uses must be evaluated at the local level.

Groundwater availability depends primarily upon the geological characteristics of an environment. Since it occurs in the subsurface, groundwater cannot be readily observed, but it usually occurring in large and complex aquifer systems with highly variable spatial characteristics. Therefore, scientific evaluations of this resource may be quite complex. Nevertheless, groundwater is a readily available source in most areas at relatively low cost compared to surface water. Most groundwater resources are potable without treatment and employ low cost technologies for production and distribution.

One of the most challenging issues in determining the availability of groundwater resources is the evaluation of complex hydrogeological settings in which groundwater resides. Areas overlying fractured or karst terrain such as the Tennessee Valley and the Valley and Ridge Provinces of north Alabama (plate 1-1) have abundant groundwater resources. Yet these resources are difficult to develop given the uncertainty of where fractures or karst features occur.

Conversely, in the unconsolidated sediments of the Gulf Coastal Plain of south and west Alabama, where groundwater that flows through pores or spaces between grains of sand or

gravel, is much easier to identify as it resides within extensive, permeable aquifers. The hydraulic conductivity of unconsolidated aquifers varies, depending upon sorting and composition of aquifer materials (for example, the amount of silt and clay present), but generally conductivity is high. Aquifer thickness ranges from a few or tens of feet (ft) in the upgradient areas to several hundred ft downgradient into the Gulf of Mexico basin. Groundwater in unconsolidated, shallow, thin aquifers flows along relatively short flow paths typical of local flow systems. Longer and deeper flowpaths that form regional flow systems generally occur in thick basin-fill and alluvial aquifers. Most high production wells are developed in regional groundwater flow systems where readily available groundwater is the main or sole source of freshwater.

The Geological Survey of Alabama was tasked with investigating the potential for large-scale irrigation from groundwater sources in the state. To evaluate groundwater resources available for large-scale irrigation, a series of evaluations were conducted: (a) observation of soils distribution and characteristics; (b) geological/hydrogeological investigations to build a first concept on groundwater resource; (c) observations of land-use/land-cover (LULC), particularly agricultural class distribution in relation to geology, soils, and elevation; (d) observations of public supply well and corresponding source water assessment area (SWAA) distribution; (e) observations of groundwater levels; (f) examination of pumping tests that test the response of groundwater extraction (specific capacity); and (g) evaluation of groundwater quality to assess freshwater resource availability. Additional investigations need to be employed for better resource development planning and protection at the local scale.

METHODOLOGY

The investigation focused on six major areas where agriculture is present and/or where increased agricultural production and diversity may lead to improved economic conditions for

this economically depressed area of the state. These areas are the Tennessee River Valley; Sand Mountain; Black Belt; Southeast Alabama; South-Central Alabama; and Southwest Alabama (fig. 1-1, plate 1-1).

Soils are formed as a result of the interaction of factors such as climate, animal and plant life, parent material, relief, and time that act simultaneously as destructive and constructive forces (McBride and Burgess, 1964). Depending on the location and the parent material, one of these factors may dominate soil formation and consequently is accountable for the majority of soil properties (McBride and Burgess, 1964). In most cases, weathered geologic materials as well as underlying geologic materials provide a good foundation for soils (McBride and Burgess, 1964). Soil evaluations were conducted using the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) database. This is a simplified classification of soils according to common taxonomic characteristics (USDA-NRCS, 2009b) and offers sufficient information to fulfill the objectives of this study.

Geologic and hydrogeologic investigations help create a framework of potential groundwater sources. Aquifer identification for the present study was conducted using the digital geologic map of Alabama (Geological Survey of Alabama, 2006), which includes a detailed classification of stratigraphic formations.

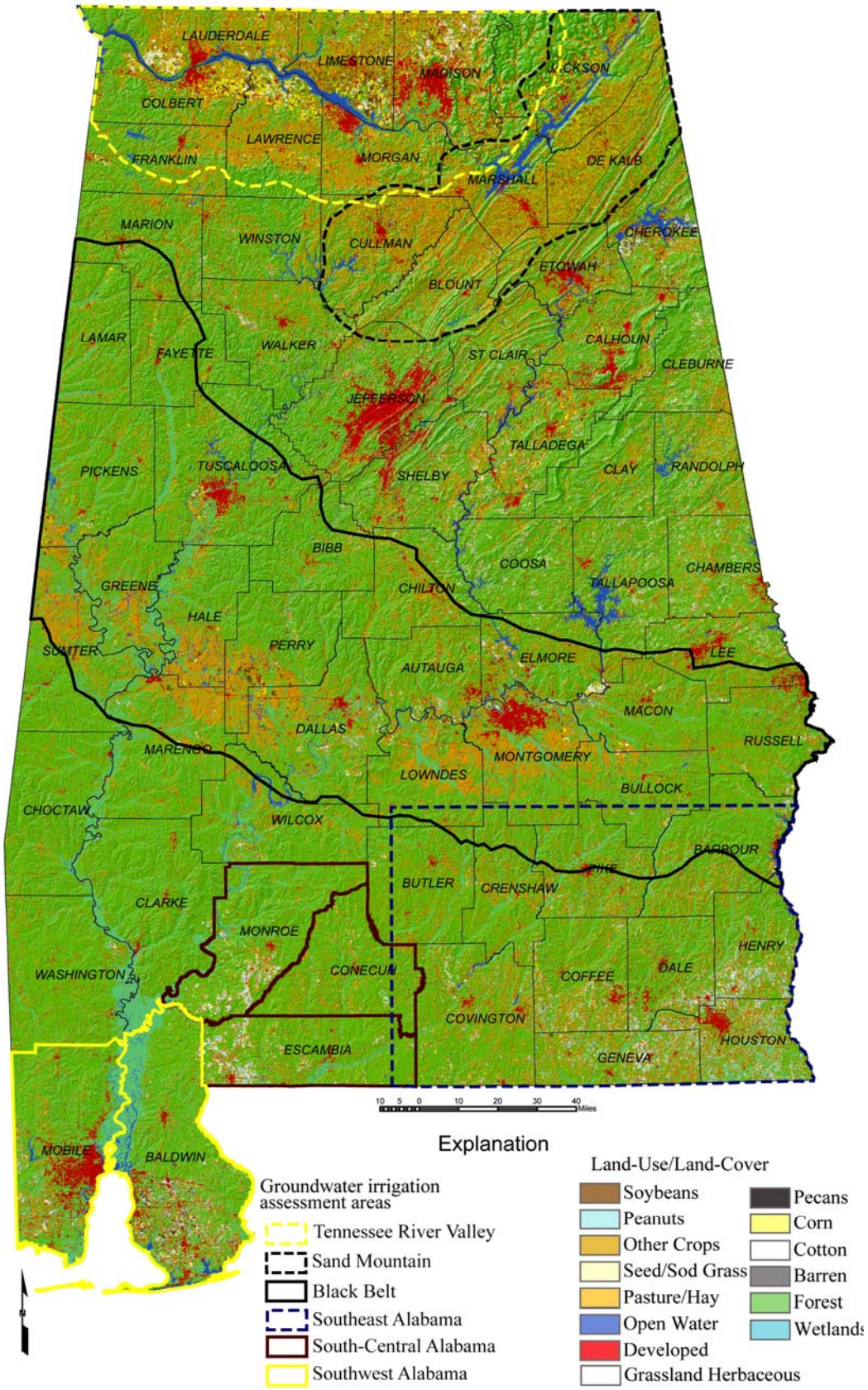

Figure 1-1. Alabama groundwater irrigation assessment areas index map.

Land-use practices are important factors that influence water quality and availability, but their impact may be difficult to accurately determine on a regional scale. Landscape patterns are influenced by both natural processes and those related to human activity. However, in recent decades, human-generated processes have been the dominant force in shaping landscape patterns in the United States. Land-use/Land-cover analyses conducted for the purpose of this study, except for the Black Belt area, were performed using the 2010 USDA, National Agricultural Statistics Service (NASS) Cropland Data Layer (CDL) for the Southeast States. The CDL is a raster, crop-specific data layer that has a ground resolution of 56 meters. These data were generated using satellite imagery from the Indian Remote Sensing RESOURCESAT-1 (IRS-P6) Advanced Wide Field Sensor (AWiFS) collected during the current growing season and were supplemented by various ancillary inputs such as the United States Geological Survey (USGS) National Elevation Dataset (NED), the USGS National Land Cover Dataset 2001 (NLCD, 2001), and the National Aeronautics and Space Administration (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS) 250-meter 16-day Normalized Difference Vegetation Index (NDVI) composites. The NLCD 2001 is used to delineate and validate non-agricultural data. Agricultural cover type classification was validated using the Farm Service Agency (FSA) Common Land Unit (CLU) Program. The accuracy is generally 85% to 95% correct for the major crop-specific land cover categories. See chapter 4 for LULC data source and description for the Black Belt groundwater irrigation area.

An important part of a groundwater flow system assessment is the evaluation and reconstruction of flow directions. Potentiometric surface maps and potentiometric profiles offer insight into regional groundwater flow patterns, identification of recharge and discharge zones, impacts associated with pumping rates (for example, cones of depression), and groundwater/surface-water interaction processes (for example, diverging flowpaths caused by

river/lake groundwater recharge). The potentiometric water level is the elevation to which water rises in a properly constructed well that penetrates a confined aquifer. The potentiometric surface is an imaginary surface representing the confined pressure (hydrostatic head) throughout all or part of a confined aquifer (Driscoll, 1986). This surface is helpful in determining directions of groundwater movement, hydraulic gradients, and depths from which water can be pumped at particular locations.

Potentiometric surfaces in conjunction with flow line analyses are essential tools in visualizing directions of groundwater flow and changes in hydraulic gradients. These depictions do not reveal enough information concerning vertical gradients and flow components. However, induced vertical gradients caused by the influence of pumping wells and rivers/lakes affect the configuration of equipotential lines (for example, cones of depression and hydraulic gradients sloping towards rivers/lakes). The presence of cones of depression is an indication of groundwater overdevelopment that may lead to freshwater resource depletion and limited availability.

The depth to water maps are similar to the potentiometric surface maps except the depth to water surface is feet below land surface (ft bls). This information can be used to determine the depth to water at any location in the assessment area and can be used to determine pump settings and size or areas where flowing wells may be constructed.

One of the exploration techniques that utilizes pump testing data to predict the occurrence of groundwater is specific capacity mapping. When adequate data are available and mapped, this technique provides basic information about the geographic distribution and aquifer production capability. Aquifer or pump testing is a technique used to evaluate the production capacity of a well by pumping a well at a known rate over an extended period of time while recording water level drawdown and recovery. Although some wells, especially public water supply wells,

undergo formal aquifer testing and professional evaluation, most wells are only pumped for a few hours with maximum pump rate and drawdown recorded. These data, although not optimum, can be used to calculate specific capacities. Specific capacity maps are useful for the evaluation of aquifer producing capabilities but do not necessarily represent the actual capacity of the investigated aquifers. Specific capacity, a measure of aquifer transmissivity (T) and the yield of a well, is determined from pumping tests obtained from wells at the time of development using yield (pumping rates (Q)) and drawdown (s) values (SC=Q/s) (Fetter, 1994) and is expressed in gallons per minute per foot (gpm/ft) of drawdown. Initial specific capacity values (obtained just after a well is drilled) are considered to be the highest and the most precise ones and can be used as benchmarks for future evaluations (Driscoll, 1986).

In an effort to identify new areas that may provide sustainable amounts of water for agricultural practices that would not adversely impact public water supply sources, public supply well locations and source water assessment area s (SWAA) were evaluated. Pumping in close proximity to public supply wells may impact the quality and quantity of water for public supplies. In developing and managing new groundwater resources for irrigation purposes, the public supply source water freshwater must be considered and protected.

Three major factors control the viability of irrigation from groundwater sources. First, the water source must supply an adequate volume of water for the particular crop being irrigated and the supply must be sustainable over the long term. Secondly, application of groundwater onto the land surface for irrigation for an extended period of time must not degrade the land-surface or surface-water environment. Thirdly, if large-scale irrigation from groundwater sources is successful, it must be economically feasible. The potential for contamination from sources associated with land farming (for example nutrients, pesticides, and others) or aquifer overdevelopment can adversely impact water quality and availability in some areas.

Furthermore, the expense of irrigation should not prevail over the benefits derived from irrigation for the farmer.

If development of irrigation from groundwater sources is successful, it must be economically feasible. The cost of delivery of water to crops must not create an inordinately large financial burden, so that the expense of irrigation outweighs the benefits derived from irrigation for the farmer. The major costs involved with development of groundwater for irrigation are drilling and equipping water supply wells and constructing the delivery system that applies water to crops. Since delivery systems are common to both groundwater and surface-water sources, costs addressed in this report are limited to well construction only. Costs for drilling and equipping wells capable of supplying adequate quantities of water for large-scale irrigation are based on the well depth and diameter, casing, screen, and pump specifications.

The major costs involved with development of groundwater for irrigation are drilling and equipping water supply wells and constructing the delivery system that applies water to crops. Individual evaluations are available in this report for each of the investigated areas.

Chapter 2

POTENTIAL FOR LARGE-SCALE IRRIGATION FROM GROUNDWATER SOURCES IN THE TENNESSEE RIVER VALLEY AREA

By Stephen P. Jennings

INTRODUCTION

This chapter of the report focuses on the groundwater resources of the Tennessee River Valley and surrounding area of northern Alabama, herein termed the Tennessee River Valley groundwater irrigation assessment area (TRVGIAA), and the potential for expansion of groundwater use in agricultural irrigation. This area has long been a center for cotton, corn, and soybean production, but irrigation for these and other row crops has not seen widespread application.

LOCATION

The area of investigation includes all or parts of Colbert, Cullman, Franklin, Jackson, Limestone, Lauderdale, Lawrence, Madison, Marshall, and Morgan Counties in northern Alabama and comprises an area of approximately 4,958 square miles (mi^2) (plate 2-1). Major cities or census designated places and their 2010 populations (shown in parentheses) include Huntsville (180,105), Decatur (55,683), Florence (39,319), Madison (42,938), Athens (21,897), Hartselle (14,255), Muscle Shoals (13,146), Sheffield (9,039), Russellville (9,830), Tuscumbia (8,423), Moores Mill (5,682), Meridianville (6,021), Hazel Green (3,630), and Moulton (3,471) (U.S. Census Bureau, 2011). The area's history has been dominated by development in the Tennessee River Valley. Favorable climate, terrain, water supply, and fertile soils have provided the basis for making the area one of Alabama's leading row crop areas as well.

PHYSIOGRAPHY AND TOPOGRAPHY

Though comprised principally of the Tennessee River Valley physiographic region, the TRVGIAA also includes the Little Mountain and Moulton Valley physiographic regions as well as portions of the Fall Line Hills, Jackson County Mountains, and Warrior Basin physiographic regions (plate 2-2). Elevations range from approximately 414 ft above sea level (normal pool elevation of Pickwick Lake in Lauderdale County) to approximately 1,880 ft above sea level with the principal low areas along the Tennessee River and higher elevations found in the eastern and southern portions of the TRVGIAA.

The Tennessee River Valley physiographic region is characterized by gently rolling lowlands and small hills with topographic features reflecting karst development. Elevations in the region range generally from 300 to 800 ft above sea level. Steep-sided hills and bluffs are common along the banks of the Tennessee River and its tributaries, though much of this relief has been inundated by flood waters resulting from the several dams constructed on the Tennessee River for navigation, flood control, and hydroelectric power generation. Away from the Tennessee River and its tributaries, generally higher elevations occur along the Alabama-Tennessee state line; along the lower boundary of the region with the Little Mountain region; and in some isolated highlands, which are the result of incomplete erosion of the rock strata, principally in Madison County. The eastern part of the investigated area is a plateau, termed the Jackson County Mountains, which is dissected by downward cutting streams. The highest elevations and greatest relief in the study area lie in this physiographic region.

South of the Tennessee River Valley region is the Little Mountain physiographic region, which extends from south-central Colbert County eastward to central Morgan County (plate 2-2). It is an area of low to moderate relief hills that is bordered on the north by a low-relief escarpment; the topography generally slopes southward from the escarpment.

Extending from northeastern Franklin County through southern Morgan County, the Moulton Valley physiographic region is a low relief plateau bordered on the south by an escarpment marking the boundary with the Warrior Basin region. This escarpment is of greater relief than the northern edge of the Little Mountain region and is generally at higher elevations. The northern part of the Warrior Basin forms the southern boundary of the area of investigation and is a dissected plateau marked by locally steep-sloped areas, owing to deep erosion.

The western portions of Lauderdale, Colbert, and Franklin Counties lie in the Fall Line Hills physiographic region (plate 2-2), an area characterized by moderate relief comprised of

poorly consolidated sediments on uplands and much older consolidated rock strata in the valleys and hillsides.

GEOLOGY

Sedimentary rocks of Paleozoic age comprise the greater part of the investigated area, whereas Cretaceous aged sediments overlap the Paleozoic strata to the west and southwest, primarily in the Fall Line Hills physiographic region (plate 2-3). Paleozoic rocks range from Middle Ordovician limestone beds that crop out in the northernmost part of the area to Pennsylvanian sandstone and shale beds that cap the highlands to the east and south. The TRVGIAA lies on the flank of the Nashville Dome with structural dips of the strata about 40 ft per mile (ft/mi) to the south. Delineation of regional geologic structure is shown by a map of the top of Chattanooga Shale (plate 2-4), which ranges in elevation from lower than 500 ft below sea level in Franklin County to higher than 850 ft above sea level in northwestern Madison County, an overall structural change of about 1,350 ft over a distance of approximately 60 miles.

The oldest rocks exposed in the investigated area are limestone and shale beds of the Ordovician System. The Ordovician rocks, labeled as "Ordovician System undifferentiated" on the geologic map shown in plate 2-3, is comprised variously across the study area of limestone and shale beds of the Sequatchie Formation, Elkmont Formation, Leipers Limestone, Inman Formation, Nashville Group, and Stones River Group (Szabo and others, 1988; Osborne and others, 1988). Ordovician rocks crop out in valleys and lower slopes of hills in the northern part of the study area in northern Limestone County and in small areas in northern Madison County, where exposure has resulted from erosion of overlying geologic units. In Limestone County, limestone of the Middle and Upper Ordovician, considered part of the Chickamauga Limestone by McMaster and Harris (1963) and McMaster (1963), is gray to buff colored, fossiliferous, and is generally a dense compact rock that locally contains thin shale and siltstone beds. In north-central Madison County, the outcropping Ordovician rocks are considered part of the Upper Ordovician Sequatchie Formation (Chaffin and Szabo, 1975; Szabo and Chaffin, 1982). There, the limestone is medium-gray to grayish-red to grayish-green and is locally interbedded with shale, which becomes the predominant lithology in Ordovician outcrops northwest of New Market in Madison County.

Unconformably overlying the Ordovician rocks on the flanks of the Nashville Dome are medium-gray, reddish-gray to greenish-gray limestone and shale beds of the Silurian Wayne Group in Lauderdale County and the Brassfield Limestone in Madison County. The Silurian is

absent in northern Limestone County. The Silurian rocks are shown as undifferentiated on plate 2-3.

Upper Devonian Chattanooga Shale unconformably overlies Silurian rocks or, where the Silurian is absent, Ordovician rocks. The Chattanooga Shale is a thin, black, organic-rich shale with local occurrences of sandstone and siltstone, especially in the lower part of the unit. The Chattanooga Shale commonly emits a distinctive sulfurous and petroliferous odor and a color change of cuttings when penetrated during drilling. For those reasons and because it is only locally absent in the area of investigation, it is an excellent marker bed for mapping purposes. The top of the Chattanooga Shale also marks the base of the principal water-bearing unit in the study area—the Fort Payne Chert and overlying Tuscumbia Limestone. Between the Chattanooga Shale and the basal Fort Payne Chert beds is a very thin but widespread green, glauconitic, and locally phosphatic shale—the Maury Formation. The Maury is the basal Mississippian geologic formation and is a transitional unit from the Chattanooga Shale to the limestone and chert beds of the Fort Payne Chert. The overlying Fort Payne Chert is a locally porous and permeable, fossiliferous chert and cherty limestone unit that occurs across the region. Conformably overlying the Fort Payne Chert is the Tuscumbia Limestone, a grain-rich limestone composed of abundant fossil fragments and other calcium carbonate sand-sized grains. Tuscumbia Limestone grainstones are generally dense with intergranular calcium carbonate cement, but locally, primary and secondary porosity results in a porous and permeable rock. Silica (chert) content in the Tuscumbia is much reduced compared to the Fort Payne Chert. The Fort Payne Chert and Tuscumbia Limestone crop out in most of the area of the Tennessee River Valley physiographic region.

Beginning about 2 miles east of Interstate Highway 65 in Morgan County and extending in an easterly direction, the Monteagle Limestone overlies the Tuscumbia Limestone and consists of 200 to 300 ft of light- to medium-gray, bioclastic limestone. The Monteagle forms only a locally significant aquifer due to the general lack of porosity and permeability. From the same beginning location mentioned above and extending across an approximately 15-mile wide outcrop area, the Monteagle Limestone grades into and is interbedded with the Pride Mountain Formation, a unit consisting principally of shale but also containing thin limestone, sandstone, and siltstone intervals. The Pride Mountain Formation extends from a short distance west of the Morgan-Lawrence County line westward into Mississippi. The Pride Mountain Formation is not considered an aquifer, but thin limestone beds are known locally to transmit groundwater.

The Hartselle Sandstone, a 20 to 200 ft thick formation consisting principally of sandstone and lesser shale, overlies the Monteagle Limestone and Pride Mountain Formation. The unit's principal area of outcrop is a 2- to 10-mile wide, east-west trending band that extends from Mississippi to western Marshall County and crops out locally on mountain sides and upland areas in Madison County. Erosion-resistant sandstone beds of the Hartselle Sandstone form the escarpment along the northern margin of the Little Mountain physiographic region and cap higher elevations in that area. The Hartselle Sandstone yields only small quantities of water for domestic supply wells.

Overlying the Hartselle Sandstone is the Bangor Limestone, a 300 to 400 ft thick unit of medium-gray, grain-rich limestone with thin interbeds of reddish-gray and greenish-gray shale in the upper part. The Bangor Limestone is the principal geologic unit forming the Moulton Valley physiographic region, which exhibits karst topographic features such as sinkholes, relatively thick soils, and gently rolling terrain. While the Bangor yields widely varying amounts of groundwater to wells located in and south of its area of outcrop (Dodson and Harris, 1965), the unit is not widely utilized as an aquifer. The potential for increase in row crop agriculture in the Moulton Valley region warrants further exploration of the Bangor as a potential irrigation water supply source.

The Parkwood Formation lies above the Bangor Limestone in the western part of the study area extending from Franklin County to southwestern Morgan County where it pinches out. In eastern Morgan County and extending through Marshall, Jackson, and Madison Counties, the Pennington Formation occupies the same stratigraphic position above the Bangor as the Parkwood Formation. Terrigenous clastics consisting of medium- to dark-gray shale and sandstone are the predominant lithologies of the Parkwood and Pennington Formations, with thin limestone and coal beds present locally. The Pennington is the uppermost Mississippian geologic unit in the eastern part of the investigated area, and the Parkwood is considered Upper Mississippian to Lower Pennsylvanian. Both the Parkwood and Pennington are considered non-aquifer units.

Sandstone, siltstone, shale, and coal beds comprise the overlying Pennsylvanian Pottsville Formation. The Pottsville clastic rocks crop out in the southern and eastern parts of the study area where they comprise much of the higher elevations. Pottsville rocks locally contain usable quantities of groundwater for small capacity wells, but the aquifer commonly exhibits low permeability and problems with water quality.

In the Fall Line Hills physiographic region of the western part of the area of investigation, generally thin sand, gravel, and clay deposits of the Cretaceous Gordo Formation (Tuscaloosa Group) and locally the overlying Eutaw Formation cap many of the hills and ridges. These relatively loosely consolidated sediments are remnants of Gulf Coastal Plain deposits that have largely been removed by erosion to reveal underlying Paleozoic rocks. The contact of the Cretaceous sediments with the underlying Paleozoic rocks constitutes a great unconformity with no identified Upper Pennsylvanian through Lower Cretaceous sediments known to exist in the region and representing a gap in the geologic record spanning about 200 million years from mid-Pennsylvanian Period to the latter part of the Cretaceous Period. Groundwater in the Cretaceous units primarily provides recharge to underlying aquifers or is discharged at the contact with Paleozoic rocks as springs.

SOILS

The natural factors and processes that produce soil are not constant across the investigated area, and therefore have resulted in a variety of soil types with varying properties. Soils in the Tennessee Valley region are all within the "thermic" soil temperature regime, defined as a mean annual soil temperature between 15º and 22º C (59º to 71.6° F), and the difference between mean winter and summer soil temperatures greater than 6º C (42.8º F) either at a depth of 50 centimeters (19.685 inches) from the soil surface or at a densic, lithic, or paralithic contact, whichever is shallower (USDA-NRCS, 1999).

There are 23 soil taxonomic classes from four soil orders present across the investigated area (plate 2-5) as classified in the State Soil Geographic (STATSGO) Database classification (USDA-NRCS, 2009b). However, a smaller number of these types are the principal soils important to agricultural row crops, which are shown in table 2-1 along with the area covered and taxonomic class. The parent materials in the principal crop areas are limestone, dolomite, and chert with minor amounts of shale, siltstone, and sandstone. Row crop agriculture is most developed in a belt extending from north-central Madison County to southern Lauderdale County, in Ultisols, more specifically in clayey, rhodic paleudults; clayey, typic paleudults, and to a lesser extent in fine-silty, glossic fragiudults (compare plates 2-5, 2-6). There is also some row crop agriculture in fine-smectitic, thermal vertic Hapludalfs (Alfisols) of the Moulton Valley region; in fine-loamy, siliceous, typic paleudults (Ultisols) in Morgan and southeastern Madison Counties; and in fluvaquentic dystrudepts in Marshall, Madison, and northeastern Morgan Counties.

Table 2-1.-- Soil order names, areas, and taxonomy.				
No.	Order	Soil order area (mi^2)	Percent total area	Taxonomic classes
1	Ultisols	3,692.2	77.0	Paleudults, Hapludults, Fragiudults
2	Alfisols	824.6	17.2	Hapludalfs, Fragiudalfs
3	Inceptisols	221.5	4.6	Dystrudepts, Dystrochrepts
4	Entisols	54.1	1.1	Fluvaquents

LAND USE /LAND COVER

The scale of this investigation is limited to regional land use/land cover (LULC) as delineated by satellite imagery. There are readily apparent relationships among the topography, physiography, geology, soils, and LULC in the study area. The uses of land are highly varied across the TRVGIAA (plate 2-6), but forested area and pasture/hay lands together comprise nearly 70 percent of the total land area (table 2-2). Most of the upland and steeply sloped areas, of which there are large tracts in the eastern, western and southern portions of the study area, are forested and are not suited for any large-scale agricultural use.

Crop lands (including seed/sod grass) make up 14.7 percent of the total land area with most of that primarily lying in a belt extending from Madison County westward along the Tennessee River Valley physiographic province (plate 2-6). Corn and soybeans are the largest crop land areas, whereas cotton, once the largest crop in the region, now only accounts for about 10 percent of the tilled crop land and only about 1.5 percent of the total land area (USDA, 2010). Other crops include wheat, vegetables, melons, water cress, potatoes, sweet potatoes, fruits, nursery, and floriculture. Average farm size across the TRVGIAA is approximately 144 acres (USDA, 20010).

Table 2-2.--Classes, areas, and proportions of LULC for the TRVGIAA.		
LULC class	LULC class area (mi^2)	Percent of LULC
Agricultural Cover Type		
Corn	203.11	4.10
Cotton	74.42	1.50
Soybeans	196.92	3.97
Peanuts/Pecans	0.04	<0.01
Aquaculture	0.01	<0.01
Pasture/Hay/Grass	1,247.76	25.17
Seed/Sod Grass	1.05	0.02
Other crops	254.61	5.14
Total Agricultural Cover	**1,977.92**	**39.90**
Non-Agricultural Cover Type		
Open Water	190.97	3.85
Developed	443.79	8.95
Grassland/Herbaceous	9.62	0.19
Barren	2.52	0.05
Forest	2,210.07	44.58
Wetlands	122.71	2.48
Total Non-Agricultural Cover	**2,979.67**	**60.10**

The largest developed (urban and suburban) areas are also located within the principal agriculture belt. The net effect of steady growth of urbanized areas is the removal of prime crop land from potential agricultural use. Some of this removal has been offset by increases in

agricultural use away from the developed areas, especially in northern Madison County, adjacent portions of Limestone County, in northern portions of Lawrence and Colbert Counties, and in Lauderdale County.

HYDROGEOLOGY

Chert and limestone beds of the Fort Payne Chert and the Tuscumbia Limestone commonly contain intervals capable of storing and transmitting groundwater in much of the area of investigation. Porous and permeable intervals in these geologic units are largely the result of carbonate dissolution and fracturing. The water-bearing intervals of these two geologic formations are considered in hydraulic communication and are termed the Tuscumbia-Fort Payne aquifer. Most of the data and analyses presented in this section and throughout the following sections centers around the Tuscumbia-Fort Payne aquifer. This hydrogeologic unit constitutes the principal aquifer of the investigated area, except in the southern and eastern areas where the depth to the aquifer generally is considered too great for its use, porosity and permeability is much reduced, and/or mineralization of its contained groundwater exceeds recommended or practical limits.

A well-defined downdip limit to groundwater production from the aquifer has not been delineated, however, largely due to a lack of data. Geophysical well logs from petroleum test wells across central Lawrence County indicate the presence of a consistent and widespread interval of chert in the upper Fort Payne Chert with porosity measurements of about 10 to 18 percent at depths ranging from about 800 to 500 ft bls (in the area shown on plate 2-4 in Lawrence County for the top of Chattanooga Shale extending from approximately 250 ft below sea level to about 50 ft above sea level). This relatively porous chert has not been tested in these downdip areas, but projection of the strata updip to the northeast and northwest indicates the likelihood of reaching the interval at depths of 200 to 400 ft in an area extending from near Trinity in western Morgan County to near Cherokee in Colbert County.

The Tuscumbia-Fort Payne aquifer provides a significant amount of water for public water supplies and industry across the investigated. Well discharge rates to several thousand gpm have been recorded from wells, especially in areas of extensive drilling and well development such as the Huntsville area. A small number of large capacity irrigation wells are known from well records in Madison and Limestone Counties. Groundwater is also withdrawn from numerous home and small farm wells completed in the aquifer, though volumetrically, this

pumpage is probably relatively small. The groundwater is generally of excellent quality for most purposes though, locally, levels of sulfur and or other dissolved constituents are problematic.

In the Tuscumbia Limestone and Fort Payne Chert outcrop area, groundwater is considered to be under unconfined conditions, whereas to the south and east the overlying shaly Pride Mountain Formation and the generally dense, well-cemented limestone beds of the Monteagle Limestone result in semi-confined to confined conditions. To the west, where overlain by Cretaceous sediments, the aquifer is likely semi-confined where sand beds predominate in the Gordo and Eutaw Formations and confined where the overlying beds are predominantly composed of clay.

Recharge to the Tuscumbia-Fort Payne aquifer is from rainfall on the outcrop, through permeable residuum, and through hydraulic communication with overlying units such as sand intervals in the Gordo and Eutaw Formations, especially where they directly overlie porous and permeable beds of the Tuscumbia-Fort Payne aquifer.

Groundwater is also withdrawn from wells completed in geologic units underlying and overlying the Tuscumbia-Fort Payne aquifer, but they constitute relatively minor aquifers, especially with respect to consideration of potential for irrigation in the principal row crop areas of the TRVGIAA. The Chattanooga Shale forms the base of the practical limit of fresh water in much of the area, because groundwater from this unit is mostly unfit for drinking water use and the Silurian and Ordovician rocks below generally exhibit poor aquifer potential and/or commonly contain highly mineralized water. Ordovician and Silurian limestone beds are, however, locally significant aquifers in the northern part of the investigated area, especially where the Tuscumbia-Fort Payne aquifer is thin or absent due to erosion. In the southern part of the study area, rocks of the upper Mississippian stratigraphic section contain groundwater that is utilized on a local basis.

DEPTH TO WATER

A map showing static water levels below ground surface (depths to water) (plate 2-7) provides generalized but useful information in calculation of total dynamic head against which a well pump must work to lift water, data for well design purposes, and in estimating costs in well construction and operation. Depths to water are relatively shallow for most of the investigated area. Depth to water in an area where the Tuscumbia-Fort Payne aquifer (or any aquifer) is unconfined is the same as the depth to the water table in that area. Because the data shown in plate 2-7 are primarily static water level measurements made by drillers over a wide time range

and because of the large range of possible water level fluctuations discussed below, no attempt was made to contour the data.

The abundant water level data collected for many years, primarily in areas where the Tuscumbia-Fort Payne aquifer is unconfined (or only semi-confined beneath regolith), show significant variability across the study area and through time (fluctuations) within each well. Moreover, variations in water levels measured in wells in areas where the aquifer is confined are commonly greater than those water level measurements from wells in unconfined aquifer settings. This greater sensitivity is a result of water level variations in confined conditions, representing pressure head variations, not actual water level variations in the aquifer itself. The available water level data indicate that fluctuations of water levels are in large part seasonal, with lower water levels commonly occurring in the late summer and early fall months when evaporation rates are high and recharge to the aquifer is reduced. Malmberg and Downing (1957) and Geological Survey of Alabama (1975) reported water level fluctuations in 233 wells in Madison County ranging from 1 to 72 ft with an average of approximately 20 ft and median value of 17 ft. These variations locally represent a significant percentage of the saturated aquifer thickness in Madison County and thus constitute a significant factor to consider in drilling, designing, constructing, and pumping irrigation wells. This is of special concern during times of drought and/or in areas where there may be localized low effective porosity of the aquifer that reduces its storage capacity and transmissivity. Fluctuations in water levels in other counties of the area of investigation have not been documented to the extent as those in Madison County, but the similarity of hydrogeology, climate, and other factors would suggest that similar variability likely occurs in those areas. In the Tuscumbia Limestone and Fort Payne Chert outcrop area, the aquifer intervals are relatively close to the ground surface, meaning that well depths are relatively shallow. However, those areas have a greater susceptibility to potential problems of decreased available drawdown distance, especially during periods when heavy pumpage coupled with seasonal water level declines can cause wells to break suction when water levels fall below pump setting depths. In addition to water level, consideration of aquifer properties such as thickness, storage, and transmissivity along with well spacing, and local conditions are important in planning an effective irrigation program.

PUMPING RATES AND SPECIFIC CAPACITIES

Data from more than 1,500 wells were utilized in this study, the majority of which are for drinking water supply at individual homes and public water supply wells; records of wells drilled specifically for irrigation purposes are sparse. Aquifer tests have been performed from wells in the area, primarily in Madison and Limestone Counties where the U.S. Geological Survey (USGS) and the Geological Survey of Alabama conducted extensive research in the 1950s through the mid 1970s in and around Huntsville and Athens, primarily in efforts to construct and develop large-capacity public water supply wells. Elsewhere in the study area available aquifer test data are sparse to nonexistent. During the construction of most wells, however, relatively brief pump tests have been conducted in order to estimate practical guidelines for well yields, water-level drawdowns, pump settings, and other well construction criteria.

Pumping rate (well discharge) is commonly shown in the report submitted to the state for each well by the driller. Other sources of well discharge rates are from engineering reports, publications, or other records. Well discharge rates, in gpm, for wells across the TRVGIAA are shown in plate 2-8. The average pumping rate for 655 wells utilized in this study is approximately 113 gpm, whereas the median rate is 27 gpm. While well discharge is largely related to aquifer characteristics, it is also a function of the mechanical aspects of wells and the required flow rate to meet the needs of the users. Pumping rates therefore should not be considered the maximum yield of an aquifer at a given location. Water level and pumping rate data commonly are recorded as drawdown measured during a few hours of pumping at a specific rate or in some stepped progression of rates during the test. From these data a calculation of specific capacity can be determined and is expressed as gpm per foot of drawdown (gpm/ft). Specific capacity data along with estimates of total dynamic head are useful in well design wherein pump head-capacity curves can be combined with specific capacity curves to determine scenarios for well discharge rates (Driscoll, 1986). Specific capacity, though related in part to well construction and pump test factors, is also a general indicator of aquifer transmissivity, and empirical mathematical relationships and statistical measures have been developed for aquifers elsewhere to assist in groundwater development programs and well design (Walton and Neill, 1963; Theis, 1963; Robertson, 1963; Bradbury and Rothschild, 1985; Driscoll, 1986; and Mace, 1997).

Chert and limestone aquifers that generally have low storage capacity relative to hydraulic conductivity (low porosity relative to permeability), such as the Tuscumbia-Fort Payne

aquifer, commonly also demonstrate a very wide range of specific capacities due to localized highly productive intervals or zones. It should also be noted that a variety of other factors such as duration of the test, pumping rate, casing diameter, pump size and type, and other mechanical aspects of the well as well as possible nearby pumping wells during the test influence the specific capacity derived from each individual test. Nonetheless, these data are useful as general indicators of aquifer productivity. Specific capacities in the area of investigation (plate 2-9) range several orders of magnitude, from a fraction of a gpm/ft to 1,941 gpm/ft with most productive, larger capacity (>100 gpm) wells having specific capacity values greater than about 2 gpm/ft. The median value for the 345 wells for which a specific capacity could be determined is 2.08 gpm/ft; 75 wells have specific capacity values of 10.0 or higher and 123 wells have values of less than 1.0 (fig. 2-1). These relationships are further described by figures 2-2 and 2-3, illustrating that well flow rate has a positive relationship to casing size and specific capacity has a positive relationship to flow rate. The data are somewhat biased, however, because wells that exhibit few indications during drilling of being successfully completed are the number of attempts to construct wells with higher flow rates because only relatively small (5 to 20 gpm) flow rates are needed to satisfy the generally small demands of homeowners. Many of these smaller capacity wells are drilled to a depth that reaches the first aquifer interval that will supply the homeowners' needs and thus the entire prospective aquifer interval remains undrilled.

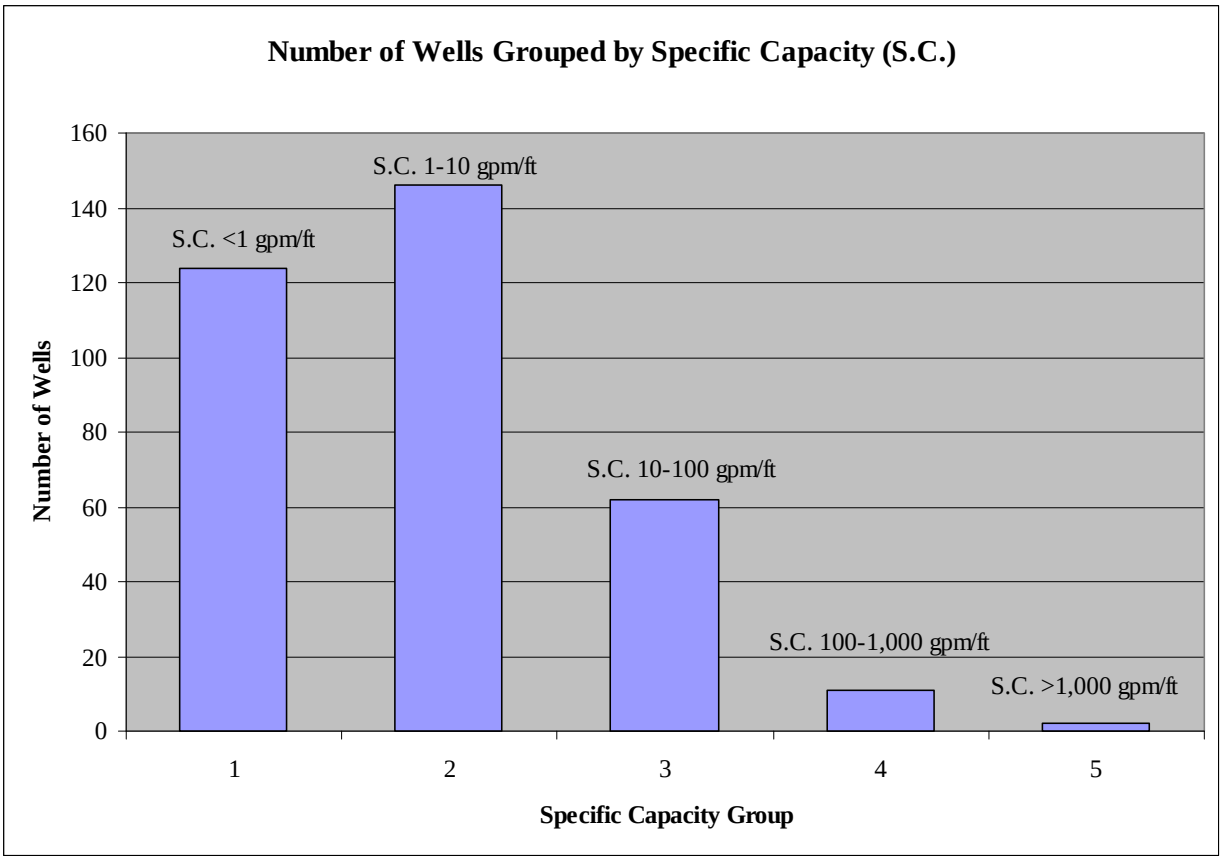

Figure 2-1.--Number of wells grouped (logarithmically) by ranges of specific capacities from selected wells in the Tennessee River Valley groundwater irrigation assessment area.

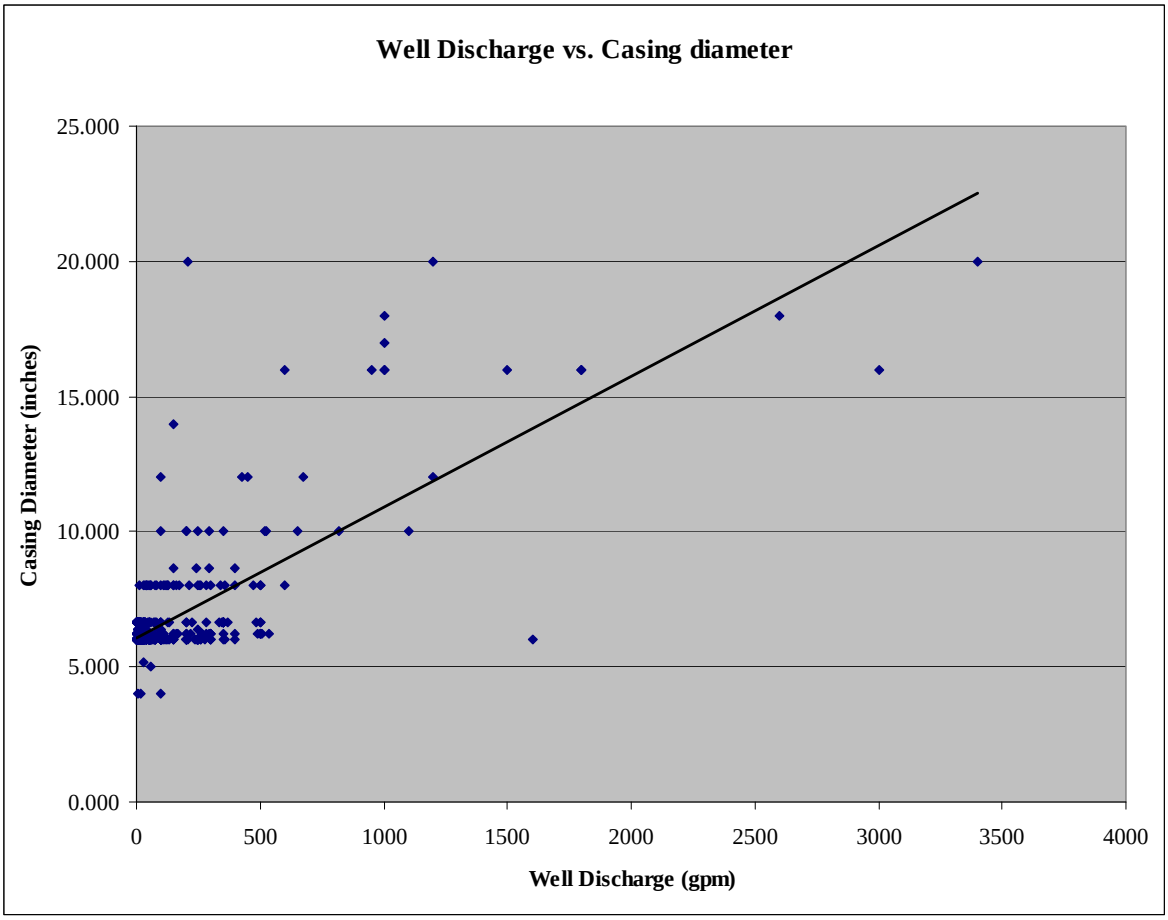

Figure 2-2.--Discharge rate related to casing diameter for 655 wells in the Tennessee River Valley groundwater irrigation assessment area.

SOURCE WATER ASSESSMENT AREAS AND PUBLIC SUPPLY WELLS

In the TRVGIAA, the largest defined SWAA are in the Huntsville-Madison-Harvest area in Madison and Limestone Counties, the Athens area in Limestone County, and the Tuscumbia-Muscle Shoals area (plate 2-10). Smaller but significant areas are located in Madison, Limestone, Colbert, Lauderdale, and Franklin Counties. Most of the areas where irrigation wells are likely to be developed are outside the SWAP areas, and therefore few impacts on current public water supply wells are anticipated.

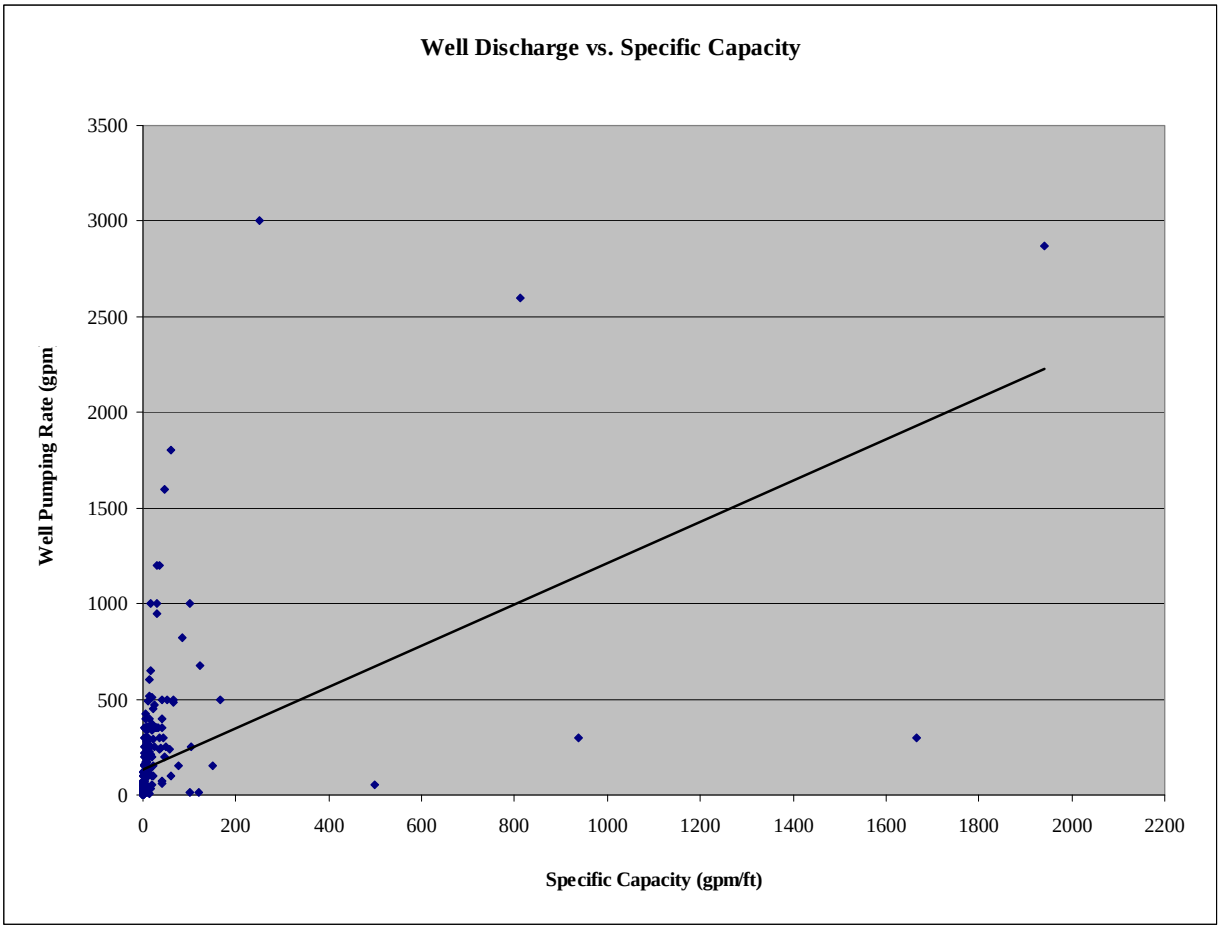

Figure 2-3.--Specific capacity related to discharge rate for 345 wells in the Tennessee River Valley groundwater irrigation assessment area.

GROUNDWATER QUALITY AFFECTING POTENTIAL AGRICULTURAL IRRIGATION

Calcium, magnesium, and bicarbonate are the most abundant mineral constituents in groundwater in most areas of the TRVGIAA. Locally the amounts of iron, sulfate, nitrate, chloride (Cl), and fluoride exceed recommended health standards for drinking water, but only in some cases would there likely be concern for use as irrigation water. Groundwater from aquifers composed primarily of limestone generally exhibits hardness higher than is desirable for drinking water but poses no threat for irrigation use. As discussed in the introductory portion of this report series, high Cl concentrations pose problems for plant growth at various levels for typical row crops grown in north Alabama. Excessive Cl concentrations can be found in groundwater in areas where the Tuscumbia-Fort Payne aquifer lies at depths below which there has been incomplete flushing of original saline formation waters and commonly in geologic units below

the Chattanooga Shale, e.g. the Ordovician and Silurian carbonate rocks. Water quality data is too sparse to precisely delineate downdip limits of fresh groundwater in the aquifers. High sulfate and Cl concentrations are found in groundwater in or suspected to have been in contact with the Chattanooga Shale.

ECONOMIC FACTORS AFFECTING POTENTIAL AGRICULTURAL IRRIGATION

Much of the cost to implement agricultural irrigation is incurred in the initial stages of well drilling, development, and construction of the system. Costs for drilling and well construction are based on well depth, casing depth, diameter, and type of material, and the pump necessary to provide an adequate supply of water for large-scale irrigation. Typically wells drilled in "hard rock" areas such as the TRVGIAA are drilled by the air rotary method, which utilizes compressed air as the drilling "fluid".

Costs for drilling in the area currently are typically in the range of $35 to $46 per foot for an 8-inch diameter well (drilled by advancing casing, under-reaming method), not including casing, testing, development, and pump costs; costs range upward to $71 per foot for larger diameter wells or drilling by the dual rotary method. Using specifications for two hypothetical well scenarios, further explained below, the costs for drilling and constructing irrigation wells are presented here as general estimates and options. In both options the well is assumed to be in an area where water table fluctuations of 30 ft are known to occur; the aquifer intervals are from 140 to 250 ft depth in the Tuscumbia-Fort Payne aquifer; and the depth to the top of bedded rock is 30 ft. Specific capacity is assumed to be approximately 8 gpm/ft. In both options estimated costs for mobilization to the site, drilling, 30 ft of surface casing, production casing, perforating, pump and electric motor, well development, testing, and labor are included. No costs for center pivot or other irrigation system equipment, materials, operation, and labor are included.

The first hypothetical well option involves drilling and constructing a well with nominal 10-inch diameter casing installed to 250 ft and installing a submersible 25 horsepower, 5-stage pump and 230-volt electric motor producing 300 gpm at 70 pounds per square inch (psi) against 255 to 285 ft of total dynamic head with a pumping water level ranging from 68 to 98 ft bls, for a total estimated construction cost of $58,000. A well thus constructed should be able to adequately supply a center pivot irrigation system. The second hypothetical option involves drilling a well with nominal 8 inch diameter casing installed to 250 ft with a submersible 7.5 horsepower (230-volt three phase electric motor), 4-stage pump producing 50 gpm at 40 psi

against 160 to 190 ft of total dynamic head with a pumping water level that varies from 38 ft to 68 ft below ground level, for a total estimated construction cost of $49,000. The utility of this second option is discussed below.

An additional factor in the overall consideration of the economic viability of using groundwater for crop irrigation is the current lack of data and/or exploration methodology to predict the productivity of aquifers in specific locations with a reasonable degree of accuracy. The current method of well drillers and farmers is to drill a series of test wells until an adequate aquifer interval can be located and tested, if possible, in order to determine the feasibility of constructing a well with sufficient discharge. For the center pivot method of irrigation, which necessitates a 250 to 300 gpm well (and a high specific capacity), the "dry hole" to "producer" ratio is currently a limiting factor for economic feasibility for many farmers. Application of scientific methods such as geophysical techniques in combination with a better understanding of the hydrogeology on both local and regional scales may increase the success rate and therefore decrease the overall cost of installing irrigation systems. However, an alternative approach for irrigation with groundwater that would increase the probability of finding a suitable aquifer interval entails constructing smaller discharge wells (such as the second well option presented above) and pumping groundwater to ponds or other water storage to then be available as needed. This groundwater withdrawal could be during the wetter winter and spring months when aquifer water levels are generally higher and/or for longer periods to maintain adequate pond storage. Although water losses to evaporation and seepage could pose some problems, the overall effectiveness may prove beneficial and economically feasible. The smaller discharge well option discussed above is intended to present an estimate of well costs for a smaller capacity well that could discharge to a pond.

SUMMARY OF FINDINGS

The principal area of row crop agriculture in the Tennessee River Valley groundwater irrigation area is in the Tennessee River Valley physiographic region, though the investigated area also includes the Moulton Valley and Little Mountain physiographic regions, and portions of the Fall Line Hills, Jackson County Mountains, and Warrior Basin regions. Row crops are grown primarily in soils classified as clayey to silty and fine-loamy, siliceous Ultisols. These soils are developed on bedrock geology comprised for the most part of Mississippian-aged carbonate rocks. Crop land makes up approximately 14.7 percent of the total acreage of the area

of investigation, with corn and soybeans the principal crops, and cotton, once the dominant crop of the TRVGIAA, now only constituting about 1.5 percent of the total land area.

Limestone, dolomite, and chert of the Mississippian-aged Tuscumbia Limestone and Fort Payne Chert contain the primary aquifer intervals, and they generally occur at relatively shallow (< 400 ft) depths. There has been some use of groundwater from limestone beds of Ordovician age, especially in those updip areas where the Tuscumbia-Fort Payne aquifer is thin or absent, and flushing of mineralized water from the Ordovician units has occurred. There are also a relatively small number of wells completed in rocks that occur stratigraphically above the Tuscumbia-Fort Payne such as the Bangor Limestone in the Moulton Valley physiographic region.

The Tuscumbia-Fort Payne aquifer is unconfined in most of the area where it serves as a water source, and the depth to water in most wells is a few ft to a few tens of ft. The water table, however, is subject to considerable fluctuation, a result of seasonal rainfall patterns and longer term drought/wet period cycles. Though data to characterize the aquifer's hydraulic properties, such as transmissivity and storage coefficient are sparse, specific capacities can be calculated from water level data and discharge recorded for many wells. Although specific capacities vary by several orders of magnitude from place to place, trends can be mapped, and therefore some degree of predictability can be attempted from the data to assist in well construction and planning. Water quality is generally excellent from the Tuscumbia-Fort Payne aquifer, but problems with objectionable odors, high iron, nitrate, and Cl occur in some localized areas, especially in those wells or areas in which groundwater has been in contact with the Chattanooga Shale.

Costs for drilling, construction, and development of a 300 gpm irrigation well to supply a center pivot irrigation system are estimated to be approximately $58,000 for a well 250 ft deep. Estimated costs for a well to the same depth designed to produce 50 gpm are $49,000. As a result of the many factors to consider such as well location, hydrogeology, groundwater flow, and aquifer properties and due to factors such as size, scope, and type of irrigation system needed matched to crop demands, the economic viability of large-scale irrigation can vary considerably. The ranges of variability shown in this report for such parameters as specific capacity, flow rates, and water level fluctuations present challenges to the practical implementation of a successful irrigation program. Conversely, the relatively shallow well depths, shallow water levels, general lack of serious problems for well drilling and completion, general lack of water quality concerns,

and limited situations for competition for groundwater with public water supply wells indicate that groundwater-based row crop irrigation should be considered a viable option in the TRVGIAA.

Chapter 3

POTENTIAL FOR LARGE-SCALE IRRIGATION FROM GROUNDWATER SOURCES IN THE SAND MOUNTAIN AREA

By Neil E. Moss

LOCATION

The investigated area is located in northeast Alabama and includes portions of Cullman, Blount, St. Clair, Etowah, Marshall, DeKalb, and Jackson Counties (plate 3-1), comprising an area of approximately 3,800 mi² (plate 3-1). The major cities included in this area are Cullman (population 14,090), Albertville (population 18,598), Boaz (population 7,729), and Rainsville (population 5,048).

PHYSIOGRAPHY AND TOPOGRAPHY

The area of investigation is located in the Cumberland Plateau section of the Appalachian Plateau physiographic province. The physiographic districts investigated include Sand Mountain and Warrior Basin.

The Sand Mountain district stretches from the Alabama, Tennessee, and Georgia border 90 miles southwest to Blount County, Alabama, and is a synclinal plateau capped by resistant sandstone and is characterized by rolling topography of moderate relief (Sapp and Emplaincourt, 1975) (plate 3-2). Elevations range from approximately 1,900 ft near the Tennessee state line to less than 600 ft in Blount County. The Sand Mountain district is bounded on the northwest by the Sequatchie Valley district, a narrow, elongate, anticlinal valley of moderate relief; on the northeast by the Wills Valley district, three limestone anticlinal valleys separated by resistant sandstone ridges; on the southeast by the Murphrees Valley district, a faulted anticlinal valley of moderate relief; and on the southwest by the Warrior Basin district relief (Sapp and Emplaincourt, 1975) (plate 3-2).

The Warrior Basin district in the investigated area is primarily located in Cullman County and is a submaturely to maturely dissected sandstone and shale plateau of moderate relief. Elevations in the upland areas range from 1,100 ft in the northern part of the area to approximately 600 ft in the lower part of the area (Sapp and Emplaincourt, 1975).

GEOLOGY

The geologic unit that crops out in the Sand Mountain and Warrior Basin area is the Pottsville Formation, composed of interbedded sandstone, siltstone, shale, conglomerate, and coal (Raymond and others, 1988) (plate 3-3). Sandstones are usually gray to greenish in color, thin to thick bedded, fine to coarse grained (Faust, 1967). Shales are usually gray to greenish in color, but weather to various shades of brown, and the conglomerates are light colored, coarse grained, and massive (Faust, 1967). Thickness of the Pottsville Formation varies from less than 300 ft to greater than 1,000 ft throughout the area but tends to thicken toward the southwest on Sand Mountain and toward the south in the Warrior Basin (Faust, 1967).

The Pottsville Formation overlies the Pennington and Parkwood Formations undifferentiated, which is composed of predominately shale, with lesser amounts of siltstone, sandstone, silty dolomite, limestone, and mudstone. It varies between 300 and 500 ft in thickness and is not considered a reliable source of groundwater (Faust, 1967).

The Sequatchie Valley, Wills Valley, and Murphrees Valley districts, which border the Sand Mountain and Warrior Basin are composed of several formations of limestone, chert, dolostone, and shale with sandstone forming resistant ridges within the valleys (Faust, 1967).

SOILS

There are five soil orders present in the Sand Mountain and Warrior Basin area; however, Ultisols is the most dominant soil order comprising over 98 percent of the area (plate 3-4). Ultisols, commonly known as red clay soils, are strongly leached, acid forest soils with relatively low native fertility (NRCS, 2009). They are found primarily in humid temperate and tropical areas, typically on older, stable landscapes and when intense weathering of primary minerals has occurred in these soils (NRCS, 2009). Ultisols often support mixed forest vegetation and many have been cleared for agricultural use, though the addition of fertilizer and lime is required for the soil to be productive (NRCS, 2009). In addition to Ultisols, Inceptisols, Mollisols, Alfisols, and Entisols are present in the Sand Mountain and Warrior Basin area but have relatively limited range (table 3-1).

Table 3-1.--Soil order names, area, and taxonomy in the Sand Mountain and Warrior Basin area.				
No.	Order	Soil order area (mi2)	Percent total area	Taxonomic class
1	Ultisols	2,002	98.1	fine, mixed
2	Inceptisols	23	1.1	fine silty, mixed
3	Mollisols	9	0.4	clayey, mixed
4	Alfisols	4	0.2	fine, smectitic
5	Entisols	4	0.2	loamy skeletal, mixed

LAND USE/LAND COVER

Land use/land cover is influenced by the geology, soils, physiography, and topography and climate. LULC analyses were conducted during this investigation for the Sand Mountain and Warrior Basin areas and are tabulated in table 3-2. Existing LULC are given in table 3-2 and LULC patterns are shown on plate 3-5. LULC patterns indicate that forest represents the largest land use encompassing 855.9 mi² or 41.8 percent of the area.

Table 3-2.--Classes, area, and proportion of LULC for the Sand Mountain and Warrior Basin area (modified from the USDA-CDL for the Southeast States, 2010)		
LULC class	LULC class area (mi²)	Percent of LULC class
Corn	33.0	1.6
Other Crops	72.0	3.5
Soybeans	60.7	3.0
Pasture/Hay	811.6	39.6
Forest	855.9	41.8
Open Water	13.2	0.6
Developed	185.2	9.0
Barren	0.8	0.04
Grassland Herbaceous	13.7	0.7
Wetlands	2.8	0.1

Pasture/hay is the next largest land use with 811.6 mi² or 39.6 percent of the area and a relatively small amount of land cultivated in row crops (corn, soybeans, other crops), (165.7 mi² or 8.1 percent) (table 3-2). The poultry industry, specifically broiler houses, has a significant presence in the Sand Mountain and Warrior Basin area and has an influence on land use, by providing litter to spread on pastures to enhance nutrient poor soil.

HYDROGEOLOGY

The Pottsville Formation is the only geologic unit evaluated as an aquifer in the Sand Mountain and Warrior Basin area due to the excessive thickness of the Pottsville, poor aquifer characteristics of the Pennington and Parkwood Formations, and limited data availability for the underlying Bangor Limestone. Groundwater in the Pottsville Formation occurs in fractures and joints and along bedding plane openings. Most wells developed in the Pottsville Formation produce less than 50 gpm, with a majority of those producing less than 10 gpm, and are only suitable for domestic use and small farming operations such as broiler houses. Plate 3-6 shows selected wells in the Sand Mountain and Warrior Basin area that produce 50 gpm or greater along with well depth. Generally, wells with larger production rates are in low topographic areas because the rocks tend to be more permeable and the water table is generally shallow; therefore a greater thickness of more permeable rocks near land surface is saturated with water (Faust and Jefferson, 1980). Specific capacity data for the selected wells in plate 3-6 are limited and variable and range from less than 1 gpm/ft to greater than 20 gpm/ft of drawdown, though most are less than 8 gpm/ft of drawdown. This variability in specific capacity is due to the number and size of saturated fractures and is difficult to predict. Often, several wells are drilled to find an adequate water supply for a particular need, which would make using groundwater in the Sand Mountain and Warrior Basin area for large scale irrigation difficult to implement.

Water produced from the Pottsville Formation in the Sand Mountain and Warrior Basin is naturally soft and often contains excessive amounts of iron and manganese, which is not a health hazard but can limit the suitability of the water for many uses (Baker and Moser, 1989). Water quality is also impacted by the activities of man; population growth, use of organic and inorganic fertilizers, and the increasing numbers of broiler and swine houses are potential sources of groundwater contamination (Baker and Moser, 1989).

SUMMARY OF FINDINGS

The investigated area of Sand Mountain and the Warrior Basin of Alabama includes parts of seven counties and is located in the Cumberland Plateau section of the Appalachian Plateau physiographic province. The main geologic unit is the interbedded sandstone, siltstone, shale, conglomerate, and coal of the Pottsville Formation. Ultisols, commonly known as red clay soils, is the most dominant soil order comprising over 98 percent of the area. Forest represents the largest land use, encompassing 41.8 percent of the area, followed by pasture/hay with 39.6 percent of the area and only 8.1 percent cultivated in row crops.

The majority of wells developed in the Pottsville Formation produce less than 50 gpm and are suitable for domestic use and small farming operations. Wells producing greater than 50 gpm are sparse and generally located in low topographic areas. The amount of water needed for large scale center pivot type irrigation would be difficult to obtain in the Sand Mountain and Warrior Basin area. However, low volume production for replenishing irrigation ponds is possible in areas where the Pottsville Formation has adequate porosity and permeability associated with fractures, joints, and open bedding planes.

Chapter 4

POTENTIAL FOR LARGE-SCALE IRRIGATION FROM GROUNDWATER SOURCES IN THE BLACK BELT REGION OF ALABAMA

By Marlon R. Cook,
Dorina Murgulet and Neil E. Moss

INTRODUCTION

Increased agricultural production and diversity in the Black Belt area may lead to improved economic conditions for this economically depressed area of the state. In the 1820s and 30s, the Black Belt was identified as a strip of rich, dark, cotton-growing dirt. Immigrants, primarily from Georgia and the Carolinas, were drawn to this rich farming area in an epidemic called "Alabama Fever" (Tullos, 2004). Following the forced removal of Native Americans, the Black Belt emerged as the core of a rapidly expanding plantation area and center of the agrarian economy of the South. Black Belt commerce on the Alabama, Black Warrior, and Tombigbee Rivers transformed towns such as Montgomery, Selma, Demopolis, and Tuscaloosa and established Mobile as a major port on the Gulf Coast (Tullos, 2004). In the first half of the twentieth century, soil erosion and boll weevil infestation led to the collapse of the southern cotton-based agriculture, as well as the failure to develop a diversified economy and the subsequent urban exodus. All of these factors combined to send the Black Belt into agricultural and economic decline (Tullos, 2004).

LOCATION

The investigated area is located in central Alabama and includes portions of Pickens, Sumter, Greene, Hale, Perry, Marengo, Autauga, Dallas, Lowndes, Montgomery, Macon, Bullock, and Russell Counties (plate 4-1), comprising an area of approximately 3,745 mi^2. The major cities included in this area are Montgomery (population 202,696), Union Springs (population 4,702), Selma (population 18,847), Marion (population 3,290), Greensboro (population 2,564), Demopolis (population 7,350), and Eutaw (population 2,976) (U.S. Census Bureau, 2008) (plate 4-1).

PHYSIOGRAPHY AND TOPOGRAPHY

The area of investigation is located in the East Gulf Coastal Plain section of the Coastal Plain physiographic province. The physiographic districts in the area of investigation include the

Fall Line Hills, the Black Prairie, and Chunnenuggee Hills (Sapp and Emplaincourt, 1975) (plate 4-2). Alluvial deposits are shown along major streams.

The Fall Line Hills district is located in the northern part of the investigated area and is characterized by dissected uplands and broad, flat ridges that extend from Pickens County eastward to Russell County and exhibit elevations from 250 to 700 ft (Davis, 1987). The Black Prairie district, located south of the Fall Line Hills, is underlain primarily by chalk and marl and is characterized by low rolling topography and black top soil. The area is not present in east Alabama due to changes in lithology (the absence of the Selma Group chalk). Elevations in this area vary from 150 to 450 ft (Davis, 1987). The southern boundary of the area of investigation is formed by the Chunnenuggee Hills district, which is underlain by chalk that grades to clay, siltstone, and sandstone (Davis, 1987). Elevations in the Chunnenuggee Hills district exceed 650 ft.

GEOLOGY

The investigated area was divided into two parts: the recharge area, located in the Fall Line Hills district, consists of Cretaceous aquifers including the Eutaw, Gordo, Coker, and the Tuscaloosa Group undifferentiated, and the area of potential agricultural groundwater irrigation, located in the Black Prairie district, consists of groundwater sources overlain by the lower Selma Group chalks (Demopolis Chalk and Mooreville Chalk) (plate 4-3). The recharge area includes thick wedges of unconsolidated and poorly consolidated sedimentary strata composed of sand, gravel, and clay. Sediments of Upper Cretaceous age generally dip to the south and southwest at an average rate of 30 ft/mi (Cook, 1993a, 2002) and vary in thickness from a few ft along the area's northern boundary to more than 3,000 ft along its southern boundary.

Geologic units of interest that crop out in the investigated area include, in stratigraphic order, the Gordo and Coker Formations (west-central Alabama) of the Tuscaloosa Group, which in an eastward direction (east of Elmore County) gradually become undifferentiated (the Tuscaloosa Group undifferentiated), the Eutaw Formation, and the Demopolis Chalk and Mooreville Chalk of the lower part of the Selma Group. All other geologic formations presented in plate 4-3 will not be described in this report due to their insignificant contribution to the present investigation. These formations are grouped and presented as a single unit referred to as other Cretaceous formations (plate 4-3). All other Tertiary and Paleozoic strata are designated as Tertiary formations and Paleozoic formations, respectively (plate 4-3).

The Tuscaloosa Group underlies the Eutaw Formation, is composed of clay, sand, and gravel (Raymond and others, 1988), and forms the northern limit of the Coastal Plain (Raymond and others, 1988). The thickness of the Tuscaloosa Group varies from 600 to 900 ft in western Alabama (updip Tuscaloosa Group) to 300 ft or less in eastern Alabama (Tuscaloosa Group undifferentiated). In the easternmost part of the state, the Tuscaloosa Group is mapped as the Tuscaloosa Group undifferentiated and consists of poorly sorted kaolinitic, arkosic sand and gravel with beds of yellowish-orange to reddish-green mottled kaolinitic clay (Raymond and others, 1988). In west and central Alabama, the updip part of the group is divided into the Coker and Gordo Formations. The Coker Formation forms the base of the Tuscaloosa Group and ranges in thickness from 230 to more than 500 ft. The unit is composed of micaceous and crossbedded sand and micaceous clay (Raymond and others, 1988). The Gordo Formation ranges in thickness from 115 to 300 ft and consists of massive crossbedded sand with locally interbedded gravel and clay layers that are generally ventricular and locally carbonaceous (Raymond and others, 1988).

The Eutaw Formation overlies the Tuscaloosa Group undifferentiated in east Alabama and the Gordo Formation in west and central Alabama. The unit consists of light-greenish-gray fine- to medium-grained well-sorted micaceous crossbedded sand, partially fossiliferous and glauconitic, with greenish-gray micaceous silty clay and medium-dark-gray carbonaceous clay (Raymond and others, 1988). The thickness of the Eutaw Formation varies from a few ft along the northern limit of the outcrop (Cook, 1993a) to 350 and 400 ft in outcrop in western and central Alabama and thins eastward to 100 to 150 ft (easternmost Alabama) (Raymond and others, 1988). Downdip, the formation has a maximum thickness of 500 ft, but generally is about 400 ft thick (Cook, 1993a).

The area of potential agricultural groundwater irrigation includes the lower part of the Selma Group, comprising the Demopolis Chalk and Mooreville Chalk (plate 4-3), which consist primarily of chalk and marl (Raymond and others, 1988), marine sediments that overlie the Eutaw formation from Pickens and Sumter Counties eastward to Bullock and Russell Counties (plate 4-3). The Demopolis Chalk (light-gray to medium-light-gray, fossiliferous chalk) overlies the Mooreville Chalk in west and central Alabama and grades into other Cretaceous formations in extreme eastern Alabama (plate 4-3). The Mooreville Chalk consists of yellowish-gray to dark-bluish-gray clayey compact fossiliferous chalk and chalky marl. The formation ranges in thickness from 270 ft in west Alabama to 600 ft in Montgomery County and thins to 100 ft in

southern Macon County, grading into other Cretaceous formations in Bullock and Russell Counties (Raymond and others, 1988).

SOILS

There are six soil orders present in the Cretaceous aquifer recharge areas (plate 4-4). However, for the most part, agriculture is developed in areas with soils described as Inceptisols and to a limited extent with Alfisols and Vertisols soils (plate 4-4). These soils occur in humid, warm areas and are characterized by the properties of their parent material, in this case predominantly the lower Selma chalks (soft limestone containing mostly calcium carbonate), alluvial sediments deposited on flood plains and terraces, as well as from other Cretaceous geologic formations that crop out in the recharge area (for example, the Eutaw Formation and Tuscaloosa Group). These soils range from finely silty and calcareous to very fine to fine smectitic and are formed on sloping topography in the Black Prairie district (USDA-NRCS, 2009a). Most of the less-sloping areas are cleared and used chiefly for growing hay and to a small extent for growing small crops (USDA-NRCS, 2009a). The organic material that accumulated through many generations of grass decomposition along with the nature of the parent material and climatic conditions produced the region's unique black, organic-rich, and clayey soils.

Several soil types are identified by the USDA-NRCS (2007a) within the recharge area. However, for the purpose of this study, the State Soil Geographic (STATSGO) Database, NRCS classification, which grouped the soils according to common taxonomic characteristics, was used (USDA-NRCS, 2007a). Major soil series and their taxonomic characteristics for the potential large-scale agricultural irrigation area are tabulated in table 4-1 and depicted in plate 4-4. All other series are referred to as "all other" orders in table 4-1.

Table 4-1. Soil order names, area, and taxonomy in the recharge area				
No.	Order	Soil order area (mi^2)	Percent total area	Taxonomic class
1	Inceptisols	1,415	37.8	fine silty, carbonatic
2	Vertisols	207	5.5	very fine, smectitic
3	Alfisols	746	19.9	fine, smectitic
4	All other	1,377	36.8	Other

LAND USE/LAND COVER

The 2001 USGS LULC data (Homer and others, 2004) were used in delineating LULC (LULC) classes and contaminant sources and in predicting future impacts. This dataset was compiled from Landsat Thematic Mapper Plus (ETM+) satellite imagery (circa 2001), and it was supplemented by various ancillary data such as the National Land Cover Database 2001 for mapping zone 46, produced by the Multi-Resolution Land Characteristics (MRLC) Consortium. Landsat 7, the Landsat Thematic Mapper Plus (ETM+), is a multispectral scanning radiometer that scans bands 1 through 5 and 7 (3 visible, 2 middle infrared, and 1 near infrared,) with 30-meter (m) pixel resolution, and the thermal infrared, band 6, with a 60-m resolution. From this dataset, nine Level I LULC classes were identified for the area under investigation and are depicted in plate 4-5. The Level I classification includes the following classes: water, developed, barren, natural forested upland, vegetated natural shrubland, herbaceous upland natural/semi-natural vegetation (grassland/herbaceous), herbaceous planted/cultivated (pasture/hay), herbaceous planted/cultivated (cultivated crops), and wetland (plate 4-5). Most of the recharge area is dominated by forest with lesser agriculture (plate 4-5). However, when considering only the potential large-scale agricultural irrigation area, agriculture (pasture/hay and cultivated crops) is the prevailing land use followed by forest (plate 4-5).

Boundaries for cultivated/agricultural areas can be derived by assessing the geology, soils, physiography, topography, and land-use patterns. There is an obvious relationship between particular geologic formations (plate 4-3), soil types (plate 4-4), and the distribution of cultivated areas (plate 4-5). Based on these analyses, it is observed that agriculture is developed

primarily in areas underlain by Cretaceous chalk of the Selma Group (Demopolis and Mooreville Chalk) (plates 4-3, 4-5). Furthermore, agricultural lands in this area are associated with the moderately deep, well drained, slowly permeable Inceptisols that were formed in marly clays and chalk of the Black Belt prairies (plates 4-4, 4-5).

Land-use/land-cover analyses were conducted for the area associated with the black-rich topsoil developed from the chalk formations in the area of potential large-scale agricultural irrigation. Results of the LULC analysis for the area of potential large-scale agricultural irrigation are tabulated in table 4-2 and indicate three major classes of LULC: agriculture, forest, and other land uses.

Table 4-2.--Classes, area, and proportion of LULC for the area of potential agricultural groundwater irrigation.

LULC class	LULC class area (mi^2)	Percent of LULC class
Water	116.3	3.1
Developed	206.0	5.5
Barren	1.9	0.05
Natural forested upland	1,154.1	30.8
Vegetated natural scrubland	342.7	9.16
Grassland/herbaceous	5.3	0.1
Pasture/hay	926.9	24.8
Cultivated crops	292.2	7.8
Wetlands	697.7	18.6

Agriculture occupies an area of approximately 1219.1 mi^2, equivalent to 32.6 percent of the total potential agricultural groundwater irrigation (3,743.1 mi^2) (table 4-2). However, it should be noted that scattered agricultural fields are also present within the recharge area (plate 4-5).

The geology, soils, physiography, and topography collectively create an environment favorable for the land uses observed in the area of potential large-scale agricultural irrigation (plate 4-5), which, in large part, are pasture and hay with only limited amounts of row crop agriculture (table 4-2).

HYDROGEOLOGY

The Eutaw and Tuscaloosa Group aquifers are the major water bearing units in the area of investigation (plate 4-6). In the recharge area, the Eutaw Formation provides the major source of freshwater (Cook, 1993a). The excellent quality of groundwater combined with increased groundwater use in the area resulted in withdrawals of water that locally exceeded aquifer recharge (Cook, 1993a). Other than small, domestic supplies from alluvium in floodplains of large streams, the Eutaw aquifer represents the shallowest source of major water supplies both in the recharge area and further south where the aquifer underlies the Selma Group (western and central Alabama) and becomes confined (Davis, 1987). In the area of potential agricultural groundwater irrigation, the Eutaw aquifer serves as the main source of freshwater. Flowing wells constructed in the Eutaw aquifer are generally situated in areas of low elevation. Municipal supply wells are generally screened in the coarse sands in the lower part of the aquifer, which provide relatively good water quality compared to the upper part of the aquifer where water quality is generally poor due to the presence of elevated iron concentrations (Davis, 1987). Municipal well yields from the Eutaw aquifer range from 0.5 to 1.0 million gallons per day (mgd) (Davis, 1987).

Wells constructed in the Coker and Gordo aquifers located west of Elmore County have the capacity of producing between 0.5 and 1 (Lines, 1975). East of Elmore County, the majority of municipal wells are screened in the sands of the Tuscaloosa Group undifferentiated (Davis, 1987). Water in the Coker and Gordo aquifers is under water table conditions within the outcrop area, under flowing conditions in low-lying areas, and under artesian conditions downdip where the Tuscaloosa Group is confined by the overlying Eutaw Formation.

Due to the availability of relatively shallow water from the Eutaw Formation, water resources in the Coker and Gordo Formations are underdeveloped in the area of potential large-scale agricultural irrigation.

POTENTIOMETRIC SURFACES

Water levels used to construct the potentiometric surface for this assessment were measured from pumping and non-pumping wells. Water levels from non-pumping wells result in

a static potentiometric surface. When water is removed from an aquifer by pumping, the potentiometric surface will fluctuate accordingly (drawdown). Water levels measured from pumping wells may be indicative of drawdown due to recent pumping intensity. However, water levels from pumping wells used in this assessment represent residual drawdown, resulting from minimal recovery times prior to water level measurement. Residual drawdown is the difference between the pre-pumping static water level and the partially recovered water level affected by pumping (Driscoll, 1986). It is important to note that as long as the potentiometric surface remains above the stratigraphic top of the aquifer, the aquifer media remains saturated so that the declining surface only represents a decline in hydrostatic pressure. If the water level declines below the stratigraphic top of the aquifer, the aquifer becomes unconfined, possibly causing irreversible formation damage. Therefore, the potentiometric surface provides important information to determine the affects of water production, strategies for water source development and protection, and future water availability.

The potentiometric surface displayed in plate 4-6 is composed from water levels measured in wells constructed in the Eutaw, Gordo, Coker, and Tuscaloosa Group undifferentiated aquifers. The ability to use water levels from four different confined aquifers to construct a single potentiometric surface indicates equivalent hydraulic head for each aquifer. The hydraulic gradient is the slope of a potentiometric surface and when considered with the dip direction, characterizes the direction and rate of movement of water through the subsurface. The highest elevations of the potentiometric surface constructed for this investigation range from about 510 to about 700 ft above mean sea level (msl) along the upgradient margin of the Coker aquifer (plate 4-6). The hydraulic gradient in the recharge areas of the subject aquifers is southwestward at about 12 ft/mi in the western and central parts of the area and southward at about 17 ft/mi in the eastern part of the area (plate 4-6). The hydraulic gradient generally flattens to about 3 ft/mi in much of the western and central parts of the area of potential agricultural groundwater irrigation and about 9 ft/mi in the eastern part of the area (plate 4-6). The change in gradient is primarily caused by the influence of the Tombigbee, Black Warrior, Alabama, and Tallapoosa Rivers (plate 4-1) and relatively low topography in the river valleys combined with unspecified water production from some wells. The range of water-surface elevations in these areas of potential agricultural groundwater irrigation is from about 75 to 225 ft above msl (plate 4-6). Additionally, the potentiometric surface indicates two groundwater sinks: one in southeastern Greene, southwestern Hale, northern Marengo, and northeastern Sumter Counties

influenced by relatively low elevations at the confluence of the Tombigbee and Black Warrior Rivers and probable water production, and the other in southeastern Autauga County, probably caused by groundwater production by the city of Prattville (plate 4-6).

DEPTH TO WATER

The depth to water map (plate 4-7) can be used to determine the depth to water at any location in the assessment area and can be used to determine pump settings and size or areas where flowing wells may be constructed. Although wells constructed in the area of potential agricultural groundwater irrigation penetrate Cretaceous aquifers at depths from 20 to 1,160 ft, hydraulic head causes the depth to water from these aquifers to range from 0 to 240 ft bls (plate 4-7). The shallowest water levels occur in the major river valleys where flowing wells can be constructed in southwestern Autauga and eastern Dallas Counties and northeastern Marengo, southwestern Perry, western Dallas, and northern Wilcox Counties (plate 4-7). The deepest water levels (100 to 240 ft bls) occur in southeastern Lowndes, Montgomery, and Bullock Counties.

SPECIFIC CAPACITIES AND PUMPING RATES

There is a large body of information related to water well locations, drillers' logs, geophysical logs, and well construction and testing data in the Black Belt area of Alabama. Although formal aquifer tests are usually not performed when production wells are installed in this area, wells are normally test pumped for at least a few hours and the maximum yield and water-level drawdown are recorded. Data from 154 wells in the area of potential groundwater irrigation were examined to determine specific capacities. Wells were divided into two groups: wells drilled to depths ranging from 60 to 500 ft (67 wells) and wells drilled to depths greater than 500 ft (87 wells).

Plate 4-8 shows the specific capacity for well depths ranging from 60 to 500 ft. Specific capacities varied from less than 1 to more than 10 gpm/ft of drawdown. Plate 4-9 shows the specific capacity for wells with depths greater than 500 ft. Specific capacities varied from less than 1 to more than 30 gpm/ft of drawdown. The larger populations of urban areas require more water than rural areas and this trend is shown in both specific capacity maps where the higher capacity wells are concentrated around cities and towns with public water supply systems. Higher capacity wells outside of urban areas were limited to county fire and water utilities and wells for industrial use. The maps indicate that higher capacity wells in the Black Belt are located based on need and do not necessarily indicate that aquifer production capability would be diminished in other areas.

One of the criteria used to calculate specific capacity for wells is the pumping rate. Pumping rates are affected by the well diameter, type of pump used, and also by the characteristics of the aquifer and are expressed in gpm. Mapping pump rate data can also be useful in determining aquifer production capability. Pumping rate data were examined from the same wells used to map specific capacity and were divided into the same two groups based on well depth. Plate 4-10 shows the pumping rates for wells with depths from 60 to 500 ft. Pumping rates ranged from less than 20 up to almost 1,500 gpm with 16 of 67 wells having pumping rates of 300 gpm or higher. Plate 4-11 shows the pumping rates for wells greater than 500 ft. Pumping rates range from less than 50 up to 1,300 gpm with 45 of 67 wells having pumping rates of 300 gpm or higher. Again wells with higher pumping rates were centered around the larger urban areas, which indicates that well construction is a major factor that controls volumes of water yielded from the available aquifers.

The specific capacities of the 59 wells with pumping rates greater than 300 gpm ranged from 1.9 to 42 gpm/ft of drawdown. Interestingly, the lowest specific capacity of those wells was from a 1,296-foot deep well pumping 450 gpm. Deeper wells with higher hydraulic head accommodate production of larger amounts of water and larger drawdowns and compensate for areas of relatively low hydraulic conductivity.

SOURCE WATER ASSESSMENT AREAS AND PUBLIC SUPPLY WELLS

In an effort to identify new areas that may provide sustainable amounts of water for agricultural practices, the assessed source water areas should be considered. Pumping in close proximity to public supply wells may impact the quality and quantity of water for public supplies. In the Black Belt area of potential groundwater irrigation, the largest source water area is located in Montgomery (plate 4-3). However, public supply wells are dispersed within most of the investigated area accompanied by small SWAA for some of these wells (plate 4-3). Nevertheless, a large part of the investigated area remains outside of SWAA and have no public supply wells (plate 4-3) so that irrigation from groundwater sources may be developed with no impact on current public water supplies.

GROUNDWATER QUALITY AFFECTING POTENTIAL AGRICULTURAL IRRIGATION IN THE BLACK BELT

Water contains a number of different dissolved inorganic constituents in ionic form. The major ions constitute the bulk of the mineral matter contributing to concentrations of total dissolved solids (TDS) (Fetter, 1994). The primary cations (ions with a positive electrical charge) in water from the Eutaw and Gordo aquifers underlying the Black Belt are sodium and calcium (Cook, 1993a). High concentrations of sodium ions in groundwater are generally in downgradient parts of the aquifers where optimum conditions exist for ionic exchange between calcium and sodium, resulting in elevated concentrations of sodium (Cook, 1993a).

The primary anions (ions with a negative charge) in water from the Eutaw and Gordo aquifers are bicarbonate and Cl. Bicarbonate water facies account for about 80 percent of the groundwater in the assessment area. Chloride water facies make up the other 20 percent and result from three processes (discussed below) related to environments of deposition and water movement through the aquifers (Cook, 1993a, 1993b, 1997, 2002).

Water with excessive concentrations of Cl is unacceptable for human consumption or agriculture. The maximum contaminant level (MCL) for Cl is 250 milligrams per liter (mg/L) (U.S. Environmental Protection Agency, 2009). The Mississippi State University Extension Service (MSUES, 2009) has established salinity guidelines for water used for irrigation. Crop tolerance levels in these guidelines are based on water conductivity and indicate that cotton is one of the most salinity tolerant row crops, Bermuda grass is the most tolerant grass, and beets, kale, asparagus, and spinach are the most tolerant garden crops. Corn, wheat, and soybeans have medium tolerance, and peanuts have low tolerance. The MSUES has also established guidelines for the hazard to crops related to Cl concentrations in irrigation water. For root absorption, 0 to 142 mg/L is a low hazard, 143 to 355 mg/L is a medium hazard, and 356 mg/L and above is a high hazard to crop production. For foliar absorption, 0 to 106 mg/L is a low hazard, 107 and above is a medium hazard. No data are available for a high hazard. The maximum low level hazard (106 mg/L) is exceeded in water from the Eutaw and Gordo aquifers in the area of potential groundwater irrigation in parts of Sumter, Greene, Hale, Marengo, Dallas, and Lowndes Counties (plates 4-12, 4-13). Immediately south from the of area of potential groundwater irrigation, all water in the Eutaw and Gordo aquifers is sodium-chloride type water with Cl concentration that exceeds crop hazard guidelines and drinking water standards (plates 4-12, 4-13).

Two areas of groundwater with excessive Cl in the Eutaw and Gordo aquifers occur in the area of potential groundwater irrigation. One includes most of Lowndes County and a small part of southeastern Dallas County and the other includes western Hale, eastern Greene, northern Marengo, and most of Sumter Counties (plates 4-12, 4-13). Groundwater with excessive Cls in the Gordo aquifer in southern Lowndes County extends farther upgradient than similar type water to the east or west. One of the probable causes for this area of anomalous water chemistry is relatively recent recharge mixing with much older Cl-rich water from underlying Paleozoic rocks and from the overlying Eutaw Formation. Groundwater with elevated Cl in the Eutaw aquifer underlies most of Lowndes County and extends upgradient well beyond the high Cl water in the underlying Gordo aquifer (plates 4-12, 4-13). Cook (1993b) suggested that water with excessive Cl concentrations in the Eutaw Formation in Lowndes County may have originated from sea water that was trapped during deposition of the Eutaw sediments. Cook (1997) confirmed this suggestion with data that indicated that the sodium to Cl ratio for this water was almost identical to the sodium to Cl ratio for seawater. Also, the calcium concentration in the water from the Eutaw Formation is very similar to that of seawater and is anomalously high when compared to other sodium-Cl type waters in the coastal plain of Alabama. The Alabama River probably forms a barrier to downgradient movement of fresh water from the recharge areas of the Eutaw and Gordo aquifers. However, since Cl concentrations in the anomalous area are much less than for seawater, it is apparent that some dilution with relatively fresh water has occurred. This may be from movement of recharge along strike or limited downward movement from the land surface or from the recharge area.

Excessive Cl concentrations in western Hale, eastern Greene, northern Marengo, and most of Sumter Counties probably originate from a different source than the Lowndes-Dallas County area. Cook (1997) states that the isotopic and geochemical signatures of groundwater in the Cretaceous aquifers suggest mixing of deep saline-rich water from Paleozoic clastic and carbonate rocks and meteoric water of local origin. The pathways of movement for the deep mineralized water are along the Eutaw thrust sheet (Cook, 1997), a part of the subsurface extension of the Appalachian fold and thrust belt (Thomas, 1973). Groundwater in both of the anomalous water quality areas is being used in aquaculture for production of shrimp and catfish.

ECONOMICS AFFECTING POTENTIAL AGRICULTURAL IRRIGATION IN THE BLACK BELT

If development of irrigation from groundwater sources is successful, it must be economically feasible. The cost of delivery of water to crops must not create an inordinately large financial burden, so that the expense of irrigation outweighs the benefits derived from irrigation for the farmer. The major costs involved with development of groundwater for irrigation are drilling and equipping water supply wells and constructing the delivery system that applies water to crops. Since delivery systems are common to both groundwater and surface-water sources, costs addressed in this report are limited to well construction only.

Costs for drilling and equipping wells capable of supplying adequate quantities of water for large-scale irrigation are based on well depth and diameter, casing, screen, and pump specifications. Costs for irrigation well construction for this project were supplied by Griner Drilling Service, Inc. from information supplied by GSA.

Specifications for a typical irrigation well in the Black Belt area of potential agricultural groundwater irrigation are based on a borehole depth of 1,000 ft: 950 ft of 10.75 inch diameter steel casing, and 50 ft of 10 inch diameter stainless steel screen with 0.012 to 0.016 inch openings. A typical well will be equipped with an 8-stage pump with a 30 horse power submersible motor set at a depth of about 250 ft below ground surface, capable of delivering 300 gpm at 300 ft total dynamic head with a pumping level of 210 ft below ground surface. The estimated cost of a typical irrigation well will be from $150,000 to $200,000.

SUMMARY OF FINDINGS

Three major factors control the viability of irrigation from groundwater sources. First, the water source must supply an adequate volume of water for the particular crop being irrigated and the supply must be sustainable over the long term. Secondly, application of groundwater onto the land surface for irrigation for an extended period of time must not degrade the land-surface or surface-water environment. Thirdly, if large-scale irrigation from groundwater sources is to be successful, it must be economically feasible.

The investigated area in the Black Belt region of Alabama includes all or part of 11 counties and is contained in the Fall Line Hills, Black Prairie, and Chunnenuggee Hills physiographic regions. The study area was divided into two parts: the recharge area, located in the Fall Line Hills district, consisting of Cretaceous aquifers including the Eutaw, Gordo, Coker, and the Tuscaloosa Group undifferentiated; and the area of potential agricultural groundwater

irrigation, located in the Black Prairie district, consisting of groundwater sources overlain by the lower Selma Group chalks.

Agriculture occupies approximately 51.2 percent of the area of potential agricultural groundwater irrigation. However, less than 8 percent of the area is currently in row crop production. The geology, soils, physiography, and topography collectively create an environment favorable for the land uses observed in the area which is primarily pasture and hay production, but much of the area would be suitable for row crops.

In the area of potential agricultural groundwater irrigation, the Eutaw aquifer serves as the main source of freshwater; however, due to the availability of relatively shallow water from the Eutaw Formation, water resources in the Coker and Gordo Formations are underdeveloped in the area of potential large-scale agricultural irrigation. Specific capacity and pumping rate data indicate that wells could be drilled and constructed in the area of potential large-scale agricultural irrigation with production rates greater than 300 gpm.

The maximum low level hazard for Cl concentrations in irrigation water (106 mg/L) is exceeded in water from the Eutaw and Gordo aquifers in the area of potential groundwater irrigation in parts of Sumter, Greene, Hale, Marengo, Dallas, and Lowndes Counties. However, about 70 percent of the area is underlain by groundwater with excellent quality, suitable for irrigation.

For large scale irrigation from groundwater sources to be viable, the water source must be of adequate quantity and quality, but it must also be economically feasible. Surface infrastructure for irrigation using groundwater or surface-water sources is similar. However, the cost of groundwater development must be compared to development of possible surface-water sources in order to determine viability of an irrigation system. Costs for drilling and equipping wells capable of supplying adequate quantities of water for large-scale irrigation are based on the well depth and diameter, casing, screen, and pump specifications. The estimated cost of a typical irrigation well capable of supplying at least 300 gpm will be from $150,000 to $200,000.

Chapter 5

POTENTIAL FOR LARGE-SCALE IRRIGATION FROM GROUNDWATER SOURCES IN SOUTHEAST ALABAMA

By Marlon Cook

LOCATION

The investigated area is located in southeastern Alabama and includes portions of Barbour, Pike, and Crenshaw Counties and all of Covington, Coffee, Dale, Henry, Houston, and Geneva Counties (plate 5-1) and comprises an area of about 6,000 mi^2. The major cities included in this area are Troy (population 18,033), Enterprise (population 26,562), and Dothan (population 65,496) (U.S. Census Bureau, 2010) (plate 5-1).

PHYSIOGRAPHY AND TOPOGRAPHY

The investigated area is located on the east Gulf Coastal Plain section of the Coastal Plain physiographic province. Most of the investigated area is contained within the Dougherty Plain, Southern Red Hills, and Chunnenuggee Hills physiographic districts (Sapp and Emplaincourt, 1975) (fig. 5-1).

The Dougherty Plain district is in the southern part of the investigated area and covers all of Houston County, southwestern Henry, southeastern Dale, most of Geneva, southern Coffee, and most of Covington Counties. It is characterized by limestone uplands, undifferentiated limestone residuum, bedded sand and clay, and surficial terrace material. Limestone solution has led to development of sinkholes, many of which are expressed as topographic depressions that may contain water. The topography of the district consists of low cuestas that are extensively cultivated (Sapp and Emplaincourt, 1975).

The Southern Red Hills district is in the central part of the investigated area and covers northern Henry, southern Barbour, southern Pike, northern Dale and Coffee Counties, and most of Crenshaw County. It is characterized by southward-sloping uplands of moderate relief (Sapp and Emplaincourt, 1975). The northern part of the district is extensively cultivated.

The Chunnenuggee Hills district forms the northern part of the investigated area and is characterized by pine-forested, sand hills and cuestas developed on resistant clay, siltstone, and sandstone in east Alabama.

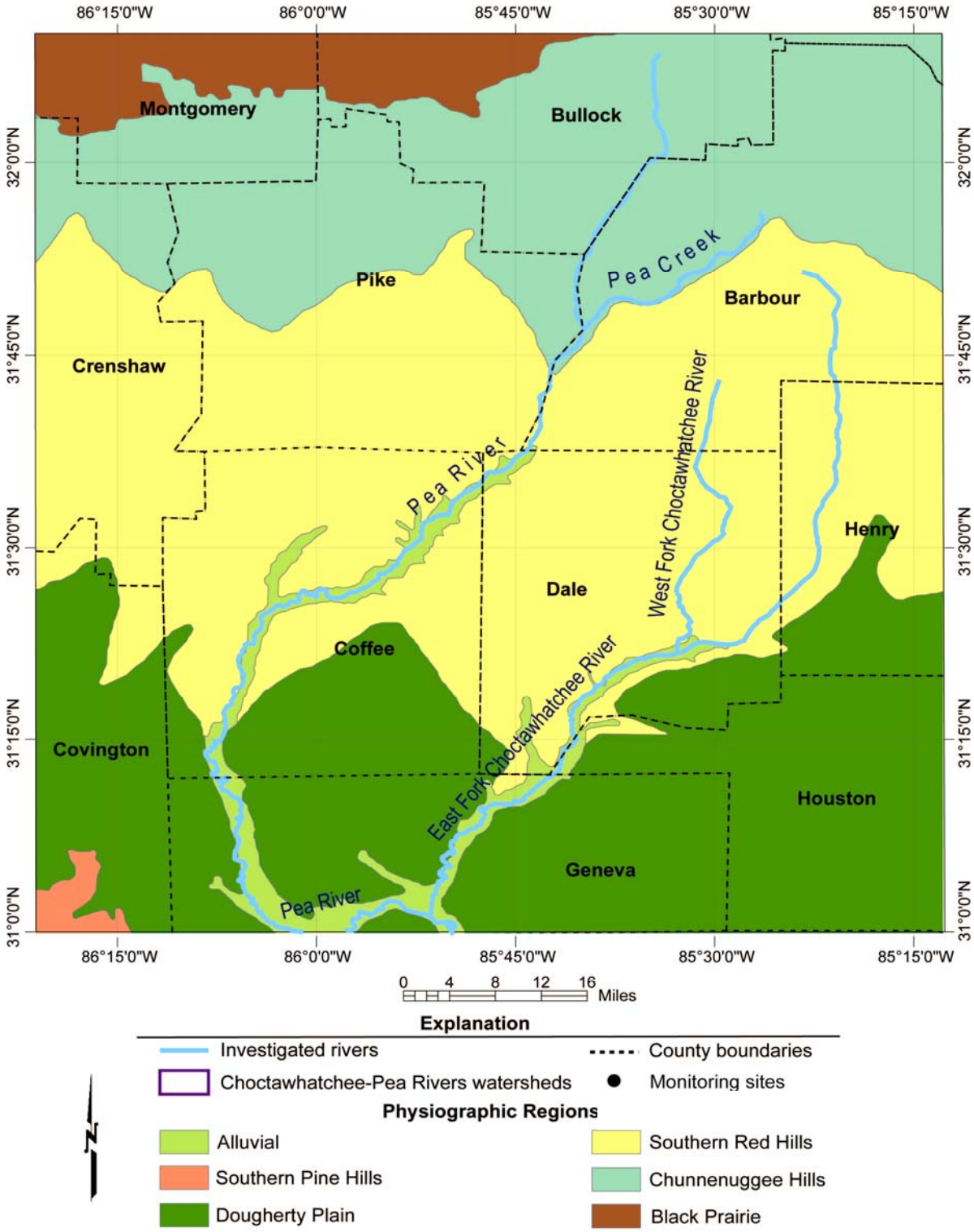

Figure 5-1.—Physiographic districts in the investigated area (physiography from Sapp and Emplaincourt, 1975; graphics from Murgulet and Cook, 2010).

LAND USE/LAND COVER

The investigated area can be divided into four distinctive LULC areas (plate 5-2). Upland areas in the northern part of the investigated area, consisting of southwestern Barbour, southern Pike, and central Crenshaw Counties, are dominated by cultivated cropland. Northern and eastern Barbour, northern Henry, northern Dale, northern Coffee, and southern Crenshaw Counties are primarily forested. Upland areas of southern Henry, southern Dale, southern Coffee, most of Houston and Geneva, and northern Covington Counties are dominated by cultivated agriculture. Southwestern Geneva and southern and western Covington Counties are primarily forested. The dominant LULC categories correlate well with topographic, geologic, and soil characteristics that support each area's specific LULC (see physiographic, geologic, and soil sections).

Table 5-1.--Classes, area and proportion of LULC for the area of potential agricultural groundwater irrigation. (see plate 5-2 for mapped area).

LULC class	LULC class area (mi^2)	Percent of LULC class
Water	67.7	0.9
Developed	418.4	5.5
Barren	0.8	0.01
Natural forested upland	4,707.0	65.0
Grassland/herbaceous	4.3	0.06
Pasture/hay	911.4	12.6
Cultivated crops	292.2	7.8
Other Crops	377.5	3.7
Wetlands	315.8	4.4

The USDA, 2009 Alabama Agricultural Statistics report (USDA, NASS, 2010) indicates that cultivated corn acreage in the investigated area is 15 percent of total Alabama corn acreage, cotton acreage is 40 percent, peanut acreage is 64 percent, and soybean acreage is 8 percent.

The geology, soils, physiography, and topography collectively create an environment favorable for the land uses observed in the area of potential large-scale agricultural irrigation (plate 5-2), which, in large part, are pasture and hay and cultivated crops (table 5-1).

HYDROGEOLOGY

Twenty-four different geologic units in the Upper Cretaceous, Tertiary, and Quaternary Systems, varying in age from about 100 million years to recent, underlie the investigated area (fig. 5-2). However, only 10 of these have hydrogeologic characteristics that define them as aquifers and of these, 6 are major aquifers capable of producing adequate quantities of water for sustainable irrigation water supply. These major aquifers are the Gordo Formation, Ripley Formation (including the Cusseta Sand Member), Clayton Formation (including the Salt Mountain Limestone, which is hydraulically connected), Nanafalia Formation, Lisbon Formation, and the Crystal River Formation.

GORDO AQUIFER

The upper part of the Tuscaloosa Group is composed of the Late Cretaceous aged Gordo Formation. These sediments consist of ferruginous stained, coarse grained sands and gravels in varicolored shades of pink or orange with coarse grains of white to light-gray feldspar and varicolored clays in shades of yellow, orange, pink, red, purple, and brown (Smith, 2001). Smith (2001) also reported that the top of the Gordo Formation (top of the Tuscaloosa Group aquifer) dips uniformly southward and southwestward at a rate of approximately 35 ft/mi (ft/mi). The top of the formation varies in depth from approximately -500 ft relative to msl in northern Pike County to approximately to more than -2,700 ft msl in southern Houston County to more than -4,000 ft msl in southern Covington County (Cook, 2002). Sands and gravels comprising productive zones of the Gordo aquifer are thickest from eastern Crenshaw County across southwestern Pike, northern Coffee, and northwestern Dale Counties. The Gordo aquifer also thickens along the eastern side of the study area toward the Chattahoochee River area (plate 5-3) (Cook and others, 2007).

SYSTEM	SERIES	GROUP	GEOLOGIC UNIT	LITHOLOGY AND THICKNESS (feet)
Quaternary	Holocene and Pleistocene		Alluvial and Terrace deposits	0 - 50
Tertiary	Miocene		Miocene undiff.	30 - 100
	Oligocene		Chickasawhay Ls.	50 - 150
		Vicksburg	Bucatunna Clay	10 - 50
			lower Vicksburg undifferentiated	150 - 200
	Eocene	Jackson	Crystal River Fm.	100 - 150
			Yazoo Clay	20 -80
			Moodys Branch Fm.	40 - 80
		Claiborne	Lisbon Formation	100 - 300
			Tallahatta Fm.	100 - 200
		Wilcox	Hatchetigbee Fm.	30 - 100
	Paleocene		Tuscahoma Sand	100 - 250
			Nanafalia Fm.	150 - 300
			Salt Mountain Ls.	100 - 300
		Midway	Porters Creek Fm.	0 - 30
			Clayton Formation	100 - 250
Cretaceous	Upper Cretaceous	Selma	Providence Sand	100 - 250
			upper Ripley Fm.	150 - 200
			Cusseta Sand Mbr.	50 - 150
			Blufftown Fm.	600 - 1200
			Eutaw Formation	100 - 300
		Tuscaloosa	Gordo Formation	400 - 550
			middle marine shale	50 - 150
			Coker Formation	? 400

EXPLANATION

Sand, Clay, Sandstone, Dolomitic Ls.

Gravel, Marl, Limestone, Fossils

Fig. 5-2.--Stratigraphy of southeast Alabama (Smith, 2001).

The recharge area for the Gordo aquifer extends from the Chattahoochee River in northern Russell and southern Lee Counties westward to southern Elmore County (Szabo and others, 1988a). The downdip (southerly) limit of fresh-water production in the Gordo aquifer is currently estimated to extend from near Newville in southern Henry County, westward across central Dale and Coffee Counties and northern Covington County. The limit shown was based on increasing sodium concentrations instead of high Cl or a lack of sand and gravel. However, the limit is poorly defined, with the most southerly fresh-water production established to date from the aquifer 4 mi north of Ozark in northern Dale County, at a depth of more than 2,700 ft (-2,200 ft msl). Although fresh water may extend farther south from this location, the aquifer in most of the assessed area is too deep for economical water production for agricultural uses and therefore did not undergo a detailed assessment for its potential for large scale irrigation. Thus, only productive zones and potentiometric surface evaluations are discussed here.

POTENTIOMETRIC SURFACE

Water level elevations in the Gordo aquifer vary from 180.0 ft msl in central Barbour County to 14.8 ft msl at Eufaula in eastern Barbour County (Cook and others, 2007) (plate 5-4). The hydraulic gradient is approximately 0.0005 (2.6 ft/mi) in the central portion of the study area in western Barbour, eastern Pike, and northern Dale Counties (Cook and others, 2007). The gradient increases to 0.001 (5 ft/mi) in northern Pike and southern Montgomery Counties and 0.002 (11 ft/mi) in eastern Barbour and northern Henry Counties (Cook and others, 2007). Ground-water flow is south 20° east in eastern Barbour and eastern Henry Counties, southward in southeastern Bullock, western Barbour, and northern Dale Counties, south 20° west in southern Pike and northern Coffee Counties, and west-southwest in southwestern Bullock, northern Pike, and southern Montgomery Counties (Cook and others, 2007). Disruptions in the potentiometric surface occur near producing wells in Eufaula (eastern Barbour County), northwestern Barbour County at a State of Alabama Forestry Commission well, and at Troy in central Pike County (Cook and others, 2007) (plate 5-4).

RIPLEY AQUIFER

In eastern Alabama, the Cusseta Sand is recognized as the lower member of the Ripley Formation (fig. 5-2). In outcrop, it consists predominately of cross-bedded coarse quartzose sand and granular gravel with subordinate beds of dark-gray to black carbonaceous clay (Smith, 2001). The recharge area extends from the Chattahoochee River in northern Barbour County westward through central Bullock and eastern Montgomery Counties (Szabo and others, 1988a).

In the subsurface, the Cusseta Sand varies from about 60 to more than 200 ft in thickness. The thickest probable productive intervals of the Ripley/Cusseta aquifer (plate 5-5) extend from southeastern Crenshaw County across southern Pike County and probably connect to a thick area in south-central Henry County. Another thick area is in northwestern Houston County, but the sands there appear to contain brackish water (Cook and others, 2007). Although it can be mapped to northern Houston County, Smith (2001) suggests that the viability of the Cussetta Sand as an aquifer may not extend southward from southern Pike and Barbour Counties. The depth of the Cusseta Sand varies from -100 ft msl in southern Barbour and Pike Counties to more than -1,000 ft msl in southern Dale and northern Houston Counties (Smith, 2001).

The upper unnamed member of the Ripley Formation consists of massive-bedded to cross-bedded, glauconitic fine sands and sandy clay with thin indurated beds of fossiliferous sandstone having a total thickness of about 135 ft (Smith, 2001). However, downgradient in the subsurface the Ripley Formation is predominantly composed of fine sandy clay, marl, and clay and is not a viable aquifer. The downdip limit of freshwater occurrence extends from southernmost Crenshaw County southeastward through Coffee County and eastward across southern Dale and Henry Counties.

POTENTIOMETRIC SURFACE

Water level elevations in the Ripley aquifer vary from 514.3 ft msl near the recharge area in southern Bullock County to 54.3 ft above sea level at Ozark in north-central Dale County (Cook and others, 2007) (plate 5-6). The hydraulic gradient is approximately 0.003 (16 ft/mi). Groundwater flow is southward in Crenshaw and western Pike Counties, approximately south 30° west in eastern Pike, western Barbour, and northern Dale Counties, and south 70° east in eastern Barbour and eastern Henry Counties where the Chattahoochee River appears to influence the direction of groundwater flow in the aquifer (Cook and others, 2007). Disruptions in the potentiometric surface occur near producing wells in Ozark (north-central Dale County), Luverne (central Crenshaw County), and at the Fort Rucker Cairns Landing Field in southeastern Dale County (Cook and others, 2007) (plate 5-6).

WELL DEPTH

Depths of wells constructed in the Ripley aquifer vary from less than 200 ft in central Barbour, southern Bullock, and northern Pike Counties to more than 900 ft near the downdip limit of adequate water quality in southern Dale, northern Coffee, and southern Crenshaw Counties (plate 5-7).

DEPTH TO WATER

The depth to water in the Ripley aquifer in the investigated area varies from 0 to more than 360 ft bls (plate 5-8). Depth to water increases gradationally downgradient at a rate of about 15 ft/mi from less than 30 ft in the recharge area in central Barbour and southern Bullock Counties to more than 350 ft in central Pike and central Dale Counties (plate 5-8). The Chattahoochee River also profoundly affects the depth to water, with a measured water level in well A-3 in northern Henry County less than 20 ft (plate 5-8).

SPECIFIC CAPACITIES AND PUMPING RATES

Plate 5-9 shows the specific capacity for wells constructed in the Ripley aquifer. Specific capacities vary from less than 1 to more than 26 gpm/ft. The largest specific capacities correlate well with areas of thick water productive intervals in central Crenshaw, southern Pike, and northern Coffee and Dale Counties shown on plate 5-9.

Pumping rate data were examined from the same wells used to map specific capacity. Pumping rates range from 10 to 1,200 gpm with 8 of 12 wells having pumping rates of 500 gpm or higher (plate 5-10). As with specific capacity, pumping rates correlate well with areas of thick water productive intervals in central Crenshaw, southern Pike, and northwestern Coffee and southern Dale Counties.

CLAYTON AND SALT MOUNTAIN AQUIFERS

The Clayton Formation outcrop in southern Barbour and Pike and central Crenshaw Counties varies from 70 to about 125 ft in thickness and consists predominantly of deeply weathered thick beds of highly fossiliferous sandy limestone interbedded with relatively clean quartzose sand (Smith, 2001). The recharge area extends from the Chattahoochee River in central Barbour County westward through central Pike and Crenshaw Counties (Szabo and others, 1988a). In the subsurface, the thickness of the Clayton Formation is about 100 ft near the recharge area and in northern Dale and Coffee Counties (Smith, 2001). It thickens gradationally southeastward to more than 300 ft in northwestern Houston County and southwestward to more

than 200 ft in Covington County (Smith, 2001). As shown in plate 5-11, a thick area of probable productive sand and/or limestone in the Clayton Formation extends from northwestern Houston County across southern Dale County and south-central Coffee County. The Clayton appears to thin away from this "fairway," though this thinning is poorly defined, especially in the downdip (southerly) direction (Cook and others, 2007). The thickest probable productive part of the Salt Mountain Limestone extends from northern Covington County southeast into southwestern Coffee County, north-central Geneva County, and southwestern Dale County (Cook and others, 2007). The depth of the Clayton Formation varies from -100 ft msl in central Henry, Dale, and Coffee Counties and southern Crenshaw County to -800 ft msl in central Houston, northern Geneva and Covington Counties (Smith, 2001).

The hydrology of the Clayton aquifer for this investigation includes the Salt Mountain Limestone. The Salt Mountain Limestone is the only stratigraphic unit in southeast Alabama that does not have an outcrop exposure (Smith, 2001). The Salt Mountain Limestone can be mapped to the northern boundaries of Coffee, Dale, and Henry Counties. It consists of white to very light- gray, massive, highly porous and permeable, more rarely dense and indurated, rarely fine to medium quartzose sandy, highly fossiliferous limestone. Although the Salt Mountain Limestone is considered stratigraphically separate from the Clayton Formation (fig. 5-2), hydrologic data indicates that the two are hydraulically connected. Therefore, for the purposes of hydrologic discussion for this evaluation they are considered together. The downdip (southerly) limit of water production in the Clayton aquifer (plate 5-11) extends across south-central Covington and southwestern Geneva Counties and is due primarily to higher salinity of the formation waters downdip.

POTENTIOMETRIC SURFACE

Water level elevations in the Clayton aquifer vary from 406.2 ft msl near the recharge area in north-central Crenshaw County to -118.0 ft msl at Dothan in northwestern Houston County (plate 5-12). The hydraulic gradient is approximately 0.002 (11 ft/mi). Ground-water flow directions vary from south to south 20° west in Pike and northern Coffee Counties to south 70° east in eastern Barbour and eastern Henry Counties where the Chattahoochee River appears to influence the direction of groundwater flow. Disruptions in the potentiometric surface occur near producing wells in the Dothan area (northwestern Houston and southeastern Dale Counties), Enterprise (southeastern Coffee County), Dozier (southern Crenshaw County), and at the Fort Rucker Cairns Landing Field in southwestern Dale County (plate 5-12).

WELL DEPTH

Depths of wells constructed in the Ripley aquifer vary from about 200 ft in northern Barbour, northern Pike, and southern Crenshaw Counties to about 1,000 ft near the downdip limit of adequate water quality in northern Houston, and southern Dale, and Coffee Counties (plate 5-13).

DEPTH TO WATER

The depth to water in the Clayton aquifer in the investigated area varies from 0 to more than 330 ft bls (plate 5-14). The shallowest water levels in the confined part of the aquifer occur in the major river valleys in Dale and Coffee Counties. The deepest water levels (more than 200 ft bls) occur in southeastern Coffee County in the Enterprise area and northwestern Houston County in the Dothan area where impacts of water production for public water supply are observed (plate 5-14).

SPECIFIC CAPACITIES AND PUMPING RATES

Plate 5-15 shows the specific capacity for wells constructed in the Clayton and Salt Mountain aquifers. Specific capacities varied from less than 1 gpm/ft near the updip limit in southern Barbour County to more than 60 gpm/ft in southern Dale County. Specific capacities correlate well with thicknesses of water productive intervals with the thickest intervals and largest specific capacities in northwestern Houston and southern Dale Counties shown on plate 5-15.

Pumping rate data were examined from the same wells used to map specific capacity. Pumping rates range from less than 100 gpm in southern Barbour and northern Dale Counties to more than 1,500 gpm in southern Dale and northwestern Houston Counties (plate 5-16). Twenty-three of 34 wells have pumping rates of 500 gpm or higher. As with specific capacity, larger pumping rates correlate well with areas of thick water productive intervals in southern Coffee, Dale, and Henry Counties and northwestern Houston County.

NANAFALIA AQUIFER

Where the Nanafalia Formation outcrops in southern Barbour and Pike and central Crenshaw Counties it is about 125 ft in thickness and consists of massive cross-bedded sand, and glauconitic and fossiliferous fine sands (Smith, 2001). The recharge area extends from the Chattahoochee River in southern Barbour County westward through southern Pike and central Crenshaw Counties (Szabo and others, 1988a). In the subsurface, the thickness of the Nanafalia

Formation is about 100 ft and consists of greenish-colored and glauconitic-stained coarse to very coarse quartzose sand, fragments of marine fossils, and abundant medium to coarse glauconite (Smith, 2001). Some usually dense, indurated, frequently sandy limestone beds occur in the Nanafalia Formation (Smith, 2001). The thickness of the Nanafalia Formation is about 200 ft in western Houston, southern Dale, and Coffee Counties and increases to more than 300 ft in central Covington County. The thickest area of probable productive sands and limestone occurs in two main areas – one centered in the northwestern Houston County "panhandle," including southern Dale County and the other thick area centered in southern Coffee County west of Enterprise (plate 5-17). The depth of the Nanafalia Formation varies from sea level in southern Henry, Dale, and Coffee Counties and northern Houston County to -600 ft MSL in southern Houston and central Geneva and Covington Counties (Smith, 2001).

The interpreted downdip limit of Nanafalia aquifer water production extends in a general northwest to southeast line across southern Covington County and southwestern Geneva County (plate 5-17). This limit is the result of a general decrease in the net sand/limestone content and greater salinity to the southwest (Cook and others, 2007).

POTENTIOMETRIC SURFACE

Water level elevations in the Nanafalia aquifer vary from 487.0 ft msl near the recharge area in east-central Barbour County to -38.0 ft msl at Dothan in northwestern Houston County (plate 5-18). The hydraulic gradient varies from 0.002 (11 ft/mi) in the northern portion of the aquifer to 0.003 (16 ft/mi) in the southern portion of the aquifer. Groundwater flows approximately south 10° west. Disruptions in the potentiometric surface occur near producing wells in the Dothan area (northwestern Houston and southeastern Dale Counties), Daleville (southwestern Dale County), and Andalusia (central Covington County) (plate 5-18).

WELL DEPTH

Depths of wells constructed in the Nanafalia aquifer vary from less than 200 ft in central Barbour, southern Bullock, and northern Pike Counties to more than 900 ft near the downdip limit of adequate water quality in southern Dale, northern Coffee, and southern Crenshaw Counties (plate 5-19).

DEPTH TO WATER

The depth to water in the Nanafalia aquifer in the investigated area varies from 0 to more than 280 ft bls (plate 5-20). The shallowest water levels in the confined part of the aquifer occur in the major river valleys in Dale and Coffee Counties. The deepest water levels (> 200 ft bls) occur in southwestern Dale and eastern Houston Counties.

SPECIFIC CAPACITIES AND PUMPING RATES

Plate 5-21 shows the specific capacity for wells constructed in the Nanafalia aquifer, which varied from less than 1 to 23 gpm/ft. The largest specific capacities correlate well with areas of thick water productive intervals shown on plate 5-17 in southern Coffee and Dale Counties and northwestern Houston County.

Pumping rate data were examined from the same wells used to map specific capacity. Pumping rates range from 10 to >800 gpm. Pumping rates generally increase from north to south with the highest rates in northwestern Houston, southwestern Dale, and Geneva County (plate 5-22).

LISBON AQUIFER

The Lisbon Formation outcrop and recharge area extends across southern Henry, Dale, Coffee, and northern Covington Counties (Szabo and others, 1988a) where the formation is about 110 ft in thickness near the Chattahoochee River and thins westward to about 75 ft in Covington County. Toulmin and LaMoreaux (1963) reported that the Lisbon Formation outcrop in southeast Alabama consists primarily of sand but also contains significant amounts of limestone and sandy limestone. Smith (2001) described subsurface Lisbon sands as greenish-gray to yellowish-gray, sparingly glauconitic, quartzose silty, varying from poorly sorted to well sorted, fine to medium grained. Lisbon limestones are light-gray, indurated, quartzose sandy, and highly fossiliferous, frequently vugular, highly porous and permeable from leaching and solution of fossils and fossil fragments (Smith, 2001). In the subsurface, the thickness of the Nanafalia Formation is 60 to 80 ft in central Covington County and thickens southeastward to more than 350 ft in central Geneva County (Smith, 2001). The depth of the Lisbon Formation varies from 200 ft msl in central Houston, southern Dale, and Coffee Counties and northern Covington County to sea level in southern Houston and Geneva Counties and central Covington County (Smith, 2001).

POTENTIOMETRIC SURFACE

Water level elevations in the Lisbon aquifer vary from 356.7 ft msl near the recharge area in west-central Henry County to 84.2 ft msl in south-central Geneva County (plate 5-19). The hydraulic gradient is 0.002 (11 ft/mi). Groundwater flow directions are locally variable but are generally southward regionally. Disruptions in the potentiometric surface occur near producing wells in southwestern Coffee, western Geneva, and central Covington Counties (plate 5-23).

WELL DEPTH

Depths of wells constructed in the Lisbon aquifer vary from less than 30 ft in the recharge area of central Henry, Dale, and Coffee Counties, and northern Covington County to more than 400 ft in Geneva County (plate 5-24).

DEPTH TO WATER

The depth to water in the Lisbon aquifer in the investigated area varies from 0 to more than 100 ft bls (plate 5-25). The shallowest water levels in the Lisbon aquifer occur in the recharge area and in the Choctawhatchee River valley in Geneva County. The deepest water levels (> 80 ft bls) occur in northeastern Geneva and eastern Houston Counties.

SPECIFIC CAPACITIES AND PUMPING RATES

Plate 5-26 shows the specific capacity for wells constructed in the Lisbon aquifer. Specific capacities varied from less than 1 to more than 6 gpm/ft. Values of specific capacity generally increase from the recharge area in southern Henry, Dale, and Coffee Counties southward to the Florida state line in Geneva and southwestern Houston Counties where the values vary from 4.6 to 6.2 gpm/ft of drawdown.

Pumping rate data were examined for most of the wells used to map specific capacity. Pumping rates range from 6 to 503 gpm. The largest pumping rates were observed in a southwestward trend along the Choctawhatchee River valley from southwestern Henry County through southern Dale and central Geneva Counties (plate 5-27).

CRYSTAL RIVER AQUIFER

The Crystal River Formation outcrop and recharge area in Alabama is included in an area of thick Tertiary residuum that extends from central Henry County, southern Dale and Coffee Counties, and northern Covington County on the north to the Florida State line in Houston and Geneva Counties and central Covington County on the south (Szabo and others, 1988a). In the

shallow subsurface in northwestern Houston, southern Geneva, and central Covington Counties, the Crystal River Formation consists of 100 to 150 ft of calcareous sand, sandy clay, and marl with thin interbedded limestone. In southern Houston, Geneva, and Covington Counties, Crystal River sediments are composed of pinkish-gray to very pale-orange, very fossiliferous, somewhat dolomitized and vugular, highly porous and permeable limestone (Smith, 2001). The thickness of the Crystal River Formation is about 100 ft in southern Covington County and increases to more than 150 ft in southern Geneva County and to more than 200 ft in southern Houston County (Smith, 2001).

POTENTIOMETRIC SURFACE

Water level elevations in the Crystal River aquifer vary from 213.5 ft msl near the recharge area in east-central Covington County to 88.1 ft msl in southern Geneva County (plate 5-28). The hydraulic gradient is approximately 0.002 (11 ft/mi). Groundwater flow is southward with a slight southwestward component in central Geneva County. Minor disruptions in the potentiometric surface occur near producing wells in Geneva County and southern Houston County.

WELL DEPTH

Depths of wells constructed in the Crystal River aquifer vary from 76 to 380 ft with most of the deepest wells occurring in southwestern Geneva and southern Covington Counties, indicating the southwestern dip of the formation (plate 5-29).

DEPTH TO WATER

Depth to water in the Crystal River aquifer in the investigated area varies from 3 to more than 90 ft bls (plate 5-30). The shallowest water levels in the Lisbon aquifer were observed in central Houston County and the deepest water levels (> 60 ft bls) occur along the Florida state line in southern Covington, Geneva, and Houston Counties. Water depths were not contoured due to variability of the values.

SPECIFIC CAPACITIES AND PUMPING RATES

Plate 5-31 shows the specific capacity for wells constructed in the Ripley aquifer. Specific capacities varied from less than 1 to 750 gpm/ft. The largest specific capacities occurred in southeastern Covington and southeastern Geneva Counties. Specific capacities were not contoured due to variability of the values.

Pumping rate data were examined for most of the wells used to map specific capacity. Pumping rates range from 23 to 1,100 gpm. Pumping rates generally increase southward from the recharge area with the largest rates occurring in southern Houston, Geneva, and Covington Counties (plate 5-32).

PUBLIC WATER SUPPLY WELLS, SOURCE WATER ASSESSMENT AREAS, AND WELL CAPTURE ZONES

All public water supplies in southeast Alabama are from groundwater sources. There are about 80 public water supply systems in the area of investigation (Alabama Rural Water Association, 2006). Each aquifer evaluated in this investigation also serves as a source of public water supply. Therefore, locations and contributing aquifers for public water supply wells must be considered prior to development of agricultural groundwater sources so that interference of contribution areas is avoided. Plate 5-33 shows that there are more than 300 public water supply wells in the investigated area. The largest concentrations of wells are in northwestern Houston County, in and around the city of Dothan, southwestern Dale County including the Fort Rucker area, and southeastern Coffee County in the city of Enterprise area. Plate 5-33 also shows SWAA, which are designated for special protection of public water supply wells from sources of contamination.

A well capture zone is the estimated area of water contribution to a well. Determinations of well capture zones are important for several reasons. Knowledge of capture zones may be used to construct wells with proper spacing and production rates to avoid multiple wells producing water from the same areas. Also, it is important to know the area of water contribution to a well so that contaminant sources may be monitored and controlled.

Capture zones were modeled, using the GPTrac program by Cook and others (2007), for approximately 120 wells constructed in eight major aquifers in southeast Alabama. Hydrologic data, including well location, aquifer confinability, transmissivity, hydraulic gradient, flow direction, the quantity of water production, and production time, were input to the model and the resulting optimum well spacing guidelines are shown in table 5-2.

Table 5-2.--Well capture zone and spacing data for southeast Alabama aquifers (Cook and others, 2007).			
Aquifer	Average capture zone area (mi^2)	Optimum well spacing (miles)	
		Along strike of hydraulic gradient direction	Up or down gradient direction
Gordo	1.9	1.5	2.0
Ripley	2.6	1.0	2.5
Clayton	2.0	1.0	2.0
Nanafalia	1.2	1.0	2.0
Lisbon	0.6	1.0	1.0
Crystal River	1.0	1.0	1.0

SOILS

The USDA Soil Conservation Service (SCS) (currently the NRCS (2007b)) lists five major factors that influence the formation of soils: climate, parent material, plant and animal life, time, and topography. Soils in southeast Alabama form in a warm, humid climate, with extreme leaching of soluble materials and downward transport of fine particles, resulting in characteristically acid, sandy soils with little natural fertility. Warm, humid conditions promote abundant bacterial activity, causing rapid decomposition of organic material, leaving most soils with low organic content. Soils in southeast Alabama can be characterized by like parent material and topography. Upland soils formed from Tertiary aged clastic and carbonate sediments cover most of the area dominated by agriculture. Soils at lower elevations along major streams are formed from Quaternary aged alluvial deposits, which support agriculture in flood plains.

Four soil orders occur in the Southeast Alabama investigated area, shown in table 5-3 and plate 5-34. However, most agriculture is developed in areas with soils in the Ultisols order (table 5-3). The northern area of agricultural development is dominated by soils in the coarse-loamy, siliceous, semiactive, thermic Typic Paleudults and loamy, kaolinitic, thermic Grossarenic Kandiudults taxonomic classes. The southern area of agricultural development is dominated by soils in the fine-loamy, kaolinitic, thermic Plinthic Kandiudults and fine-loamy, siliceous, thermic Typic Kanhapludults taxonomic classes (plate 5-34).

Table 5-3. --Soil order names and aerial extent in the investigated area.			
No.	Order	Soil order area (mi^2)	Percent total area
1	Inceptisols	581	8.1
2	Histosols	186	2.6
3	Alfisols	45	0.6
4	Ultisols	6,398	88.7

ECONOMICS AFFECTING POTENTIAL AGRICULTURAL IRRIGATION FROM GROUNDWATER SOURCES IN SOUTHEAST ALABAMA

Costs for irrigation well construction for this project were supplied by a licensed drilling company with extensive drilling experience in southeast Alabama and from information supplied by GSA. Specifications were based on four scenarios for various irrigation needs. Scenarios 1 and 3 would provide a source of groundwater for recharge of irrigation ponds during the non-growing season with minimal recharge during the growing season. Scenarios 2 and 4 would provide an adequate water source for spray irrigation or rapid pond recharge. All well scenario costs include drilling, casing, screen, and pumping equipment.

Scenario 1 consists of a relatively shallow well (maximum depth 400 ft) constructed of 4-inch steel casing, capable of producing less than 50 gpm. The cost of this well is $22,400.00. Scenario 2 consists of a relatively shallow well (maximum depth 400 ft) constructed of 10-inch steel casing, capable of producing greater than 300 gpm. The cost of this well is $59,000.00. Scenario 3 consists of a relatively deep well (maximum depth 900 ft) constructed of 4-inch steel casing, capable of producing <50 gpm. The cost of this well is $64,600.00. Scenario 4 consists of a relatively deep well (maximum depth 900 ft) constructed of 10-inch steel casing, capable of producing >300 gpm. The cost of this well is $129,500.00.

SUMMARY OF FINDINGS

The investigated area in southeastern Alabama comprises an area of about 6,000 mi^2 and includes all or part of nine counties contained in the Chunnenuggee Hills, Dougherty Plain, and the Southern Red Hills physiographic districts. The investigated area can be divided into four distinctive LULC areas. Upland areas in the northern part of the investigated area, consisting of southwestern Barbour, southern Pike, and central Crenshaw Counties, are dominated by

cultivated cropland. Northern and eastern Barbour, northern Henry, northern Dale, northern Coffee, and southern Crenshaw Counties are primarily forested. Upland areas of southern Henry, southern Dale, southern Coffee, most of Houston and Geneva, and northern Covington Counties are dominated by cultivated agriculture. Southwestern Geneva and southern and western Covington Counties are primarily forested.

Agriculture occupies approximately 24 % of the investigated area with about 12 percent of the area currently in row crop production. Major row crops include corn, cotton, peanuts, and soy beans. Corn acreage in the investigated area is 15 percent of total Alabama corn acreage, cotton acreage is 40 percent, peanut acreage is 64 percent, and soybean acreage is 8 percent.

Twenty-four geologic units in the upper Cretaceous, Tertiary, and Quaternary Systems, varying in age from about 100 million years to recent, underlie the investigated area. However, only six of these are major aquifers capable of producing adequate quantities of water for sustainable irrigation water supply. These major aquifers are the Gordo Formation, Ripley Formation (including the Cusseta Sand Member), Clayton Formation (including the Salt Mountain Limestone, which is hydraulically connected), Nanafalia Formation, Lisbon Formation, and the Crystal River Formation.

Characteristics the impact sustainable groundwater production were evaluated including aquifer productive intervals, potentiometric surfaces, well depth, depth to water, specific capacity, and pumping rates.

All public water supplies in southeast Alabama are from groundwater sources. There are about 80 public water supply systems that operate more than 300 production wells.in the area of investigation. Locations and aquifers that make up public water supply sources must be considered prior to development of large scale agricultural irrigation using groundwater.

Soils in southeast Alabama can be characterized by like parent material and topography. Upland soils formed from Tertiary aged clastic and carbonate sediments cover most of the area dominated by agriculture. Soils at lower elevations along major streams are formed from Quaternary aged alluvial deposits, which supports agriculture in flood plains. Four soil orders occur in the Southeast Alabama investigated area. However, most agriculture is developed in areas with soils in the Ultisols order.

Costs for irrigation well construction can be considered in 4 scenarios. Scenario 1 consists of a relatively shallow well (maximum depth 400 ft) constructed of 4-inch steel casing,

capable of producing less than 50 gpm. The cost of this well is $22,400.00. Scenario 2 consists of a relatively shallow well (maximum depth 400 ft) constructed of 10-inch steel casing, capable of producing greater than 300 gpm. The cost of this well is $59,000.00. Scenario 3 consists of a relatively deep well (maximum depth 900 ft) constructed of 4-inch steel casing, capable of producing <50 gpm. The cost of this well is $64,600.00. Scenario 4 consists of a relatively deep well (maximum depth 900 ft) constructed of 10-inch steel casing, capable of producing >300 gpm. The cost of this well is $129,500.00.

Southeast Alabama is underlain by multiple aquifers capable of producing groundwater with adequate quantity and quality for sustainable large-scale irrigation. Development of these sources must include consideration of public water supply sources, proper well spacing, and sustainable production rates. Most of these aquifers are confined and are not drastically impacted by drought or surface sources of contamination. However, wells constructed in these aquifers will be relatively deep and must be evaluated for economic viability.

Chapter 6

POTENTIAL FOR LARGE-SCALE IRRIGATION FROM GROUNDWATER SOURCES IN SOUTH-CENTRAL ALABAMA

By Blakeney Gillett

INTRODUCTION

Chapter 6 includes results of investigation for potential large-scale irrigation in Conecuh, Escambia and Monroe Counties, in the south-central Alabama. Aquifers in the study area are the Nanafalia, Lisbon, and Crystal River Formations, the undifferentiated Miocene-Pliocene, and the watercourse aquifer. Geologic units comprising these aquifers crop out north of the study area. Only the Nanafalia, Lisbon, and Miocene aquifers are capable of yielding more than 1 in the study area and are the main focus of this report.

The Nanafalia aquifer consists of permeable units of the lower Wilcox Group in the subsurface. The Lisbon aquifer includes the upper part of the Tuscahoma Sand, the Hatchetigbee Formation, the Claiborne Group, and the Moodys Branch Formation of the Jackson Group. The Miocene-Pliocene aquifer consists predominantly of the Citronelle Formation and the undifferentiated deposits of the Miocene Series and locally includes the Paynes Hammock Sand and Chickasawhay Limestone of late Oligocene age.

Water in these aquifers is generally unconfined in the outcrop areas and is under artesian conditions downdip. The largest pumping centers are at Atmore and Monroeville. Groundwater use at Atmore is more than 2.94. Groundwater use at Monroeville is about 2.58. Estimated groundwater withdrawal for all uses in the area is about 17.18 (Hutson and others, 2009).

Groundwater withdrawals have caused depressions in the potentiometric surface of the Nanafalia aquifer in the vicinities of Monroeville and Beatrice. A depression has also formed in the potentiometric surface of the Miocene aquifer in the vicinity of Brewton.

LOCATION AND EXTENT OF THE STUDY AREA

The study area is in south-central Alabama and includes about 2,840 mi^2 (Hutson and others, 2009) in Conecuh, Escambia, and Monroe Counties (plate 6-1). Although predominantly rural, significant urban and suburban areas include Evergreen, Monroeville, Atmore, Brewton, East Brewton, Flomaton, and Beatrice. The total population of the area was 75,072 in 2005

(Hutson and others, 2009). All the population is dependent on groundwater for public supply and

household use.

PHYSIOGRAPHY AND TOPOGRAPHY

The three county area includes parts of five physiographic districts within the East Gulf Coastal Plain section of the Coastal Plain physiographic province (fig. 6-1).

Northeastern Monroe and northern Conecuh Counties are in the Southern Red Hills district. This area is characterized by a southward gently sloping upland of moderate relief, with elevations ranging from about 100 ft above sea level in northern Monroe County to about 550 ft above sea level in northern Conecuh County. Drainage in the area is southward to the Conecuh River and westward to the Alabama River.

The westernmost part of Monroe County is in the Alluvial Plain district. This area is characterized by broad, flat flood plains and terraces and is periodically inundated by floods on the Alabama River. The land surface ranges from about 25 ft above sea level in southwestern Monroe County to about 120 ft above sea level in northwestern Monroe County.

The north-central part of Monroe County and the northwestern and eastern parts of Conecuh County are in the Lime Hills district. This area consists mainly of a rugged hilly terrain. The land surface ranges from about 100 ft above sea level in creek valleys to as much as 450 ft above sea level on hilltops. Drainage in the area is westward to the Alabama River and southward to the Conecuh River.

The east-central part of Monroe County, the northeastern part of Escambia County, and the central parts of Conecuh County are in the Dougherty Plain district. This area is dominated by low cuestas underlain by weathered limestone (residuum). The land surface ranges from 100 to 400 ft above sea level. Drainage is westward to the Alabama River, southward and northward to the Conecuh River, and southward and westward to the Yellow River. The southern part of Monroe County, the southwestern part of Conecuh County, and all except the northeasternmost part, of Escambia County, are in the Southern Pine Hills district. This area is characterized by upland in the north with relief of up to 250 ft and it slopes gradually to the south where the relief is less than 100 ft. The land surface ranges from 35 to 400 ft above sea level. Drainage is westward to the Alabama River, southward and northward to the Conecuh River.

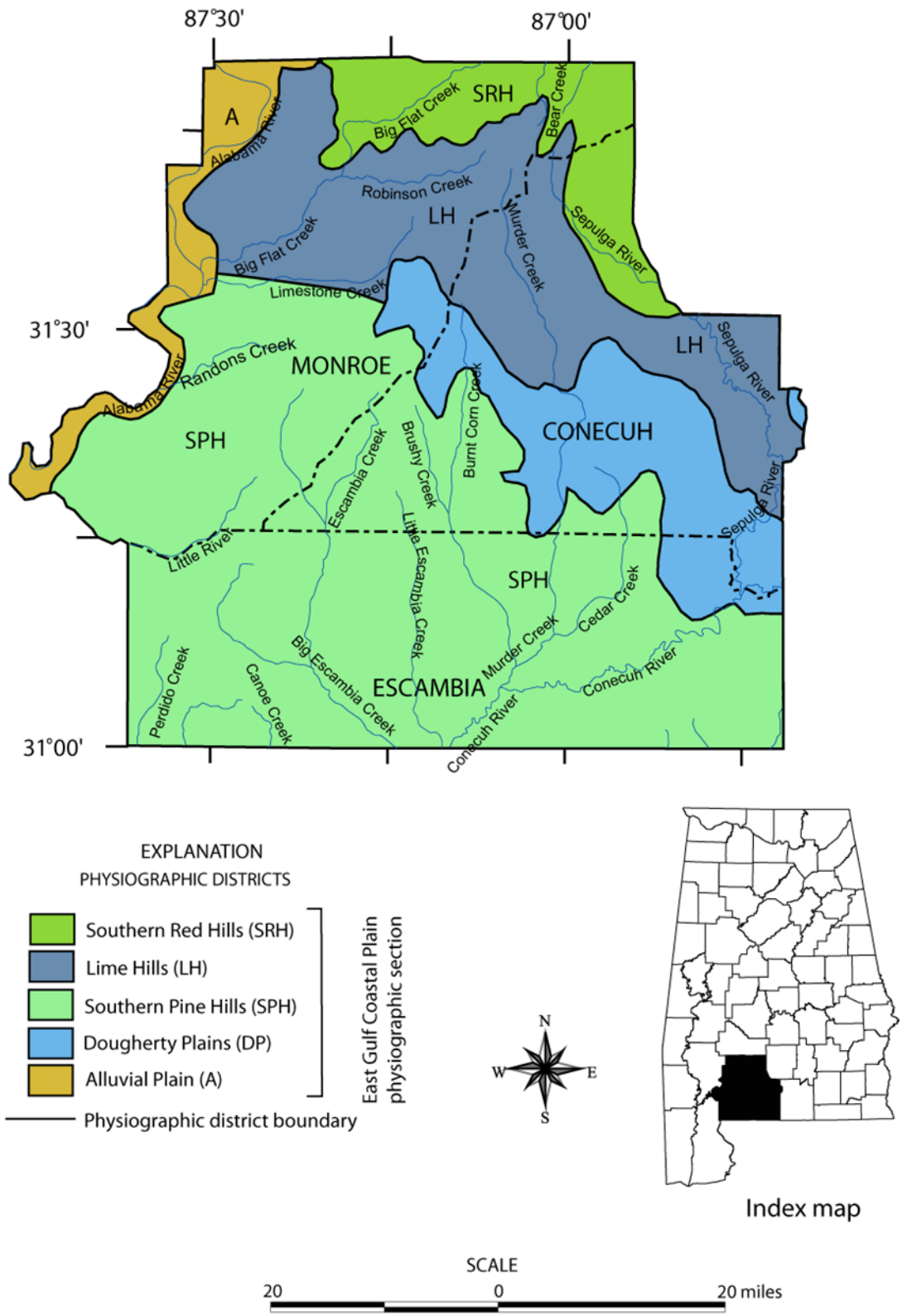

Figure 6-1.—Physiographic divisions in the south-central Alabama groundwater irrigation assessment area (Sapp and Emplaincourt, 1975).

GEOLOGY

Geologic units that underlie the study area range in age from Tertiary to Quaternary (table 6-1, plate 6-2). Sediments of Tertiary age crop out in all parts of the study area. Alluvial and terrace deposits of Quaternary age overlie older sediments in and adjacent to the flood plains of the Alabama and Conecuh Rivers and tributaries. Plates 6-3 and 6-4 are cross sections illustrating the generalized subsurface geology and major aquifers in the area. A summary of the thickness, lithology, and water-bearing properties of each geologic unit and major aquifer underlying the study area is given in table 1. Stratigraphy of the units underlying the study area is given in table 6-1. The geologic map provided in plate 6-2 was compiled from maps at scales of 1:250,000 by Szabo and Copeland (1988a, b) and 1:500,000 by Osborne and others (1989) and is the most accurate mapping currently available for the area. Geologic units strike northwestward and dip southwestward about 30 to 40 ft/mi.

TERTIARY SYSTEM

A thick sequence of Tertiary sediments underlies the study area. Units underlying the study area include the Midway, Wilcox, Claiborne, and Jackson Groups, the Oligocene Series undifferentiated and the Miocene Series undifferentiated. Quaternary sediments include the Citronelle Formation and alluvial and terrace deposits (plate 6-2; table 6-1). Tertiary sediments overlie the Providence Sand in northern Crenshaw and northeastern Butler Counties and overlie the Prairie Bluff Chalk westward from the town of Greenville in Butler County. These formations generally strike west-northwestward and dip southward and southwestward 30 to 50 ft/mi.

PALEOCENE SERIES

MIDWAY GROUP

The Midway Group of Paleocene age includes the Clayton Formation, Porters Creek Formation, and Naheola Formation (MacNeil, 1946a, b) and overlies the Providence Sand and Prairie Bluff Chalk. These units crop out in northern Butler and north-central Crenshaw Counties (plate 6-2). In northwestern Monroe County (plate 6-4, P-456) the Midway Group is over 750 ft thick and consists of over 500 ft of Naheola, 200 ft of Porters Creek, and 50 ft of Clayton (Charles Smith, 1999, unpublished data). However, the Midway Group thins to the east

Table 6-1.—Geologic units in the study area and their water-bearing properties (modified from Castleberry and others, 1989)

System	Series/ Group		Geologic units		Aquifer[1]	Thickness (feet)	Lithology	Water-bearing properties	Quality of water
Quaternary	Holocene and Pleistocene		Alluvium and terrace deposits		Water-course	5-50	Silt, clay, sand, and gravel, varicolored, unconsolidated.	Potential source of large water supplies in the flood plains of the Alabama and Conecuh Rivers.	Generally soft but may contain iron in excess of 0.3 mg/L.
Tertiary	Pliocene and Miocene		Citronelle Formation and Miocene undifferentiated		Mio-cene-Plio-cene	50-650	Gravel, sand, and clay; sand, medium to coarse, gravelly; micaceous silty fine sand; mottled sandy clay; and silty fine-grained sandstone; deeply weathered silty, sandy clay with fractured chert boulders forms residuum in updip exposures.	Wells produce 50 to 500 gallons per minute (gpm) from the Miocene Series. The Citronelle is not a major aquifer because of its thinness but is hydraulically connected to the Miocene.	Soft to moderately hard, generally contains iron in excess of 0.3 mg/L.
	Oligocene	Vicksburg Group	Oligocene Series		Crystal River	50-200	Limestone, fossiliferous, and carbonaceous sandy clay; deeply weathered to silty sandy clay updip. Limestone, fossiliferous, indurated to soft; deeply weathered to clay with fractured chert boulders updip.	Source of water supply in Escambia County	Soft to very hard, locally contains iron in excess of 0.3 mg/L.
	Eocene	Jackson Group	Yazoo Clay	Crystal River Fm.		35-140	Limestone, sparsely glauconitic, and sandy in upper part; updip areas weather to residual clay and sand with chert boulders. Yazoo Clay is a sandy, silty clay and silty sand; updip areas weather to a residual clay and sand with chert boulders.	Yazoo Clay is relatively impermeable and is not a source of ground water.	Generally moderately hard, iron content may locally exceed 0.3 mg/L.
		Claiborne Group	Moodys Branch Formation of the Jackson Group, Gosport Sand, and Lisbon Formation		Lisbon	20-315	Moodys Branch is fine to coarse, glauconitic, fossiliferous, calcareous sand and sandy limestone that weather to sand and clay with chert boulders updip. Gosport and Lisbon are fine to coarse sand and sandy clay.	Source of water supply in eastern Escambia County wells, produce as much as 350 gpm; not a major aquifer in the study area because the unit becomes less permeable.	Soft to hard, locally contains iron in excess of 0.3 mg/L. Lower sands contain more than 1,000 mg/L total dissolved solids in southwestern part of Monroe County.

[1] Black indicates an aquiclude or aquitard.

Table 6-1.—Geologic units in the study area and their water-bearing properties-Continued

System	Series/ Group		Geologic units		Aquifer[1]	Thickness (feet)	Lithology	Water-bearing properties	Quality of water
Tertiary	Eocene	Claiborne Group	Tallahatta Formation		Lisbon	40-260	Claystone, thin-bedded to massive, siliceous, aluminous, interbedded with thin layers of clay, sandy clay, and sand; upper and lower zones of coarse sand; middle zone of thin-bedded siltstone, clay, and claystone.	Source of water supply in central Conecuh County, eastern and Escambia County, wells produce as much as 350 gpm.	Soft to moderately hard, iron content is generally less than 0.3 mg/L. Not a major aquifer in the western-most part of the study area because water contains more than 1,000 mg/L total dissolved solids.
					Lisbon				
		Wilcox Group	Hatchetigbee Formation			5-275	Sand and clay, varicolored, laminated to thin-bedded, and carbonaceous.	Relatively impermeable; not a source of ground water in this area.	Soft to hard, iron content is generally less than 0.3 mg/L.
			Bashi Marl Mbr.		Lisbon	20	Abundantly glauconitic fossiliferous fine sand; calcareous fossiliferous sandstone.		
	Paleocene		Tuscahoma Sand			120-375	Clay, carbonaceous, micaceous, and laminated to massive, and very fine to coarse sand; lower zone of massive to laminated medium to coarse sand in western part of area.	Relatively impermeable. Some wells are developed in conjunction with the rest of the Nanafalia aquifer.	Soft to very hard; iron content may be in excess of 0.3 mg/L; locally hydrogen sulfide odor.
					Nana-falia				
			Nanafalia Formation	Grampian Hills Mbr.		90-110	Siltstone, silt, and sandy clay.	Relatively impermeable; not a source of ground water.	Soft to moderately hard, iron content is locally less than 0.3 mg/L.
				"Ostrea thirsae beds"		20-40	Clay, with fine to medium sand and abundant Odontogryphaea thirsae (Gabb) and other fossils.	Relatively impermeable; not a source of ground water.	
				Gravel Creek Mbr.	Nana-falia	0-45	Sand, gravelly, micaceous, coarse.	Source of large water supplies in Monroe and Conecuh Counties. Wells produce 75 to 925 gpm. Not an aquifer in southern Monroe County because unit becomes relatively impermeable.	Water in Escambia, and southern Conecuh, and Monroe Counties contains more than 250 mg/L of chlorides.
		Midway Group	Naheola Formation			20	Clay, carbonaceous, and sandy; micaceous clay and silt.	Relatively impermeable; not a source of ground water.	
			Porters Creek Formation			70-250	Sand, fine to medium; fine fossiliferous clayey sand and silt; and limestone.	Source of water supply only in southern Crenshaw County; wells developed in conjunction with Clayton produce 600 gpm.	Moderately hard to very hard, may contain iron in excess of 0.3 mg/L in some areas.

1 Black indicates an aquiclude or aquitard.

Table 6-1.--Geologic units in the study area and their water-bearing properties-Continued

System	Series/ Group		Geologic units	Aquifer[1]	Thickness (feet)	Lithology	Water-bearing properties	Quality of water
Tertiary	Paleocene	Midway Group	Clayton Formation	Clayton	50-170	Sand, fine to medium; fine fossiliferous clayey sand and silt; and limestone.	Wells produce 140 to 190 gpm in the eastern part of study area; relatively impermeable west of Greenville.	Water is moderately hard to hard; locally contains iron in excess of 0.3 mg/L.
Creta-ceous	Upper Cretaceous	Selma Group	Providence Sand		0-150	Sand in upper part, fine to coarse, and gravelly; lower part is laminated fine sand and silty clay, locally lignitic at base.	Not a major aquifer in study area; east of study area the upper sands of the Providence are a major aquifer.	Water generally is soft; contains iron in excess of 0.3 mg/L.
			Prairie Bluff Chalk		25-180	Clay, sandy, and calcareous; fossiliferous sandy chalk.	Relatively impermeable; not a source of ground water.	
			Ripley Formation	Ripley	125-300	Sand, sandy clay, and calcareous sandstone; fossiliferous sand and sandy chalk.	Source of water in Crenshaw, Butler, and northeasternmost Monroe Counties; wells produce 200 to 600 gpm.	Water in Conecuh, Covington, Escambia and southern Monroe Counties contains more than 1,000 mg/L of chlorides. Locally contains iron in excess of 0.3 mg/L.
			Demopolis Chalk		400-450	Chalk, marl, calcareous clay, and sandy clay.	Relatively impermeable; not a source of ground water.	

1 Black indicates an aquiclude or aquitard.

and is only about 125 ft thick in eastern Escambia County. Formations within the Midway are not differentiated in the eastern part of the study area.

The Clayton Formation generally consists of fine to medium sand and fine, fossiliferous, clayey sand and silt in eastern exposures in the study area (MacNeil, 1946b). The Clayton generally contains beds of limestone, sand, silt, and clay and is relatively impermeable. The Clayton is about 50 ft thick in northwestern Monroe County (plates 6-2, 6-4).

The Porters Creek Formation is composed of fine to medium micaceous clayey sand, sandy clay, and silt (MacNeil, 1946b). In the subsurface in well P-456 northwest of Monroeville in Monroe County, the Porters Creek consists of about 200 ft of clay and minor amounts of sand, limestone, glauconite, and sideritic claystone (plate 6-3).

The Naheola Formation overlies the Porters Creek Formation. The Naheola typically consists of about 20 ft of carbonaceous sandy clay and micaceous clay and silt in the study area (MacNeil, 1946b). The Naheola generally is divided into a lower Oak Hill Member consisting of dark-gray carbonaceous clay interbedded with muscovitic quartzose silt to sand and an upper Coal Bluff Marl Member consisting of fossiliferous, glauconitic, and muscovitic sand and sandy marl. A thin lignite bed at the top of the Oak Hill Member separates the upper and lower members.

In well P 456 (plate 6-3) in northwest Monroe County, the Naheola is over 500 ft thick (Charles Smith, 1999, unpublished data). Baker and Smith (1999) reported about 150 ft of Naheola in the subsurface in the vicinity of Beatrice in Monroe County.

WILCOX GROUP

The Wilcox Group of Eocene and Paleocene age includes the Nanafalia Formation, Salt Mountain Limestone, Tuscahoma Sand, and the Hatchetigbee Formation (plates 6-2, 6-3, 6-4). The Nanafalia and the Hatchetigbee Formations serve as aquifers in the study area, but most of the Tuscahoma is an aquiclude (table 6-1).

The Nanafalia Formation overlies the Midway Group and crops out in northeastern most Monroe County (plate 6-2). It was named for exposures at Nanafalia Landing on the Tombigbee River in southwestern Marengo County (Smith, 1886). The Nanafalia was formally divided into three units by LaMoreaux and Toulmin (1959).

The Nanafalia has a basal zone of coarse gravelly micaceous sand known as the Gravel Creek Sand Member (MacNeil, 1946a), which ranges in thickness from 0 to 40 ft. Baker and Smith (1999) reported 40 to 45 ft of Gravel Creek in northern Monroe County. The Gravel Creek Sand

Member is overlain by a unit informally called the "*Ostrea thirsae* beds," which consists of 20 to 40 ft of fine to medium glauconitic sand and sandy clay that contains the abundant small oyster *Odontogryphaea thirsae* (Gabb) and other fossils (plate 6-4). This unit is overlain by the Grampian Hills Member, which consists of 90 to 110 ft of siltstone, silt, and calcareous sandy clay.

The Salt Mountain Limestone, known only from the subsurface in the study area, is equivalent to the middle part of the Nanafalia Formation (plates 6-3, 6-4) and consists of white, massive, indurated fossiliferous limestone and irregular beds of soft friable limestone. Thickness of the Nanafalia Formation ranges from about 100 ft in outcrop in Clarke County, west of the study area, to over 600 ft in the subsurface in Escambia County (plate 6-3). Plate 6-5 shows configuration of the top of the Nanafalia Formation.

The Tuscahoma Sand crops out southwest of the Nanafalia Formation in northern Monroe and Conecuh Counties (plate 6-1). The Tuscahoma generally consists of olive-gray to brown laminated to thin-bedded carbonaceous micaceous clay and silt and light-gray to grayish-brown very fine to fine sand. LaMoreaux and Toulmin (1959) reported thin discontinuous beds of lignite in the upper part of the formation. Medium to coarse massive to laminated sands are locally present in the middle and lower parts of the formation. These sands generally pinch out to the east across Alabama (Toulmin, 1977). The Tuscahoma ranges in thickness from 275 ft at outcrops in northern Monroe County to 375 ft thick in Escambia County (plate 6-3).

EOCENE SERIES

HATCHETIGBEE FORMATION

The Hatchetigbee Formation of the Wilcox Group overlies the Tuscahoma Sand and crops out in a narrow northwest-trending belt in northern Conecuh and Monroe Counties (plates 6-2). The formation was named for exposures at Hatchetigbee Bluff on the Tombigbee River in Washington County, Alabama (Smith, 1886). The Bashi Marl Member at the base of the Hatchetigbee Formation consists of highly glauconitic fossiliferous sand and fossiliferous calcareous sandstone generally less than 20 ft in thickness. The Hatchetigbee Formation consists of gray carbonaceous and lignitic thin-bedded to laminated clay and sand, glauconitic fossiliferous sand, and fossiliferous calcareous sandstone (MacNeil, 1946a; Baker and Smith, 1999). The formation ranges in thickness from 5 ft in the eastern part of the study area to about 275 ft near the Alabama River.

CLAIBORNE GROUP

The Claiborne Group of Eocene age consists of the Tallahatta Formation, Lisbon Formation, and Gosport Sand. These formations, along with the overlying Moodys Branch Formation, serve as a major aquifer, the Lisbon aquifer, in the study area (table 6-1).

The Tallahatta Formation overlies the Hatchetigbee Formation and crops out in a narrow belt in north-central Monroe County and northern Conecuh Counties (plates 6-2). The formation is not mapped separately from the Lisbon Formation east of the Conecuh River because of lithologic similarities of the two units. The formation was named for the Tallahatta Hills in central Choctaw County (Dall, 1898). The outcrop of the Tallahatta Formation is characterized by rugged topography with steep hills forming a north-facing escarpment. The formation consists of white to light-gray, thin-bedded, indurated, siliceous claystone interbedded with thin lenses of clay, sandy clay, sand, indurated sandstone, and coarse-grained sand layers in the top and bottom of the formation (MacNeil, 1946a; Baker and Smith, 1999). These sand layers are 15 to 20 ft thick in the vicinity of Evergreen, but are not consistent throughout the study area. Downdip, the formation contains thin-bedded, sandy, fossiliferous limestone. The thickness of the Tallahatta Formation in outcrop ranges from 40 ft in parts of Monroe County to 120 ft in parts of Butler County. The unit thickens in the subsurface to as much as 260 ft (plates 6-3, 6-4).

The Lisbon Formation overlies the Tallahatta Formation and crops out in a northwestward-trending belt in central Monroe and Conecuh Counties (plate 6-2). The Lisbon Formation is named for Lisbon Bluff on the Alabama River at Claiborne, Monroe County, and is generally a light- to yellowish-gray calcareous glauconitic sand and sandy clay. To the west and south, limestone replaces the clastics in the Lisbon Formation in the study area, becoming dominant in Escambia County (plate 6-2). The Gosport Sand, which overlies the Lisbon, is a calcareous, fossiliferous, glauconitic sand named for Gosport Bluff on the Alabama River in Monroe and Clarke Counties. The Gosport does not crop out extensively east of the Conecuh River and in that area the Gosport and the Lisbon are mapped with the Tallahatta Formation. Plate 6-6 shows the configuration of the top of the Lisbon Formation. Combined thickness of the Lisbon and Gosport is 15 ft in outcrop to about 280 ft in the subsurface (plates 6-2, 6-3, 6-4).

JACKSON GROUP

The Jackson Group of Eocene age is comprised of the Moodys Branch Formation, Yazoo Clay, and the Crystal River Formation. The formations overlie the Lisbon and Gosport Formations

and crop out in an irregular, northwestward-trending belt in southeastern and western Covington County and central Conecuh and Monroe Counties (plates 6-2). In updip areas of Conecuh and Covington Counties, the formations weather to residual clay and sand containing chert boulders and are mapped as part of an undifferentiated unit of residuum (plates 6-2, 6-4).

The Moodys Branch is a greenish-gray, fine to coarse, glauconitic, calcareous, fossiliferous sand in the western part of the study area and is a glauconitic, fossiliferous, sandy limestone in the eastern part of the study area (Castleberry and others, 1989). The formation ranges in thickness from about 5 ft near the Alabama River to as much as 110 ft in the central and eastern parts of the study area (plates 6-3, 6-4).

The Yazoo Clay is primarily sandy, silty clay with interbeds of silty sand and marl. The Yazoo thins from 50 ft in the eastern part of the study area to 10 ft in Monroe County. The Yazoo grades eastward and southward into the calcareous marine facies of the Crystal River Formation (plate 6-2, 6-3). In Escambia County the formation grades into over 70 ft of fossiliferous limestone and some sand assigned to the Crystal River Formation (plate 6-2).

The Crystal River Formation overlies and grades into the Yazoo Clay in the study area and consists of sparsely glauconitic, fossiliferous, sandy limestone throughout the study area (MacNeil, 1946a; Toulmin, 1977; Huddlestun, 1965, Huddlestun and Toulmin, 1965;). In outcrop, the formation thickens eastward from 25 ft in Monroe County. Southward in the subsurface in eastern Escambia County, the formation reaches 120 ft or more in thickness.

OLIGOCENE SERIES

The Oligocene Series crops out in an irregular northwest-trending belt in northeastern Escambia County, southwestern and western Conecuh County, and central Monroe County (plate 6-2). The Oligocene Series is comprised of the Vicksburg Group (Red Bluff Clay, Bumpnose Limestone, Marianna Limestone, and Byram Formation) and the Chickasawhay Limestone and Paynes Hammock Sand. These units are deeply weathered over much of the study area where they are mapped together as undifferentiated residuum (plate 6-2). Collectively, in the subsurface, these units consist of indurated to soft-fossiliferous limestone in the lower part and carbonaceous-sandy clay and fossiliferous limestone in the upper part (MacNeil, 1946a). Total thickness ranges from 50 ft at the surface to 200 ft in the subsurface.

MIOCENE-PLIOCENE SERIES UNDIFFERENTIATED

Sediments of the Miocene-Pliocene Series overlie the Oligocene sediments and crop out in southern Monroe, all of Conecuh, and most of Escambia County (plate 6-2). The Miocene-Pliocene Series undifferentiated consists of medium- to coarse-gravelly sand, fine-micaceous-silty sand, mottled-sandy clay, and fine-grained-silty sandstone (MacNeil, 1946a; Castleberry and others, 1989). Updip, deeply weathered beds of this geologic unit are mapped as residuum (plate 6-2). The Miocene-Pliocene Series ranges from 50 ft in updip areas to as much as 650 ft in thickness in southwestern Escambia County.

PLIOCENE-PLEISTOCENE SERIES

CITRONELLE FORMATION

The Citronelle Formation of Pliocene age overlies the Miocene Series and crops out in southern Monroe County and Conecuh County, and western and southern Escambia County (plate 6-2). The Citronelle consists of gravel, sand, and sandy clay (MacNeil, 1946a) and ranges in thickness from 5 to 50 ft.

QUATERNARY SYSTEM

Quaternary alluvial deposits overlie older formations in the western and south-central parts of the study area (plate 6-2).

PLEISTOCENE SERIES

HIGH TERRACE DEPOSITS

High terrace deposits unconformably overlie older sediments along the major rivers. These deposits are remnants of old alluvial deposits that now form relatively flat uplands in several parts of the study area. The high terrace deposits are up to 40 ft thick and consist of varicolored silt, sand, clay, and gravel.

PLEISTOCENE AND HOLOCENE SERIES

ALLUVIAL AND LOW TERRACE DEPOSITS

Alluvial and low terrace deposits overlie older sediments along streams in the study area. These deposits underlie flood plains or former flood plains of streams and rivers and consist of sand, silt, gravel, and clay. Terrace and alluvial deposits range in thickness from 10 to 50 ft and are undifferentiated on the geologic map because lithologies are similar.

SOILS

Soil orders in the investigated area include Ultisols, Inceptisols, and Vertisols (plate 6-7). Although most agriculture is developed in areas underlain by Ultisols (plate 6-7). Ultisols occur in humid, warm areas and are characterized as red clay soils from well weathered sands and clays with no calcareous material. Parent material includes the Miocene-Pliocene Series and alluvial sediments deposited on flood plains and terraces. Most less steeply sloping areas are cleared and used chiefly for growing hay and limited row crops (USDA-NRCS, 2009b).

Several soil types are identified by the USDA-NRCS (2009b) within the recharge area. However, for the purpose of this study, the State Soil Geographic (STATSGO) Database, NRCS classification, which groups soils according to common taxonomic characteristics, was used (USDA-NRCS, 2007a). Major soil series and their taxonomic characteristics for the investigated area are tabulated in table 6-2 and depicted in plate 6-7.

Table 6-2.--Soil order names, area, and taxonomy in the recharge area

Order	Soil order area (mi^2)	Percent total area	Taxonomic class
Ultisols	2,359.81	83.67	Fine-mixed, kaolinitic
Inceptisols	378.67	13.43	Fine-mixed, acid
Vertisols	81.80	2.90	Very-fine, smectitic

LAND USE/LAND COVER

The Level I classification of LULC includes the following: water, developed, barren, forest, herbaceous upland natural/semi-natural vegetation (grassland/herbaceous), herbaceous planted/cultivated (pasture/hay), herbaceous planted/cultivated (cultivated crops), and wetland (plate 6-8). Most of the recharge area north of the investigated area is dominated by forest with limited agriculture (plate 6-8). However, the dominate LULC for the area is agriculture (pasture/hay and cultivated crops), followed by forest (plate 6-8).

Agriculture occupies an area of approximately 410.6 mi^2, equivalent to 14.5 percent of the total investigated area (2,827.2 mi^2) (table 6-3; plate 6-8). The geology, soils, physiography, and topography collectively create an environment favorable for the land uses observed in the

investigated area (plate 6-8), which, in large part, are pasture and hay with only limited amounts of row crop agriculture (table 6-3). Most row crop agriculture occurs in areas with soils underlain by the Citronelle Formation (plates 6-2, 6-7, 6-8).

Table 6-3.--Classes, areas, and proportion of land-use/land-cover for area of potential agricultural irrigation.

Class	Area (mi^2)	Percentage (%)
Forest	2,103.32	74.40
Pasture/Hay	226.61	8.02
Wetlands	186.42	6.59
Cultivated crops	174.02	6.16
Developed	105.79	3.74
Open Water	17.40	0.62
Grassland Herbaceous	10.04	0.35
Barren	3.62	0.13
Total	2,827.21	100

HYDROGEOLOGY

Geologic units that underlie the study area contain beds of permeable sand and limestone that serve to store and transmit water. These permeable beds, called “aquifers” when saturated with water, dip southwestward and supply water to wells in and downdip from their outcrop areas (plate 6-2). Water in these aquifers, with the exception of the watercourse aquifer, which is totally unconfined, is under water table conditions in outcrop and becomes confined downdip. In their outcrop areas, the aquifers also provide the base flow for streams, which prevents most streams from going dry, even during extreme drought.

Groundwater of adequate quantity and quality for domestic use generally can be obtained at depths of 100 ft or less in most parts of the investigated area. Large yield wells (greater than 50 gpm) are generally deeper than 100 ft. The shallowest wells are commonly constructed in the Miocene-Pliocene or watercourse aquifers. The deepest well in the area is located in Monroeville

and is constructed to a depth of 1,394 ft in the Nanafalia aquifer.

The major aquifers in the study area are, in ascending order, the Nanafalia, the Lisbon, the Crystal River, and the Miocene-Pliocene (plate 6-2; table 6-1). The recharge area for the Nanafalia aquifer includes northeastern Monroe County, and Wilcox and Butler Counties north of the study area. Recharge areas for the Lisbon and Miocene-Pliocene aquifers are in central Monroe and northeastern Conecuh Counties and southern Monroe, southern Conecuh, and Escambia Counties, respectively. In most of the study area, water in these aquifers is confined.

NANAFALIA AQUIFER

The Nanafalia aquifer (plate 6-2; table 6-1) consists of the Nanafalia Formation and the lower part of the Tuscahoma Sand. The Salt Mountain Limestone, a subsurface equivalent of part of the Nanafalia Formation, is also part of the Nanafalia aquifer. The Nanafalia aquifer is separated from the overlying Lisbon aquifer by impermeable beds of the Tuscahoma Sand.The Nanafalia aquifer is a source of water for the towns of Evergreen, Beatrice, Monroeville, and Vredenburgh.

The Nanafalia aquifer is one of the major water sources in the study area (plate 6-2) and is one of the most productive aquifers in the Alabama Coastal Plain. Near the outcrop, the formation serves as the source of water for numerous private wells. Downdip, the Nanafalia is a source of supply for large-capacity municipal wells. In Beatrice in northern Monroe County, water for public supply wells is derived exclusively from the middle and lower units of the Nanafalia Formation (Baker and Smith, 1999). The formation is not a major source of water in southern Conecuh and Monroe Counties and Escambia County because Cl concentrations in the water exceed 250 mg/L (Reed and others, 1968; Scott and others, 1972). Plate 6-9 shows the potentiometric surface map and outcrop of the Nanafalia aquifer. Wells developed solely in the Nanafalia Formation produce from 75 gpm at Beatrice to as much as 1,016 gpm at Evergreen in Conecuh County.

LISBON AQUIFER

The Lisbon aquifer includes the uppermost part of the Tuscahoma Sand, sands in the Hatchetigbee and Tallahatta Formations, the Lisbon Formation, the Gosport Sand, and the Moodys Branch Formation. Impermeable sediments of the overlying Jackson Group and the basal Vicksburg Group confine the Lisbon aquifer. Most of the Vicksburg Group and locally parts of the Jackson Group are included in the Crystal River aquifer in the study area.

The uppermost part of the Tuscahoma Sand, the Bashi Marl Member of the Hatchetigbee Formation, the upper and lower Tallahatta Formation, the Lisbon Formation, and the Gosport Sand combine with the overlying Moodys Branch Formation to form the Lisbon aquifer. The Lisbon aquifer is a major source of groundwater in the southeastern part of the study area. In the western part of the study area, the Lisbon Formation and the Gosport Sand contain more clay and silt and are not a major source of water. The Lisbon aquifer is the sole source of water for the towns of Castleberry, Fairview, Ridge Road, and East Brewton and is a major source of water for the towns of Evergreen and Brewton. Wells developed solely in the Lisbon aquifer in the southeastern part of area produce as much as 750 gpm. East Brewton's well ESCO-02 has a specific capacity of 31.4 gpm /ft and is capable of producing more than 750 gpm. The Lisbon aquifer is also a major source of water east of the study area. A map of the potentiometric surface for the Lisbon aquifer is shown on plate 6-10.

A few wells are developed in sand beds of the Bashi Marl Member at the base of the Hatchetigbee Formation in conjunction with the Lisbon aquifer and may yield up to 10 gpm to drilled shallow wells (Scott and others, 1972). However, the remainder of the Hatchetigbee Formation is relatively impermeable and is not a major source of groundwater in this part of Alabama.

The Tallahatta Formation is a minor source of water in the southern part of the study area and is considered to be a part of the Lisbon aquifer. No public supply wells in the area are completed in the Tallahatta. The Tallahatta is not a major source of water in Conecuh County because of its limited areal extent and thinness. In Monroe County thin sands of the formation supply up to 10 gpm of good quality water to dug and shallow drilled wells.

CRYSTAL RIVER AQUIFER

The Crystal River aquifer consists of a limestone interval underlain by the Yazoo Clay of the Jackson Group and separated from the overlying Miocene by clays in the Oligocene Series. It is shown on plate 6-2 as residuum where weathered and as Oligocene Series where seen in outcrop. The aquifer is not used extensively but provides several hundreds of gpm of water to the town of Repton in Conecuh County and Atmore, Brewton, McCall, and Riverview in Escambia County. It is thickest in southern Escambia County where it reaches approximately 70 ft and thins northward. In Repton in western Conecuh County it is only 30 ft thick. The most productive well in the Crystal River is well ESCK-06, which has been test pumped at 600 gpm and has a specific capacity of more than 14 gpm/ft. Atmore's well ESCK-011 pumps at more than 600 gpm but has a specific

capacity of only 5.0 gpm/ft. This indicates ESCK-06 is not pumped at its maximum pumping capacity.

MIOCENE-PLIOCENE AQUIFER

The Miocene-Pliocene aquifer is comprised of the Citronelle Formation, the Miocene Series undifferentiated, and the Upper Oligocene Series (the Paynes Hammock Sand and the Chickasawhay Limestone). In the subsurface in part of Escambia County, the impermeable Bucatunna Clay Member (Byram Formation, Oligocene Vicksburg Group) hydraulically separates the Miocene-Pliocene aquifer from the underlying Crystal River aquifer.

The Miocene-Pliocene aquifer includes the Citronelle Formation, the Miocene Series undifferentiated, and Upper Oligocene sediments (the Paynes Hammock Sand and the Chickasawhay Limestone) and is hydraulically separated from the underlying Crystal River aquifer by the relatively impermeable Bucatunna Clay Member of the Oligocene Byram Formation. Because of its stratigraphic location and limited use in this area, it is lumped with the Miocene aquifer. The Miocene-Pliocene aquifer is a major source of water in southern Monroe County and Escambia County. This aquifer is the sole source of water for the towns of Frisco City, Excel, and Uriah in Monroe County and McCall, Huxford, Pollard, Flomaton, Freemanville, and Canoe in Escambia County. Most of the Atmore wells are completed in the Miocene-Pliocene aquifer, but some produce from the Crystal River aquifer. Wells developed solely in the Miocene-Pliocene aquifer produce from 50 to 1,000 gpm. Plate 6-11 is a map showing the potentiometric surface of the Miocene-Pliocene aquifer.

The Citronelle Formation alone is not a major source of water because of the unit’s thinness; however, the Citronelle is hydraulically connected to the underlying Miocene-Pliocene aquifer in the study area and is considered part of the Miocene-Pliocene aquifer.

POTENTIOMETRIC SURFACES

Maps of the potentiometric surfaces of the major aquifers were constructed from available data (plates 6-9, 6-10, 6-11). The formation outcrop areas are also the recharge areas (plates 6-2, 6-9, 6-10, 6-11) and are shown on the maps. Also shown on plate 6-2 are locations of active public water supply wells and locations of selected large wells in the study area. Areas of major withdrawals, commonly indicated by depressions in the potentiometric surfaces, are shown on plates 6-9 through 6-11. Well construction information, water levels, and other pertinent well data

are given in tables 6-4 and 6-5.

The source of recharge to aquifers is rainfall, which averages 60 inches per year in the study area. A large part of the rainfall, about 20 inches per year, runs off during and immediately after storms or is returned to the atmosphere by evaporation and transpiration by trees and other plants. A small amount of rainfall infiltrates into the subsurface as recharge to the aquifers. On the basis of base flow of streams, recharge to the major aquifers is at least 3 to 4 inches per year (Castleberry and others, 1989). The recharge area for the Nanafalia aquifer is in Crenshaw, Butler, Conecuh, and Monroe Counties (plate 6-2); and the recharge area for the Lisbon aquifer is in Monroe and Conecuh Counties (plate 6-2). The recharge area for the Miocene-Pliocene and Crystal River aquifers Escambia, Conecuh, and Monroe Counties (plate 6-2). These recharge areas consist of rolling sand hills, weathered silty clay terraces, and carbonate terranes. The land is part wooded and part cultivated. Water moves down the hydraulic gradient from areas of recharge to areas of natural discharge or areas of groundwater withdrawals. The direction of movement generally is perpendicular to the potentiometric contour lines shown in plates 6-9, 6-10, and 6-11.

DEPTH TO WATER

The depth to water map (fig. 6-2) is similar to the potentiometric surface map except the depth to water surface is measured by the number of ft bls. The depths to water shown on this map can be used to determine pump settings and size. Although wells constructed in the area of potential agricultural groundwater irrigation penetrate Miocene and Tertiary aquifers at depths from 20 to 1,394 ft, hydraulic head causes the depth to water from these aquifers to range from +10 ft above land surface (flowing wells) to 396 ft bls (fig. 6-2). The shallowest water levels occur in the major river valleys where flowing wells can be constructed in south Conecuh County adjacent to the Sepulga River, in south-central Escambia County adjacent to the Conecuh River and the Little Escambia Creek, and in western Monroe County adjacent to the Alabama River. The deepest water levels (almost 400 ft bls) occur in the Monroeville area in central Monroe County.

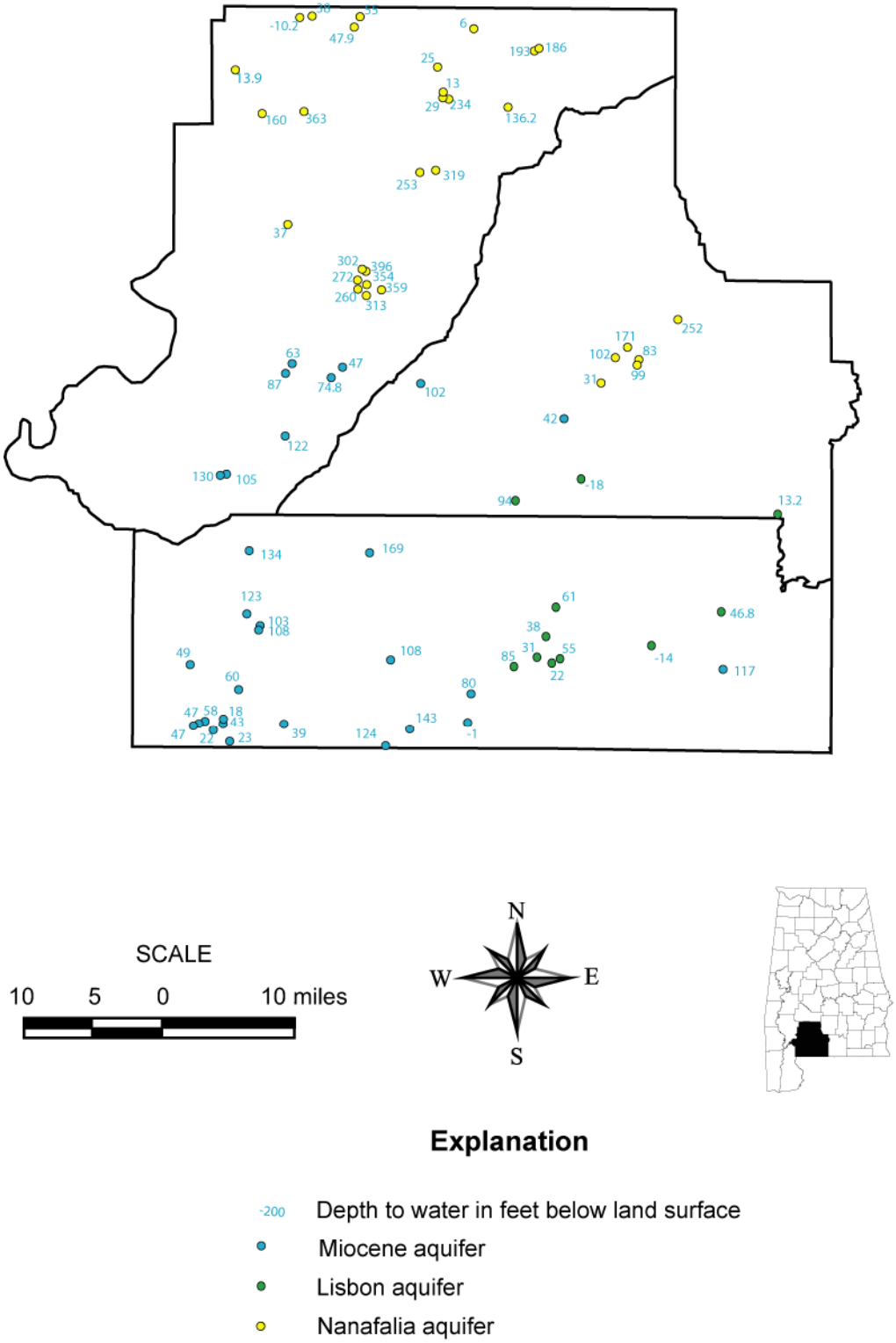

Figure 6-2.— Depth to water in the Nanafalia, Lisbon and Miocene aquifers.

SPECIFIC CAPACITIES AND PUMPING RATES

Specific capacity is a value which relates the pumping rate to drawdown of the water level in a well. It is generally expressed as gpm/ft. A well's specific capacity can be determined by a pump test of several hours duration. Specific capacity generally varies with duration of pumping; as pumping time increases, specific capacity generally decreases. Unfortunately, since well construction can make a significant difference in determining a well's specific capacity, contouring of these values can be misleading. A larger diameter well with a longer length of screen will likely have a higher specific capacity than a well completed in the same aquifer in the same area but with a smaller diameter and shorter length of screen. The accurate placement of the screens adjacent to the aquifer can also greatly affect specific capacity. Because of these variances, no contours were drawn.

Figure 6-3 shows the specific capacities of public supply wells constructed in the Nanafalia aquifer and the formations' recharge area. Specific capacities for this aquifer range from a high of 28.6 gpm/ft to a low of 0.1 gpm/ft. Pumping rates for these wells range from 1,200 gpm in Monroeville's well MONY-01 to 150 gpm for the Town of Vredenburgh's well MONE-4. Figure 6-4 shows the specific capacity of wells completed in the Lisbon aquifer and figure 6-5 shows the specific capacity of wells completed in the Miocene aquifer.

The Lisbon wells have specific capacities ranging from 31 gpm/ft for well ESCO-02 owned by the Town of East Brewton to for 3.2 gpm/ft for well ESCO-95 owned by Brewton Water Works. While this well may have a relatively low specific capacity, it pumps at 745 gpm. The well with the highest pumping rate, 804 gpm, is also owned by Brewton Water Works, well ESCO-01.

The Miocene-Pliocene aquifer has the highest specific capacities of all aquifers in the investigated area. One recently completed well, ESCJ-08 owned by Creek Indian Enterprises located in western Escambia County, reported a specific capacity of 100 gpm/ft. This is an exceptional well; the next highest specific capacity is 30.2 gpm/ft in well ESCAA-03 owned by Atmore Utility Board. The pumping rate for well ESCJ-08 is 700 gpm, although it could be pumped at a higher rate if the water system required a higher pumping rate to supply its demand. The highest pumping rate is in well ESCZ-106 in the Town of Atmore that pumps at over 1,000 gpm. Available pumping rates for all the public supply wells are listed in table 6-4 and 6-5.

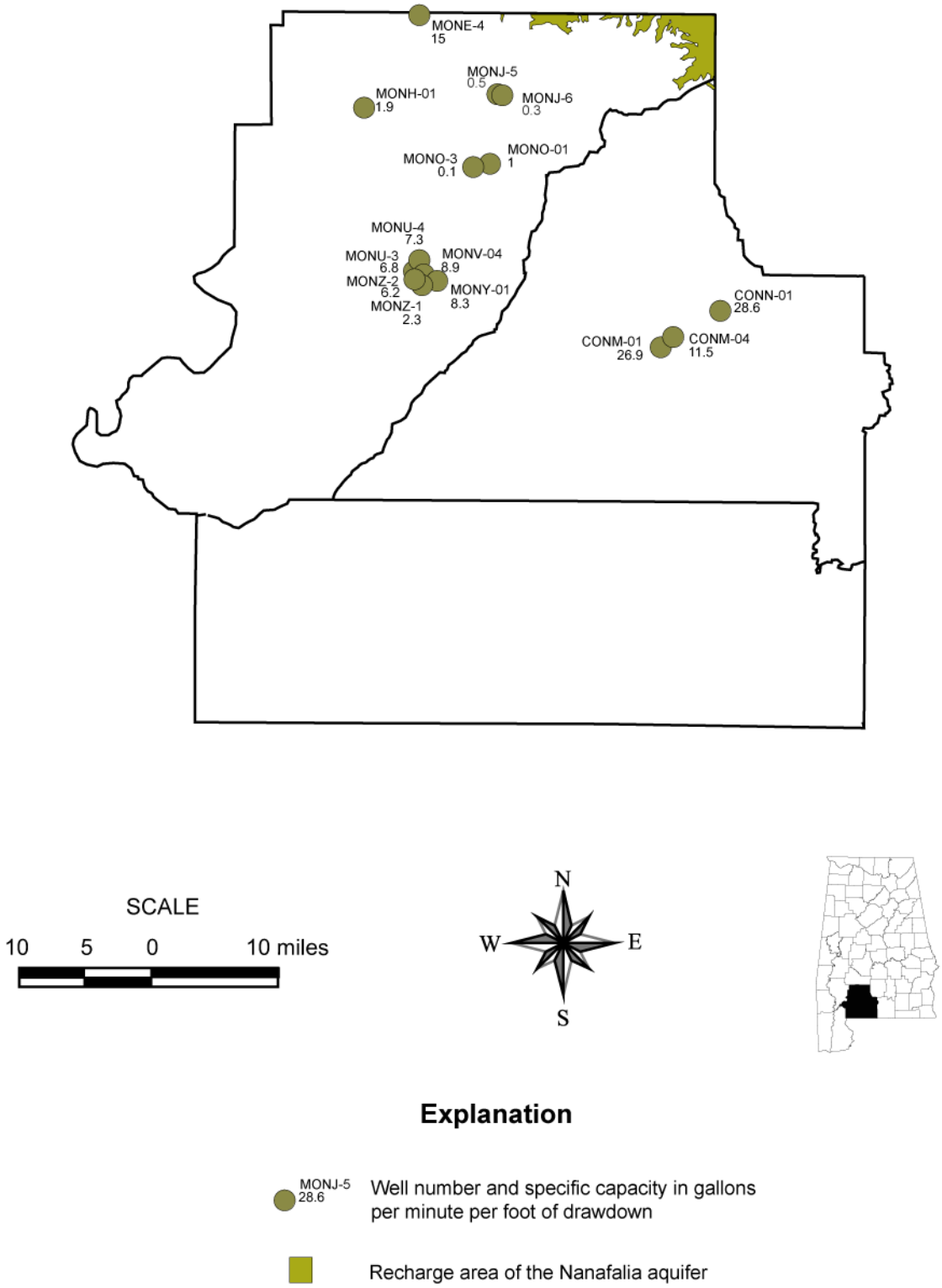

Figure 6-3. — Specific capacity for the Nanafalia aquifer in the south-central Alabama groundwater assessment area.

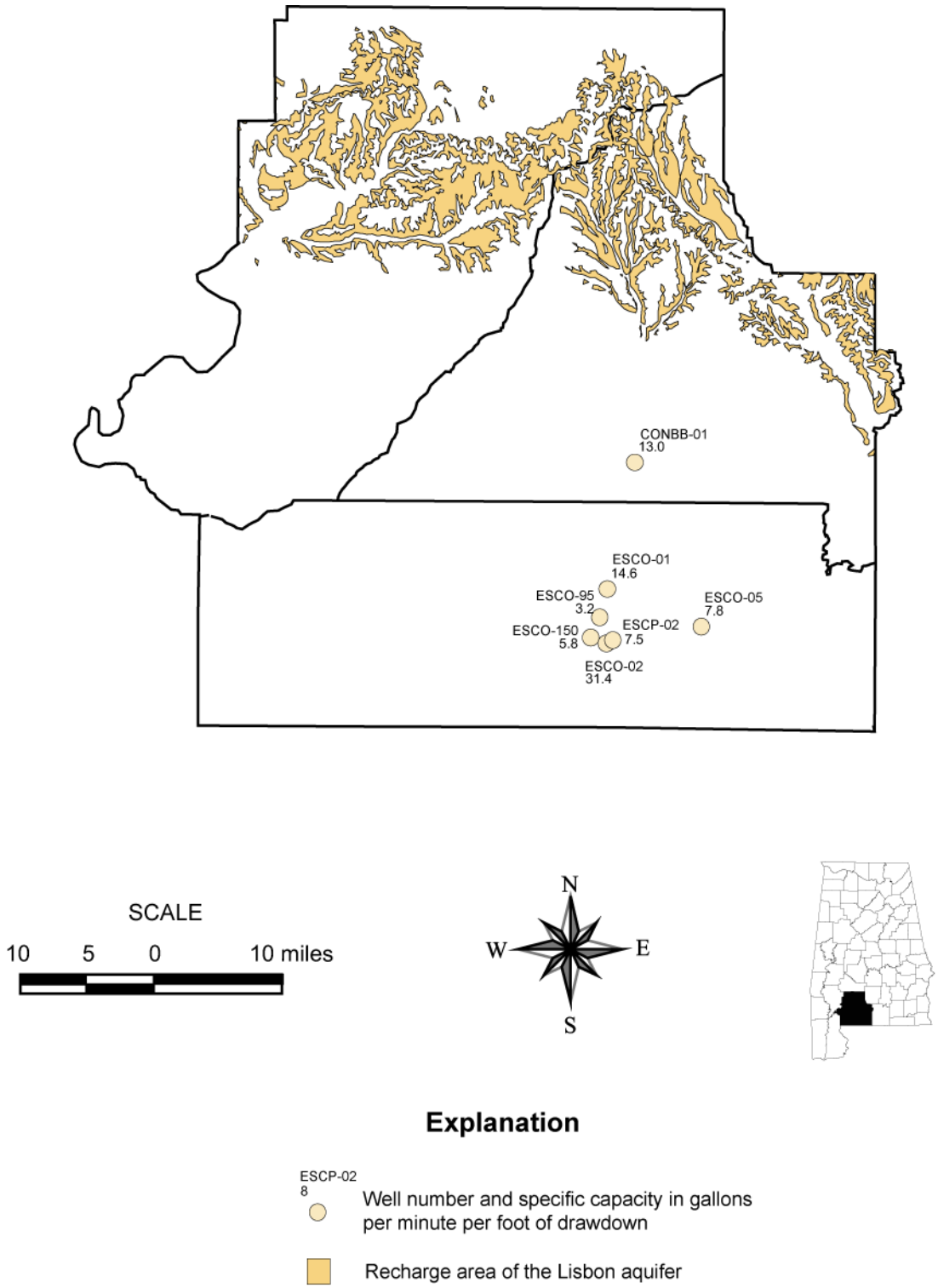

Figure 6-4. — Specific capacity for the Lisbon aquifer in the south-central Alabama groundwater assessment area.

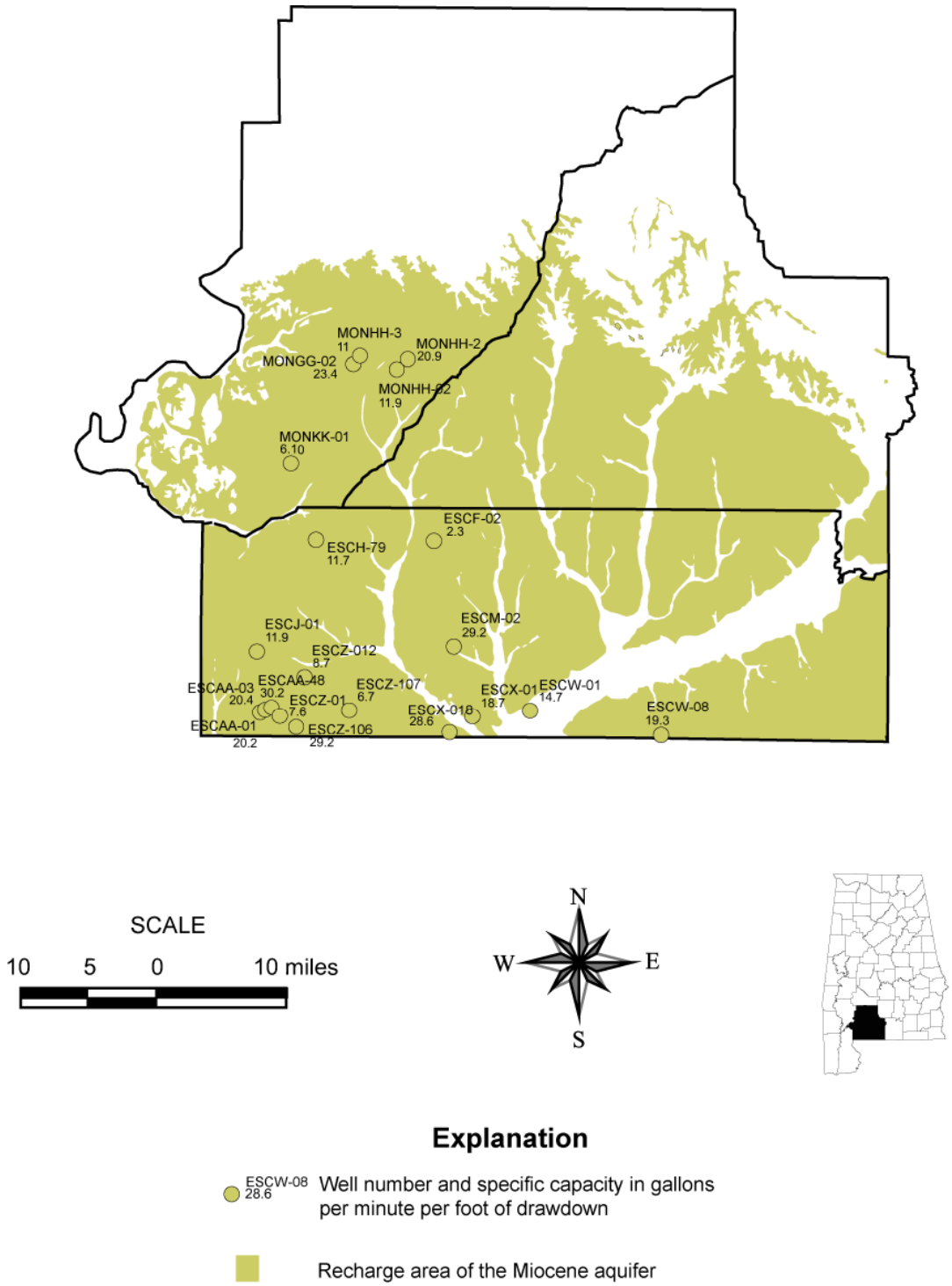

Figure 6-5. — Specific capacity for the Miocene aquifer in the south-central Alabama groundwater assessment area.

SOURCE WATER ASSESSMENT AREAS AND PUBLIC SUPPLY WELLS

The Safe Drinking Water Act (SDWA) Amendments of 1996 required each state in the United States to develop and implement a Source Water Assessment Program (SWAP). The program protects drinking water supply source waters by defining the land area around a source, in this case wells, that contributes water to the well and by analyzing existing and potential threats throughout the contribution area. The area contributing water to each public water source is called a SWAA. Possible contaminates are then identified within that defined area.

The SWAAs may be used to determine where irrigation wells may adversely impact public drinking water supplies. High pumping rates required for irrigation in close proximity to public groundwater supply sources could reduce quantity and quality of public water supplies. SWAA areas are generally relatively small and fairly well distributed throughout the area (plate 6-2). A large part of the investigated area lies outside of SWAAs and could be supply groundwater for irrigation without adversely impacting public water supplies.

GROUNDWATER QUALITY AFFECTING POTENTIAL AGRICULTURAL IRRIGATION IN THE SOUTH-CENTRAL ALABAMA GROUNDWATER IRRIGATION ASSESSMENT AREA

Major aquifers in the study area generally yield water of suitable quality for many uses. Water with dissolved solids content less than 500 mg/L can be found throughout the area. Locally, iron in excess of 0.3 mg/L may occur in waters from the Nanafalia aquifer, Lisbon aquifer, and alluvial deposits.

The Nanafalia aquifer is utilized as a source of water supply in Conecuh and Monroe Counties. Water quality is generally good; however, Cl levels increase downdip. Water from the Nanafalia aquifer in southern Conecuh and all of Escambia County has greater than 250 mg/L of chlorides, making it undesirable for most uses. In Conecuh and Escambia Counties, the Lisbon aquifer is used extensively. Water quality in the Lisbon is good. Most water from this aquifer is soft and low in iron content. Locally, however, iron content may exceed 0.3 mg/L and may be considered objectionable. The overlying Crystal River aquifer has good quality water; however, it tends to be hard to very hard. The iron content of the water from the Crystal River is generally low (Gillett and others, 2004).

Unlike water from the Crystal River aquifer, water from the Miocene deposits generally contains more than 0.3 mg/L of iron. This water is generally soft to moderately hard, except in

areas of heavy pumpage in Escambia County. In the vicinity of Brewton, Flomaton, and Pollard, levels of hardness are anomalously high compared to water in the Miocene deposits elsewhere in the county. This increase in hardness is believed to result from upwelling of water from the underlying Oligocene limestone formations (Gillett and others, 2004).

Mississippi State University Extension Service (2009) has established salinity guidelines for water used for irrigation. Crop tolerance levels in these guidelines are based on water conductivity and indicate that cotton is one of the most saline tolerant row crops, Bermuda grass is the most tolerant grass, and beets, kale, asparagus, and spinach are the most tolerant garden crops. Corn, wheat, and soybeans have medium tolerance, and peanuts have low tolerance. The MSUES has also established guidelines for the hazard to crops related to Cl concentrations in irrigation water. For root absorption, 0 to 142 mg/L is a low hazard, 143 to 355 mg/L is a medium hazard, and 356 mg/L and above is a high hazard to crop production. The depth at which groundwater has a TDS content in excess of 3,000 mg/L in the study area is shown in figure 6-6. Total dissolved solids includes other ions than chlorides but is a good indicator of where chlorides are high. Generally, beneath this depth water in aquifers is not suitable for most uses including irrigation.

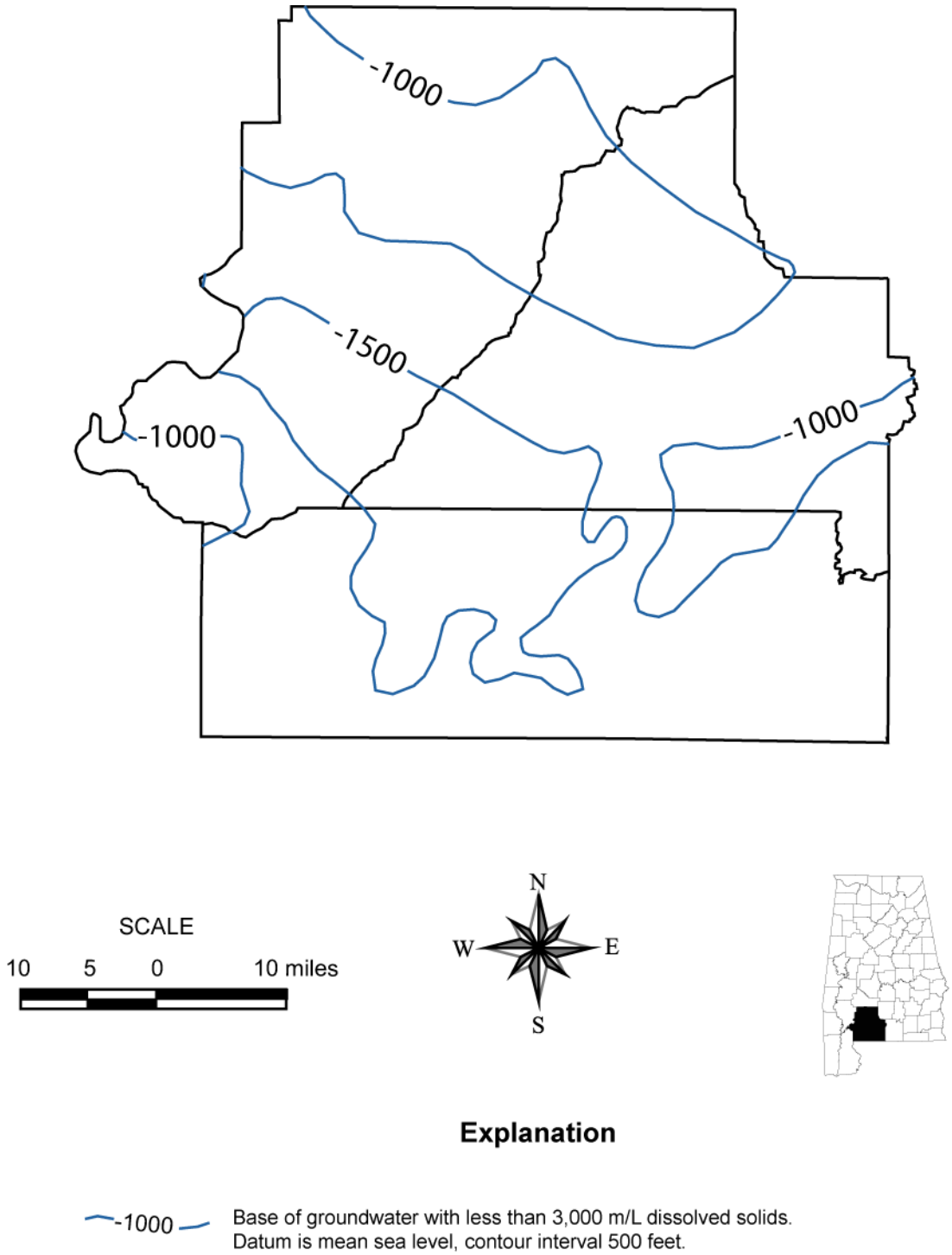

Figure 6-6.— Base of fresh- to slightly saline groundwater in south-central Alabama groundwater assessment area (Ellard, 1977).

ECONOMICS AFFECTING POTENTIAL AGRICULTURAL IRRIGATION IN THE SOUTH-CENTRAL ALABAMA GROUNDWATER ASSESSMENT AREA

If development of irrigation from groundwater sources is to be successful, it must be economically feasible. The cost of delivering water to crops must not create an inordinately large financial burden, so that the expense of irrigation outweighs the benefits derived from irrigation. The major costs involved with groundwater irrigation are drilling and well irrigation delivery system construction. Since delivery systems are common to both groundwater and surface-water sources, costs addressed in this report are limited to well construction only.

Costs for drilling and equipping wells capable of supplying adequate quantities of water for large-scale irrigation are based on well depth and diameter, casing, screen, and pump specifications. Costs for irrigation well construction for this project were supplied by a licensed water well drilling company from information supplied by the Geological Survey of Alabama. Specifications for a typical irrigation well in the investigated area are based on a borehole depth of 500 ft: 450 ft of 10.75-inch diameter steel casing, and 50 feet of 10-inch diameter stainless steel screen. A typical well will be equipped with an 8-stage pump with a 30 horse power submersible motor. The approximate cost of this type of well would be around $74,000.

SUMMARY AND CONCLUSIONS

If groundwater irrigation is to be viable, there must be sustainable large volumes of water, the application of the irrigation water must not degrade the environment, and it must be economically feasible.

Agriculture occupies approximately 410 mi^2, equivalent to 14.5 percent of the investigated area, although only 174 mi^2 (6.2 percent) are in row crop production. The geology, soils, physiography and topography are suitable for the land use observed in the area which is primarily forest and pasture and hay production but could also be utilized for row crops.

Major aquifers in the south-central Alabama study area are the Nanafalia, Lisbon, Miocene-Pliocene, and watercourse aquifers. Recharge areas for the aquifers are primarily in Conecuh, Escambia, Monroe, Wilcox and Butler Counties. The aquifers consist primarily of sand, gravel, and limestone and are overlain in most of the area by confining layers that cause water in aquifers to exist under artesian conditions.

The Miocene-Pliocene aquifer is a major source of water supply in Escambia and Monroe Counties. The aquifer has the potential to produce several hundreds of gpm to properly constructed wells in these two counties.

The Crystal River aquifer is a source of water supply in southern Escambia County. It contributes water supplies for Repton, McCall, Brewton, Atmore, and Riverview. It has the potential to produce 200 to 400 gpm where present in sufficient thickness.

The Lisbon aquifer is pumped extensively in the central and eastern parts of the study area. It is a major source of water for the towns of Evergreen, Fairview, Castleberry, River Falls, Brewton, East Brewton, and Ridge Road Water System. The Lisbon is also used with the Crystal River aquifer at Florala. Wells constructed in the Lisbon can produce from 450 to 800 gpm.

The Nanafalia aquifer is a major source of public water supply in Monroe and Conecuh Counties. It is the sole source of water supply for the towns of Monroeville, Beatrice, and Vredenburgh. Potential production from the Nanafalia can be as much as 1,200 gpm in the Monroeville area, because the high hydraulic head in the downdip wells provide over 700 ft of available drawdown.

Large long-term withdrawals of groundwater have resulted in the formation of depressions in the potentiometric surfaces of the Lisbon and Nanafalia aquifers. Depressions have formed in the potentiometric surface of the Nanafalia aquifer in the vicinities of Beatrice and Monroeville. Careful spacing of irrigation wells will be necessary for to prevent interference with public supply wells. SWAAs provide guidelines for areas under the influence of public supply wells.

Salinity in the Nanafalia aquifer in the southern portion of the study area is excessive for agricultural use. Water quality in the Lisbon and Miocene is adequate for agricultural uses throughout their occurrence in the study area.

While groundwater for large-scale irrigation is available, it must also be economically feasible. Drilling and equipping a well capable of pumping volumes of water required for large-scale irrigation can cost in excess of $74,000.

EXPLANATION FOR TABLE 6-4

SYSTEM, water system name.

PWS ID, public water system identification number as assigned by the ADEM.

SE ID, source identification number assigned by the ADEM. New wells may not have SE ID's assigned at press time.

GSA ID, well identification number assigned by the GSA and shown on plates.

DEPTH, total depth of well in ft. Number in parentheses denotes total depth of test well drilled at the same location.

YEAR DRILLED, the year the well was completed and ready for operation.

DRILLING CONTRACTOR, name of driller.

ALTITUDE, elevation of land surface in ft above msl.

AQUIFER, Qalt, alluvial and terrace deposits of Quaternary age; Tmu, undifferentiated Pliocene, Miocene and Oligocene deposits of Tertiary age; Tcr, Crystal River Formation; Tt, Tuscahoma Sand; Tl, Lisbon Formation; Tgl, Lisbon and Gosport Sand; Tnf, Nanafalia Formation; Tcl, Clayton Formation.

WATER LEVEL, water level in ft bls. The date the measurement was made is shown below the measurement. Measurements with a plus sign, indicate water levels above land surface.

WELL CONSTRUCTION, YIELD, REMARKS, gpm.

Table 6-4.--Records of public water-supply wells in study area

CONECUH COUNTY

System	PWS ID	SE ID	GSA ID	Depth	Year drilled	Drilling contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Owassa-Brownsville Water Authority	393	1	CONN-01	997	1989	Griner Drilling Service, Inc.	408	Tnf	251.73 1/9/89	Casing: 16 in. from 0 to 916 ft, 8 in. from 851.5 to 925 ft and from 966.7 to 974.6 ft. Screen: 8 in. from 925 to 966.7 ft and 974.5 to 992 ft. Drawdown 21 ft when pumped 24 hrs at 600 gpm in 1989.
Evergreen Water Works	338	1	CONS-3	455	1939	Layne-Central Co.	314	Tl	83 1939	Casing: 12 in. from 0 to 170 ft, 8 in. from 166 to 193 ft. Screen: 8 in. from 193 to 223 ft. Pumped at 300 gpm in 1965.
Evergreen Water Works	338	2	CONS-2	198	1956	Layne-Central Co.	298	Tl	99.15 8/29/67	Casing: 16 in. from 0 to 145 ft., 10 in. from 98 to 150 ft. Screen: 10 in. from 150 to 180 ft. Drawdown 22 ft when pumped 8 hrs at 363 gpm in 1956.
Evergreen Water Works	338	3	CONM-01	1,095	1973	Layne-Central Co.	300	Tnf	102 1973	Casing: 18 in. from 0 to 965 ft, 10 in. from 885 to 970 ft and 1,000 to 1,035 ft. Screen: 10 in. from 970 to 1,000 ft and 1,035 to 1,085 ft. Drawdown 28 ft when pumped 12 hrs at 754 gpm in 1973. City's Bates Road well.

Table 6-4.--Records of public water-supply wells in study area–Continued

System	PWS ID	SE ID	GSA ID	Depth	Year drilled	Drilling contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Evergreen Water Works	338	4	CONM-04	1,060	1990	Griner Drilling Service, Inc.	326	Tnf	171.22 5/1/90	Casing: 18 in. from 0 to 912 ft, 10 in. from 852 to 922 ft, 950 to 958 ft, 980 to 996 ft, 1,016 to 1,026 ft, and 1,050 to 1,060 ft. Screen: 10 in. from 922 to 950 ft, 958 to 980 ft, 996 to 1,016 ft, and 1,026 to 1,050 ft. Drawdown 88 ft when pumped 24 hrs at 1,016 gpm in 1990. City's Industrial Park well.
Fairview Water System	339	1	CONS-01	200	1972	Acme Drilling	195	Tl	31 1972	Casing: 12 in. from 0 to 170 ft, 6 in. from 122 to 166 ft. Screen: 6 in. from 166 to 196 ft. Drawdown 8 ft when pumped 4 hrs at 305 gpm in 1972.
Repton Water Works	344	1	CONV-4	204	1962	Layne-Central Co.	354	Tcr	102 1962	Casing: 12 in. from 0 to 172 ft, 8 in. from 129 to 174 ft. Screen: 6 in. from 174 to 204 ft. Drawdown 19 ft when pumped 2 hrs at 104 gpm in 1962.
Castleberry Water System	337	1	CONBB-01	336	1978	Layne-Central Co.	164	Tl	+18.0 11/9/78	Casing: 6 in. from 0 to 286 ft. Screen: 6 in. from 286 to 326 ft. Drawdown 27 ft when pumped 15 hrs at 350 gpm in 1978.

Table 6-4.--Records of public water-supply wells in study area–Continued

ESCAMBIA COUNTY

System	PWS ID	SE ID	GSA ID	Depth	Year drilled	Drilling contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
McCall Water Systems, Inc.	566	1	ESCW-011	680	1973	Tom Smith Artesian Well Company	190	Tcr	80 1973	Casing: 8 in. from 0 to 619 ft, 4 in. from 561 to 630 ft. Screen: 5-in. from 630 to 680 ft. Drawdown 140 ft when pumped 8 hrs at 250 gpm in 1973.
McCall Water Systems, Inc.	566	2	ESCM-02	277 (802)	1982	Graves Well Drilling Company, Inc.	220	Tmu	108.33 6/22/82	Casing: 16 in. from 0 to 223.5 ft, 8 in. from 197 to 223 ft. Screen: 8 in. from 223 to 275.3 ft. Drawdown 26 ft when pumped 21 hrs at 760 gpm in 1982.
McCall Water Systems, Inc.	566	4	ESCF-02	600 (743)	1996	Griner Drilling Service, Inc.	355	Tmu, Tcr	169 3/21/97	Casing: 30 in. from 0 to 250 ft, 16 in. from 0 to 497 ft. Open hole below casing. Drawdown 111 ft when pumped 32 hrs at 250 gpm in Sept. 1996.
McCall Water Systems, Inc.	566	5	CONAA-02	355 (406)	1996	Griner Drilling Service, Inc.	350	Tcr	171 10/22/96	Casing: 16 in. from 0 to 246 ft. Open hole below casing. Drawdown 54 ft when pumped 12 hrs at 200 gpm in 1996.

Table 6-4.--Records of public water-supply wells in study area–Continued

System	PWS ID	SE ID	GSA ID	Depth	Year drilled	Drilling contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Huxford Water & Fire Protection Authority	563	1	ESCH-79	233	1970	Mason Supply Company	335	Tmu	134 1970	Casing: 6 in. from 0 to 199 ft; 4 in. from 197 to 202 ft. Screen: 4 in. from 202 to 232 ft. Drawdown 11.5 ft when pumped 4 hrs at 135 gpm in 1970.
Brewton Water Works	555	1	ESCO-150	731	1954	Layne Central Company	162	Tl	31 1955	Casing: 16 in. from 0 to 596 ft; 10 in. from 563 to 600 ft and 650 to 691 ft. Screen: 10 in. from 600 to 650 ft and 691 to 721 ft. Drawdown 130 ft when pumped 8 hrs at 750 gpm in 1955. Also known as the ALCO well.
Brewton Water Works	555	2	ESCO-95	665	1948	Layne Central Company	151	Tl	22.5 2/3/57 38.25 10/27/94	Casing: 16 in. from 0 to 512 ft; 10 in. from 452 to 517 ft, 537 to 560 ft, 590 to 641 ft, and 661 to 665 ft. Screen: 10 in. from 517 to 537 ft, 560 to 590 ft, and 641 to 661 ft. Drawdown 231 ft when pumped at 745 gpm in 1948. Also known as the hospital well.
Creek Indian Enterprise			ESCJ-08	420	2009	Griner Drilling Service	292	Tmu	41.6 8/21/2009	Casing: 18 in. from) to 260 ft, 12 in. from 190 to 270 ft. Screen: 12 in. from 270 to 310 ft. Drawdown 6.41 ft when pumped 10 hrs at 700 gpm in 2009

Table 6-4.--Records of public water-supply wells in study area–Continued

System	PWS ID	SE ID	GSA ID	Depth	Year drilled	Drilling contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Brewton Water Works	555	3	ESCO-01	785	1974	Layne Central Company	200	Tgl	61 1975	Casing: 18 in. from 0 to 565 ft; 10 in. from 565 to 570 ft, 590 to 620 ft, 640 to 666 ft, and 681 to 710 ft. Screen: 10 in. from 570 to 590 ft, 620 to 640 ft, 666 to 681 ft, and 710 to 770 ft. Drawdown 55 ft when pumped 8 hrs at 805 gpm in 1974. Also known as North Tank well.
Brewton Water Works	555	4	ESCN-01	505	1993	Griner Drilling Service, Inc.	167	Tcr	85 1994	Casing: 18 in. from 0 to 425 ft; 10 in. from 373 to 434 ft. Screen: 10 in. from 434 to 505 ft. Drawdown 237 ft when pumped 24 hrs at 201 gpm in 1993. Also known as Industrial Park well.
Atmore Utilities Board	553	1	ESCZ-71	130	1935	Gray Artesian Well	287	Tmu	48 1945 41.67 11/6/84 42.87 10/16/98	Casing: 8 in. from 0 to 92 ft. Open hole below casing. Pump capacity 250 gpm. Also known as the Trammel St. well.

Table 6-4.--Records of public water-supply wells in study area–Continued

System	PWS ID	SE ID	GSA ID	Depth	Year drilled	Drilling contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Atmore Utilities Board	553	2	ESCAA-48	193	1967	Layne Central Company	292	Tmu	58 1968	Casing: 24 in. from 0 to 109 ft; 16 in. from 0 to 113 ft. Screen: 12 in. from 113 to 183 ft. Drawdown 26.5 ft when pumped 8 hrs at 800 gpm in 1968. Also known as Carpet Rd. well.
Atmore Utilities Board	553	3	ESCZ-01	182 (400)	1980	Acme Drilling Company	280	Tmu	22 1/16/80	Casing: 24 in. from 0 to 117 ft; 16 in. from 57 to 115 ft. Screen: 12 in. from 115 to 180 ft. Drawdown 46 ft when pumped 8 hrs at 351 gpm in 1980. Also known as the Fillmore Plant well.
Atmore Utilities Board	553	4	ESCZ-106	180	1960	Layne Central Company	269	Tmu	23 9/24/59	Casing: 24 in. from 0 to 103 ft; 16 in. from 0 to 113 ft. Screen: 12 in. from 113 to 167 ft. Drawdown 35 ft when pumped 8 hrs at 1,022 gpm in 1960. Also known as Lindberg Plant well.

Table 6-4.--Records of public water-supply wells in study area–Continued

System	PWS ID	SE ID	GSA ID	Depth	Year drilled	Drilling contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Atmore Utilities Board	553	5	ESCZ-72	129	1932	Layne Central Company	285	Tmu	18 8/21/45	Casing: 18 in. from 0 to 21 ft; 8 in. from 0 to 100 ft. Screen: 8 in. from 100 to 129 ft. Pump capacity 500 gpm in 1945. Also known as S. Trammel St. well.
Atmore Utilities Board	553	6	ESCAA-03	153 (400)	1980	Acme Drilling Company	290	Tmu	47 1980	Casing: 14 in. from 0 to 120 ft; 10 in. from 65 to 119 ft. Screen: 8 in. from 119 to 149 ft. Drawdown 28 ft when pumped 24 hrs at 570 gpm in 1980. Also known as Dees Dr. well.
Atmore Utilities Board	553	7	ESCAA-01	162	1980	Acme Drilling Company	290	Tmu	47 1980	Casing: 14 in. from 0 to 130 ft; 10 in. from 82 to 129 ft. Screen: 8 in. from 129 to 160 ft. Drawdown 23 ft when pumped 24 hrs at 465 gpm in 1980. Also known as Byrne's Dr. well.

Table 6-4.--Records of public water-supply wells in study area–Continued

System	PWS ID	SE ID	GSA ID	Depth	Year drilled	Drilling contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Atmore Utilities Board	553	10	ESCK-06	362	1967	Layne Central Company	290	Tcr	108 1969	Casing: 18 in. from 0 to 282 ft; 10 in. from 240 to 283 ft and 303 to 332 ft. Screen: 10 in. from 283 to 303 ft and 332 to 352 ft. Drawdown 27 ft when pumped 8 hrs at 400 gpm in 1969. Also known as Holman Prison well no. 1.
Atmore Utilities Board	553	11	ESCK-05	362	1967	Layne Central Company	290	Tcr	103 1969	Casing: 18 in. from 0 to 289 ft; 10 in. from 240 to 292 ft and 302 to 322 ft. Screen: 10 in. from 292 to 302 ft and 322 to 352 ft. Drawdown 25 ft when pumped 8 hrs at 402 gpm in 1969. Also known as Holman Prison well no. 2.
Atmore Utilities Board	553	12	ESCK-011	515	1992	Griner Drilling Service, Inc.	307	Tcr	123 7/2/92	Casing: 18 in. from 0 to 297 ft; 10 in. from 240 to 307 ft and 347 to 370 ft. Screen: 10 in. from 307 to 347 ft and 370 to 390 ft. Drawdown 120 ft when pumped 9 hrs at 603 gpm on 7/3/92. Also known as Fountain Prison well no. 1.

Table 6-4.--Records of public water-supply wells in study area–Continued

System	PWS ID	SE ID	GSA ID	Depth	Year drilled	Drilling contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Canoe Water Works	557	1	ESCZ-107	90	1966	Spillers Well & Pump	289	Tmu	39 1967	Casing: 6 in. from 0 to 70 ft,; 4 in. from 70 to 90 ft. Drawdown 24 ft when pumped 8 hrs at 160 gpm in 1967.
East Brewton Water & Sewer Board	558	1	ESCO-02	725	1974	Layne Central Company	95	Tgl	+22 1975	Casing: 18 in. from 0 to 615 ft; 10 in. from 540 to 620 ft and 670 to 690 ft. Screen: 10 in. from 620 to 670 and 690 to 710 ft. Drawdown 16 ft when pumped 4 hrs at 503 gpm in 1975. Also known as city well no. 1.
East Brewton Water & Sewer Board	558		ESCO-05	800	1987	Griner Drilling Service, Inc.	165	Tgl	55 4/16/98	Casing: 18 in. from 0 to 672 ft; 10 in. from 599 to 682 ft, 702 to 706 ft, and 724 to 744 ft. Screen: 10 in. from 682 to 702 ft, 706 to 724 ft, and 744 to 756 ft. Drawdown 97 ft when pumped 10 hrs at 752 gpm in 1997. Also known as city well no. 3.
Ridge Road Water System			ESCP-02	580 (890)	1997	Griner Drilling Service, Inc.	100	Tgl	+14 6/2/98	Casing: 16 in. from 0 to 530 ft; 8 in. from 480 to 540 ft. Screen: 8 in. from 540 to 580 ft. Drawdown 60 ft when pumped 24 hrs at 450 gpm in 1998.

Table 6-4.--Records of public water-supply wells in study area–Continued

System	PWS ID	SE ID	GSA ID	Depth	Year drilled	Drilling contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Freemanville Water System	561	1	ESCJ-01	262	1982	Griner Drilling Service, Inc.	297	Tmu	49 9/21/82	Casing: 18 in. from 0 to 222 ft; 10 in. from 167 to 232 ft. Screen: 10 in. from 232 to 262 ft. Drawdown 45 ft when pumped 5 hrs at 536 gpm in 1982.
Freemanville Water System	561	2	ESCZ-012	214	1989	Weldon Drilling Co.	300	Tmu	60 1989	Casing: 18 in. from 0 to 179 ft; 8 in. from 0 to 182 ft. Screen: 8 in. from 182 to 214 ft. Drawdown 52 ft when pumped 24 hrs at 450 gpm on 7/25/89.
Pollard Water System	546	1	ESCW-01	260 (800)	1981	Acme Drilling Company	60	Tmu	+1 1981	Casing: 12 in. from 0 to 233 ft; 6 in. from 192 to 232.5 ft. Screen: 6 in. from 232.5 to 258 ft. Drawdown 26 ft when pumped 24 hrs at 383 gpm on 9/10/81.
Canoe Water & Fire Protection Authority	557	1	ESCZ-107	90	1967	Spiller Well & Pump Co.	289	Tmu	39 1967	Casing: 6 in. from 0 to 70 ft; 4 in. from 68 to 70 ft. Screen: 4 in. from 70 to 90 ft. Drawdown 24 ft when pumped 8 hrs at 160 gpm in 1967.

Table 6-4.--Records of public water-supply wells in study area–Continued

System	PWS ID	SE ID	GSA ID	Depth	Year drilled	Drilling contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Flomaton Water Works	559	2	ESCX-01	293	1973	Alton Powell Drilling Company	180	Tmu	143 1973	Casing: 12 in. from 0 to 215 ft; 8 in. from 175 to 218 ft; 6 in. from 229 to 234 ft, 255 to 266 ft, and 286 to 288 ft. Screen: 6 in. from 218 to 229 ft, 234 to 255 ft, and 266 to 286 ft.
Flomaton Water Works	559	3	ESCX-018	269	1982	Acme Drilling Company	220	Tmu	124 1982	Casing: 12 in. from 0 to 230 ft; 8 in. from 185 to 226 ft. Screen: 6 in. from 226 to 266 ft. Drawdown 16 ft when pumped 24 hrs at 457 gpm in 1982.
Riverview Water Works	570	1	ESCV-01	444	1972	Acme Drilling Company	75	Tcr	flow 1972	Casing: 6 in. from 0 to 362 ft; 4 in. from 318 to 362 ft. Screen: 4 in. from 362 to 442 ft. Drawdown 52 ft when pumped 3 hrs at 232 gpm in 1972.
Riverview Water Works	570	1	ESCV-02	1,000	2004	Griner Drilling Service, Inc.	191	Tcr	122 7/15/03	Casing: 16 in. from 0 to 525 ft; 10 in. from 465 to 535 ft. Screen: 10 in. from 535 to 575 ft. Drawdwon 119 ft when pumped 8 hrs at 375 gpm in 2003.

Table 6-4.--Records of public water-supply wells in study area–Continued

MONROE COUNTY

System	PWS ID	SE ID	GSA ID	Depth	Year drilled	Drilling contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Beatrice Water System	1044	1	MONJ-5	448	1961	Layne Central Company	258	Tnf	13 1961	Casing: 8 in. from 0 to 424 ft; 6 in. from 0 to 428 ft. Screen: 6 in. 428 to 448 ft. Drawdown 109 ft when pumped 9 hrs at 50 gpm in 1961.
Beatrice Water System	1044	2	MONJ-6	460	1961	Layne Central Company	264	Tnf	107 1/12/61 126.8 6/16/67	Casing: 8 in. from 0 to 378 ft; 4.5 in. from 348 to 381 ft and 401 to 440 ft. Screen: 4.5 in. from 381 to 401 ft and 440 to 460 ft. Drawdown 150 ft when pumped 9 hrs at 50 gpm in 1961.
Excel Water System	1046	1	MONHH-2	133	1965	Alton Powell Drilling Company	403	Tmu	47 1965	Casing: 12 in. from 0 to 59 ft; 8 in. from 0 to 110 ft; 6 in. from 103 to 112 ft, 118 to 120 ft. Screen: 6 in. from 112 to 118 ft and 120 to 130 ft. Drawdown 8 ft when pumped 7 hrs at 167 gpm in 1965.
Excel Water System	1046		MONHH-02	150	1996	Rowe Drilling Company	405	Tmu	76 12/4/96	Casing: 16 in. from 0 to 120 ft; 8 in. from 0 to 125 ft. Screen: 6 in. from 125 to 150 ft. Drawdown 19.4 ft when pumped 24 hrs at 230 gpm in 1996.

Table 6-4.--Records of public water-supply wells in study area–Continued

System	PWS ID	SE ID	GSA ID	Depth	Year drilled	Drilling contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Frisco City Water System	1047	1	MONHH-3	132	1962	Acme Drilling Company	413	Tmu	63 1962	Casing: 18 in. from 0 to 100 ft; 12 in. from 56 to 100 ft. Screen: 12 in. from 100 to 130 ft. Drawdown 41 ft when pumped 2 hrs at 450 gpm in 1962.
Frisco City Water System	1047	2	MONGG-02	139	1970	Acme Drilling Company	405	Tmu	87 4/1/70	Casing: 18 in. from 0 to 108 ft; 12 in. from 65 to 105 ft. Screen: 12 in. from 105 to 135 ft. Drawdown 15 ft when pumped 6 hrs at 351 gpm in 1970.
Monroeville Water Service	1052	1	MONU-4	1,295	1974	Layne Central Company	350	Tnf	302 1974	Casing: 18 in. from 0 to 1,135 ft; 10 in. from 1,040 to 1,135 ft, 1,180 to 1,190 ft, 1,225 to 1,240 ft. Screen: 10 in. from 1,140 to 1,180 ft, 1,190 to 1,225 and 1,240 to 1,275 ft. Drawdown 134 ft when pumped 2 hrs at 981 gpm in 1974. Also known as the Hammond St. well.
Mexia Water System, Inc.	1050	1	MONU-01	1,704	2010	Rowe Drilling Co	385			In complete data

Table 6-4.--Records of public water-supply wells in study area–Continued

System	PWS ID	SE ID	GSA ID	Depth	Year drilled	Drilling contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Monroeville Water Service	1052	2	MONV-04	1,290	1979	Layne Central Company	310	Tnf	354 1979	Casing: 18 in. from 0 to 1,135 ft; 10 in. from 1,045 to 1,140 ft, 1,190 to 1,200 ft, 1,240 to 1,250 ft. Screen: 10 in. from 1,140 to 1,190 ft, 1,200 to 1,240 ft, and 1,250 to 1,275 ft. Drawdown 92 ft when pumped 12 hrs at 818 gpm in 1981. Also known as the Ivy St. well.
Monroeville Water Service	1052	3	MONZ-1	1,387	1965	Layne Central Company	425	Tnf	313 1967	Casing: 16 in. from 0 to 1,240 ft; 10 in. from 1,160 to 1,243 ft and 1,273 to 1,317 ft. Screen: 10 in. from 1,243 to 1,273 ft and 1,317 to 1,387 ft. Drawdown 401 ft when pumped 24 hrs at 933 gpm in 1965. Also known as the Drewry well.
Monroeville Water Service	1052	4	MONU-3	1,365	1955	Layne Central Company	414	Tnf	272 1955	Casing: 16 in. from 0 to 1,190; 10 in. from 1,110 to 1,195 ft and 1,215 to 1,285 ft. Screen: 10 in. from 1,195 to 1,215 ft and 1,285 to 1,365 ft. Drawdown 132 ft when pumped 8 hrs at 900 gpm in 1955. Also known as Cherry St. well.

Table 6-4.--Records of public water-supply wells in study area–Continued

System	PWS ID	SE ID	GSA ID	Depth	Year drilled	Drilling contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Monroeville Water Service	1052	5	MONZ-2	1,394	1953	Layne Central Company	427	Tnf	260 1953	Casing: 16 in. from 0 to 1,247 ft; 10 in. from 1,167 to 1,252 ft and 1,292 to 1,354 ft. Screen: 10 in. from 1,252 to 1,292 and 1,354 to 1,394 ft. Drawdown 145 ft when pumped 8 hrs at 900 gpm in 1953. Also known as the Poplar St. well.
Monroeville Water Service	1052	6	MONY-01	1,270	1991	Layne Central Company	340	Tnf	359 12/4/98	Casing: 18 in. from 0 to 1,110 ft; 10 in. from 1,035 to 1,114 ft, 1,154 to 1,180 ft, 1,215 to 1,235 ft, and 1,255 to 1,270 ft. Screen: 10 in. from 1,114 to 1,154 ft, 1,180 to 1,215 ft, and 1,235 to 1,255 ft. Drawdown 145 ft when pumped 8 hrs at 1,205 gpm in 1991. Also known as the Rose Drive well.
Southwest Alabama Water & Fire Protection Authority	1426	2	MONO-01	840	1989	Weldon Drilling Company, Inc.	430	Tnf	319 1989	Casing: 12 in. from 0 to 710 ft; 6 in. from 687 to 720 ft and 760 to 790 ft. Screen: 6 in. from 720 to 760 ft and 790 to 830 ft. Drawdown 320 ft when pumped at 320 gpm in 1991. Also known as the Tunnel Springs well.

Table 6-4.--Records of public water-supply wells in study area–Continued

System	PWS ID	SE ID	GSA ID	Depth	Year drilled	Drilling contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Southwest Alabama Water & Fire Protection Authority	1426	3	MONH-01	925	1994	Griner Drilling Company, Inc.	430	Tnf	363 10/31/94	Casing: 12 in. from 0 to 800 ft; 6 in. from 750 to 810 ft and 830 to 905 ft. Screen: 6 in. from 810 to 830 ft and 905 to 925 ft. Drawdown 108 ft when pumped 7 days at 200 gpm in Nov. 1994. Also known as the Franklin well.
Uriah Water System	1056	1	MONKK-3	171	1922	Logan Drilling Co.	352	Tmu	105 1962	Casing: 4 in. from 0 to unknown depth. Well pumped at 56 gpm in 1962.
Uriah Water System	1056	2	MONKK-01	280	1969	T. F. Mason	350	Tmu	130 1970	Casing: 14 in. from 0 to 44 ft; 8 in. from 0 to 260 ft; 6 in. from 255 to 265 ft. Screen: 6 in. from 265 to 280 ft. Drawdown 17 ft when pumped 8 hrs at 104 gpm in 1970.
Vredenburgh Water System	1048	1	MONE-4	274	1948	Layne Central Company	146	Tnf	55 1984	Casing: 12 in. from 0 to 235 ft; 6 in. from 180 to 240 ft. Screen: 6 in. from 240 to 270 ft. Drawdown 10 ft when pumped 4 hrs at 150 gpm in 1948.

Table 6-4.--Records of public water-supply wells in study area–Continued

System	PWS ID	SE ID	GSA ID	Depth	Year drilled	Drilling contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Vredenburgh Water System	1048	2	MONE-3	320	1912	Gray Artesian Well	146	Tnf	38 5/28/46	Casing: 10 in. from 0 to 85 ft. Open hole below casing. Pump capacity 150 gpm in 1946.

EXPLANATION FOR TABLE 6-5

WELL OWNER, water system name or owner's name.

WELL NO, well identification number used in Water Resources Investigation Report 88-4107 and shown on plates.

GSA ID, well identification number assigned by the GSA.

DEPTH, total depth of well in ft. Number in parentheses denotes total depth of test well drilled at the same location.

YEAR DRILLED, the year the well was completed and ready for operation.

DRILLING CONTRACTOR, name of driller.

ALTITUDE, elevation of land surface in ft above msl.

AQUIFER, Tmu, undifferentiated Pliocene, Miocene and Oligocene deposits of Tertiary age; Tcr, Crystal River Formation; Tl, Lisbon Formation; Tgl, Lisbon and Gosport Sand; Tt, Tuscahoma Sand; Tnf, Nanafalia Formation; Kr, Ripley Formation.

WATER LEVEL, water level in ft bls. The date the measurement was made is shown below the measurement.

WELL CONSTRUCTION, YIELD, REMARKS, gpm.

Table 6-5.--Records of selected wells and inactive public water-supply wells in study area

CONECUH COUNTY

Well Owner	Well no.	GSA ID	Depth	Year drilled	Drilling Contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Alabama Highway Department	54	CONAA-01	300	1968	Acme Drilling Company	340	Tmu	137.8 6/13/68	Casing: 6 in. from 0 to 155 ft. Open hole below casing. Drawdown 9.3 ft when pumped 24 hrs at 30 gpm in June 1968.
Alabama Highway Department	55	CONT-01	258	1968	Acme Drilling Company	231	Tmu, Tcr		Casing: 6 in. from 0 to 252 ft. Screen: 6 in. from 252 to 262 ft. Estimated yield 50 gpm.

MONROE COUNTY

Well Owner	Well no.	GSA ID	Depth	Year drilled	Drilling Contractor	Altitude	Aquifer	Water level Date measured	Well construction, yield, remarks
Frisco City Water Works	47	MONZ-	124	1935	Gray Artesian Company, Inc.	412	Tmu	67.7 6/13/67	Casing: 10 in. from 0 to 124 ft. Perforated from 86 to 124 ft. Drawdown 5.5 ft when pumped at 106 gpm in 1935.
Frisco City Water Works	48	MONZ-	129	1953	Gray Artesian Company, Inc.	412	Tmu	73 4/8/53	Casing: 16 in. from 0 to 86 ft; 10 in. from 65 to 89 ft. Screen: 8 in. from 89 to 129 ft. Drawdown 18 ft when pumped 18 hrs at 300 gpm in 1953.
Uriah Water System	51	MONGG-7	165	1964	Etheridge Plumbing	391	Tmu	119 1964	Casing: 6 in. from 0 to 143 ft. Screen: 4.5 in. from 143 to 165 ft. Drawdown 9 ft when pumped 36 hrs at 104 gpm in 1964.

Chapter 7

POTENTIAL FOR LARGE-SCALE IRRIGATION FROM GROUNDWATER SOURCES IN SOUTHWEST ALABAMA

By Dorina Murgulet

LOCATION AND DEMOGRAPHICS

The investigated area, located in South Alabama, comprises an area of approximately 2,906.6 mi^2 in Baldwin and Mobile Counties (plate 7-1). Some of the major cities in this area are the city of Mobile (population 191,022), Bay Minette (population 8,043), Dauphin Island (population 1,586), Daphne (population 19,093), Fairhope (population 17,147), Foley (population 13,807), Gulf Shores (population 10,248), and Orange Beach (population 69,231). The study area is characterized by a continuously increasing economy and rate of development. The population of Baldwin County increased by 23.4% 2000 and 2008, ranking second only to Shelby County (29.9%) in the state (U.S.Census Bureau, 2008). Mobile County ranked 24th in the statewide percentage of population increase (U.S.Census Bureau, 2008).

PHYSIOGRAPHY AND TOPOGRAPHY

The investigated area is situated entirely in the East Gulf Coastal Plain section of the Coastal Plain physiographic province, and includes the Coastal Lowlands, the Southern Pine Hills, and the Alluvial-Deltaic Plain districts (Sapp and Emplaincourt, 1975) (plate 7-2).

The Coastal Lowlands, characterized by gently undulating to flat, locally swampy plains, are located in close proximity to the shorelines along the Gulf of Mexico and Mobile, Weeks, Bon Secour, and Perdido Bays (plate 7-2). Underlying this physiographic district are terrigenous deposits of Holocene to late Pleistocene age. The geomorphology of these areas consists of wetlands, lagoons, islands, bays, a delta, and two large peninsulas. Most of the investigated area lies within the Southern Pine Hills physiographic district (Sapp and Emplaincourt, 1975) (plate 7-2), characterized by elevations that vary from approximately 400 ft above msl in the north to less than 30 ft above msl at the southern limit. Pliocene-Pleistocene sediments underlie this physiographic district. The Alluvial-Deltaic Plain is located at the terminus of Mobile Bay, northward along the Baldwin-Mobile County line. Additionally, alluvial sediments are also found along the Escatawpa River (plate 7-2).

GEOLOGY

The stratigraphy of Baldwin and Mobile Counties as well as offshore Alabama consists of relatively thick Jurassic to Holocene sediments (Chandler and others, 1985). Geologic units that crop out within this region are, in chronological order, the Eocene and Oligocene Series undifferentiated, the Miocene Series undifferentiated, the Citronelle Formation, and the alluvial and coastal deposits (fig. 7-1). At relatively shallow depths, interbedded sands, silts, gravels and clays comprise the middle Miocene to Holocene sediments that form the freshwater aquifers of the investigated area. Alluvial and coastal deposits of Quaternary age overlie Tertiary deposits and extend along the coastal areas of Mobile Bay and the Gulf of Mexico and in the floodplains of major rivers and streams (plates 7-1, 7-3). High terrace deposits overlie Tertiary sediments along the eastern margin of the Alabama, Mobile, and Tensaw River flood plains. Alluvial and high terrace deposits are referred to as the Watercourse aquifer (table 7-1).

Tertiary deposits currently used as sources of freshwater in the study area include the Miocene Series undifferentiated and the Citronelle Formation (fig. 7-1). In Alabama, the Eocene Series includes the Hatchetigbee Formation, the Claiborne Group, and the Jackson Group. These units are present only in the subsurface of the study area and include interbedded sand, silt, clay, and some limestone (Raymond and others, 1988). The Oligocene Series undifferentiated does not crop out in the study area and is comprised of the Red Bluff Clay, Forest Hill Sand, Marianna Limestone, Byram Formation, and Chickasawhay Limestone. These units consist of interbedded clay, sand, marl, and limestone (Raymond and others, 1988). The Eocene and Oligocene Series are not currently developed as sources of freshwater in the investigated area.

Table 7-1.-- Geologic units and their water-bearing properties (modified from Reed and McCain, 1972)							
System	Series	Geologic unit	Thickness (ft)	Lithology	Aquifer	Yield	Quality of water
Quaternary	Holocene and Pleistocene	Alluvium, low-terrace and coastal deposits	0-200	Sand, white, gray, orange, and red, very fine to coarse grained, contains gravel in places; gray and orange sandy clay	Watercourse	Will yield 10 gpm where saturated sands are of sufficient thickness. Potential source of 0.5 mgd per well in the Mobile River basin	Water generally suitable for most uses but commonly contains iron in excess of 0.3 mg/L and may be sufficiently acidic to be corrosive. Locally, in areas close to Mobile Bay and Mississippi Sound, water is very hard, has high Cl and dissolved solids contents, and contains iron in excess of 0.3 mg/L.
		High-terrace deposits				Will yield 10 gpm or more where saturated sands are of sufficient thickness.	Probably soft and low in dissolved solids. May contain iron in excess of 0.3 mg/L.
Tertiary	Pliocene	Citronelle Formation	0-200	Sand, brown, red, and orange, fine- to coarse-grained, gravelly in places, contains clay balls and partings; gray, orange, and brown lenticular sandy clay, ferruginous cemented sandstone.	Miocene/Pliocene	Will yield 2 mgd or more per well	Water generally is soft and low in dissolved solids but may contain iron in excess of 0.3 mg/L and may be corrosive. In areas adjacent to Mobile River, Mobile Bay, and Mississippi Sound, water may have a dissolved solids content that exceeds 1,000 mg/L, a sulfurous odor, and a Cl content that exceeds 500 mg/L.
	Miocene	Miocene Series undifferentiated	100-3,400	Sand, gray, orange, and red very fine to coarse-grained, contains gravel in places; gray thin-bedded to massive sandy silty clay.			

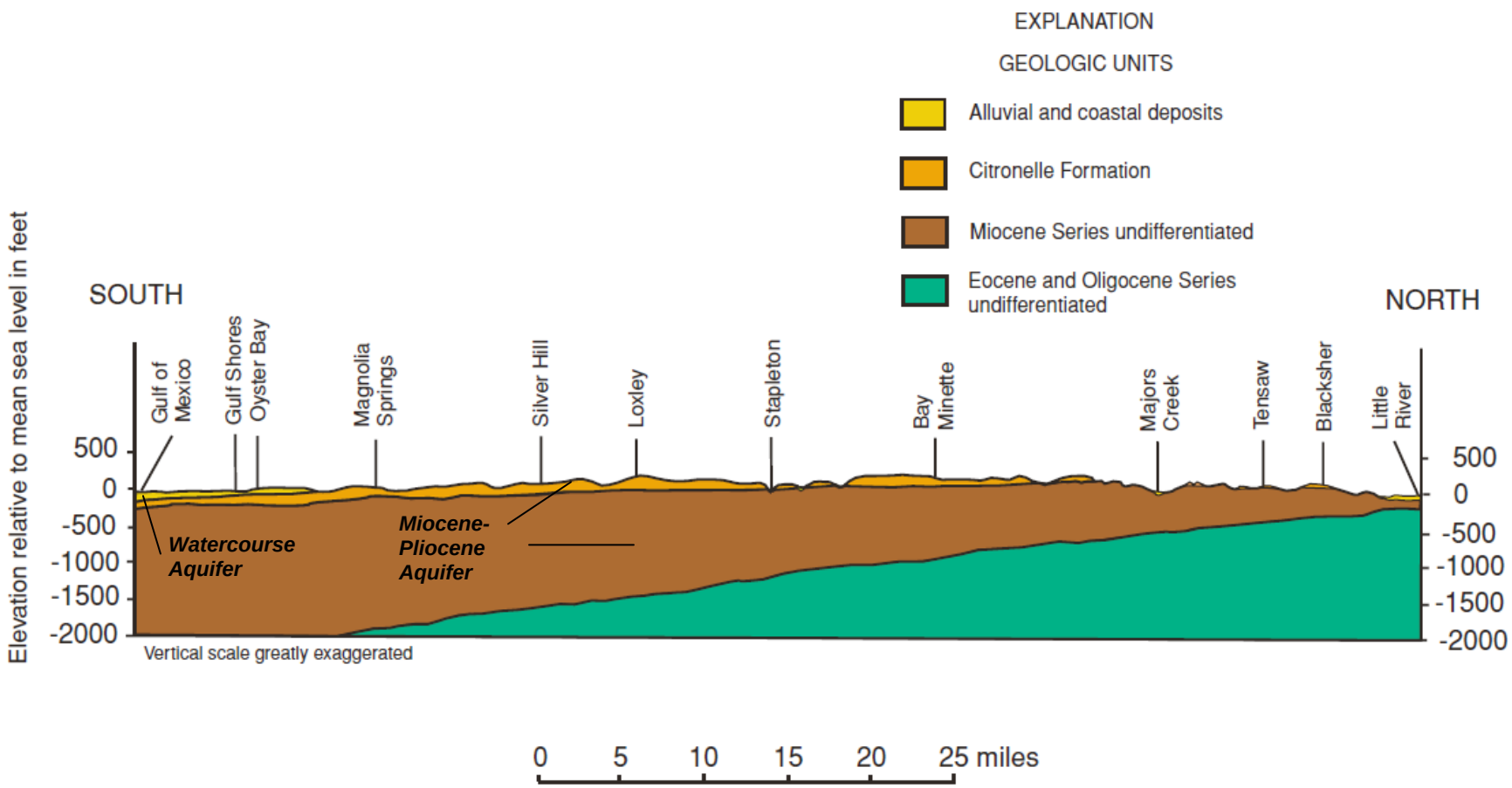

Figure 7-1.--Generalized north-south geologic cross section in Baldwin County, Alabama (modified from Mooty, 1988, and Gillette and others, 2000).

The Miocene Series undifferentiated crops out in central and northern parts of Baldwin and Mobile counties (plate 7-3) (Szabo and Copeland, 1988b), dips southwestward toward the Gulf of Mexico, and ranges in thickness from 100 ft in northern Baldwin County to 3,400 ft in southern Mobile County (Reed, 1971a). The Miocene Series undifferentiated consists of clastic sediments of marine and estuarine origin. Sands in the unit are coarse to fine grained and are locally cross bedded. In the subsurface, Miocene sediments consist of two major units: a confining layer known as the lower Pensacola Clay (Marsh, 1966; Raymond, 1985) and an overlying coarse clastic unit informally referred to as “Miocene coarse clastics” (Marsh, 1966; Raymond, 1985; Smith, 1991). The latter unit serves as a host for the deep freshwater resources in the investigated area.

Sediments of Pliocene age, known as the Citronelle Formation, overlie the Miocene Series undifferentiated and crop out in the central and southern parts of Baldwin and Mobile Counties (plate 7-3). This unit is relatively thick in the northern parts of the investigated area and thins southward in the subsurface to about 200 ft. Sediments comprising this formation consist of nonfossiliferous moderate-reddish-brown fine to very coarse quartz sand; light-gray, orange, and brown sandy clay; and clayey gravel of nonmarine origin (Reed, 1971a, b; Szabo and others, 1988b). Gravels of the Citronelle Formation consist of quartzite and chert (Isphording, 1977) and are commonly interbedded with sandy clay and clayey lenses that range in thickness from 5 to 15 ft. The Citronelle Formation is characterized by sedimentary facies that often change abruptly over short distances (Walter and Kidd, 1979).

Quaternary deposits include the high terrace deposits of Pleistocene age and the alluvial, low terrace, and coastal deposits of Pleistocene and Holocene age (Isphording and Lamb, 1971). High terrace deposits unconformably overlie Miocene sediments in many parts of Baldwin County and in the northeastern part of Mobile County in areas adjacent to the Mobile River floodplain (plate 7-3).These deposits have an average thickness of 15 to 30 ft (Gillett and others, 2000). The base of the high terrace deposits ranges in altitude from 130 to 180 ft above msl in Mobile County and from 60 to 120 ft above msl in Baldwin County. Sandy clay, fine to coarse sand, and sand that contains gravel in some places comprises this unit.

Alluvial, low terrace, and coastal deposits overlie Miocene and Pliocene formations in many parts of the study area (plate 7-3) and consist of very fine to coarse sands that are interbedded with clay and sandy clay (Walter and Kidd, 1979). These deposits range in thickness from 0 to 200 ft and represent a complex of beach, dunes, estuarine, lagoonal, and deltaic depositional environments (Chandler and Moore, 1983).

SOILS

In Baldwin and Mobile Counties, the warm-temperate, almost subtropical climate is an important factor in the development of soils. The climate in Baldwin and Mobile Counties is characterized by long, warm summers, short and relatively mild winters, and large amounts of rainfall. Consequently, most soils in Baldwin and Mobile Counties are low in organic matter and fertility and highly weathered and leached (McBride and Burgess, 1964; Glen and Owens, 1980). Climate and geologic formations are mainly uniform in this area; therefore, soils developed in these conditions do not exhibit extreme variations. The fine material composing these soils is easily flushed downward due to the large amounts of rain. This process favors the translocation of less soluble and colloidal material to lower horizons that would otherwise decrease soil conductivities (McBride and Burgess, 1964; Glen and Owens, 1980). Parental soil material consists of sediments transported by streams that flow into Mobile Bay and the Gulf of Mexico and in some instances from sediments deposited from the waters of the Gulf of Mexico (McBride and Burgess, 1964; Glen and Owens, 1980). The parental material originates from sediments deposited on beaches, floodplains, and terraces and from sediments derived from the Citronelle Formation (McBride and Burgers, 1964; Glen and Owens, 1980). Therefore, the parental material for soils of these counties originates from two major sources: (1) material transported by water and accumulated as alluvium, consisting of unconsolidated sand, silts, and/or clay; and (2) residual material originating from weathered and unconsolidated Coastal Plain sediments (McBride and Burgess, 1964; Glen and Owens, 1980).

A detailed classification of soil types (Soil Survey Geographic (SSURGO) Database) was developed by the USDA-NRCS (2007a) for Baldwin and Mobile Counties. It is not the purpose of this study to provide a thorough description of soil characteristics but to present a rather simplistic classification of soil orders and taxonomy

and their relationship with areas of current and potential future agricultural activity. The NRCS State Soil Geographic (STATSGO) database provides a simplified classification of soils according to common taxonomic characteristics (USDA-NRCS, 2007a) and offers sufficient information to fulfill the objectives of this study. Soils in the investigated area are divided into four orders: entisols, ultisols, histosols, and inceptisols (USDA-NRCS, 2007a) (plate 7-4). Soils that formed from transported material are primarily included in three orders: entisols, histosols, and inceptisols (plate 7-4). Agriculture is developed chiefly on areas with fine, loamy, and kaolinitic soils, described as ultisols, derived from weathered and unconsolidated Coastal Plain sediments (plate 7-4). Major soil orders, taxonomic characteristics, and areal extent within the investigated area are tabulated in table 7-2.

Table 7-2.-- Soil order names, area and taxonomy.

No.	Order	Soil order area (mi^2)	Percent total area	Taxonomic class
1	Ultisols	2,386.9	82.1	Coarse-loamy, fine-loamy, fine, kaolinitic, siliceous, mixed
2	Inceptisols	127.4	4.4	Fine, mixed
3	Histosols	115.5	4.0	Dysic and euic
4	Entisols	203.2	7.0	Coarse-loamy, fine, mixed

LAND USE/LAND COVER

Using the 2010 USDA, NASS-CDL for the Southeast States, LULC classes were divided into two major cover types: (1) agricultural and (2) non-agricultural classes. Agricultural LULC includes nine classes: corn; cotton; soybeans; peanuts/pecans; double crop/cotton, oats, soybeans, oats, and winter wheat; pasture/hay/grass, seed/sod grass, fallow/idle cropland, and other crops (plate 7-5, table 7-3). Furthermore, seven nonagricultural LULC classes were identified as: open water; developed/low intensity and open space; developed/medium and high intensity; barren; forest; shrubland; and wetlands (plate 7-5, table 7-3). A small part of the area (1.14 mi^2) remained unclassified (not visible on a map). Nonagricultural classes make up the largest percentage of LULC

(83.2) in the Baldwin and Mobile Counties groundwater irrigation assessment area (plate 7-5, table 7-3). Out of these, developed cover/use type classes comprise approximately 10% of the investigated area. The dominant nonagricultural classes are forest (37.6) and wetlands (21.8%) (table 7-3). However, it should be noted that the aforementioned cover/use type classes are more prevalent on the northern half of the assessment area whereas the southern half is being extensively used for agricultural practices (cultivated crops and pasture/hay/grass) (plate 7-5). In other words, although present in a small percentage (16.8) compared with nonagricultural classes, agricultural uses make up a large percentage of the southern half of both Mobile and Baldwin Counties (plate 7-5). Similarly, areas classified as developed (for example, Mobile and surrounding suburbs, Spanish Fort, Daphne, Fairhope, Foley, and Gulf Shores) are mostly concentrated in the southern half of the assessment area (plate 7-5). A large part of the developed class resides in Mobile County, in the city of Mobile and the surrounding suburbs. Agricultural LULC classes are divided between pasture/hay/grass (9.39%) and all other agricultural cover types (7.46%) (table 7-3).

Boundaries for cultivated/agricultural areas can be derived by assessing the geology, soils, physiography, topography, and land-use patterns. Analyses of these characteristics indicate that agricultural activity correlates with areas underlain by Tertiary sediments of the Citronelle Formation (plates 7-3, 7-5) and with the moderately deep, well drained, high to moderately permeable, and nearly level to gently sloping ultisols (composed of fine to coarse-loamy, siliceous, and kaolinitic sediments) (plates 7-4, 7-5). Furthermore, agricultural cover/use type areas are associated with gently sloping to flat areas that extend for the most part to the Southern Pine Hills. To a very small extent, agricultural uses are identified within the Coastal Lowlands of southern Baldwin and Mobile Counties (plates 7-1, 7-2, 7-5).

The geology, soils, physiography, and topography collectively create an environment favorable for the land uses observed in the assessment area, which, in large part, are non-agricultural in the northern part of the area and primarily agricultural in the southern part of the area (plate 7-5).

Table 7-3.--Area and proportion of LULC for the Baldwin and Mobile Counties groundwater irrigation assessment area.						
LULC class Agricultural Cover Type	LULC class area (mi^2)			Percent (%) of LULC class		
	Baldwin	Mobile	Total area	Baldwin	Mobile	Total area
Corn	11.58	2.12	13.70	0.70	0.17	0.47
Cotton	10.10	13.81	23.91	0.61	1.10	0.82
Soybeans	27.41	1.33	28.74	1.66	0.11	1.00
Peanuts/Pecans	45.15	10.55	55.70	2.74	0.84	1.92
Double Crop/Cotton, Soybeans, Oats, and Winter Wheat	16.10	0.43	16.53	0.98	0.03	0.57
Pasture/Hay/Grass	171.88	100.88	272.76	10.44	8.00	9.39
Seed/Sod Grass	16.87	0.16	17.03	1.02	0.01	0.59
Fallow/Idle Cropland	31.33	24.58	55.91	1.90	1.95	1.92
Other crops	0.00	4.94	4.94	0.00	0.40	0.17
Total Agricultural Cover Type	*330.42*	*158.80*	*489.22*	*20.06*	*12.61*	*16.83*
LULC class Nonagricultural Cover Type	LULC class area (mi^2)			Percent (%) of LULC class		
	Baldwin	Mobile	Total area	Baldwin	Mobile	Total area
Open Water	54.97	26.22	81.19	3.34	2.08	2.79
Developed/Low Intensity and Open Space	117.10	173.85	290.95	7.11	13.80	10.01
Developed/Medium and High Intensity	7.16	21.97	29.13	0.43	1.74	1.00
Barren	6.65	2.63	9.28	0.40	0.21	0.32
Forest	624.90	468.62	1,093.52	37.96	37.20	37.63
Shrubland	128.24	146.91	275.15	7.79	11.66	9.47
Wetlands	375.78	258.78	634.56	22.82	20.54	21.84
Total Nonagricultural Cover Type	*1,315.94*	*1,100.96*	*2,416.90*	*79.93*	*87.39*	*83.17*
Unclassified	1.14	1.59	3.12	0.07	0.13	0.11

HYDROGEOLOGY

Sediments that contain freshwater in the study area have been originally divided into two major aquifers: the Watercourse aquifer and the Miocene-Pliocene aquifer (table 7-1).

MIOCENE-PLIOCENE AQUIFER

The Miocene-Pliocene aquifer consists of the Miocene Series undifferentiated and the Citronelle Formation (fig. 7-1, plate 7-3). In coastal areas of southern Baldwin and Mobile Counties this unit is about 3,400 ft thick whereas in extreme northern Baldwin County, the unit is about 100 ft thick (Reed and McCain, 1971). Groundwater flows downgradient toward the Gulf of Mexico through the Miocene-Pliocene aquifer in beds of sand and gravel that are irregular in thickness and of limited lateral extent. The aquifer also has interbedded clay intervals that lack continuity and are not laterally extensive enough to prevent downward movement of groundwater. However, these clay lenses provide locally semiconfining conditions to many of the deeper sand and gravel intervals. Attempts to correlate individual sands are difficult on the basis of available well data. In the northern part of the area, the principal water-bearing intervals are at the base of the Miocene-Pliocene sequence (Reed and McCain, 1971). Within this unit, individual sand intervals range in thickness from 50 to 100 ft in many places with a thickness of about 230 ft near Loxley (Reed and McCain, 1971). Interbedded clay lenses reach 80 ft in thickness. Sands in the upper part of the formation are extensively developed for a large variety of freshwater needs, whereas sands in the lower part of the formation have yet to be developed. However, it is important to recognize that deeper horizons are being explored for new freshwater supplies.

In Baldwin County, the Miocene-Pliocene aquifer is the most important water-bearing unit and is divided into subunits by several authors using different schemes. Clay units, which are more easily correlated than sand units, were used by Walter and Kidd (1979) to divide these deposits in southern Baldwin County. Their classification included four aquifer units: the Beach Sand aquifer, the Gulf Shores aquifer, the 350-foot aquifer, and the 500-foot aquifer. Based on this classification, the Beach Sand aquifer corresponds to the Watercourse aquifer, and the Gulf Shores and the 350- and 500-foot aquifers are equivalent to the Miocene-Pliocene aquifer. Chandler and others (1985) subdivided the

same sequence of water-bearing sediments in southern Baldwin County into aquifers A1, A2, and A3. A description of the lithologic and hydrologic characteristics of this sedimentary sequence is presented by Gillett and others (2000). Their study suggests that relatively thick, predominantly clay sequences are correlative from north to south and possibly from east to west in both counties. These clay sequences divide the shallow subsurface into several intervals dominated by beds of sand. Wells constructed in the Miocene-Pliocene aquifer, except for the northeastern and easternmost parts of the outcrop, yield from 0.5 to 2.5 mgd (Gillett and others, 2000).

WATERCOURSE AQUIFER

The Watercourse aquifer (fig. 7-1) consists of Quaternary alluvial, coastal, and terrace deposits with interbedded sand, gravel, and clay. Properly constructed wells in the thicker parts of this aquifer have the potential to yield from 0.5 to 1.0 mgd (Gillett and others, 2000). Most high-yield wells are completed in sand and gravel of coastal deposits and buried river sediments. Ancient buried channels may be directly connected to the present channels of the Mobile River (Gillett and others, 2000). The watercourse aquifer is hydraulically connected to the underlying Miocene-Pliocene aquifer. The sand and gravel beds that form the Watercourse and the shallow Miocene-Pliocene aquifers are hydraulically connected to the land surface; therefore, these aquifers are considered unconfined. The presence of interbedded, discontinuous lenses of clay within the Watercourse aquifer retards locally the vertical movement of water while still facilitating local recharge for the underlying Miocene-Pliocene aquifer. Due to its vulnerability to contamination from the land surface, the Watercourse aquifer is developed mainly for private uses (for example, for irrigation in the southern extent of the study area) and to a limited extent for public supply (for example, Mt. Vernon, Saraland, Satsuma, and Dauphin Island public supply systems). In the coastal region, the freshwater supply from this aquifer is limited due to saltwater contamination from storm tides and surges.

POTENTIOMETRIC SURFACES

An important part of a groundwater flow system evaluation is the determination of flow directions. Potentiometric surface maps and potentiometric profiles offer insight into regional groundwater flow patterns, identification of recharge and discharge zones, impacts associated with pumping rates (for example, cones of depression), and

groundwater/surface-water interaction processes (for example, diverging flowpaths caused by river/lake groundwater recharge).

Potentiometric surfaces are represented by contour lines of equal hydraulic head collected from properly constructed wells screened at different depths within an aquifer system. Water levels used to construct the potentiometric surfaces for the study area were acquired beginning with 2007 from public supply wells and a limited number of private pumping wells. However, most of the data were collected during fall 2009. At public supply wells, water level measurements were conducted after aquifer recovery was attained. However, at water levels from wells with relatively high pumping rates, may represent residual drawdown. Although in Baldwin and Mobile Counties the water-bearing units belong to one major aquifer, the Miocene-Pliocene aquifer, the ability to create a single potentiometric surface for the entire system is diminished by differences in hydraulic head with depth.

The presence of intermittent and continuous clay layers within this aquifer system that create confined conditions, locally and regionally, is well documented (Walter and Kidd, 1979; Chandler and others, 1985), resulting in differences between hydraulic heads at similar locations but different depths. Therefore, for the purpose of this study, well data were grouped based on the screened interval. Available well data were grouped into two classes: (a) water levels collected from wells screened at intervals ranging between 47 and 220 ft and (b) water levels collected from wells screened at depths ranging between 200 to 1,000 ft (plates 7-6, 7-7). This resulted in the development of two potentiometric surfaces for the study area. An overlap of 20 ft occurred between the 200- and 220-ft-depth interval for the two classes given the screen interval distribution. For instance, some of the shallower wells have their top screen set in the upper 200 ft and the bottom below 200 ft but not deeper than 220 ft. Similarly, a number of deeper wells have the screen top located in the interval between 200 and 220 ft and the bottom screen below 220 ft. For the purpose of this study the shallower interval (47-220 ft)will be referred to as the upper aquifer zone and the deeper (200-1,000 ft) as the lower aquifer zone.

For the upper aquifer zone, the potentiometric surface ranges between 200 and -20 ft msl (plate 7-6). Groundwater elevations for the lower aquifer zone range between 160 and -15 ft (datum msl) (plate 7-7). Hydraulic gradients are generally different for the

two aquifer intervals. For instance, hydraulic gradient values for the upper aquifer zone range from 3.9 to 22.5 ft/mi with an average of approximately 13.3 ft/mi whereas for the lower aquifer zone, the range is between 3.2 to 17.9 ft/mi with an average of approximately 10.5 ft/mi. Different hydraulic gradients are noticed mainly in southern Baldwin County and may be the result of the occurrence of distinguished aquifer units in the southernmost part of the county (Walter and Kidd, 1979; Chandler and others, 1985). In southern Baldwin County the hydraulic gradients are oriented southwestward, southward, and southeastward towards discharge areas such as Mobile and Weeks Bays, Intracoastal Waterway and Gulf of Mexico, and Perdido Bay and Perdido River, respectively (plate 7-6). Groundwater flow from north-central Baldwin County is westward to the Mobile and Tensaw Rivers, southwestward to Mobile Bay, and southward to the Gulf of Mexico (for example, longer flow paths with gentle hydraulic gradient slopes) (plate 7-6). The steeper hydraulic gradients are oriented from north-central Baldwin County to the Mobile and Tensaw Rivers (for example, 22.5 ft/mi) and from central Baldwin County to Weeks Bay and Mobile Bay (for example, 19.1 and 19.9 ft/mi, respectively). For the aquifer system below 200 ft, hydraulic gradients have similar orientations but gentler slopes (plate 7-7).

The hydrogeologic system in Mobile County exhibits steeper hydraulic gradients for both depth intervals compared to those estimated for Baldwin County (plates 7-6, 7-7). However, similar to Baldwin County, the steepest gradients are identified for the upper aquifer zone. The general direction of flow within this part of the aquifer is mainly southeastward towards the Mobile River and Mobile Bay at approximately 15.6 ft/mi. Longer flowpaths, with gentler gradients (about 7.3 ft/mi) are present from north-central Mobile County southward (for example, to the Gulf of Mexico). For the lower aquifer zone, hydraulic gradients have similar orientations but lower slopes (for example, approximately 8.1 ft/mi from north-central Mobile County to the Mobile River and Mobile Bay).

Generally, the hydraulic gradients flatten towards the shorelines due primarily to the lower topography of the alluvial and low terrace deposits (plates 7-6, 7-7). Two minor groundwater sinks are identified in Mobile County (plate 7-7) (for example, south-central and northern Mobile County). Furthermore, lower than sea level groundwater elevations

are revealed mainly along the southern extremities of both counties (plates 7-11, 7-12). The frequency of occurrence of negative hydraulic gradients is higher in the lower aquifer zone, but limited to the interval equivalent to the lower aquifer A2. Groundwater levels below sea level were also observed along the western margin of Mobile River in Mobile County. This can be explained by the presence of productive wells in cities such as Saraland, Satsuma, Creola, and others (plate 7-3).

Analyses of both potentiometric surfaces indicate the existence of inverse vertical gradients for most of the investigated area. This behavior may be the result of water production from lower horizons and/or the intermittent occurrence of confining layers that influence (for example, decrease) the pressure within the lower water-bearing units. Vertical hydraulic gradients can be estimated using hydraulic head data collected from two different wells located in close proximity to one another but screened at different depths. The hydraulic head value from the shallower well is subtracted from the value in the deeper well and the remaining is divided by the vertical distance between the midpoints of the screen. A negative gradient will indicate the existence of a downward flow component, meaning that the hydraulic head is less at depth. On the contrary, positive gradient values reflect upward flow components and a higher hydraulic head at depth.

DEPTH TO WATER

Water depth surfaces were constructed for both depth ranges-for example, upper aquifer zone (plate 7-8) and lower aquifer zone (plate 7-9). Depth to the water in the upper aquifers ranges between 3 ft bls in the coastal area of Baldwin County, to 162 ft bls, in southwestern Mobile County (Tillmans Corner) (plate 7-8). For the lower wate-bearing unit, below 200 ft, hydraulic heads are generally lower compared to the upper aquifer zone resulting in greater depths to water. The range of water depths in this sequence is between 3 ft bls, in coastal Baldwin County to 272 ft bls in northern Mobile County (Citronelle) (plate 7-9). Although the smallest distance to water (for example, 3 ft bls) is similar for the two researched aquifer intervals, it should be noted that for the lower part of the water-bearing sequence, greater depths to the water are more pervasive (plate 7-9). The greatest depths to water are generally associated with higher ground elevation and areas where the hydraulic pressure in the aquifer is not high enough for

water to rise at greater elevations (for example, Citronelle and other areas) (plate 7-9). Furthermore, greater depths to water are present in areas where increased or prolonged aquifer development resulted in lower aquifer pressures and consequently lower water levels (for example, Tillmans Corner, Bayou La Batre, and others) (plates 7-8, 7-9).

PUMPING RATES AND SPECIFIC CAPACITIES

Pumping rates, expressed in gpm, presented in this study are representative of a wide range of well types, from domestic and small irrigation to large irrigation, industrial, and public supply wells. Consequently, pumping rates distribution within the study area is based on need rather than on aquifer producing capability. Similar to the potentiometric surface and depth to water data, pumping rates and specific capacities were divided into two groups based on the screened interval elevation: wells developed in the top 220 (47 to 220) ft bls of the aquifer (90 wells) and wells developed at depths ranging from 200 to 935 ft bls (74 wells). These intervals are referred to as the upper and the lower aquifer zones, respectively. Maps representing interpolations of the pumping rates for the Mobile and Baldwin Counties area were developed for the two depth intervals (plates 7-10, 7-11). These maps are useful for the evaluation of aquifer producing capabilities but do not necessarily represent the actual capacity of the investigated aquifer. Pumping rates for the upper aquifer zone range from 6 to 1,800 gpm (fig. 7-2) with an average value of 439 gpm (plate 7-10). In the lower aquifer zone, pumping rates vary between 60 and 1,600 gpm (fig. 7-2) with an average value of 564 gpm for the entire research area (plate 7-11). Although the highest pumping rate occurs in the shallower depth interval (plate 7-10), it should be noted that only one value was greater than 1,200 gpm (for example, 1,800 gpm) (fig. 7-2). Furthermore, there is no correlation between pumping rates and depth but exhibit a random distribution (fig. 7-2). For both intervals the highest pumping rate occurs from wells in southern Baldwin County (plates 7-10, 7-11). These high values are an indication that the investigated aquifer system is capable of producing at least 1,800 gpm.

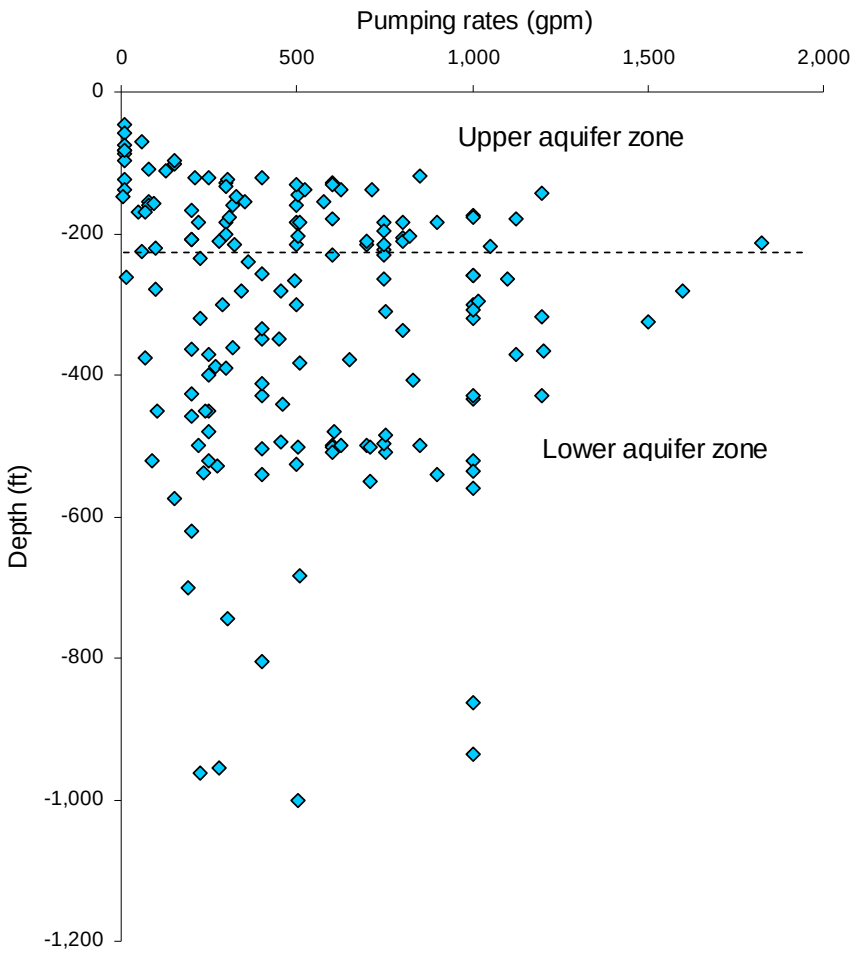

Figure 7-2--Pumping rate distribution with depth for the upper and lower aquifer zones.

Specific capacity, a measure of aquifer transmissivity (T), was estimated for the investigated area using drawdown (s) and yield (pumping rates (Q)) values obtained from 164 wells at the time of development. Initial specific capacity values (obtained just after a well is drilled) are considered to be the highest and the most precise ones and can be used as benchmarks for future evaluations (Driscoll, 1986). Driscoll (1986) provides two equations that can be used to estimate aquifer transmissivity using initial specific capacity values (for example, T=1,500*Q/s-for an unconfined aquifer and T-2,000*Q/s-for a confined aquifer).

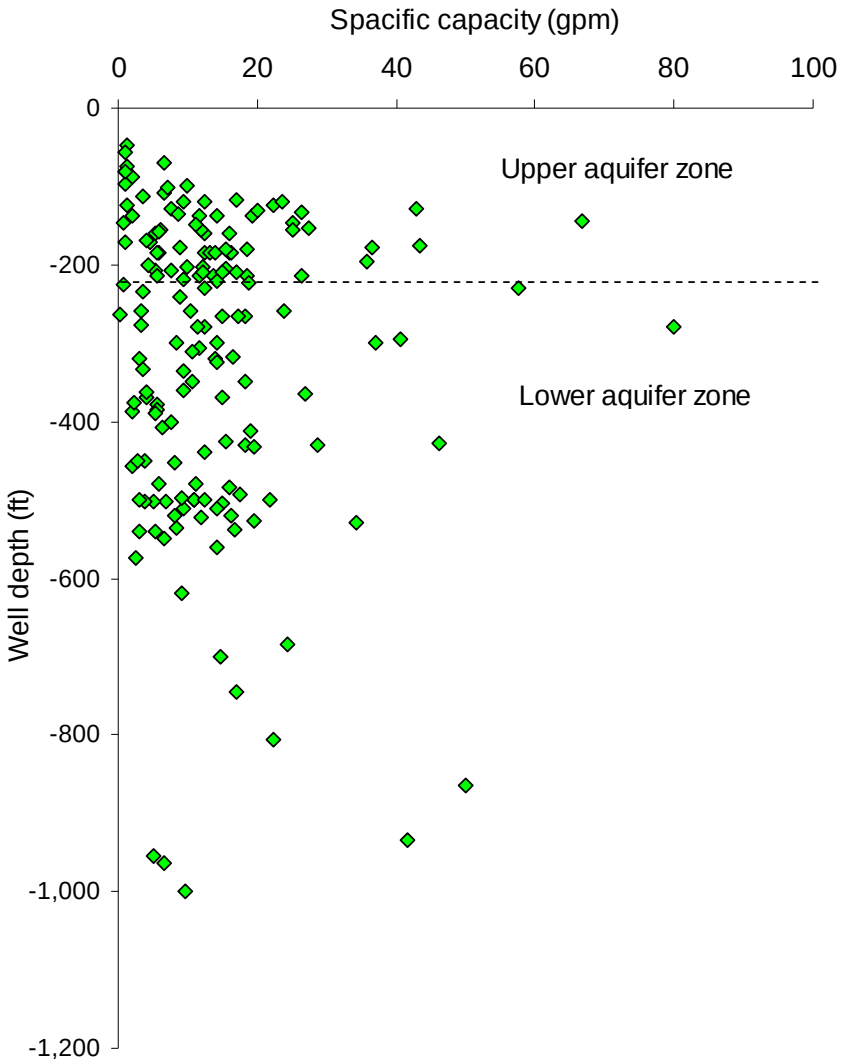

Figure 7-3--Specific capacity distribution with depth for the upper and lower aquifer zones.

As with the potentiometric surfaces, depth to water, and pumping rates, specific capacity data were divided accordingly for the two depth intervals. Specific capacity values were calculated using the aforementioned pumping rates and were interpolated to create isocontour maps for the two depth intervals (plates 7-12, 7-13). Specific capacities for wells developed in the upper aquifer zone ranged between 0.7 and 66.7 gpm/ft of drawdown with an average of 13.8 gpm/ft of drawdown (fig. 7-3, plate 7-12) whereas for those in the lower aquifer zone, specific capacity values ranged between 0.2 to 80.0 gpm/ft of drawdown with an average of 13.8 gpm/ft of drawdown (fig. 7-3, plate 7-13).

Generally, drawdown responses are not only a function of pumping rates but also of the pumping time. Therefore, inaccurate pumping tests may result in supraestimated aquifer specific capacities. Generally, the highest specific capacities calculated for this study are associated with medium pumping times (fig. 7-4).

Within the investigated aquifer system, pumping rates and corresponding specific capacities do not exhibit preferential distribution with depth. On the contrary, the upper aquifer zone seems to be able to accommodate large quantities of water with similar drawdown responses as the lower aquifer zone (figs. 7-2, 7-3). This suggests that for the investigated depth range, aquifers have similar capacities. Interpretation of these data does not include those areas where well information is deficient (for example northeast Baldwin County). Therefore, these data may be carefully extrapolated horizontally since aquifer hydrogeologic characteristics may vary from one area to another.

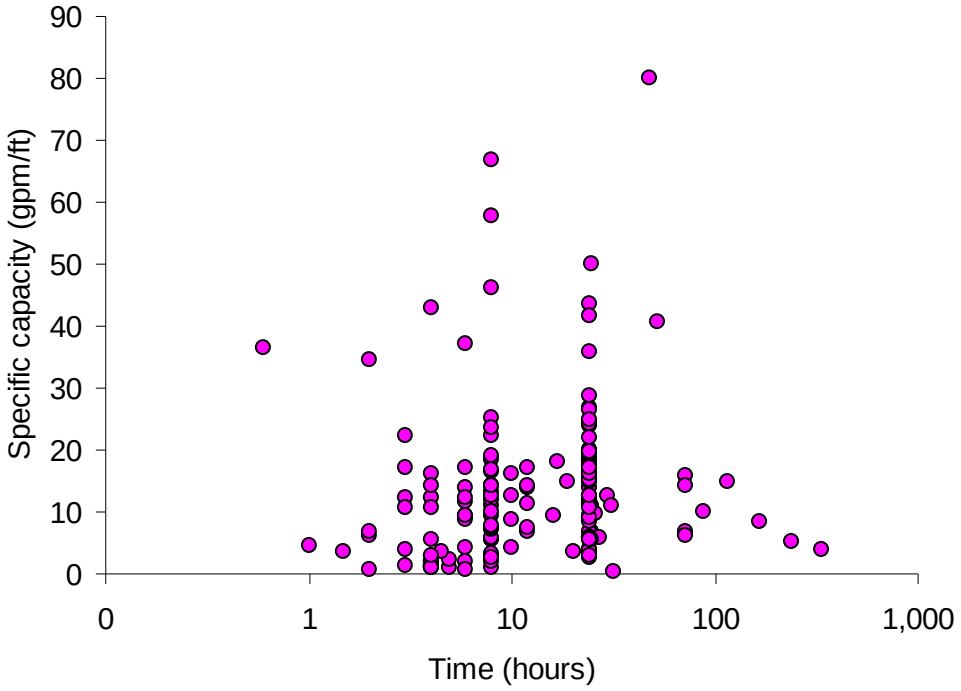

Figure 7-4--Specific capacity variation with pumping time for the upper and lower aquifer zones.

SOURCE WATER ASSESSMENT AREAS AND PUBLIC SUPPLY WELLS

Groundwater is the sole source of freshwater in Baldwin County and for most of Mobile County. Growing population, tourism, and industry is dependent upon the quality and quantity of the water resources. Protection of source waters from potential contamination is of extreme importance and should be accounted for when groundwater is used for drinking purposes. Furthermore, when assessing areas that may provide sustainable quantities of water for large-scale irrigation, SWAA developed for public supply wells should be considered. Public supply wells accompany the most developed areas in the southern half of Baldwin County and for most of Mobile County, with the highest intensity of occurrence along the western flank of the Mobile River and in the southeastern part of the county (plate 7-3). Most of the public supply wells are accompanied by a designated source water zone that enforces the protection of recharge areas (plate 7-3). This measure is intended not only to protect against groundwater contamination but also aquifer overdevelopment and resulting diminished water availability. The largest source water zones occur in Gulf Shores, Orange Beach, and the entirety of Dauphin Island. However, relatively few protection zones are located within the study area (plate 7-3).

GROUNDWATER USE AND QUALITY

Baldwin and Mobile Counties have abundant groundwater resources used for irrigation, industry, public supply, and others. In Baldwin County, groundwater is the main source of freshwater. As a result, groundwater withdrawals in Baldwin County account for 61.7 mgd or 89.4% of the total freshwater withdrawals (Hutson and others, 2009). Approximately 7.3 mgd or 10.6% are withdrawn from surface-water sources and used for irrigation purposes. Of the total groundwater withdrawal, approximately 60% (36.8 mgd) is used for irrigation purposes (84% of the total irrigation water use), 35% (21.6 mgd) is used for public supply (100% of the total public supply water use), and 4% (2.5 mgd) for residential uses (100% of the total residential water use) (Hutson and others, 2009) (fig. 7-5). The remaining 1% (0.8 mgd) is used for mining and livestock production (Hutson and others, 2009). Surface-water withdrawals in Mobile County exceed those of groundwater by 98.2% (1,110.2 mgd) (fig. 7-6). Groundwater withdrawals account for 1.8% (20.77 mgd) of the total freshwater withdrawal of 1,130.9

mgd (Hutson and others, 2009). The largest groundwater use in this area is for public supply (11.4 mgd or 15% of the total water used as public supply), followed by industry (5.67 mgd or 100% of total water used for industrial purposes) and residential (3.01 mgd or 100% of the total water used for residential purposes) (Hutson and others, 2009).

Groundwater for public supply use in Baldwin County increased from years 2000 to 2005 with 1.89 mgd whereas that for industrial use decreased with approximately 0.79 mgd (Hutson and others, 2009). Furthermore, total irrigated acreage increased with 6,860 acres in Baldwin County which resulted in an increase in water withdrawal of 37.84 mgd (USGS, 2004). There was no change recorded in groundwater withdrawal for industrial and public supply use in Mobile County (Hutson and others, 2009).

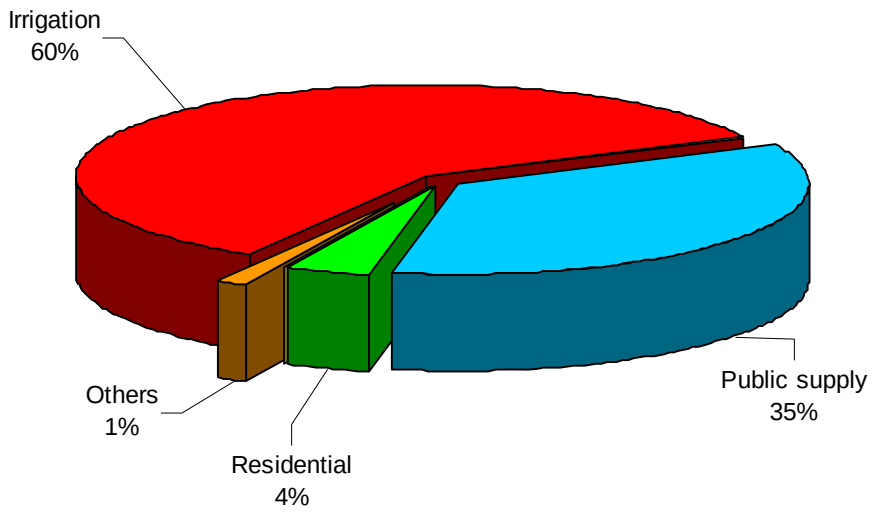

Figure 7-5.--Groundwater withdrawal (%) in Baldwin County by water-use classification.

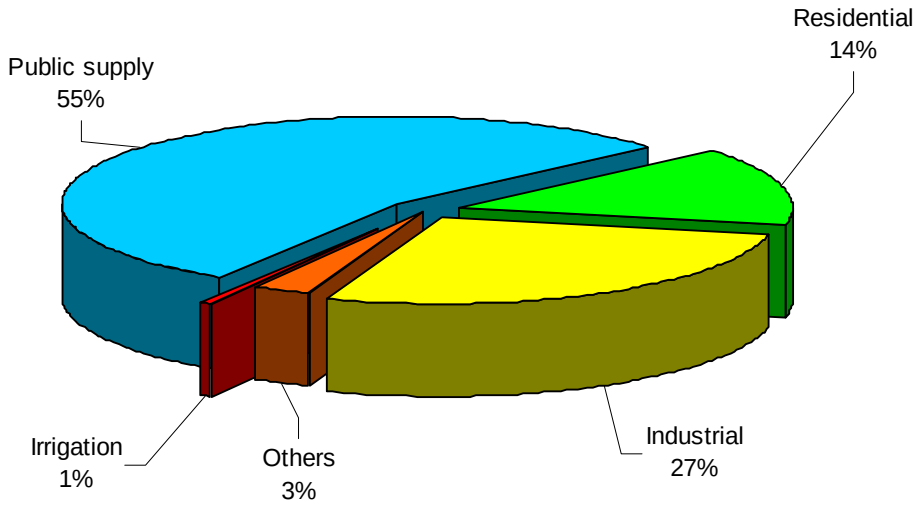

Figure 7-6.--Groundwater withdrawal (%) in Mobile County by water-use classification

Groundwater resources in Baldwin and Mobile Counties are supplied from the Miocene-Pliocene and Watercourse aquifers. Generally, groundwater in these two aquifers is soft to moderately hard with low TDS contents and is suitable for most purposes. Exceptions are those areas experiencing saltwater contamination/intrusion such as the coastal area of Baldwin County (Murgulet and Tick, 2007) and the eastern side of Mobile Bay as well as areas adjacent to the Mobile River Basin and Mississippi Sound (Reed and McCain, 1971). Objectionable amounts of iron are present locally throughout the investigated area. Groundwater with TDS concentrations of 1,000 milligram per liter (mg/L) was encountered in the past at depths ranging from 200 ft bls (in Dauphin Island, costal Baldwin County, and the Mobile River floodplain) to 1,000 ft bls (in west Mobile County) (Moser and Chermock, 1978).

The depth of water containing less than 1,000 mg/L TDS is less than 1,000 ft bls in Baldwin County with most of the area ranging between 200 and 600 ft bls (Moser and Chermock, 1978). Additional supply of water originating from the coastal sediments of Dauphin Island and Fort Morgan Peninsula (reported by Moser and Chermock, 1978) are altered due to increased salinity and Cl levels. Concentrations of Cl in the shallow upper sands can be expected to vary significantly as rainfall flushes out the salty water,

especially during overwash from storm surges. Plate 7-14 displays areas where Cl concentrations exceed 50 mg/L and the depth to groundwater with TDS greater than 1,000 mg/L. As observed in this map, the aquifer system ranging to a depth of approximately 220 ft is affected by seawater intrusion in much of coastal Baldwin County and in a small area in eastern Mobile County near Theodore (plate 7-14). This is revealed by the presence of increased Cl (higher than 50 mg/L), salinity, conductivity, and TDS concentrations in samples from selected wells constructed in this area (Murgulet and Tick, 2007). The severity and extent of Cl contamination seems to be affected by increased drought conditions and aquifer overdevelopment (Murgulet and Tick, 2007).

Dauphin Island's hydrologic settings are unique in the state, as it is surrounded by salty to brackish water from the Gulf of Mexico and the Mississippi Sound. The primary source of groundwater on the island is the freshwater lens which "floats" on top of the more dense saline water in the Watercourse aquifer. The quality of this groundwater is subject to degradation due to saltwater infiltration caused by storm tides and surges. The deeper sands underlying the watercourse aquifer also tend to be high in salt. The presence of saline water, or high Cl levels, was identified at shallow depths from surface to 30 ft bls (630 mg/L Cl) and in the deeper sand between 260 and 350 ft bls (320 mg/L Cl) (Gillett and others, 2000).

Protection of fresh groundwater from seawater encroachment is a real concern for coastal communities in this area due to water demand impacts associated with increasing population, development, local industries, and tourism. For instance, in Baldwin County, as a result of increasing population, tourism, and development, groundwater pumping increased from 7.1 mgd to 4.2 mgd between 1966 and 1995 (Reed and McCain, 1971; Robinson and others, 1996). In addition, predictions of increasing sea level and increased frequency and intensity of tropical storms and hurricanes in the region may exacerbate the saltwater encroachment problem in the future. In recent years, Baldwin County has experienced some of the most rapid growth in public and private sectors, ranking third among all Alabama counties. As a result, groundwater and surface-water quality was degraded due to increased agriculture and urban and residential expansion. Nitrate contamination has been observed in some aquifers in Baldwin County (Murgulet and Tick, 2008) where concentrations, in samples collected from selected private and

irrigation wells, exceed regulatory drinking water standards (10 mg/L NO_3^--N) (Murgulet and Tick, 2008). Fertilizers used in agricultural and residential applications and septic systems are primary sources that contribute to nutrient contamination of groundwater and surface water in the region. In addition to concerns for human health, groundwater discharge and surface runoff with elevated nitrate concentrations may adversely affect the ecological health of coastal streams, wetlands, embayments, and estuaries.

ECONOMICS AFFECTING POTENTIAL AGRICULTURAL IRRIGATION IN BALDWIN AND MOBILE COUNTIES

Aquifers in this area are developed mainly for irrigation, public and industrial supply and residential use. Most of the public supply and large irrigation wells produce water from the Miocene-Pliocene aquifer and relatively few from the Watercourse, alluvial aquifer. In the alluvial aquifer wells are constructed as deep as 135 ft bls whereas wells in the Miocene-Pliocene aquifer are constructed to depths of 1,000 ft, with most wells around 500 ft bls. Previous studies conducted in southern Baldwin County indicate that contaminants such as nitrate can be present as deep as 380 ft bls (Murgulet and Tick, 2008). Therefore, for large-scale irrigation in Baldwin and Mobile Counties to have the least impact on groundwater quantity, wells should be developed in deeper, undeveloped aquifers.

Aquifer withdrawals should be restricted to meet the safe groundwater yield. Wells can be developed to the depths above wich salinity concentrations do not exceed limits established for specific crops (for example, 200 to 1,000 ft bls). Water with excessive concentrations of Cl is unacceptable for human consumption or agriculture. The maximum contaminant level (MCL) for Cl is 250 mg/L (U.S. Environmental Protection Agency, 2009).

The MSUES (2009) has established salinity guidelines for water used for irrigation. Crop tolerance levels in these guidelines are based on water conductivity and indicate that cotton is one of the most salinity tolerant row crops, Bermuda grass is the most tolerant grass, and beets, kale, asparagus, and spinach are the most tolerant garden crops. Corn, wheat, and soybeans have medium tolerance, and peanuts have low tolerance. The MSUES has also established guidelines for the hazard to crops related to Cl concentrations in irrigation water. For root absorption, 0 to 142 mg/L is a low hazard,

143 to 355 mg/L is a medium hazard, and 356 mg/L and above is a high hazard to crop production. For foliar absorption, 0 to 106 mg/L is a low hazard, 107 and above is a medium hazard. No data are available for a high hazard. Therefore, if we account for processes such as dispersion and diffusion, a minimum interval depth should be attributed to the seawater-freshwater mixing zone at the base of the aquifer system. Furthermore, overdevelopment of aquifers underlined by water with high TDS or salinity usually results in upconing of these waters to shallower zones increasing the contamination risk. Therefore, potential safe aquifer development for large-scale irrigation may be at an average depth of approximately 700 ft bls in west Mobile County but limited to approximately 500 ft bls in Baldwin County.

For groundwater irrigation to be successful in this area, two factors should be analyzed: groundwater resources (for example safe yield and contamination) and economics. As previously mentioned, the potential for contamination from surface sources (for example nutrients and pesticides) or aquifer overdevelopment can become a potential problem in these extremely sensitive coastal areas. Furthermore, the expense of irrigation should not prevail over the benefits derived from irrigation for the farmer. The major costs involved with development of groundwater for irrigation are drilling and equipping water supply wells and constructing the delivery system that applies water to crops. Costs for drilling and equipping wells capable of supplying adequate quantities of water for large-scale irrigation are based on well depth and diameter, casing, screen, pump specifications, and distance from the irrigation field or irrigation pond. Costs for irrigation well construction for this project were supplied by Griner Drilling Service, Inc., from information supplied by GSA.

Specifications for a typical irrigation well and for wells that supply water to irrigation ponds in the Mobile and Baldwin Counties groundwater irrigation assessment area are based on a borehole depth of 500 ft: 450 ft of 10.75-inch diameter casing and 50 ft of 10-inch 304 diameter stainless steel screen with 0.012 to 0.016-inch openings. A typical well will be equipped with a Grundfos 300S250-7 pump with a 25-horsepower (H.P.) submersible motor set at a depth of about 200 ft bls, capable of delivering 300 gpm at 250 ft total dynamic head with a pumping level of 160 ft bls.

Driller's note: "These proposed wells will be one continuous string with the stainless steel well screen welded to the carbon steel casing. The casing string will be welded in place. Only the top 50 ft of the casing will be grouted. Well will be pump tested only to determine specific yield and as required for pump sizing. No water quality analysis is included in this estimate. Many rural commercial power suppliers will require reduced voltage soft starting for motors over 30 H.P. No electrical work (except pump motor) is included in this estimate. If the well pump is pumping into an irrigation pond the horse power demand may be lower. This estimate assumes that drilling make up water is available within 2 miles and that all excess drilling fluid and cutting can be disposed of on site".

Total estimated cost based on these conditions would range from $125,000 to $150,000.

SUMMARY OF FINDINGS

Irrigation using groundwater resources is more reliable, less vulnerable to droughts, and is more accessible for individual users compared to surface-water irrigation systems. The groundwater irrigation assessment area in coastal Alabama includes Baldwin and Mobile Counties where large quantities of water are available. In Mobile County a large part of the freshwater supply comes from surface-water sources whereas for most of Baldwin County, groundwater is the sole source of freshwater. Groundwater suitable for most uses is available in most of the study area from both Miocene-Pliocene and alluvial aquifers. Exceptions are those areas impacted by seawater contamination/intrusion and those areas where groundwater is more acidic or exhibits high iron concentrations.

Most of the investigated area is underlain by soils with high vertical conductivity and drainage capacities that promote infiltration of precipitation for aquifer recharge. The exceptions to this are areas adjacent to Mobile River, Mobile Bay, and Mississippi Sound where the aforementioned parameters exhibit low values. Consequently, unconfined/semiconfined aquifers are considered to be highly susceptible to contamination from surface infiltration (for example, nutrients). Slopes are relatively gentle especially for the southern parts of the assessment area. The physiographic and geologic features in this area create an environment that favors fast aquifer recharge and

sustainable agricultural practices. Agricultural land use makes up approximately 16.8% in both counties with the largest area concentrated in the southern half of both Mobile and Baldwin Counties. Agricultural land use in Baldwin County exceeds that of Mobile County by 171.6 mi^2 whereas developed land areas in Mobile County exceed Mobile County by 71.6 mi^2.

Concern over agricultural diffuse pollution sources that affect groundwater quality has been growing recently. Unless developed on highly organic rich and fertile soils, application of fertilizers to farmland fields is necessary at high rates which increases the potential for groundwater pollution and renders the freshwater resource available for public supply use. Furthermore, aquifer overdevelopment in areas such as coastal Alabama are the cause of induced reverse hydraulic gradients that result in the migration of the seawater wedge into freshwater aquifers (for example, seawater intrusion). Nevertheless, poor management can be the cause of unwanted effects, including groundwater quality degradation and other ecological impacts. These matters can have extreme impacts on water resources for public use and may be overlooked by water decision-makers and the general public. Therefore, in these highly sensitive coastal areas, priority groundwater protection areas should be delineated and should include at a minimum areas affected by or susceptible to seawater intrusion, areas where groundwater exhibits high nitrate (or any other contaminant) concentrations, and areas with depressed water table or potentiometric elevations (cones of depression).

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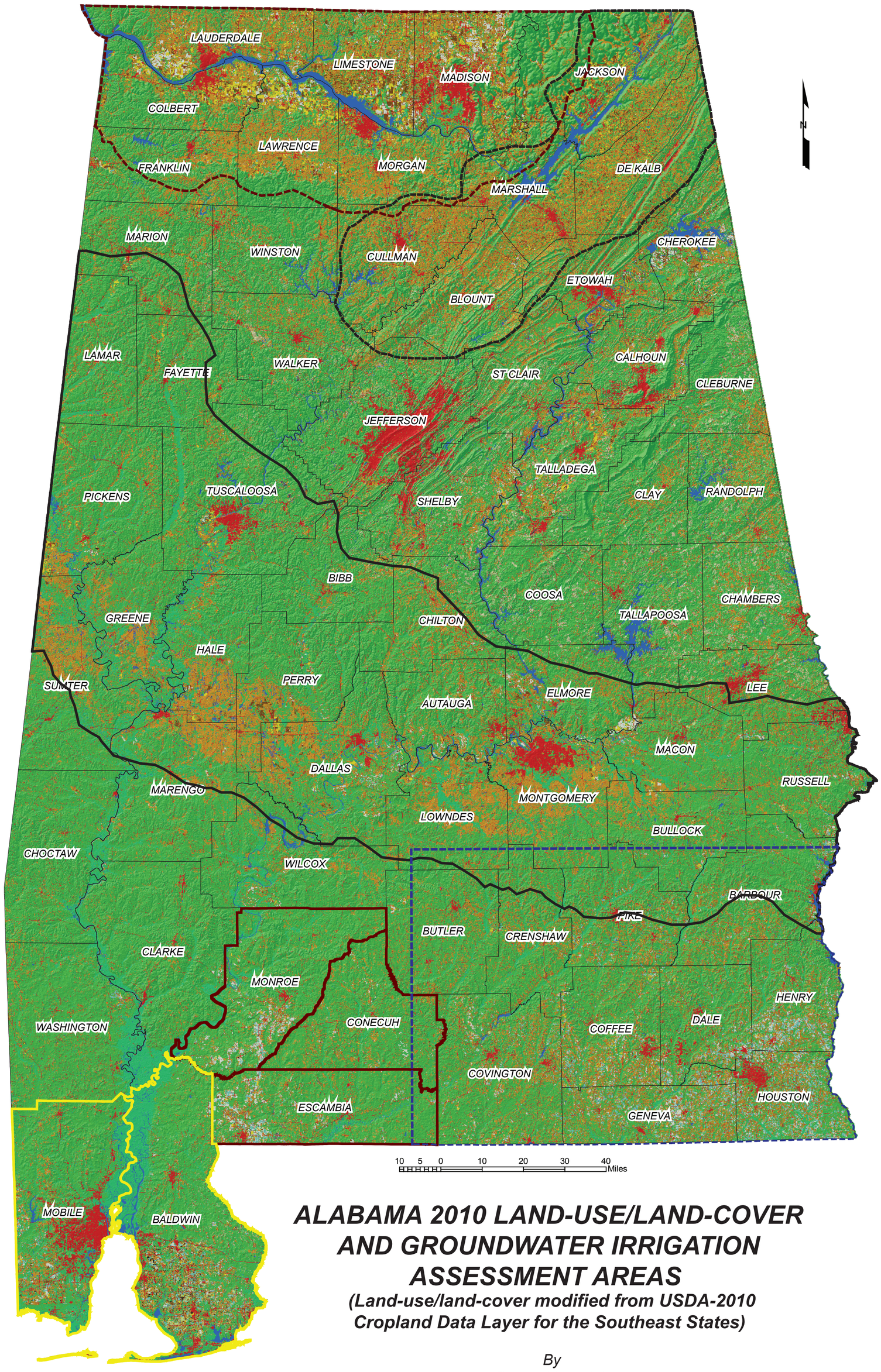

Explanation

Land-Use/Land-Cover

- Corn
- Cotton
- Soybeans
- Peanuts
- Other Crops
- Seed/Sod Grass
- Pasture/Hay
- Pecans
- Open Water
- Developed
- Barren
- Forest
- Grassland Herbaceous
- Wetlands

Groundwater irrigation assessment areas

- Tennessee River Valley
- Sand Mountain
- Black Belt
- Southeast Alabama
- South-Central Alabama
- Southwest Alabama

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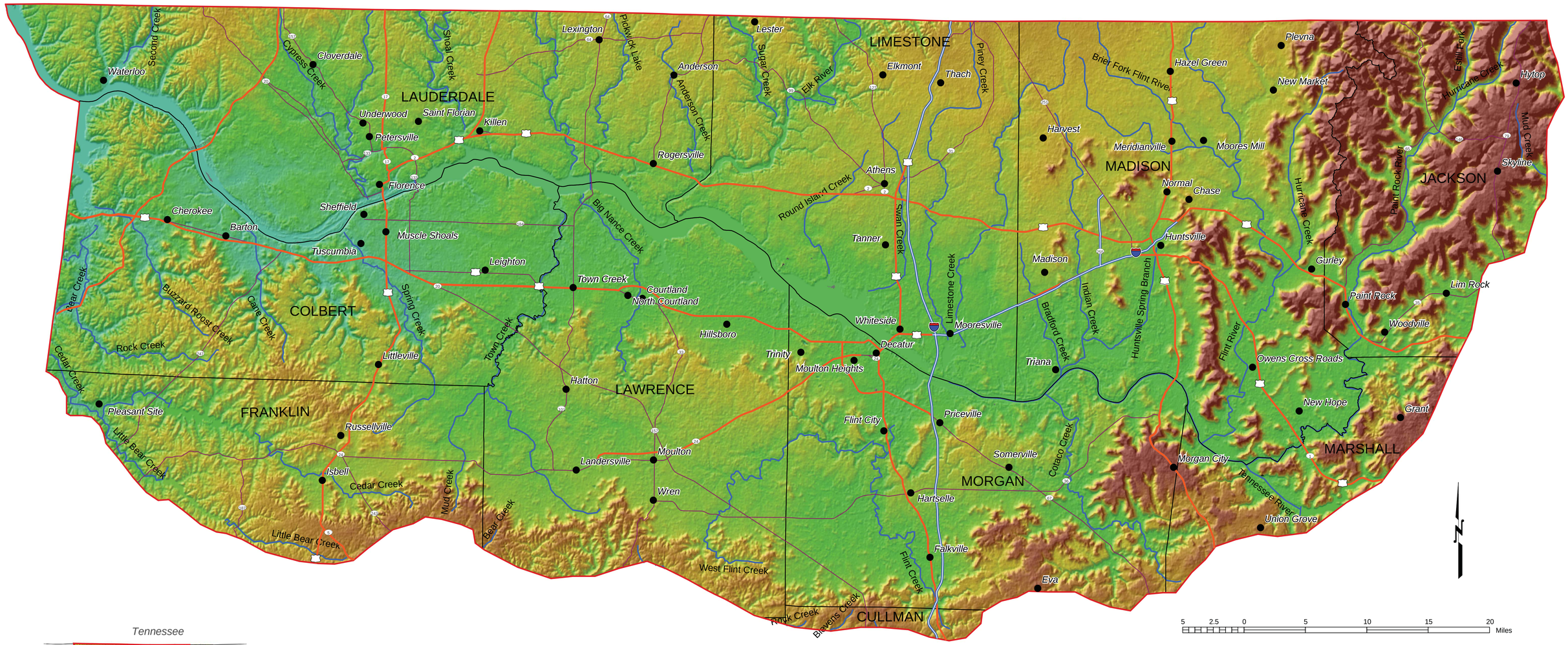
Founded 1848

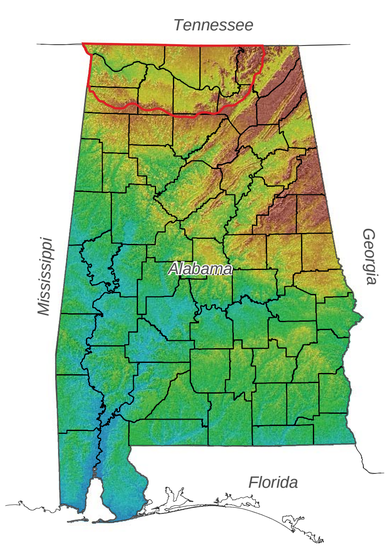
Berry H. (Nick) Tew, Jr.
State Geologist

ALABAMA 2010 LAND-USE/LAND-COVER AND GROUNDWATER IRRIGATION ASSESSMENT AREAS

(Land-use/land-cover modified from USDA-2010 Cropland Data Layer for the Southeast States)

By
Dorina Murgulet
2011





Explanation

Elevation in feet above NGVD 1929
High : 1,880
Low : 414

City

Tennessee River Valley groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

Interstate highway

United States highway

State highway

Location Map and Topography of the Tennessee River Valley Groundwater Irrigation Assessment Area

By
Stephen P. Jennings

2011

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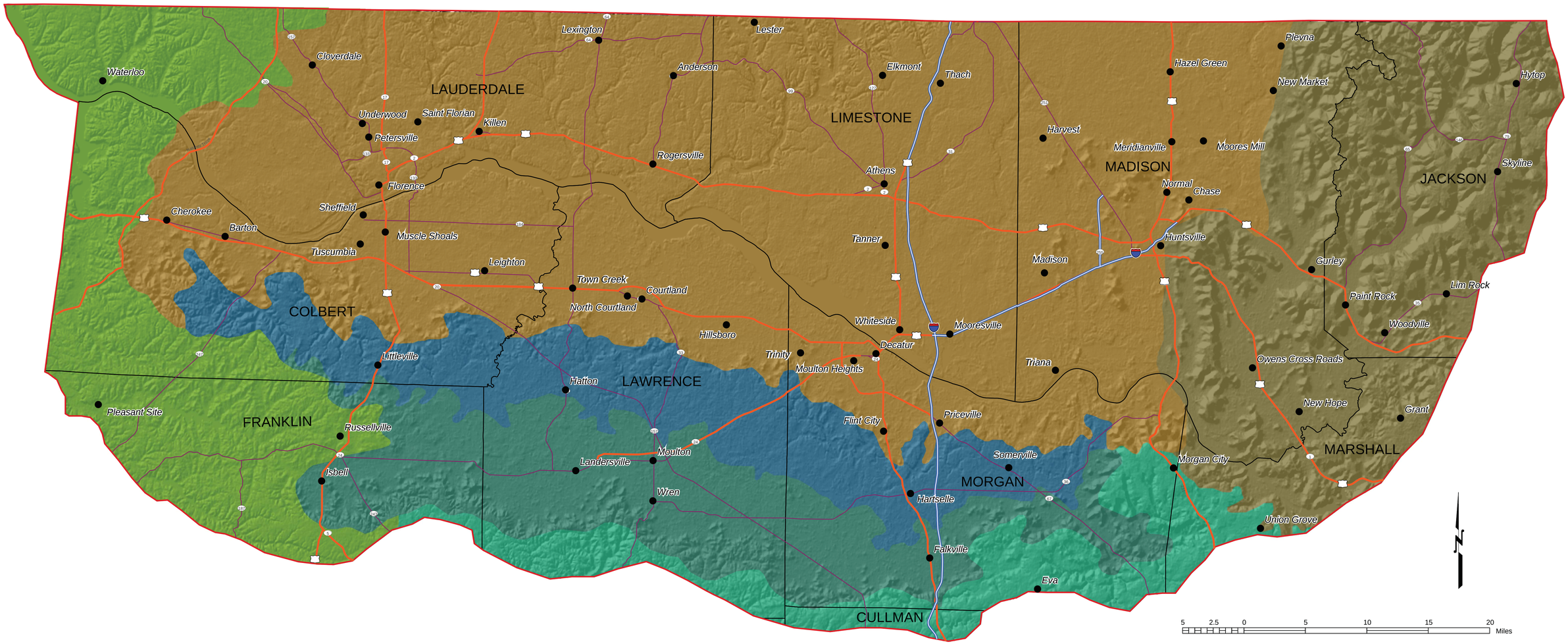

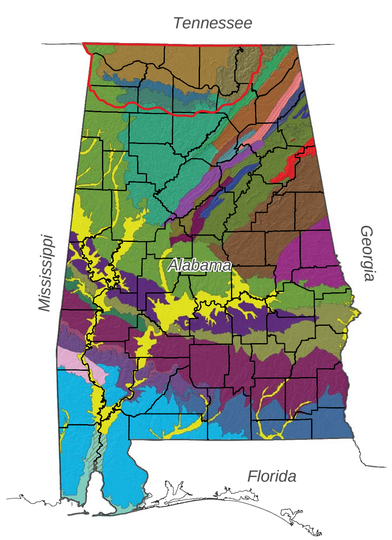

Explanation

- Fall Line Hills
- Tennessee Valley
- Little Mountain
- Moulton Valley
- Warrior Basin
- Jackson County Mountains
- Tennessee River Valley groundwater irrigation assessment area
- County boundary
- City

Physiographic Regions of the Tennessee River Valley Groundwater Irrigation Assessment Area

(modified from Sapp and Emplaincourt, 1975)

By
Stephen P. Jennings

2010

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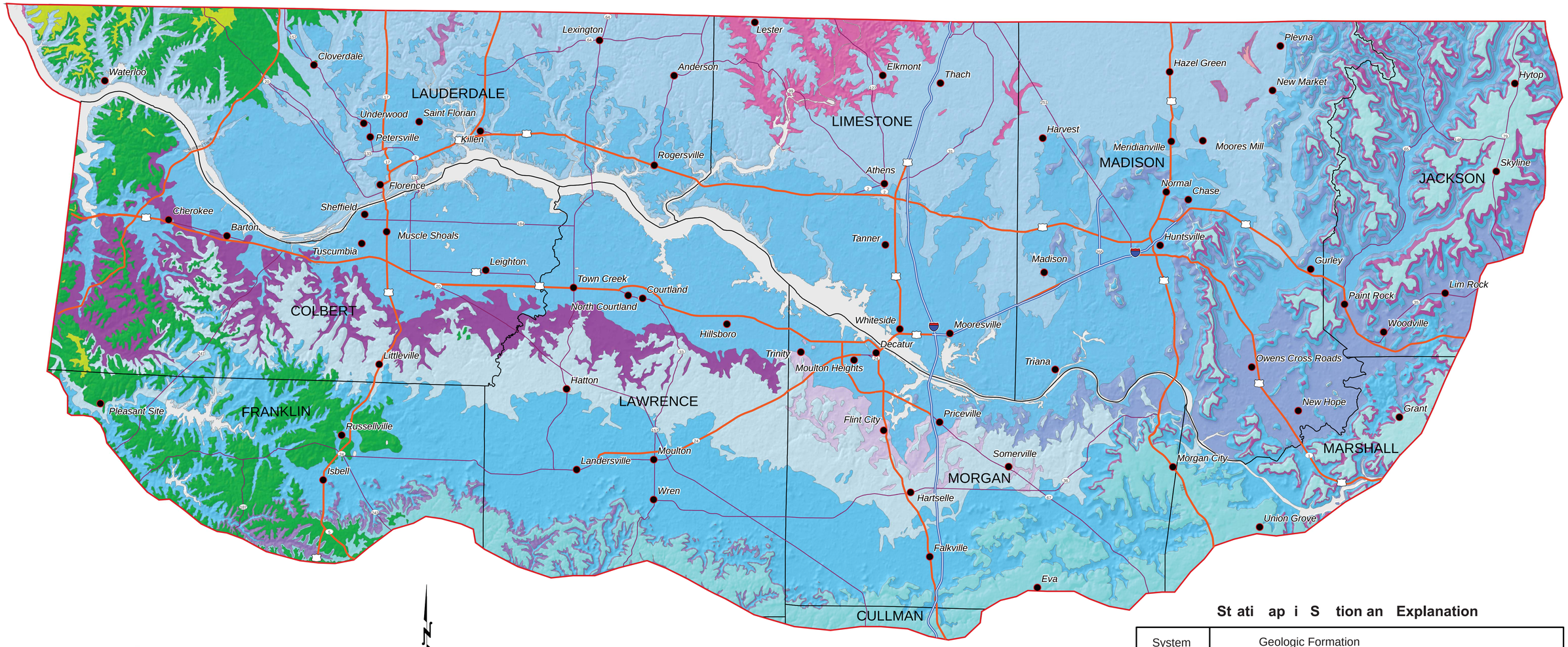

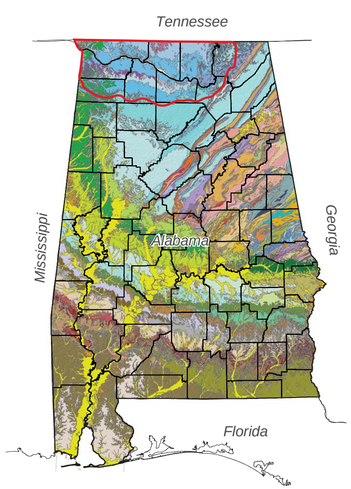

5 2.5 0 5 10 15 20 Miles

Explanation

- Tennessee River Valley groundwater irrigation assessment area
- County boundary
- City
- Water

Geologic Map of the Tennessee River Valley Groundwater Irrigation Assessment Area

(modified from Geological Survey of Alabama, 2006)

By
Stephen P. Jennings
2011

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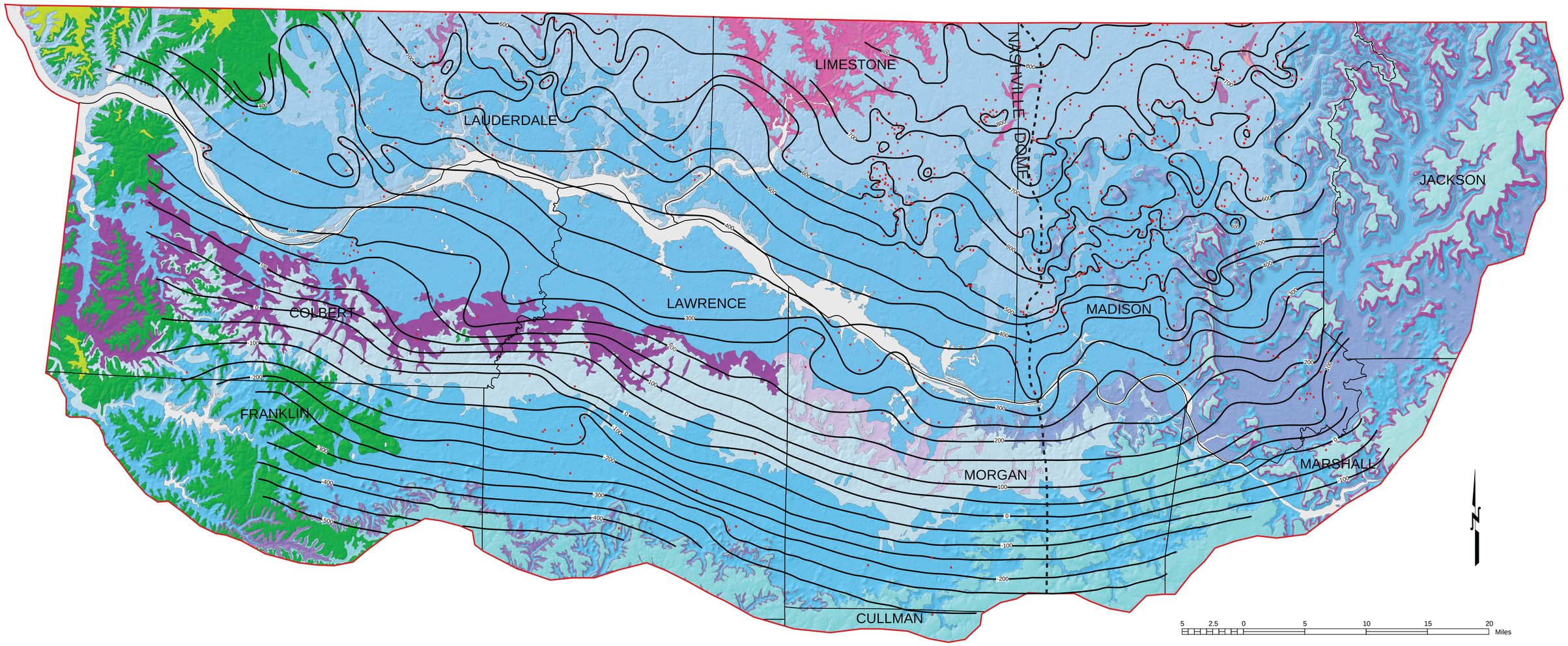
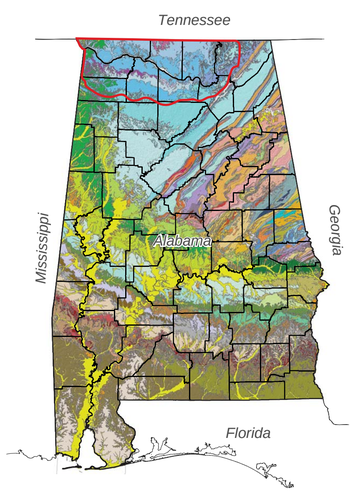
St ati ap i S tion an Explanation

System	Geologic Formation
Cretaceous	Eutaw Formation
	Gordo Formation
Pennsylvanian	Pottsville Formation
	Pottsville Formation (lower part)
	Parkwood Formation
Mississippian	Pennington Formation
	Bangor Limestone
	Hartselle Sandstone
	Monteagle Limestone
	Pride Mountain Formation
	Pride Mountain Formation and Monteagle Limestone undifferentiated
	Tuscumbia Limestone
	Fort Payne Chert (includes Maury Formation)
Devonian	Chattanooga Shale
Silurian	Silurian System undifferentiated
Ordovician	Sequatchie Formation
	Ordovician System undifferentiated





Explanation

- Eutaw Formation
- Gordo Formation
- Pottsville Formation
- Pottsville Formation (lower part)
- Parkwood Formation
- Pennington Formation
- Bangor Limestone
- Hartselle Sandstone
- Monteagle Limestone
- Pride Mountain Formation
- Pride Mountain Formation and Monteagle Limestone undifferentiated
- Tuscumbia Limestone
- Fort Payne Chert
- Chattanooga Shale
- Silurian System undifferentiated
- Sequatchie Formation
- Ordovician System undifferentiated
- Water
- Tennessee River Valley groundwater irrigation assessment area
- County boundary
- Well or test hole
- Contour of top of Chattanooga Shale (contour interval 50 feet; datum mean sea level)
- Axis of Nashville Dome

Structure Map of the Top of Chattanooga Shale in the Tennessee River Valley Groundwater Irrigation Assessment Area

(geologic map modified from Geological Survey of Alabama, 2006)

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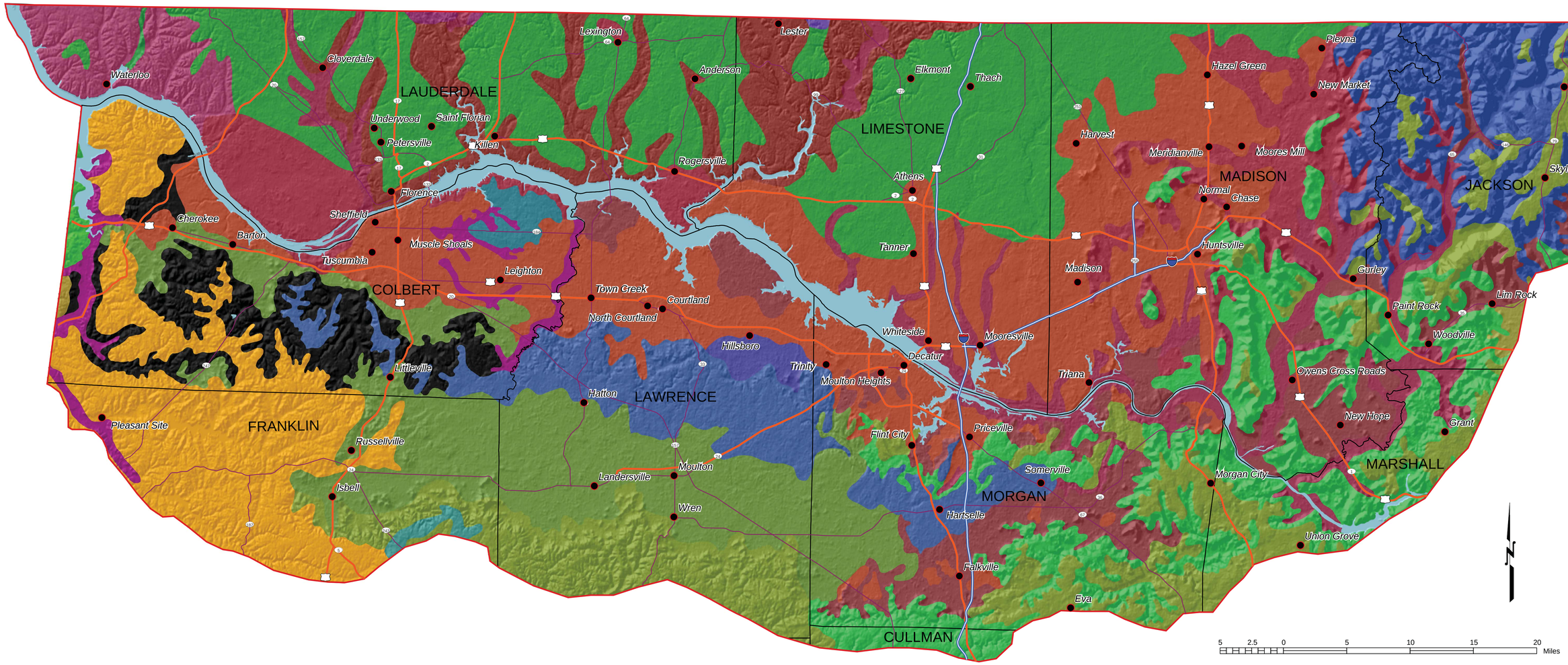

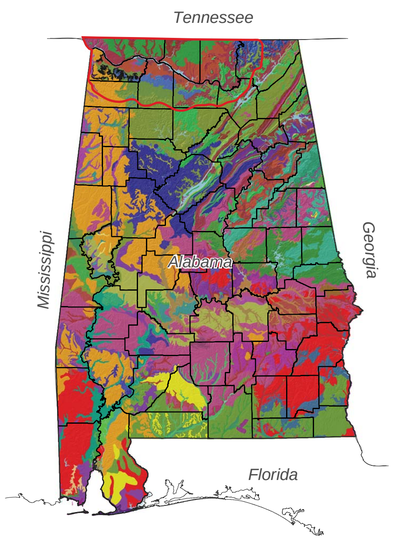

Explanation

Alfisols
- Fine-silty, Mixed, Active, Thermic Aquic Fragiudalfs
- Very-fine, Smectitic, Thermic Vertic Hapludalfs
- Fine-silty, Mixed, Active, Thermic Ultic Hapludalfs
- Fine, Smectitic, Thermic Vertic Hapludalfs
- Typic Hapludalfs, Fine, Mixed, Thermic

Entisols
- Coarse-loamy, Siliceous, Active, Thermic Typic Fluvaquents

Inceptisols
- Fluventic Dystrochrepts, Fine-loamy, Siliceous, Thermic
- Fine-silty, Mixed, Active, Thermic Fluvaquentic Dystrudepts

Ultisols
- Loamy-skeletal, Siliceous, Semiactive, Thermic Typic Hapludults
- Glossic Fragiudults, Fine-silty, Siliceous, Thermic
- Typic Paleudults, Clayey, Kaolinitic, Thermic
- Loamy-skeletal, Siliceous, Semiactive, Thermic Typic Paleudults
- Fine-silty, Mixed, Semiactive, Thermic Typic Hapludults
- Fine-loamy, Siliceous, Subactive, Thermic Typic Hapludults
- Rhodic Paleudults, Clayey, Kaolinitic, Thermic
- Fine-loamy, Siliceous, Semiactive, Thermic Typic Hapludults
- Fine-loamy, Siliceous, Subactive, Thermic Glossic Fragiudults
- Fine-loamy, Siliceous, Semiactive, Thermic Typic Fragiudults
- Typic Paleudults, Fine-loamy, Siliceous, Thermic
- Fine-silty, Siliceous, Semiactive, Thermic Glossaquic Fragiudults
- Humic Hapludults, Fine-loamy, Mixed, Thermic
- Fine-silty, Siliceous, Semiactive, Thermic Typic Paleudults
- Fine-loamy, Siliceous, Semiactive, Thermic Typic Paleudults
- Water
- Tennessee River Valley groundwater irrigation assessment area
- County Boundary
- City

Soil Order and Taxonomic Classification for the Tennessee River Valley Groundwater Irrigation Assessment Area

(modified from USDA-NRCS, Web Soil Survey, 2009)

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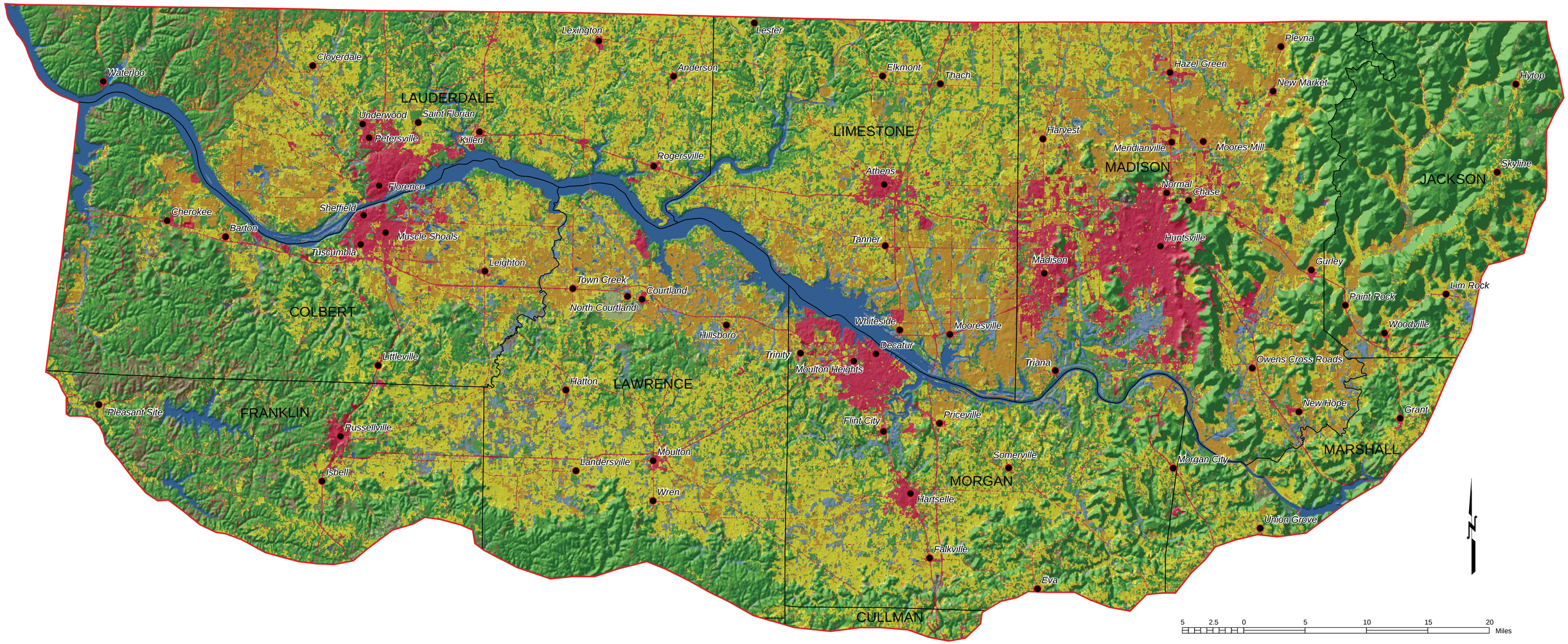

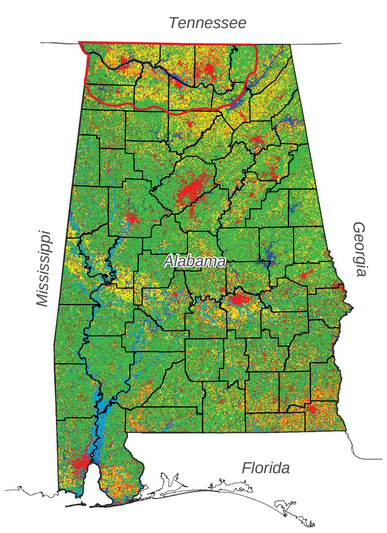

Explanation

LULC classification

- Water
- Developed
- Barren
- Vegetated; natural forested upland
- Herbaceous upland natural/seminatural (grassland/herbaceous)
- Herbaceous planted/cultivated (pasture/hay)
- Herbaceous planted/cultivated (cultivated crops)
- Wetlands
- Vegetated natural shrubland

Other symbols

- Tennessee River Valley groundwater irrigation assessment area
- County boundary
- City

Land-Use/Land-Cover Classification for the Tennessee River Valley Groundwater Irrigation Assessment Area

(modified from USDA-NRCS - Cropland Data for Southeast States, 2010)

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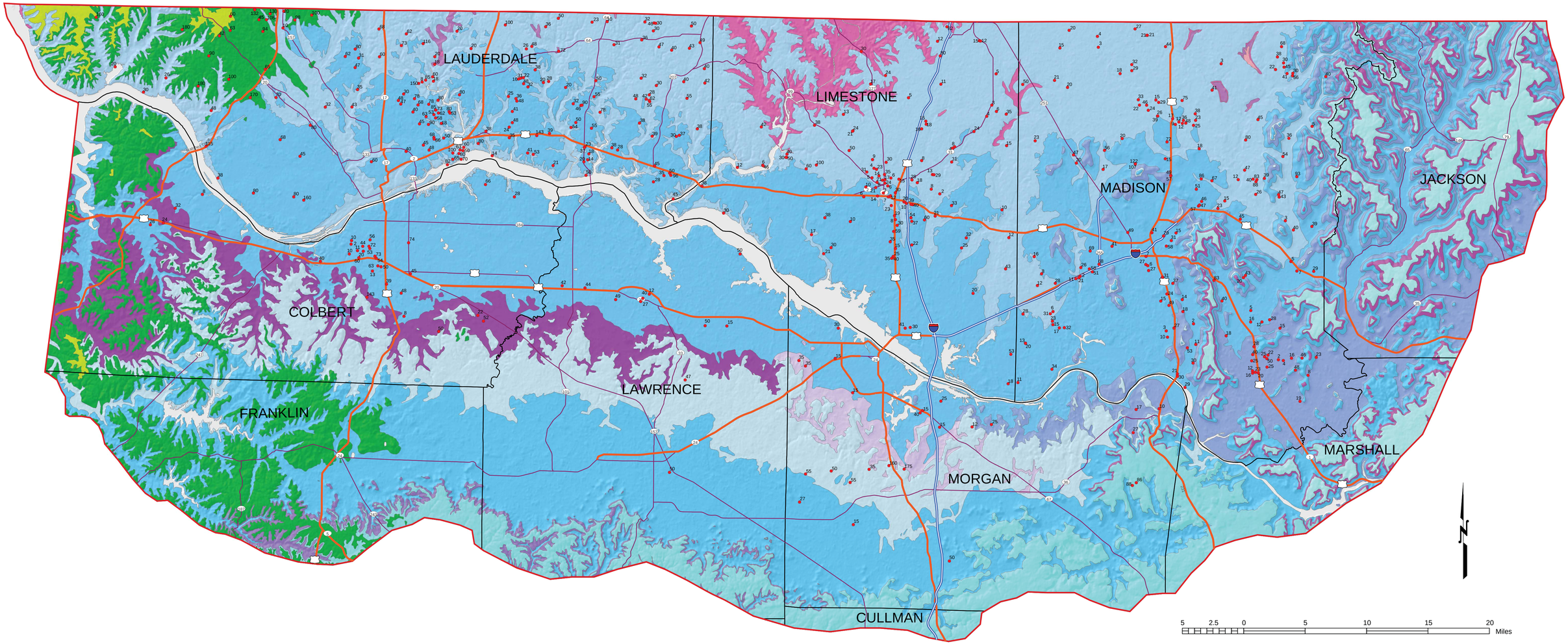

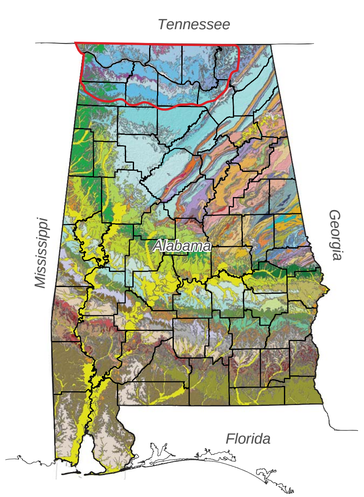

Explanation

- Eutaw Formation
- Gordo Formation
- Pottsville Formation
- Pottsville Formation (lower part)
- Parkwood Formation
- Pennington Formation
- Bangor Limestone
- Hartselle Sandstone
- Monteagle Limestone
- Pride Mountain Formation
- Pride Mountain Formation and Monteagle Limestone undifferentiated
- Tuscumbia Limestone
- Fort Payne Chert
- Chattanooga Shale
- Silurian System undifferentiated
- Sequatchie Formation
- Ordovician System undifferentiated
- Water
- Tennessee River Valley groundwater irrigation assessment area
- County boundary
- Wells with static water level, in feet below land surface (all measurements shown to nearest foot)

Depth to Water in Selected Wells in the Tennessee River Valley Groundwater Irrigation Assessment Area

(geologic map modified from Geological Survey of Alabama, 2006)

By
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2011

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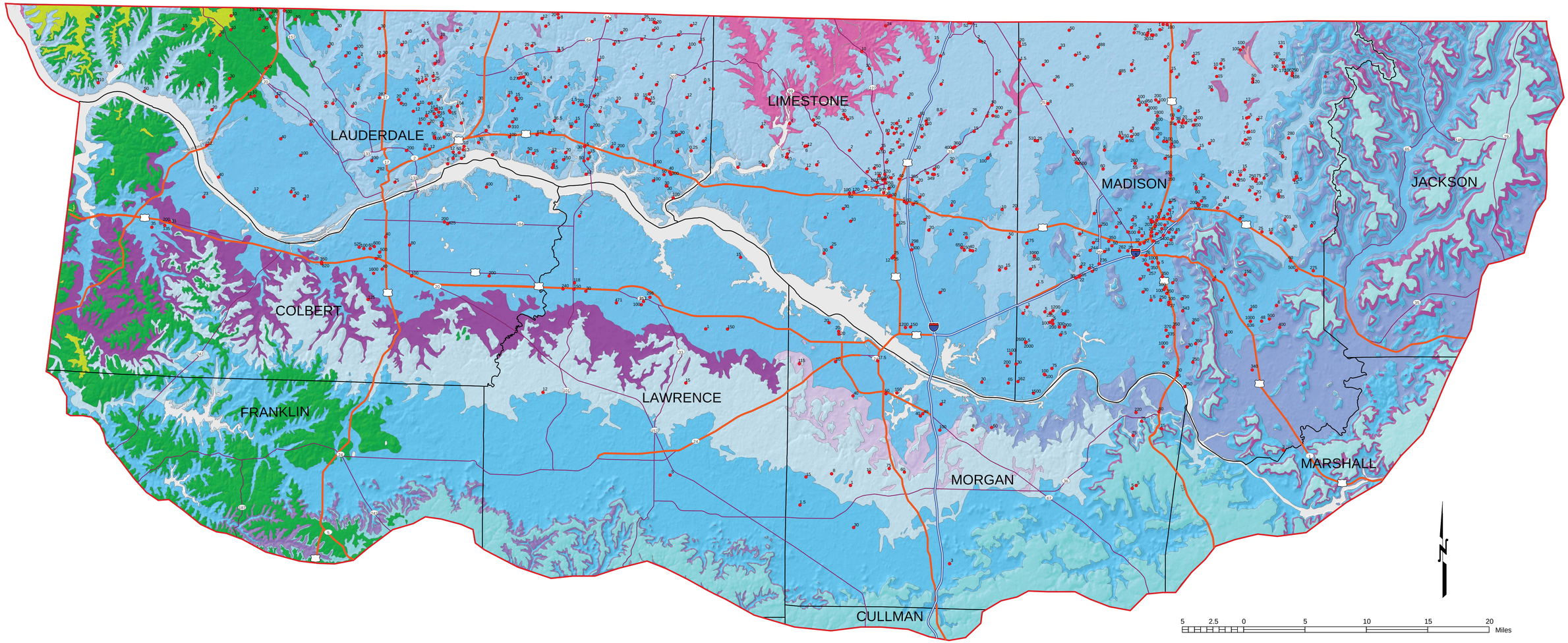

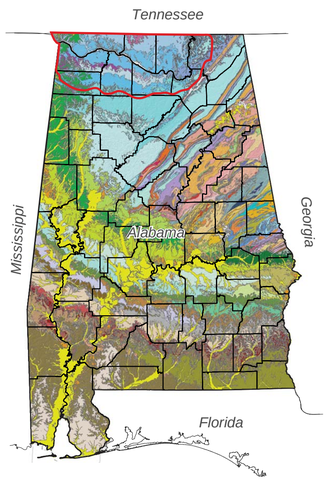

Explanation

- Eutaw Formation
- Gordo Formation
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- Pottsville Formation (lower part)
- Parkwood Formation
- Pennington Formation
- Bangor Limestone
- Hartselle Sandstone
- Monteagle Limestone
- Pride Mountain Formation
- Pride Mountain Formation and Monteagle Limestone undifferentiated
- Tuscumbia Limestone
- Fort Payne Chert
- Chattanooga Shale
- Silurian System undifferentiated
- Sequatchie Formation
- Ordovician System undifferentiated
- Water
- Tennessee River Valley groundwater irrigation assessment area
- County boundary
- City
- Well (pumping rate shown in gallons per minute)

Pumping Rates of Selected Wells in the Tennessee River Valley Groundwater Irrigation Assessment Area

(geologic map modified from Geological Survey of Alabama, 2006)

By
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2011

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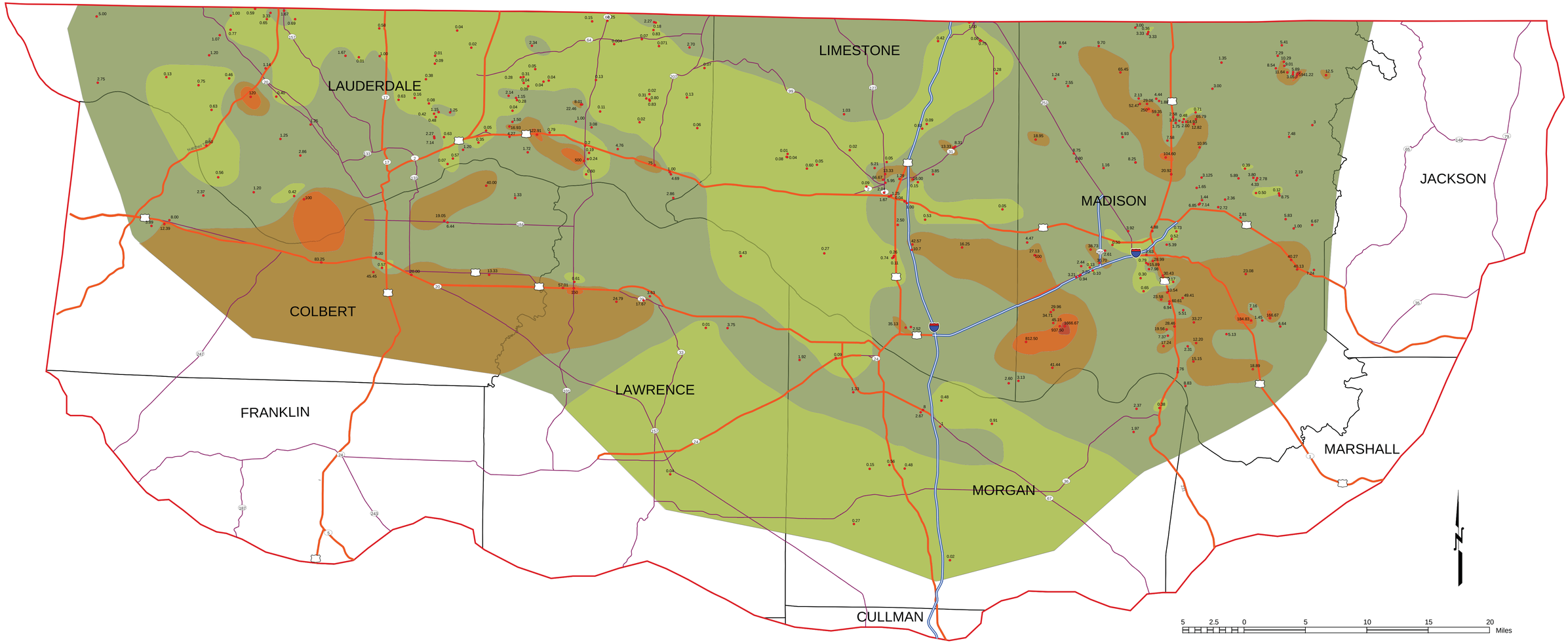

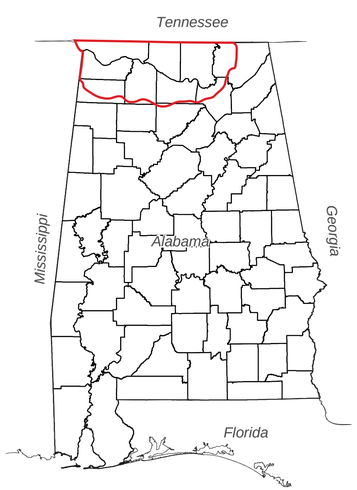

Explanation

Sp i i Capa it allon p in t p oot o a o n

- > 1,000
- 100 - 1,000
- 10 - 100
- 1 - 10
- < 1

Tennessee River Valley groundwater irrigation assessment area

County boundary

Wells with specific capacity

Specific Capacities of Wells in the Tennessee River Valley Groundwater Irrigation Assessment Area

By
Stephen P. Jennings
2011

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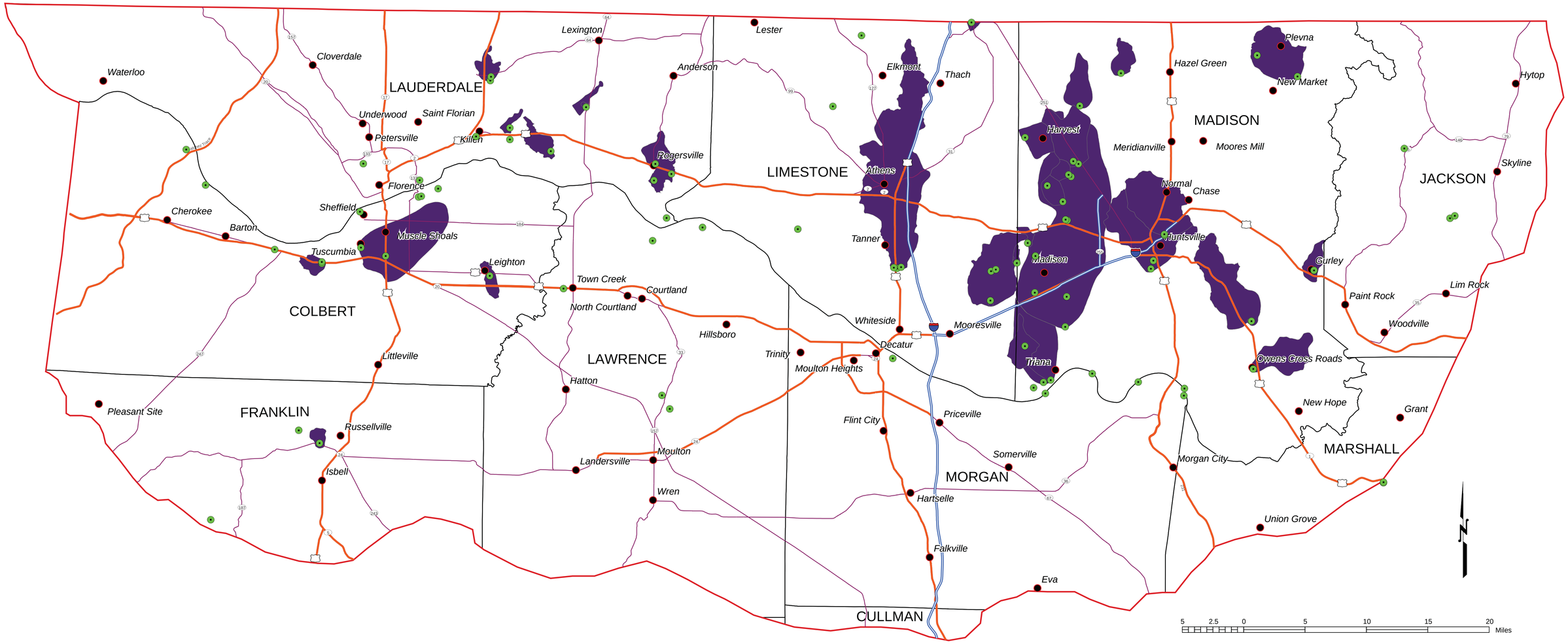

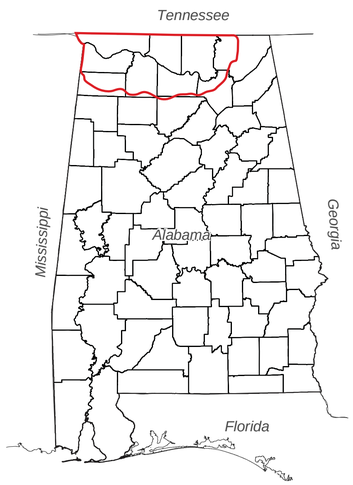

Explanation

- Tennessee River Valley groundwater irrigation assessment area
- City
- County boundary
- Public water supply well
- Source water assessment area
- Limited access interstate
- Highway
- Major road
- Interstate highway
- United States highway
- State highway

Source Water Assessment Areas and Public Water Supply Wells in the Tennessee River Valley Groundwater Irrigation Assessment Area

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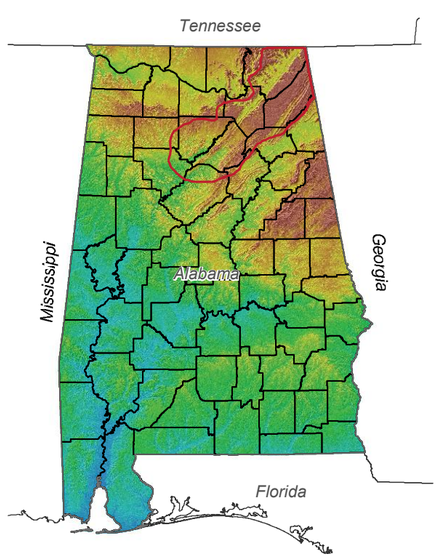
State Geologist



Explanation

Elevation in feet above NGVD 1929
High: 606
Low: 80

City

Sand Mountain groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

Interstate highway

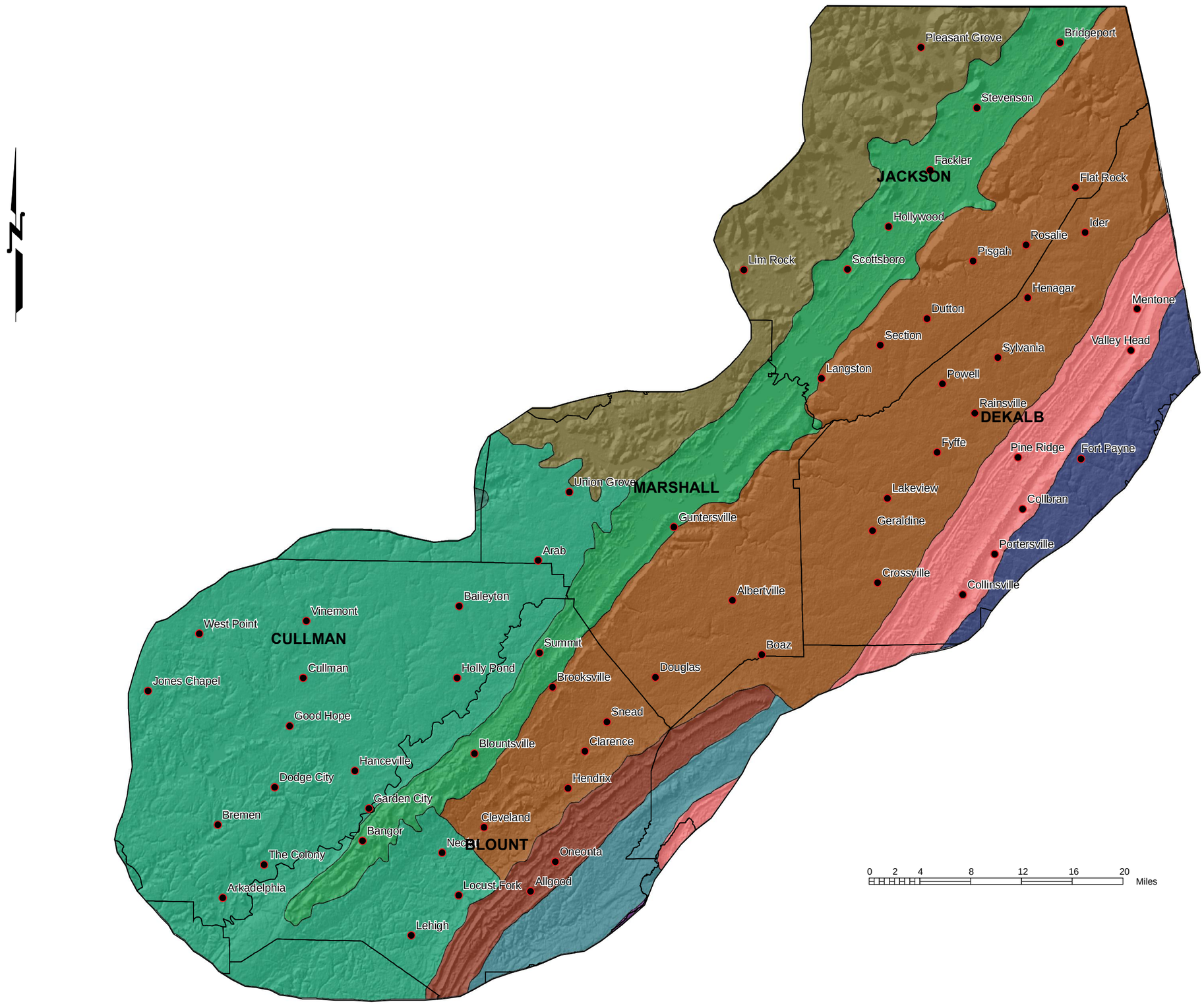
United States highway

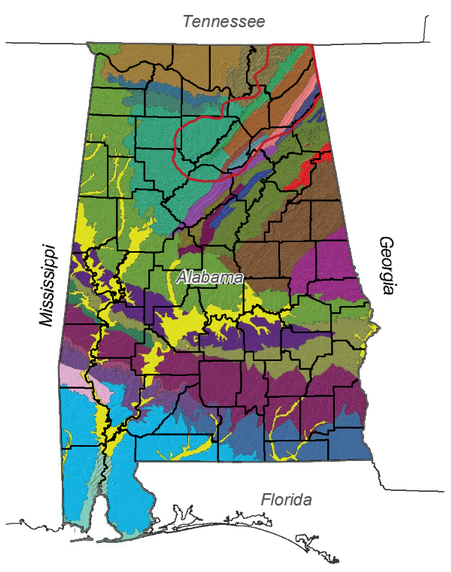
State highway

Berry H. (Nick) Tew, Jr.
State Geologist

LOCATION MAP FOR SAND MOUNTAIN ALABAMA GROUNDWATER IRRIGATION ASSESSMENT AREA

By
Neil Moss
2010





Explanation

Physiographic Regions

- Blount Mountain
- Jackson County Mountains
- Lookout Mountain
- Moulton Valley
- Murphrees Valley
- Sand Mountain
- Sequatchie Valley
- Warrior Basin
- Wills Valley

- Sand Mountain groundwater irrigation assessment area
- County boundary
- City

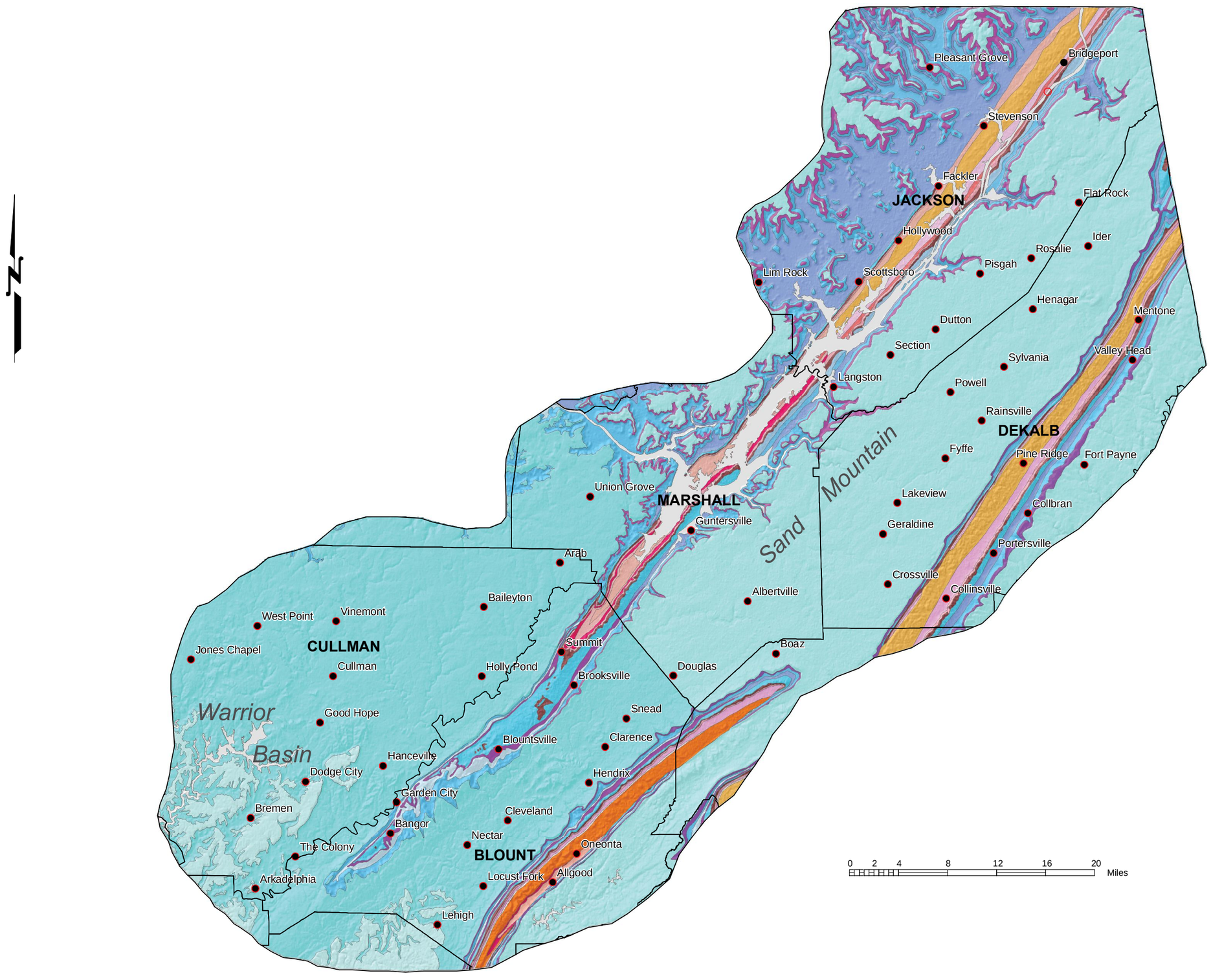
PHYSIOGRAPHIC REGIONS FOR THE SAND MOUNTAIN GROUNDWATER IRRIGATION ASSESSMENT AREA

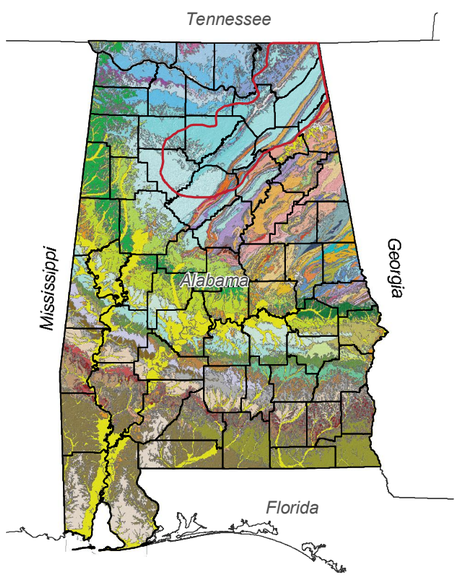
(Modified from Sapp and Emplaincourt, 1975)

By
Neil Moss
2010

GEOLOGICAL SURVEY OF ALABAMA
Founded 1848

Berry H. (Nick) Tew, Jr.
State Geologist





Explanation

Paleozoic

- Pottsville Formation upper part
- Pottsville Formation lower part
- Parkwood and Pennington Formations
- Pennington Formation
- Bangor Limestone
- Hartselle Sandstone
- Monteagle Limestone
- Pride Mountain Formation
- Tuscumbia Limestone
- Tuscumbia Limestone and Fort Payne Chert
- Red Mountain Formation
- Sequatchie Formation
- Leipers Limestone
- Chickamauga Limestone
- Nashville Group
- Stones River Group
- Chepultepec and Copper Ridge Dolomites
- Knox Group undifferentiated
- Ketona Dolomite
- Conasauga Formation

Other Symbols

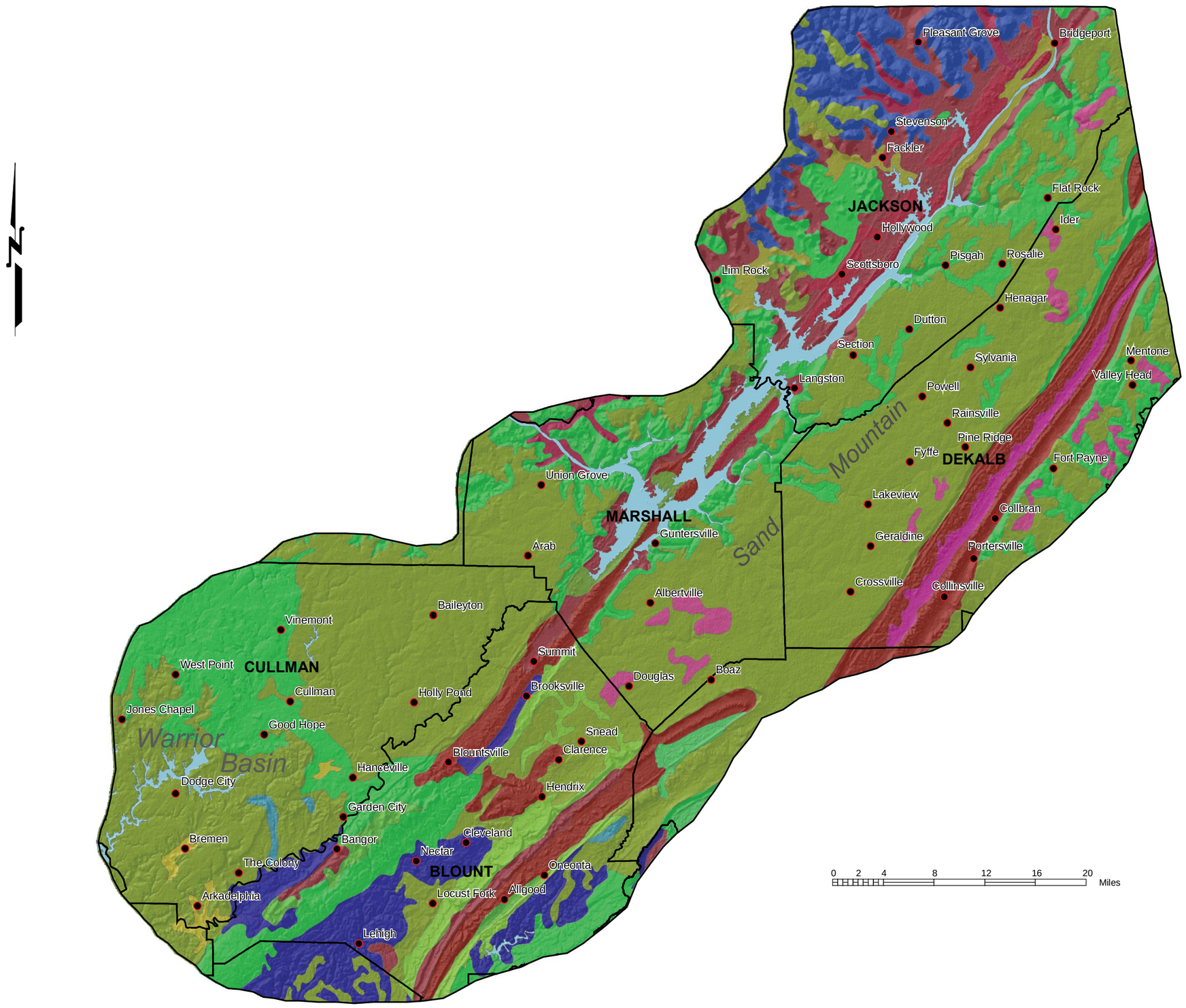
- Water
- Sand Mountain groundwater irrigation assessment area
- County boundary
- City

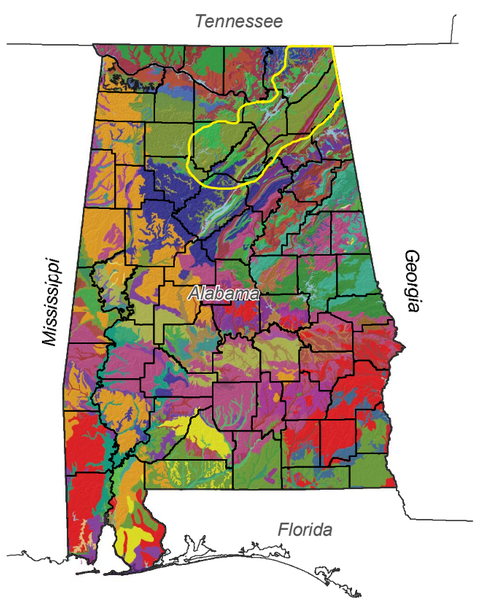
GEOLOGIC MAP AND LOCATION OF PUBLIC WATER SUPPLY WELLS AND SOURCE WATER ASSESSMENT AREAS FOR THE SAND MOUNTAIN GROUNDWATER IRRIGATION ASSESSMENT AREA

(Geology from Geological Survey of Alabama, 2006)

By
Neil Moss
2010

Berry H. (Nick) Tew, Jr.
State Geologist





Explanation

Ulti ol
- Fine-loamy, siliceous, semiactive, thermic Typic Paleudults
- Fine-loamy, siliceous, semiactive, thermic Typic Hapludults
- Loamy, siliceous, subactive, thermic Lithic Hapludults
- Fine-loamy, siliceous, semiactive, thermic Aquic Hapludults
- Loamy-skeletal, siliceous, semiactive, thermic Typic Paleudults
- Typic Paleudults, Clayey, Kaolinitic, Thermic
- Typic Endoaquults, Clayey, Mixed, Thermic
- Typic Paleudults, Fine-loamy, Silicious, Thermic

Ulti ol
- Fine, mixed, semiactive, thermic Typic Hapludults
- Fine-loamy, siliceous, subactive, thermic Typic Paleudults

n pti ol
- Fine-loamy, mixed, active, thermic Fluvaquentic Dystrudepts
- Fine-Silty, mixed, active, thermic Fluvaquentic Dystrudepts
- Loamy-skeletal, mixed, subactive, thermic,Typic Dystrudepts

Molli ol
- Clayey, mixed, active, thermic Lithic Hapludolls

Al i ol
- Fine, smectitic, thermic Vertic Hapludalfs
- Vertic Hapludalfs, Very-fine, Mixed, Thermic
- Typic Hapludalfs, Fine, Mixed, Thermic

Enti ol
- Loamy-skeletal, mixed, active, acid, thermic Typic Udorthents

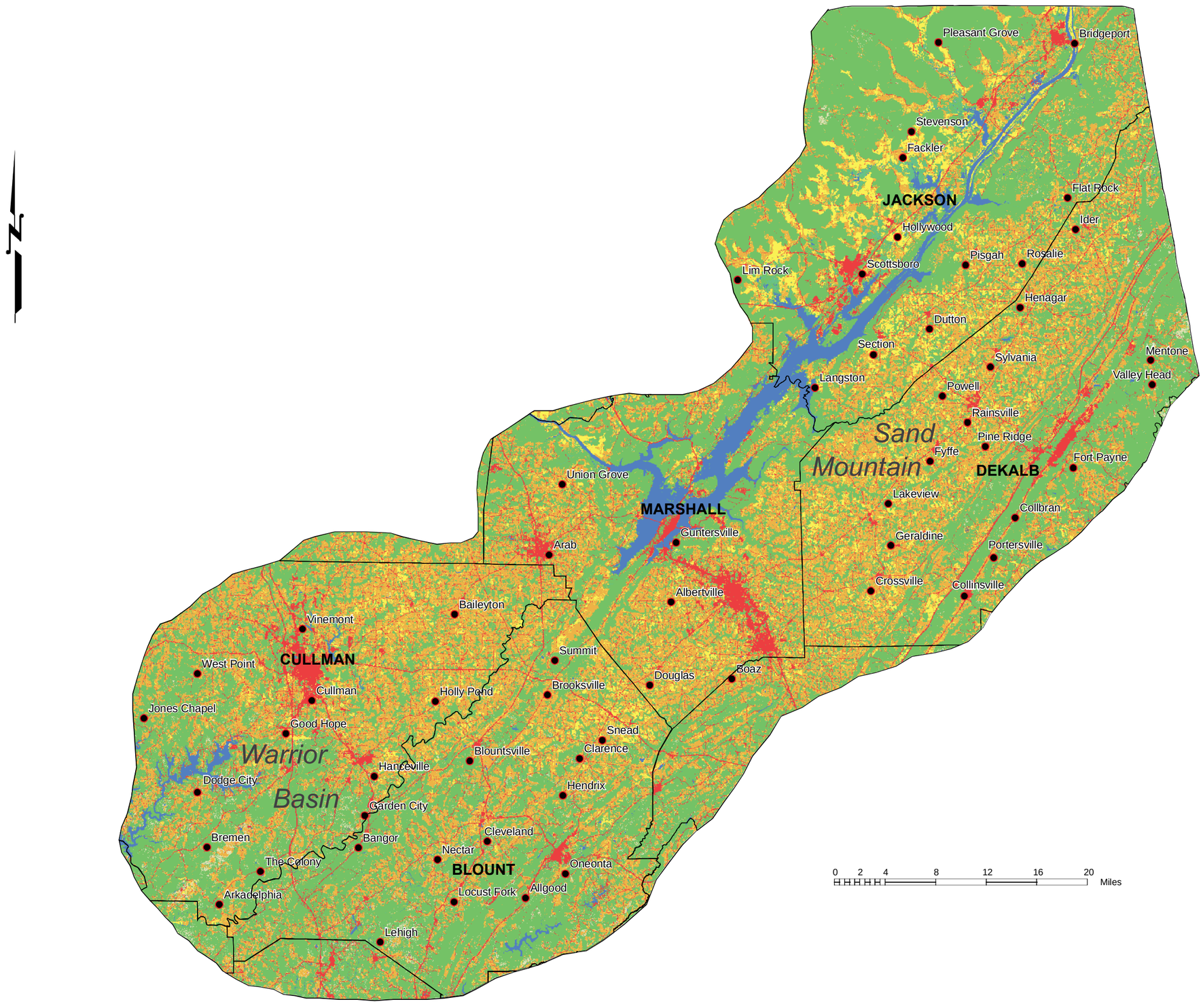
- Sand Mountain groundwater irrigation assessment area
- County boundary
- City

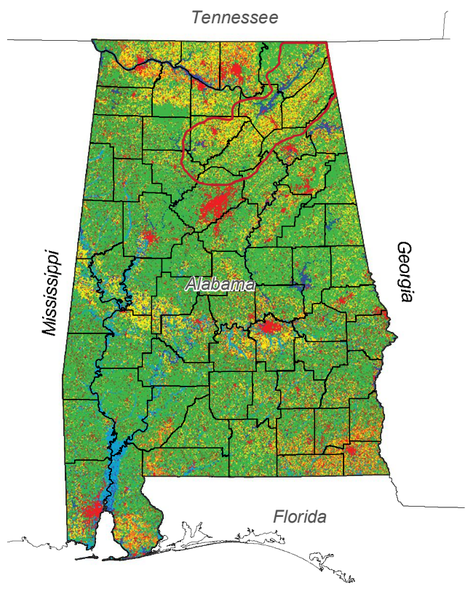
Berry H. (Nick) Tew, Jr.
State Geologist

SOIL ORDER AND TAXONOMIC CLASSIFICATION FOR THE SAND MOUNTAIN GROUNDWATER IRRIGATION ASSESSMENT AREA

(Modified from USDA-NRCS: Web Soil Survey, 2009)

By
Neil Moss
2010





Explanation

LULC Classification

- Row Crops
- Seed/Sod Grass
- Pasture/Hay
- Forest
- Pecans
- Aquaculture
- Open Water
- Developed
- Barren
- Grassland Herbaceous
- Wetlands

Other Symbols

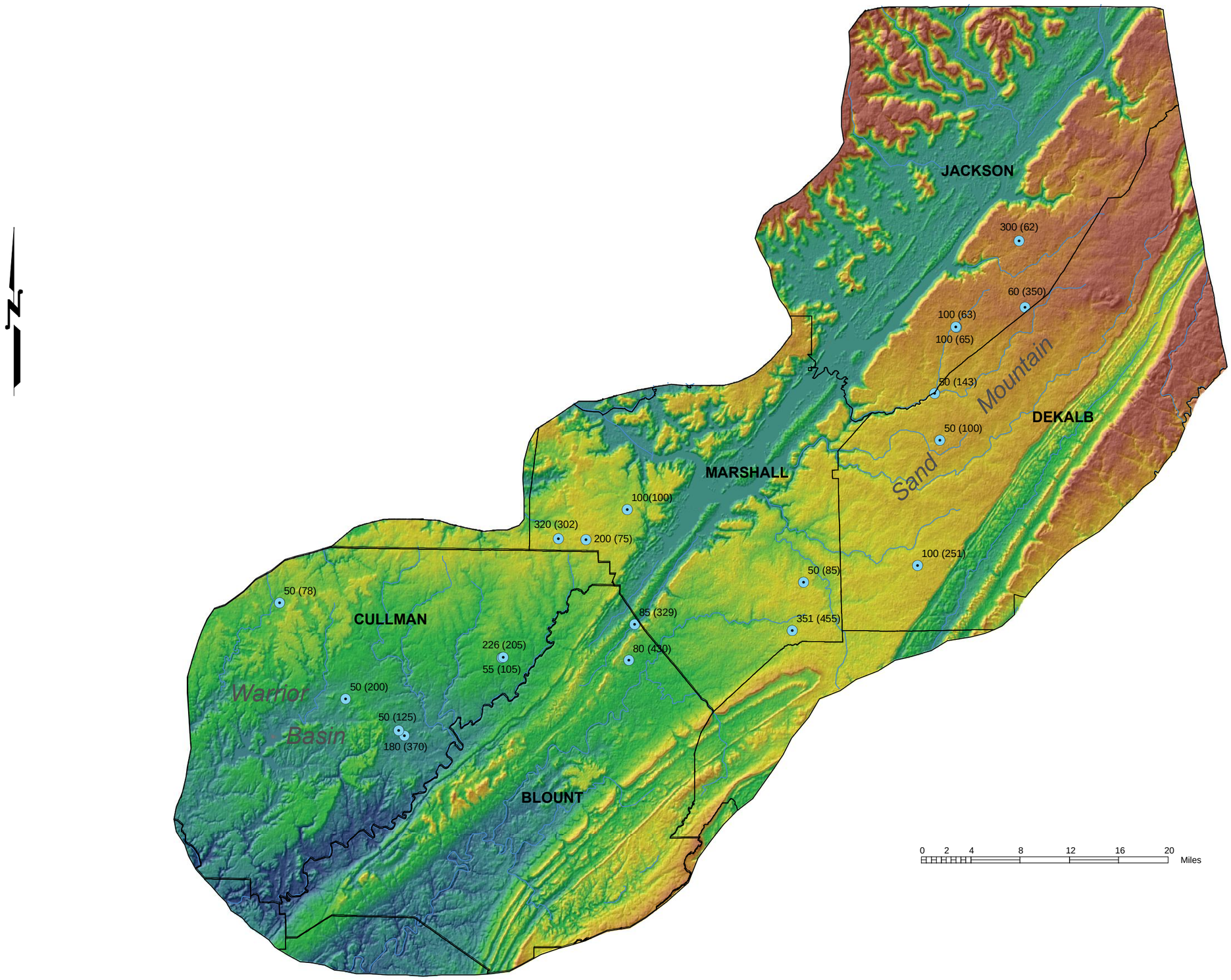
- Sand Mountain groundwater irrigation assessment area
- County boundary
- City

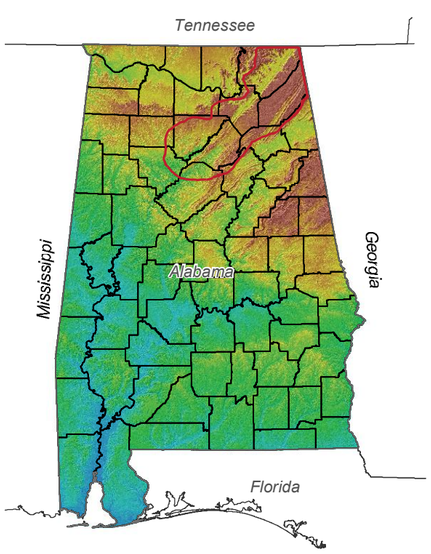
Berry H. (Nick) Tew, Jr.
State Geologist

LAND-USE/LAND-COVER CLASSIFICATION FOR THE SAND MOUNTAIN GROUNDWATER IRRIGATION ASSESSMENT AREA

(Modified from the USDA-Cropland Data Layer for Delta States, 2010)

By
Neil Moss
2010





Explanation

Elevation in feet above NGVD 1929
High : 1,880
Low : 269

Water wells
GPM (Well Depth)

Sand Mountain groundwater irrigation assessment area

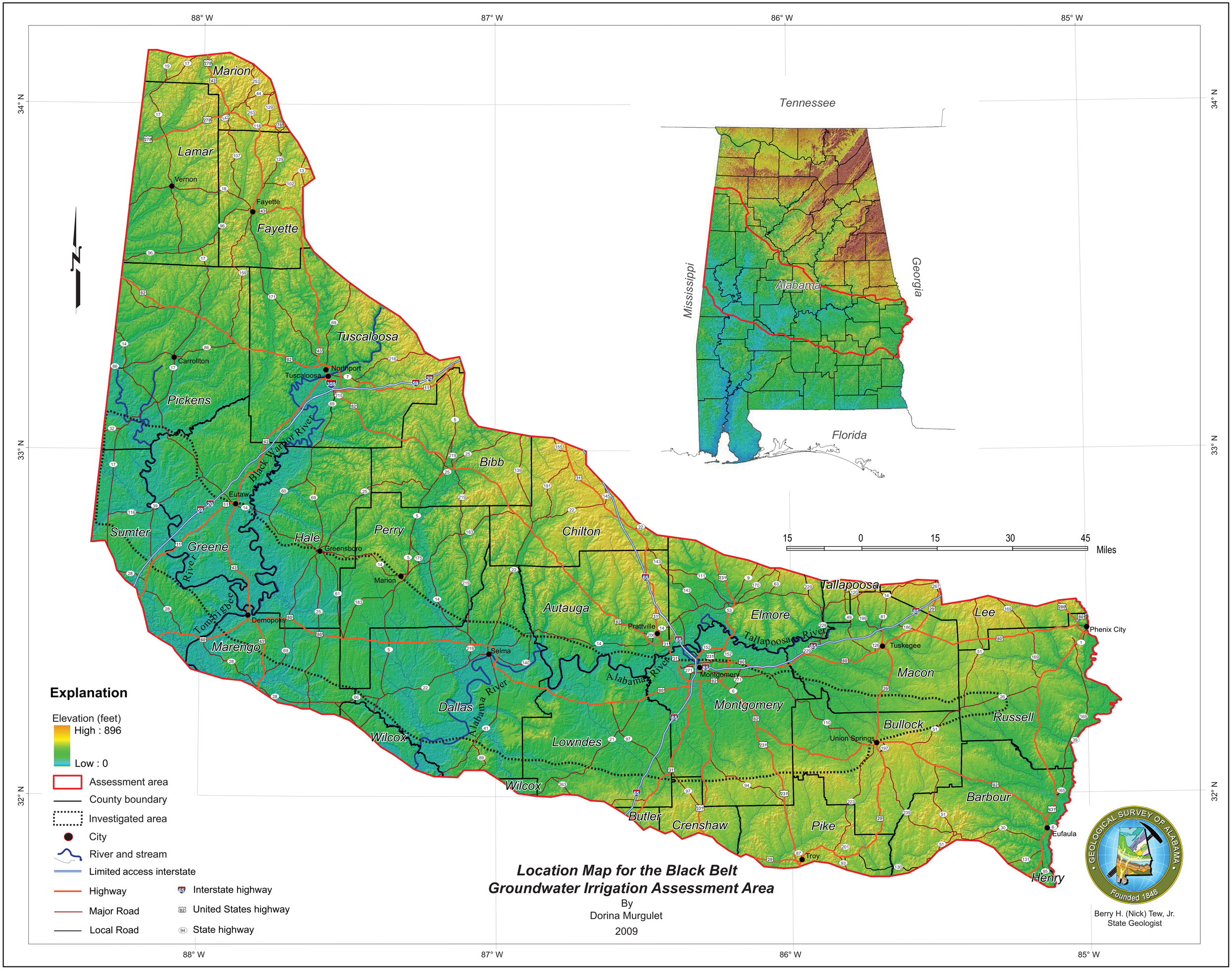
County boundary

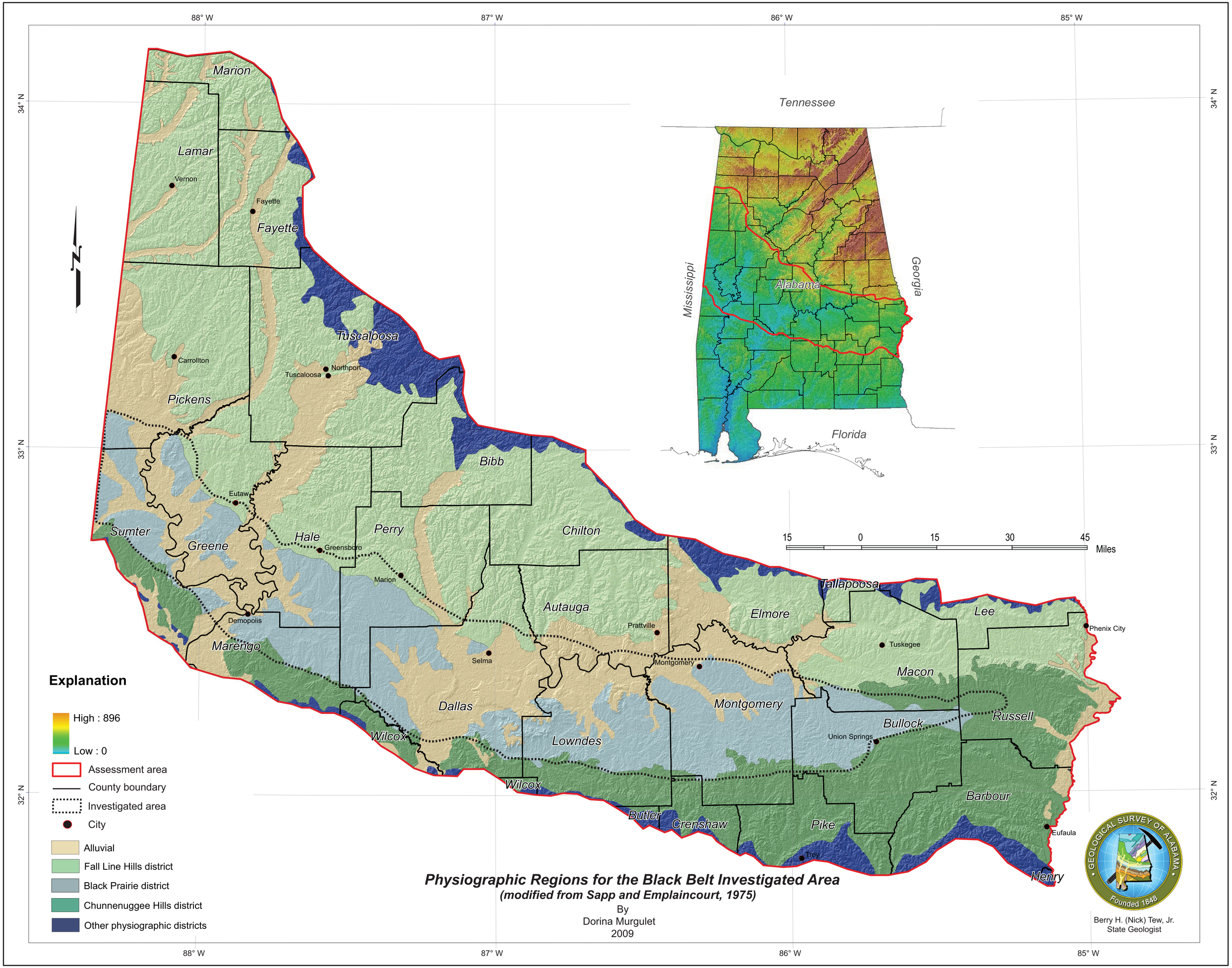
Rivers

Berry H. (Nick) Tew, Jr.
State Geologist

WELLS WITH PUMPING RATES >50 GPM IN THE SAND MOUNTAIN GROUNDWATER IRRIGATION ASSESSMENT AREA

By
Neil Moss
2010


88° W
87° W
86° W
85° W
34° N
33° N
32° N
Marion
Lamar
Vernon
Fayette
Fayette
Tuscaloosa
Carrollton
Northport
Tuscaloosa
Pickens
Black Warrior River
Bibb
Eutaw
Sumter
Greene
Hale
Greensboro
Perry
Marion
Chilton
Tombigbee River
Demopolis
Marengo
Autauga
Prattville
Selma
Elmore
Tallapoosa
Tallapoosa River
Tuskegee
Lee
Phenix City
Alabama River
Montgomery
Macon
Dallas
Alabama River
Montgomery
Bullock
Russell
Wilcox
Lowndes
Union Springs
Wilcox
Barbour
Butler
Crenshaw
Pike
Eufaula
Troy
Henry
Tennessee
Mississippi
Alabama
Georgia
Florida
15 0 15 30 45
Miles
Explanation
Elevation (feet)
High : 896
Low : 0
Assessment area
County boundary
Investigated area
City
River and stream
Limited access interstate
Highway
Major Road
Local Road
Interstate highway
United States highway
State highway
Location Map for the Black Belt
Groundwater Irrigation Assessment Area
By
Dorina Murgulet
2009
GEOLOGICAL SURVEY OF ALABAMA
Founded 1848
Berry H. (Nick) Tew, Jr.
State Geologist

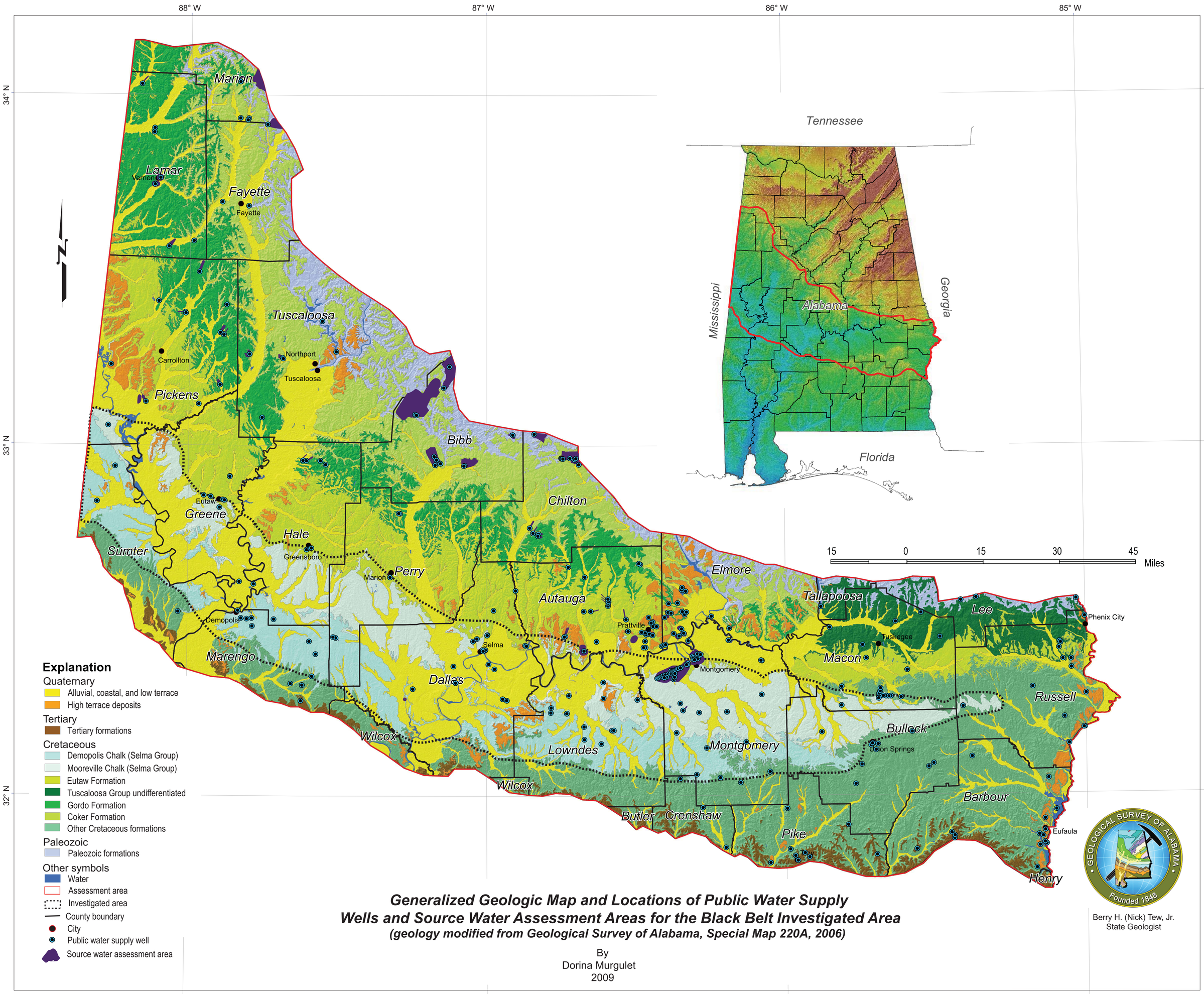


Physiographic Regions for the Black Belt Investigated Area

(modified from Sapp and Emplaincourt, 1975)

By
Dorina Murgulet
2009

Berry H. (Nick) Tew, Jr.
State Geologist

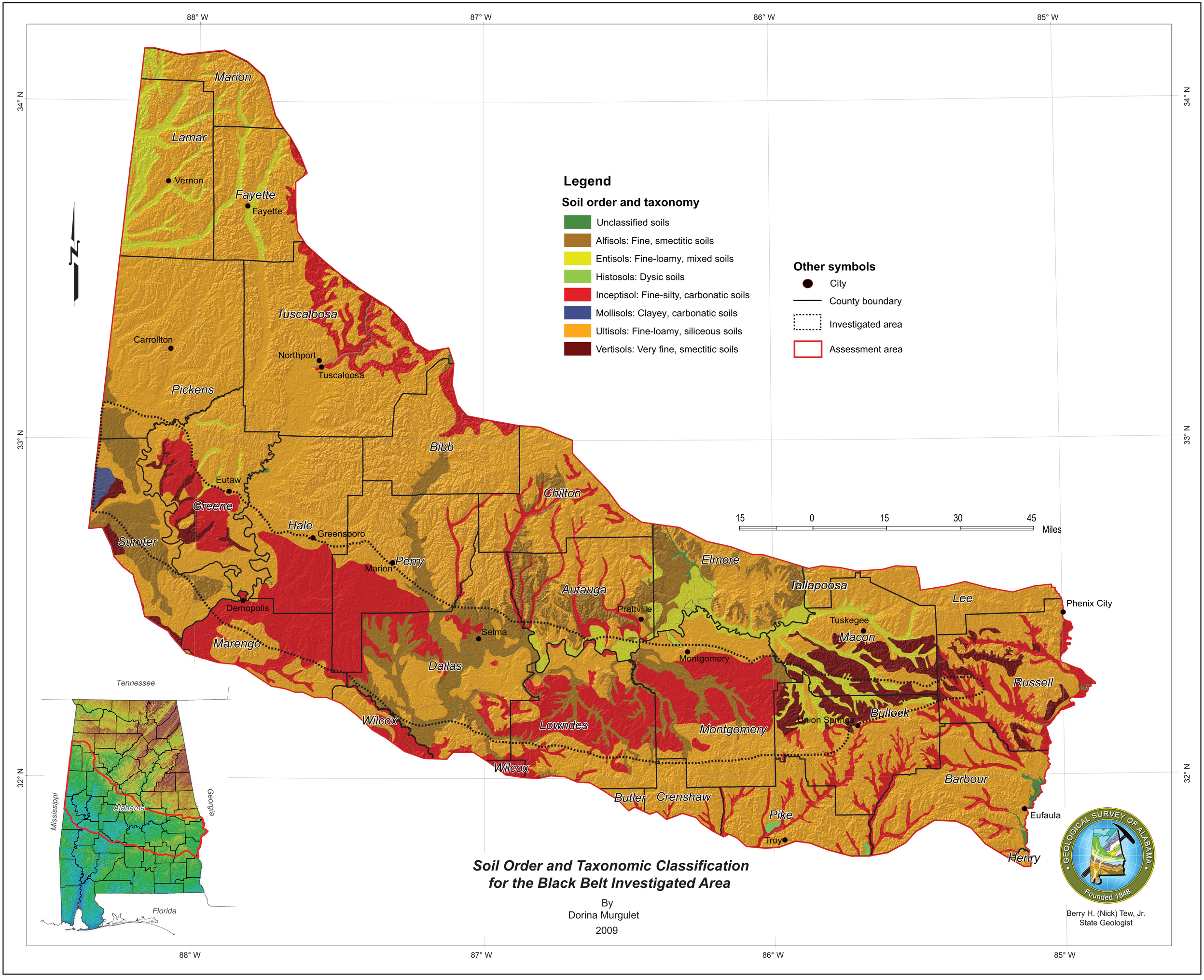


Generalized Geologic Map and Locations of Public Water Supply Wells and Source Water Assessment Areas for the Black Belt Investigated Area

(geology modified from Geological Survey of Alabama, Special Map 220A, 2006)

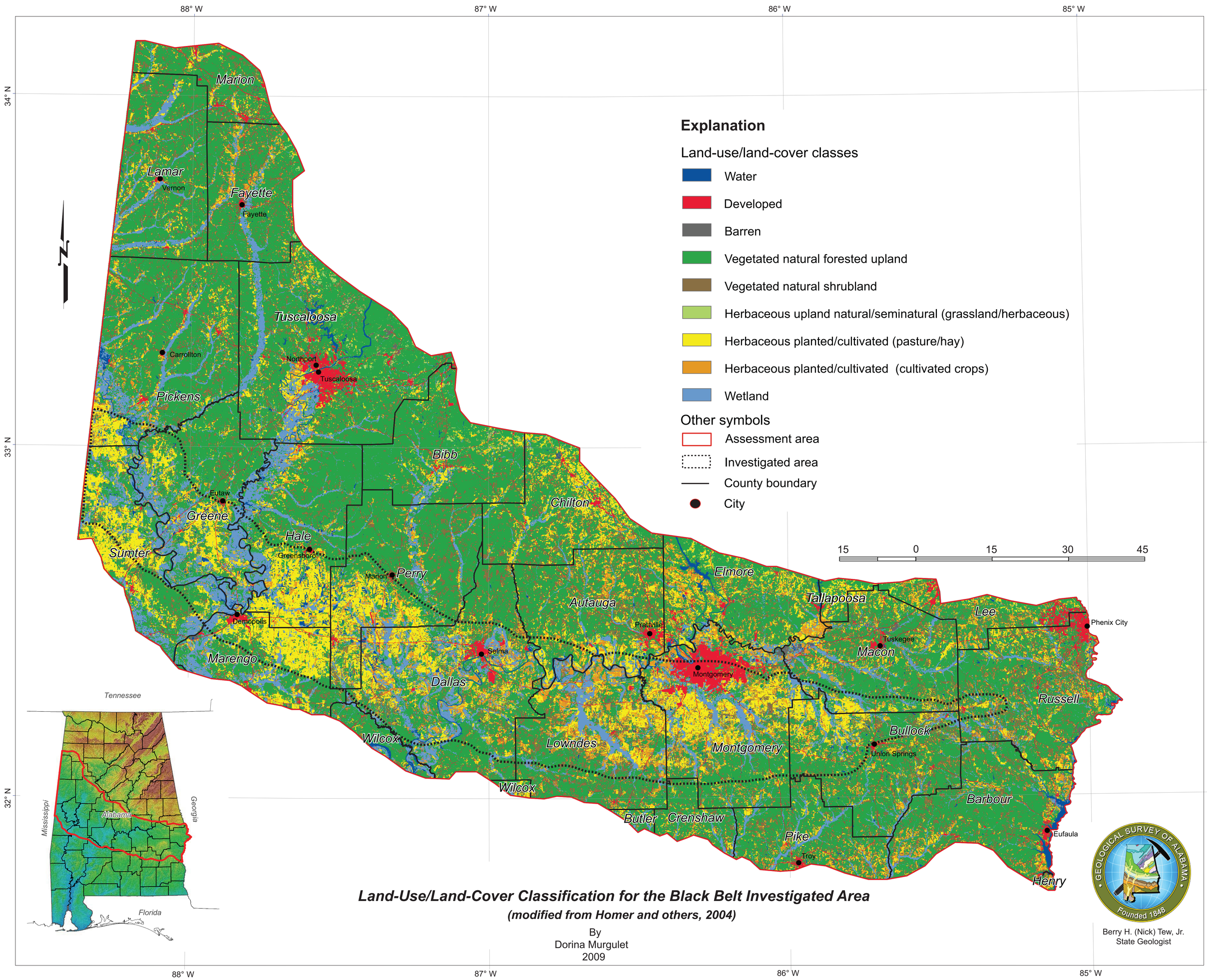
By
Dorina Murgulet
2009

Berry H. (Nick) Tew, Jr.
State Geologist



Soil Order and Taxonomic Classification for the Black Belt Investigated Area

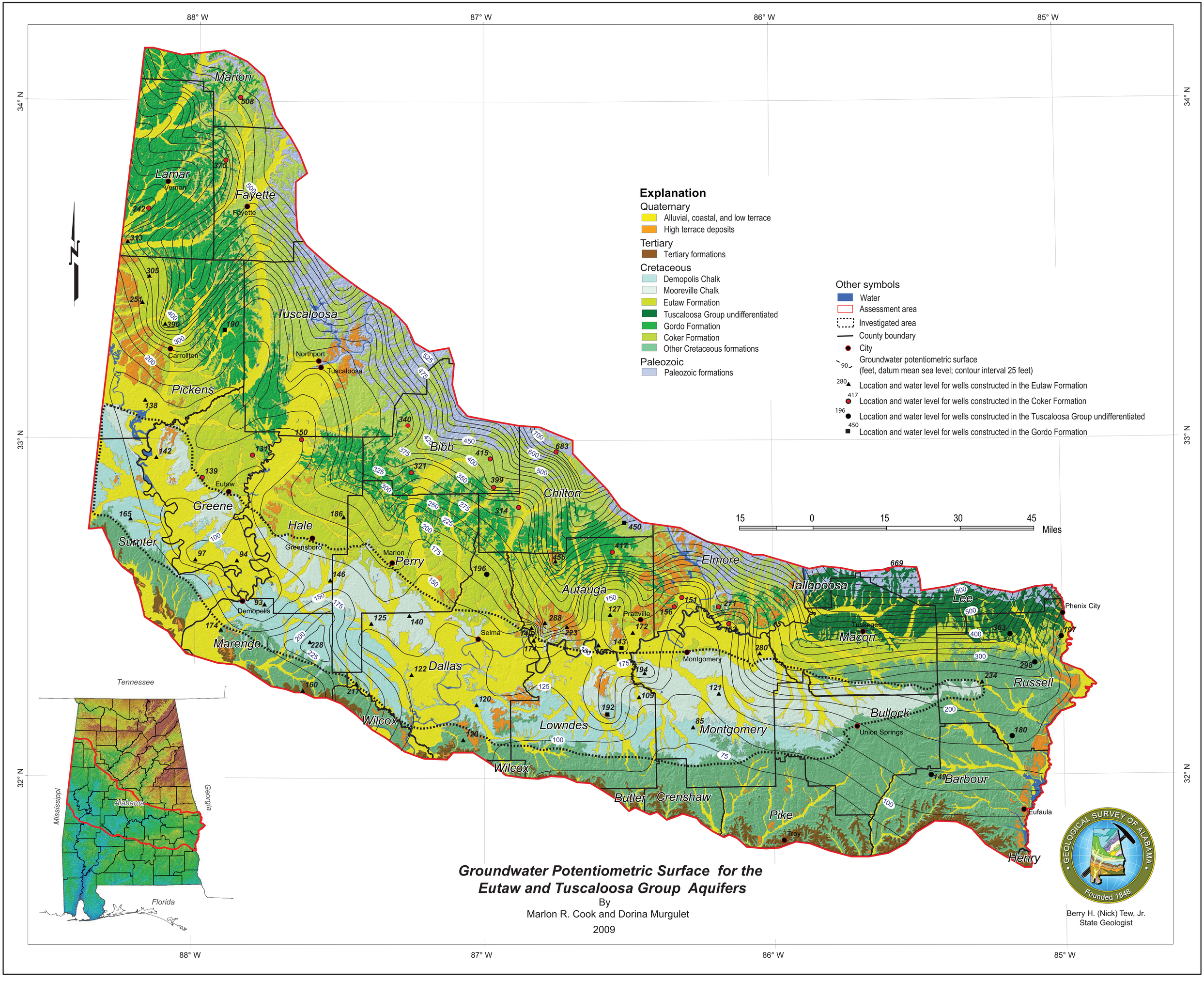
By
Dorina Murgulet
2009

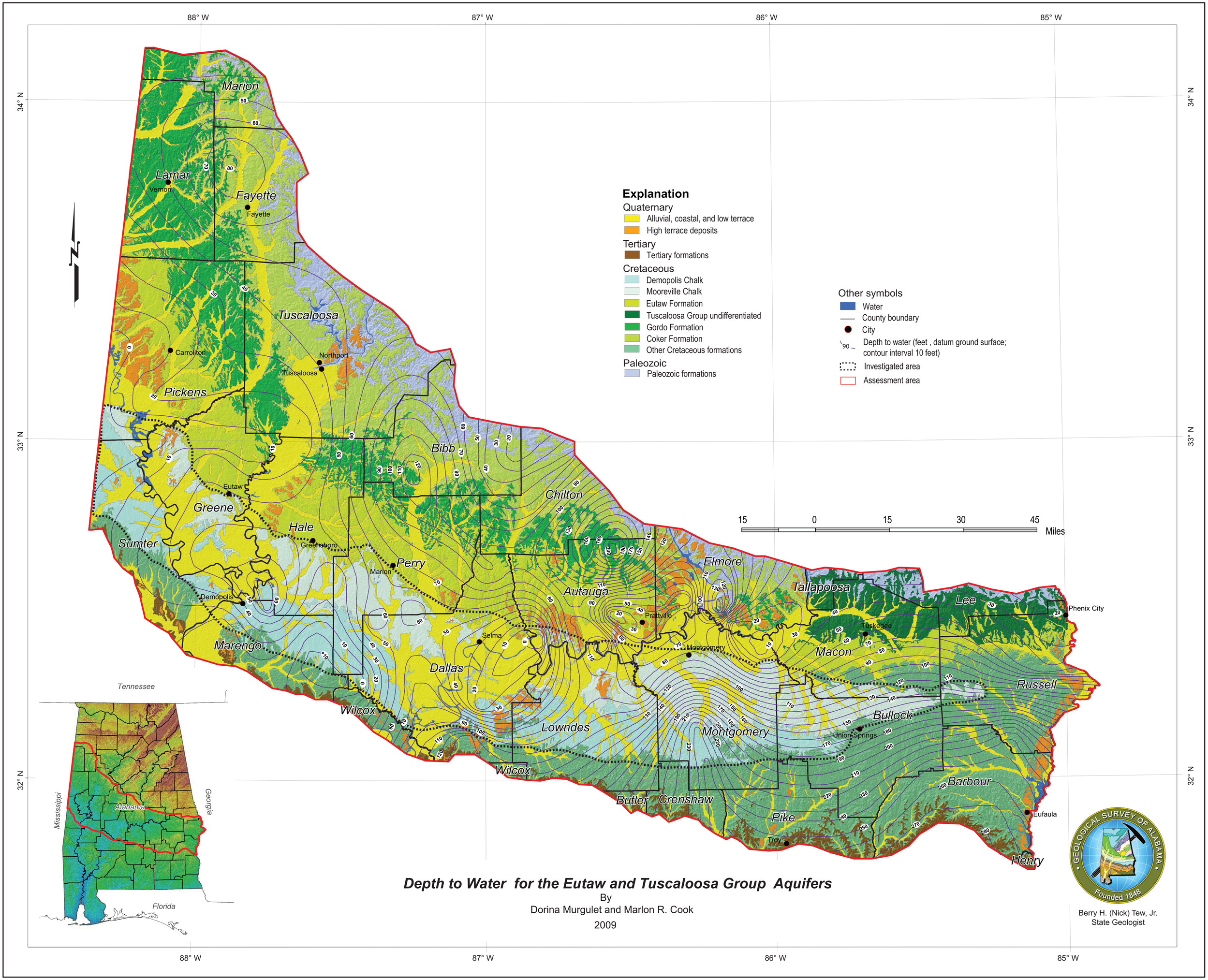


Land-Use/Land-Cover Classification for the Black Belt Investigated Area

(modified from Homer and others, 2004)

By
Dorina Murgulet
2009


88° W
87° W
86° W
85° W
34° N
33° N
32° N
Marion
Lamar
Vernon
Fayette
Fayette
Tuscaloosa
Northport
Tuscaloosa
Pickens
Carrollton
Bibb
Chilton
Greene
Eutaw
Hale
Greensboro
Sumter
Perry
Marion
Demopolis
Marengo
Elmore
Autauga
Prattville
Tallapoosa
Lee
Phenix City
Tuskegee
Macon
Selma
Dallas
Montgomery
Russell
Bullock
Union Springs
Wilcox
Lowndes
Montgomery
Barbour
Eufaula
Butler
Crenshaw
Pike
Troy
Henry
Miles
Explanation
Quaternary
Alluvial, coastal, and low terrace
High terrace deposits
Tertiary
Tertiary formations
Cretaceous
Demopolis Chalk
Mooreville Chalk
Eutaw Formation
Tuscaloosa Group undifferentiated
Gordo Formation
Coker Formation
Other Cretaceous formations
Paleozoic
Paleozoic formations
Other symbols
Water
Assessment area
Investigated area
County boundary
City
Groundwater potentiometric surface
(feet, datum mean sea level; contour interval 25 feet)
Location and water level for wells constructed in the Eutaw Formation
Location and water level for wells constructed in the Coker Formation
Location and water level for wells constructed in the Tuscaloosa Group undifferentiated
Location and water level for wells constructed in the Gordo Formation
Tennessee
Mississippi
Alabama
Georgia
Florida
Groundwater Potentiometric Surface for the
Eutaw and Tuscaloosa Group Aquifers
By
Marlon R. Cook and Dorina Murgulet
2009
GEOLOGICAL SURVEY OF ALABAMA
Founded 1843
Berry H. (Nick) Tew, Jr.
State Geologist



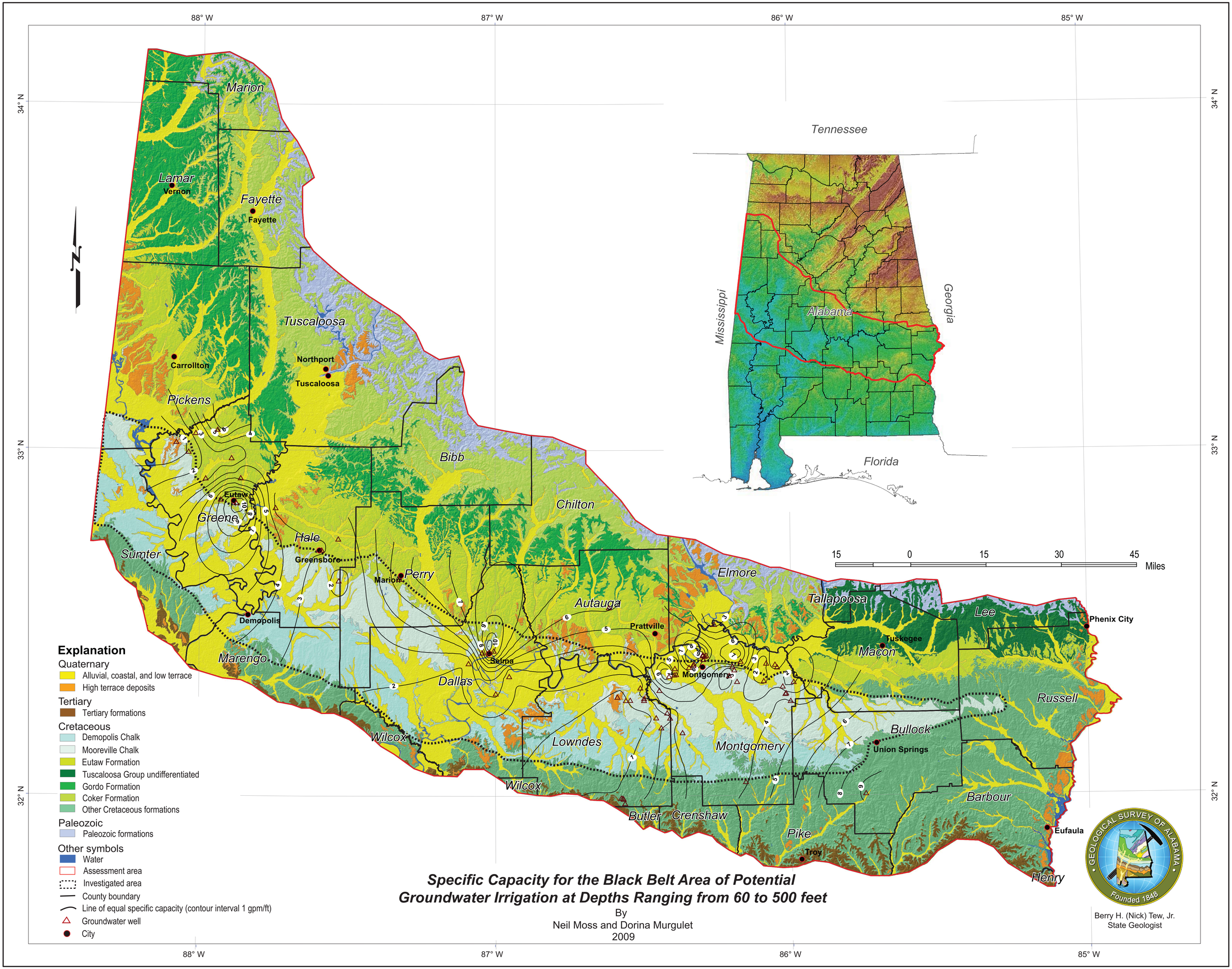
Depth to Water for the Eutaw and Tuscaloosa Group Aquifers

By

Dorina Murgulet and Marlon R. Cook

2009

Berry H. (Nick) Tew, Jr.
State Geologist



Specific Capacity for the Black Belt Area of Potential Groundwater Irrigation at Depths Ranging from 60 to 500 feet

By
Neil Moss and Dorina Murgulet
2009

88° W 87° W 86° W 85° W

34° N 33° N 32° N

Marion
Lamar
Vernon
Fayette
Fayette
Tuscaloosa
Carrollton
Northport
Tuscaloosa
Pickens
Bibb
Chilton
Eutaw
Greene
Hale
Greensboro
Sumter
Marion
Perry
Demopolis
Elmore
Autauga
Tallapoosa
Lee
Phenix City
Prattville
Tuskegee
Macon
Selma
Montgomery
Marengo
Dallas
Russell
Union Springs
Bullock
Wilcox
Lowndes
Montgomery
Wilcox
Barbour
Butler
Crenshaw
Pike
Eufaula
Troy
Henry

Tennessee
Mississippi
Alabama
Georgia
Florida

15 0 15 30 45
Miles

Explanation

Quaternary
- Alluvial, coastal, and low terrace
- High terrace deposits

Tertiary
- Tertiary formations

Cretaceous
- Demopolis Chalk
- Mooreville Chalk
- Eutaw Formation
- Tuscaloosa Group undifferentiated
- Gordo Formation
- Coker Formation
- Other Cretaceous formations

Paleozoic
- Paleozoic formations

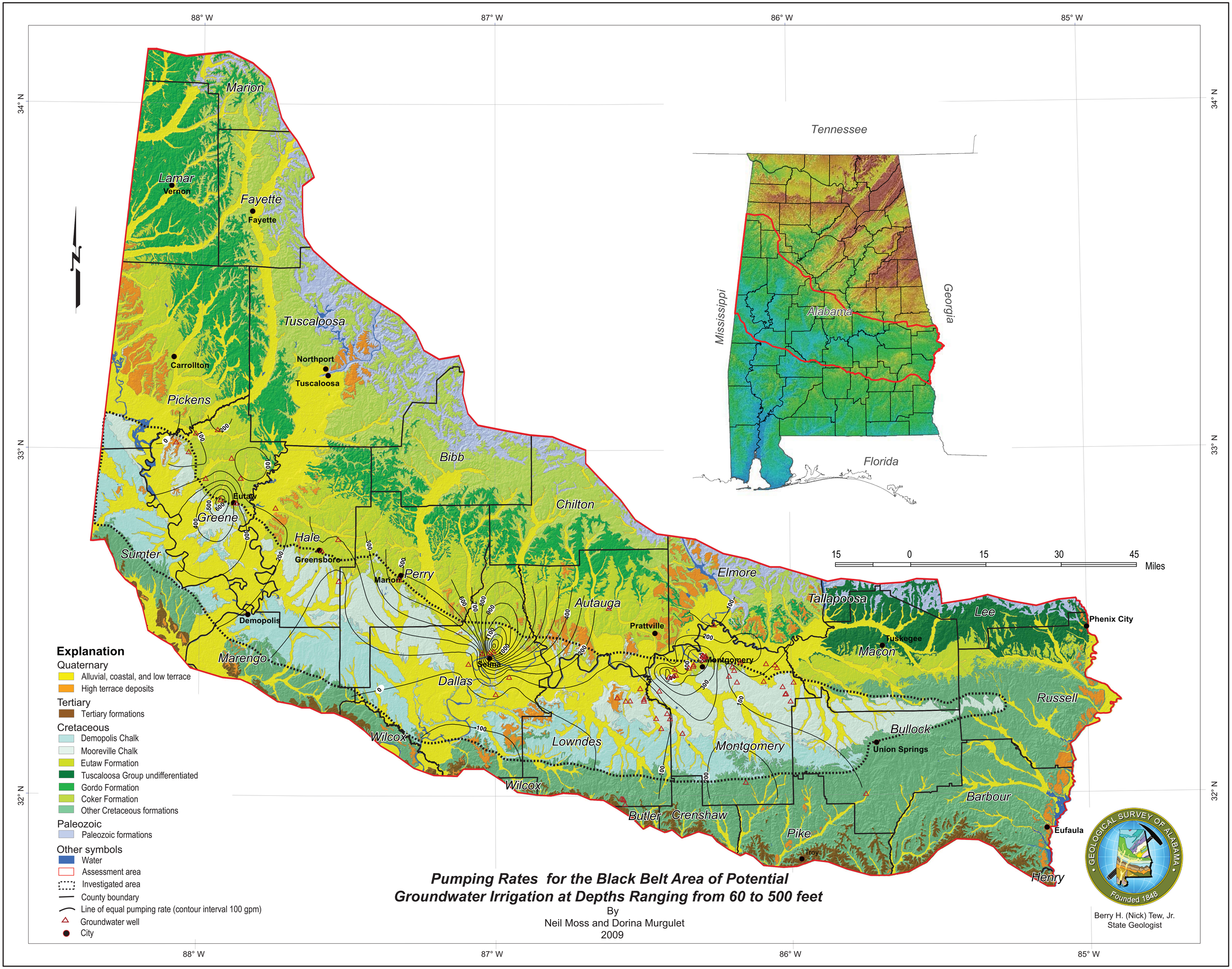
Other symbols
- Water
- Assessment area
- Investigated area
- County boundary
- Line of equal specific capacity (contour interval 3 gpm/ft)
- Groundwater well
- City

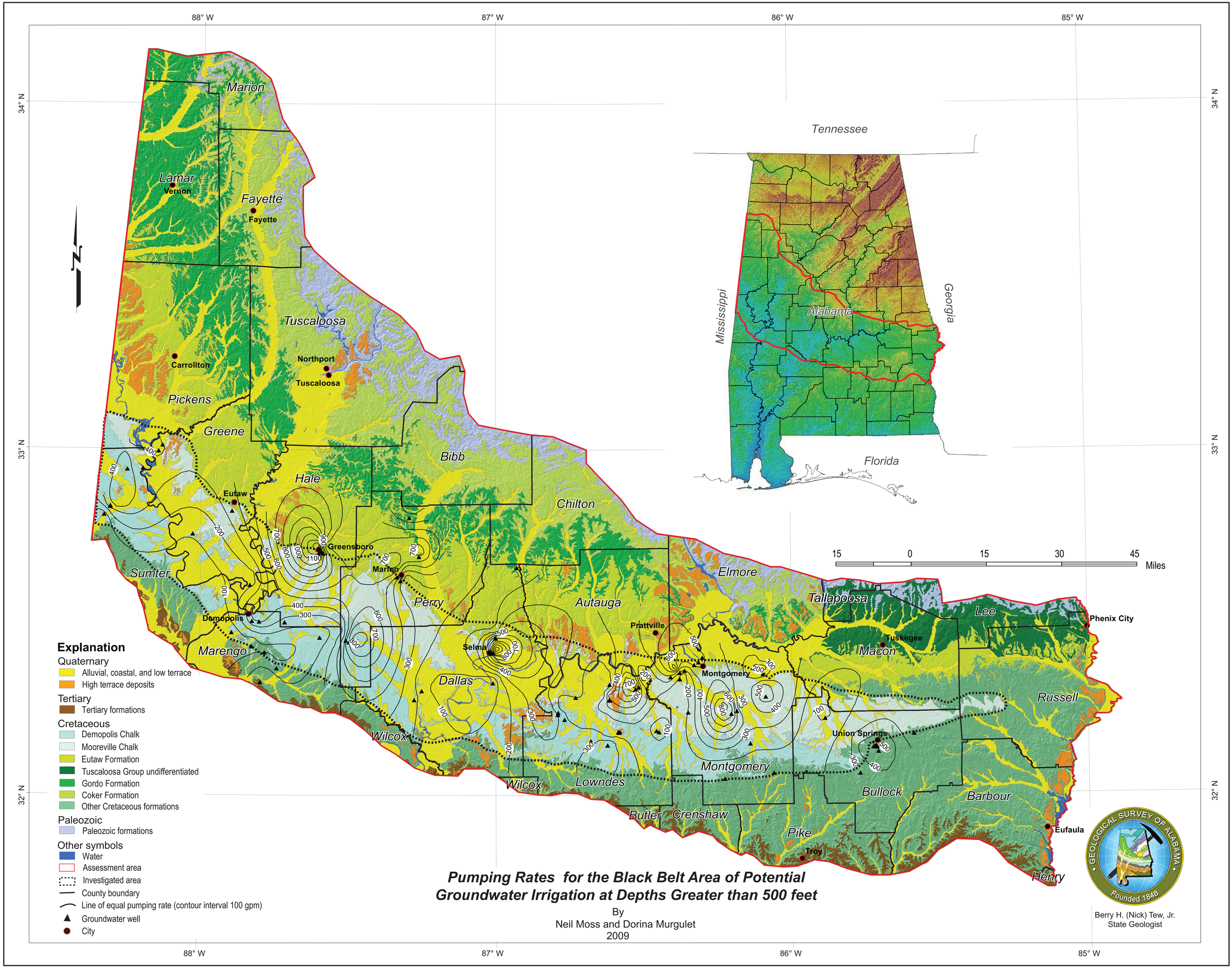
Specific Capacity for the Black Belt Area of Potential Groundwater Irrigation at Depths Greater than 500 feet

By
Neil Moss and Dorina Murgulet
2009

GEOLOGICAL SURVEY OF ALABAMA
Founded 1848

Berry H. (Nick) Tew, Jr.
State Geologist


88° W
87° W
86° W
85° W
34° N
33° N
32° N
Marion
Lamar
Vernon
Fayette
Fayette
Tuscaloosa
Carrollton
Northport
Tuscaloosa
Pickens
Bibb
Eutaw
Greene
Chilton
Hale
Greensboro
Sumter
Perry
Marion
Elmore
Autauga
Tallapoosa
Lee
Phenix City
Demopolis
Prattville
Tuskegee
Macon
Marengo
Selma
Montgomery
Dallas
Russell
Bullock
Union Springs
Wilcox
Lowndes
Montgomery
Wilcox
Barbour
Butler
Crenshaw
Pike
Troy
Eufaula
Henry
Tennessee
Mississippi
Alabama
Georgia
Florida
15 0 15 30 45
Miles
Explanation
Quaternary
Alluvial, coastal, and low terrace
High terrace deposits
Tertiary
Tertiary formations
Cretaceous
Demopolis Chalk
Mooreville Chalk
Eutaw Formation
Tuscaloosa Group undifferentiated
Gordo Formation
Coker Formation
Other Cretaceous formations
Paleozoic
Paleozoic formations
Other symbols
Water
Assessment area
Investigated area
County boundary
Line of equal pumping rate (contour interval 100 gpm)
Groundwater well
City
Pumping Rates for the Black Belt Area of Potential
Groundwater Irrigation at Depths Ranging from 60 to 500 feet
By
Neil Moss and Dorina Murgulet
2009
GEOLOGICAL SURVEY OF ALABAMA
Founded 1848
Berry H. (Nick) Tew, Jr.
State Geologist


88° W
87° W
86° W
85° W
34° N
33° N
32° N
Marion
Lamar
Vernon
Fayette
Fayette
Tuscaloosa
Northport
Tuscaloosa
Carrollton
Pickens
Greene
Bibb
Hale
Eutaw
Chilton
Greensboro
Marion
Sumter
Perry
Elmore
Autauga
Tallapoosa
Lee
Phenix City
Demopolis
Prattville
Tuskegee
Macon
Marengo
Selma
Montgomery
Dallas
Russell
Union Springs
Wilcox
Montgomery
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Lowndes
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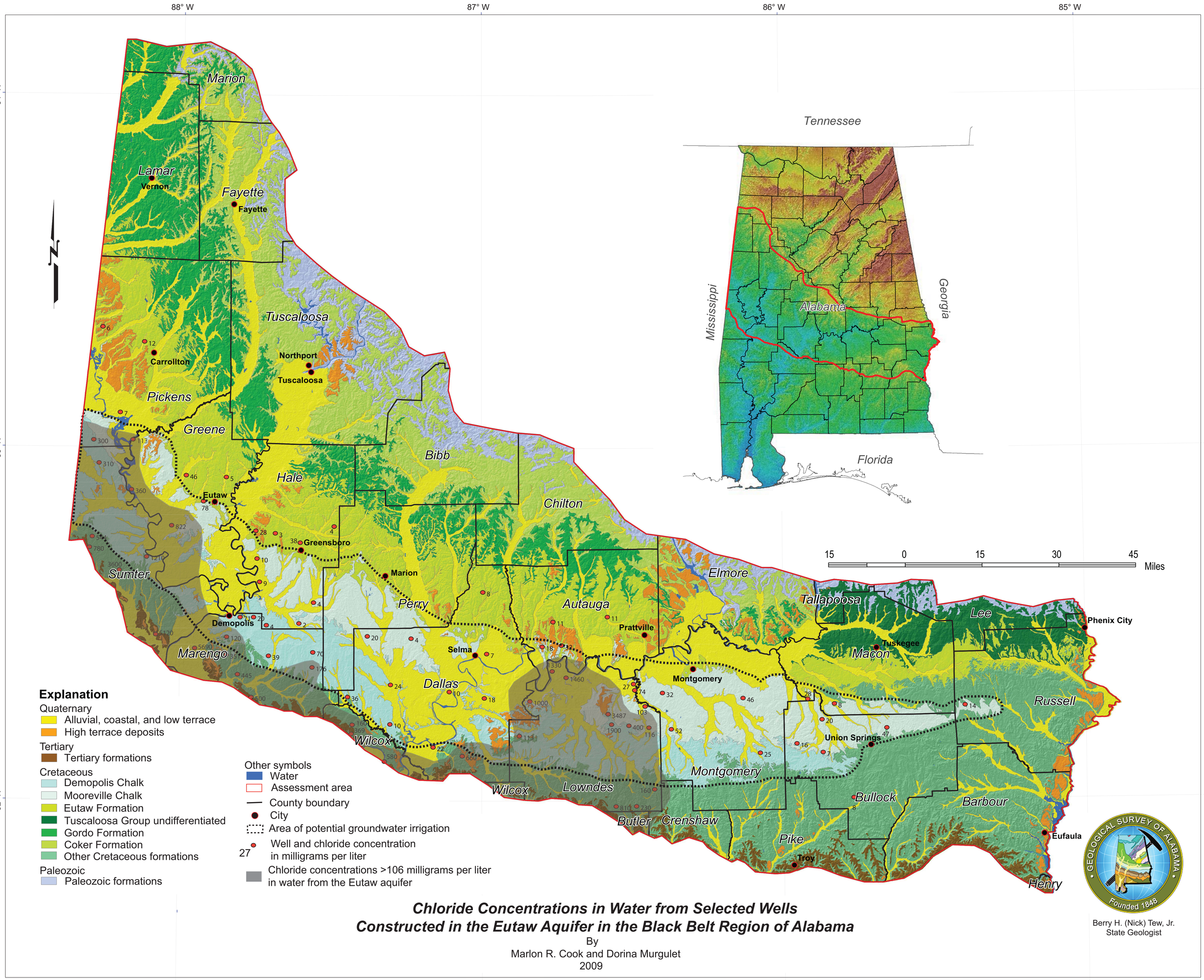
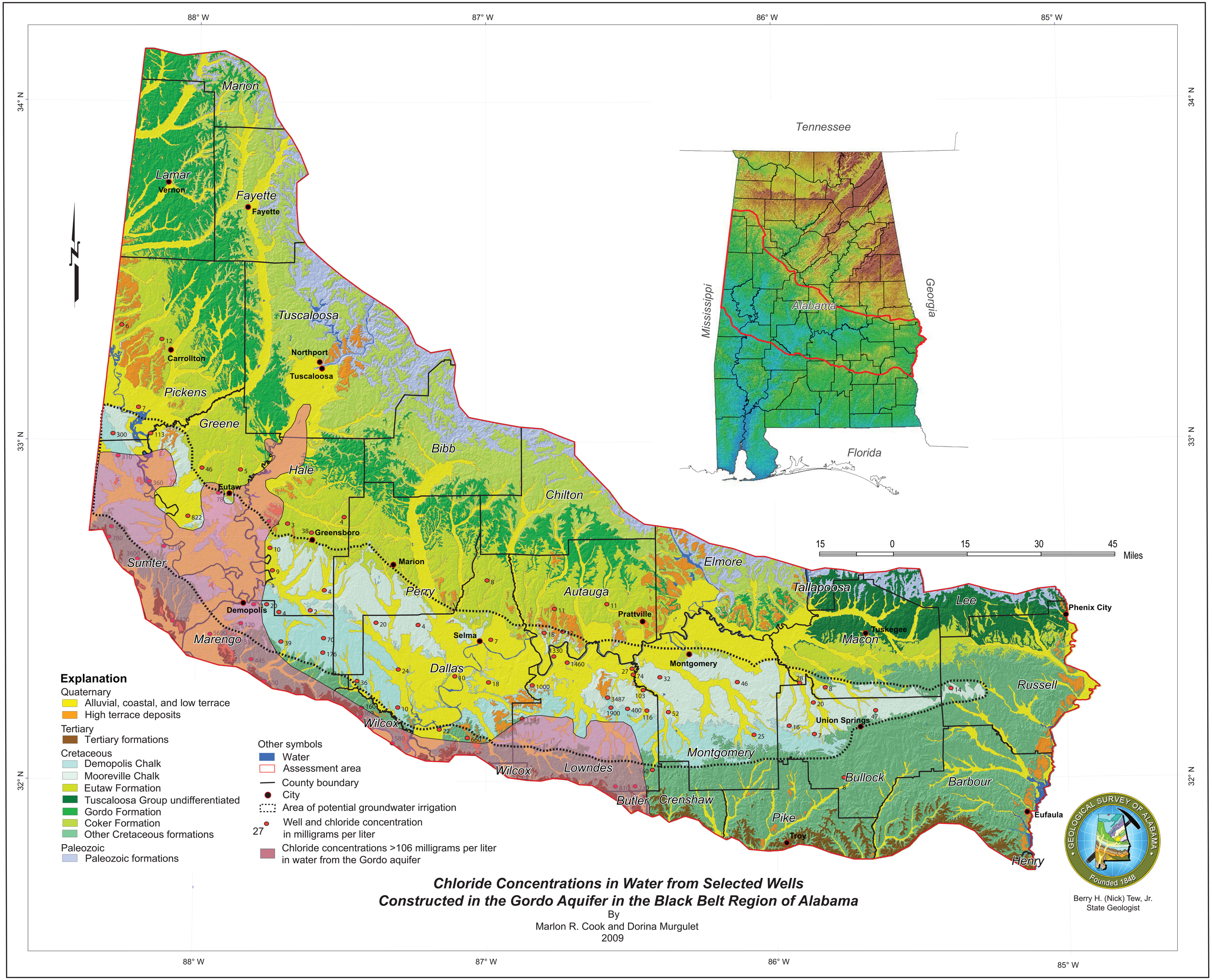
Pike
Eufaula
Troy
Henry
Tennessee
Mississippi
Alabama
Georgia
Florida
15 0 15 30 45
Miles
Explanation
Quaternary
Alluvial, coastal, and low terrace
High terrace deposits
Tertiary
Tertiary formations
Cretaceous
Demopolis Chalk
Mooreville Chalk
Eutaw Formation
Tuscaloosa Group undifferentiated
Gordo Formation
Coker Formation
Other Cretaceous formations
Paleozoic
Paleozoic formations
Other symbols
Water
Assessment area
Investigated area
County boundary
Line of equal pumping rate (contour interval 100 gpm)
Groundwater well
City
Pumping Rates for the Black Belt Area of Potential Groundwater Irrigation at Depths Greater than 500 feet
By
Neil Moss and Dorina Murgulet
2009
GEOLOGICAL SURVEY OF ALABAMA
Founded 1848
Berry H. (Nick) Tew, Jr.
State Geologist



Chloride Concentrations in Water from Selected Wells Constructed in the Eutaw Aquifer in the Black Belt Region of Alabama

By
Marlon R. Cook and Dorina Murgulet
2009

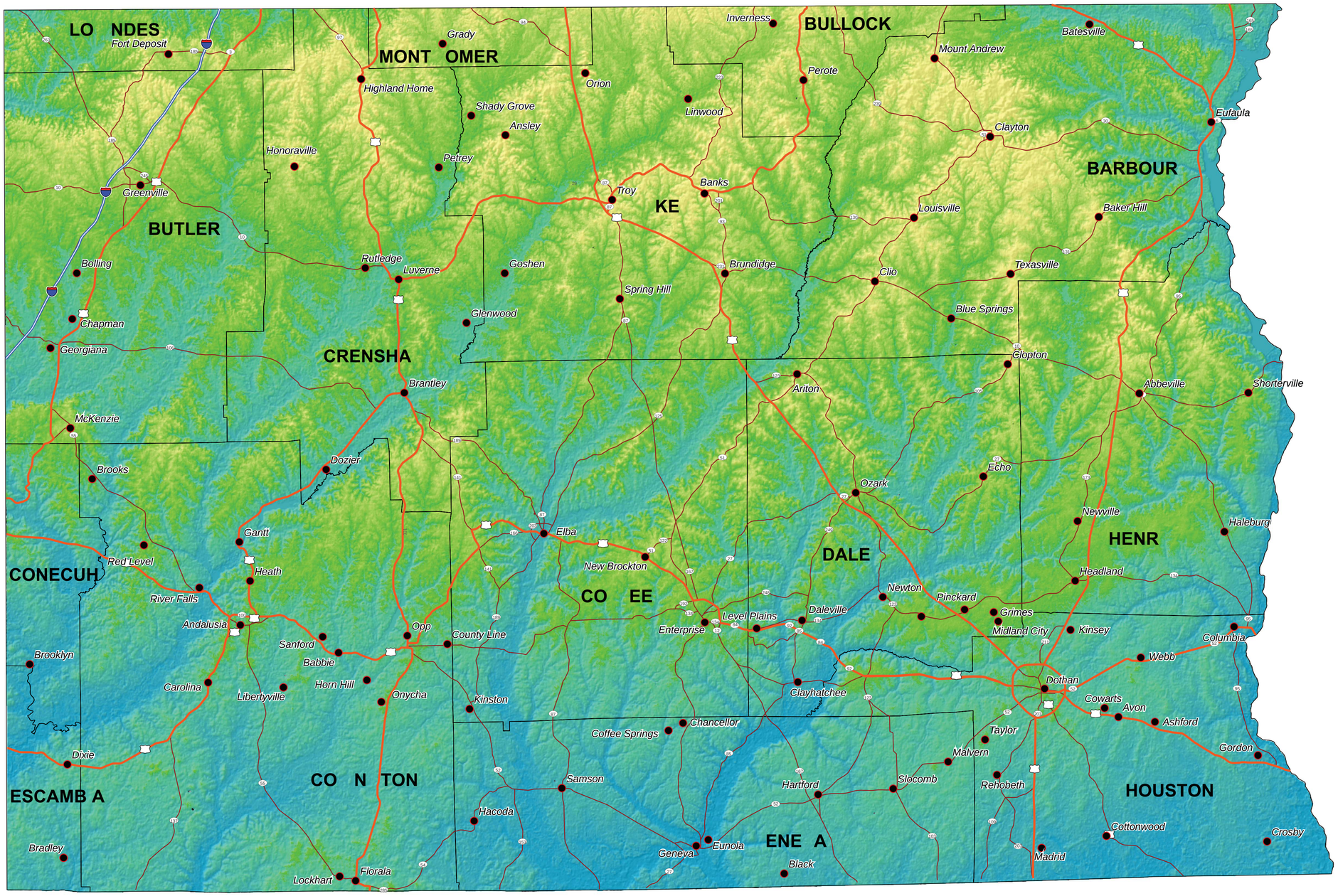


Chloride Concentrations in Water from Selected Wells Constructed in the Gordo Aquifer in the Black Belt Region of Alabama

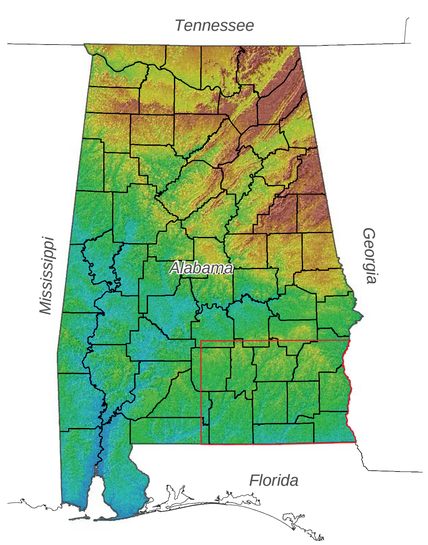
By

Marlon R. Cook and Dorina Murgulet

2009



0 2 4 8 12 16 20 Miles



Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

Interstate highway

United States highway

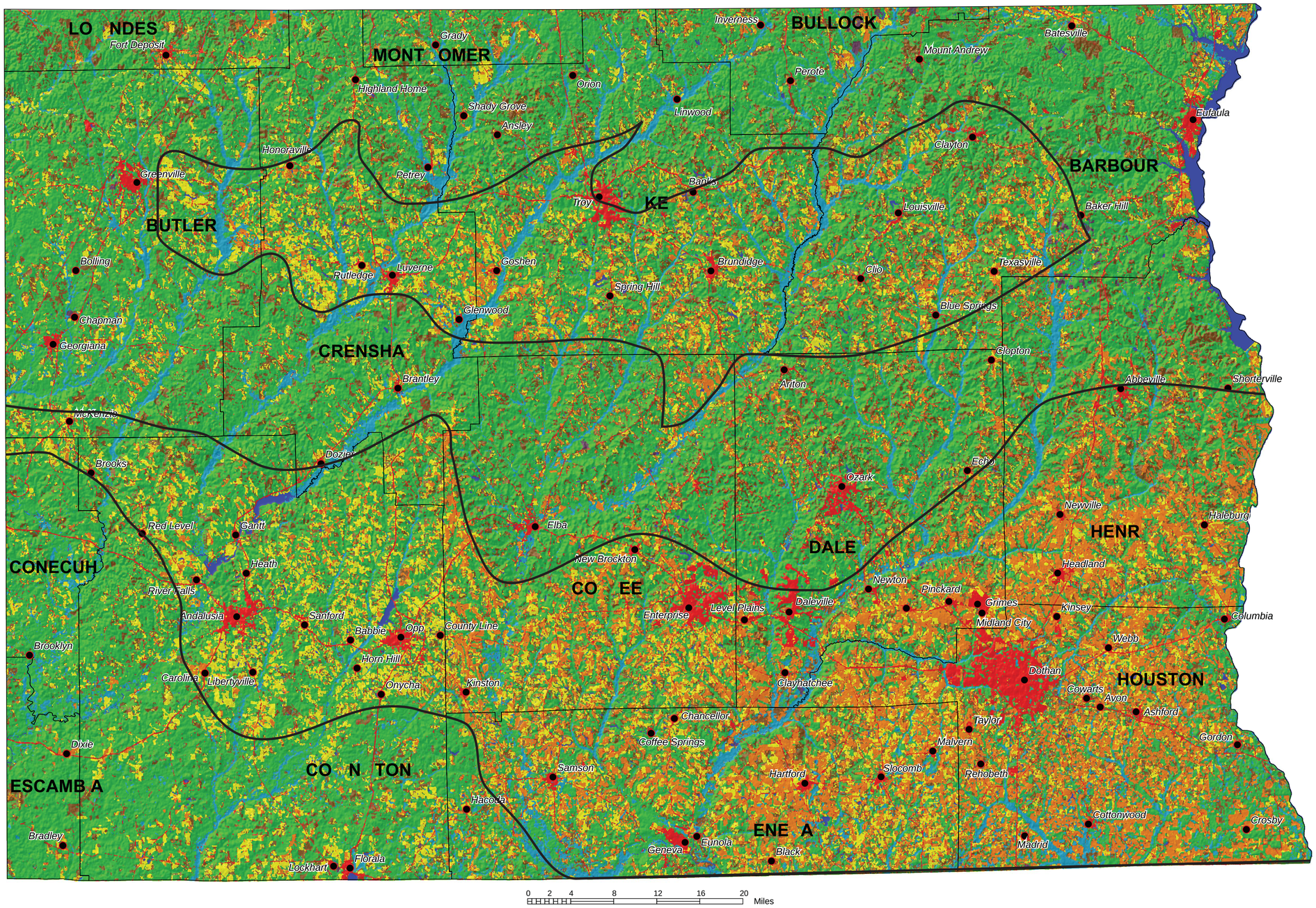
State highway

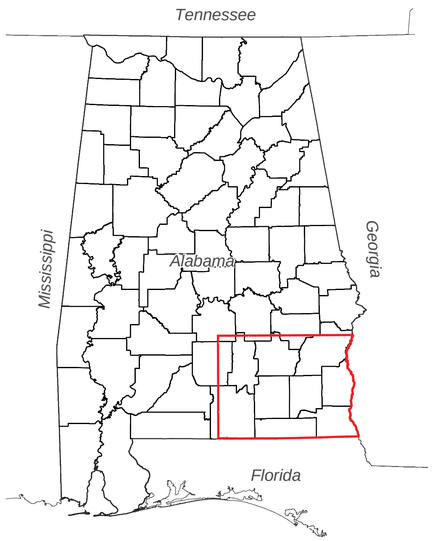
Location Map for the South East Alabama Groundwater Irrigation Assessment Area

By
Dorina Murgulet
2011

GEOLOGICAL SURVEY OF ALABAMA
Founded 1848

Berry H. (Nick) Tew, Jr.
State Geologist





Explanation

LULC classification

- Water
- Developed
- Barren
- Vegetaded; natural forested upland
- Herbaceous upland natural/seminatural (grassland/herbaceous)
- Herbaceous planted/cultivated (pasture/hay)
- Herbaceous planted/cultivated (cultivated crops)
- Wetlands
- Vegetated natural shrubland

Other symbols

- Southeast Alabama groundwater irrigation assessment area
- County boundary
- City
- Area dominated by agricultural land use

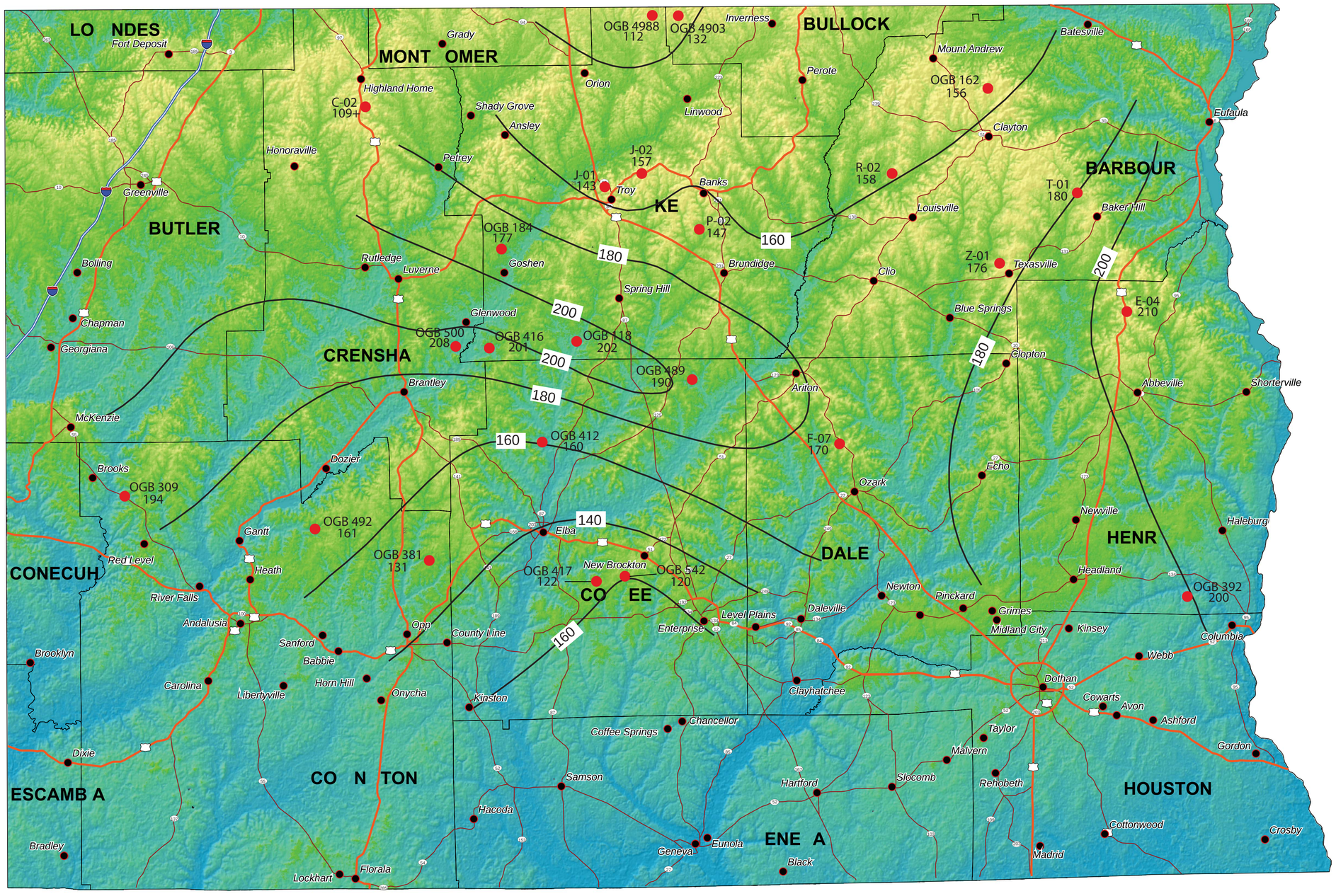
Land-Use/Land-Cover Classification for the Southeast Alabama Groundwater Irrigation Assessment Area

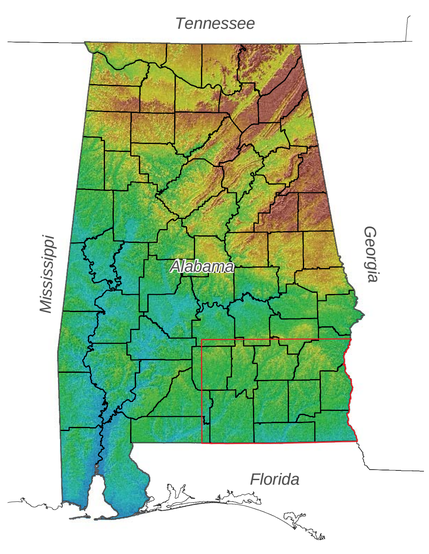
(LULC- modified from the USDA-Cropland Data Layer for Southeast States, 2010)

By
Dorina Murgulet

2011

Berry H. (Nick) Tew, Jr.
State Geologist





Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

F-07 170 Gordo well and net sand value (ft.)

Limited access interstate

Highway

Major road

Gordo line of equal net sand (contour interval 20 ft.)

Interstate highway

United States highway

State highway

Net Sand Map for the Gordo Aquifer in Southeast Alabama

By
Marlon R. Cook

2011

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Founded 1848

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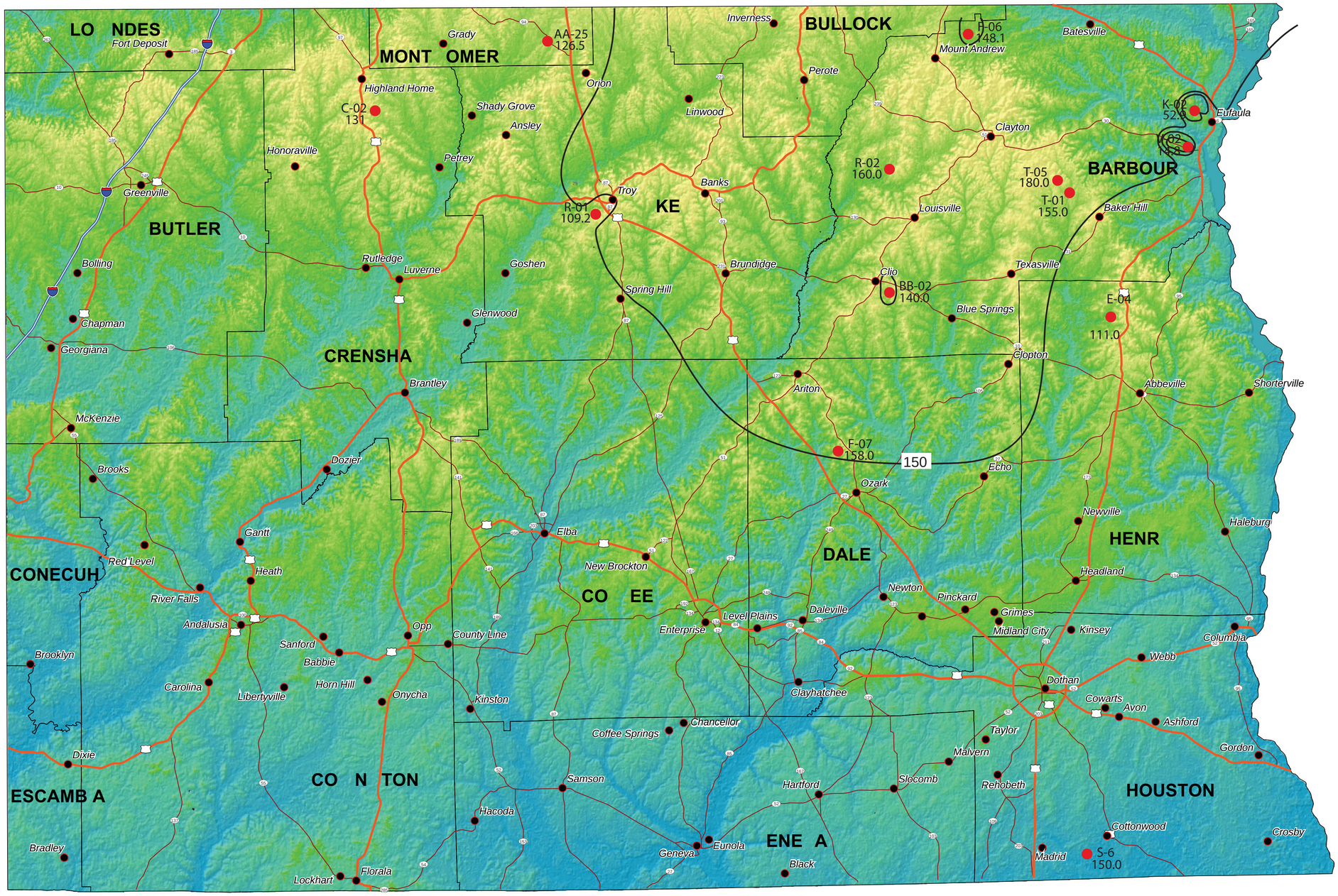
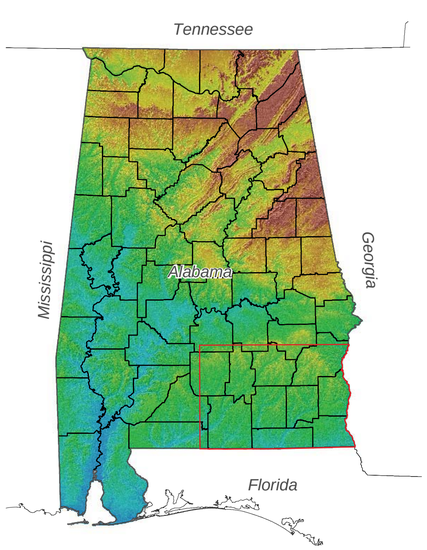
State Geologist





Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

S-6 150.0 Well and water level elevation (ft. MSL)

Interstate highway

United States highway

State highway

Line of equal water level elevation (ft. MSL) (contour interval 50 ft.)

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State Geologist

Potentiometric Surface for the Gordo Aquifer in Southeast Alabama

By
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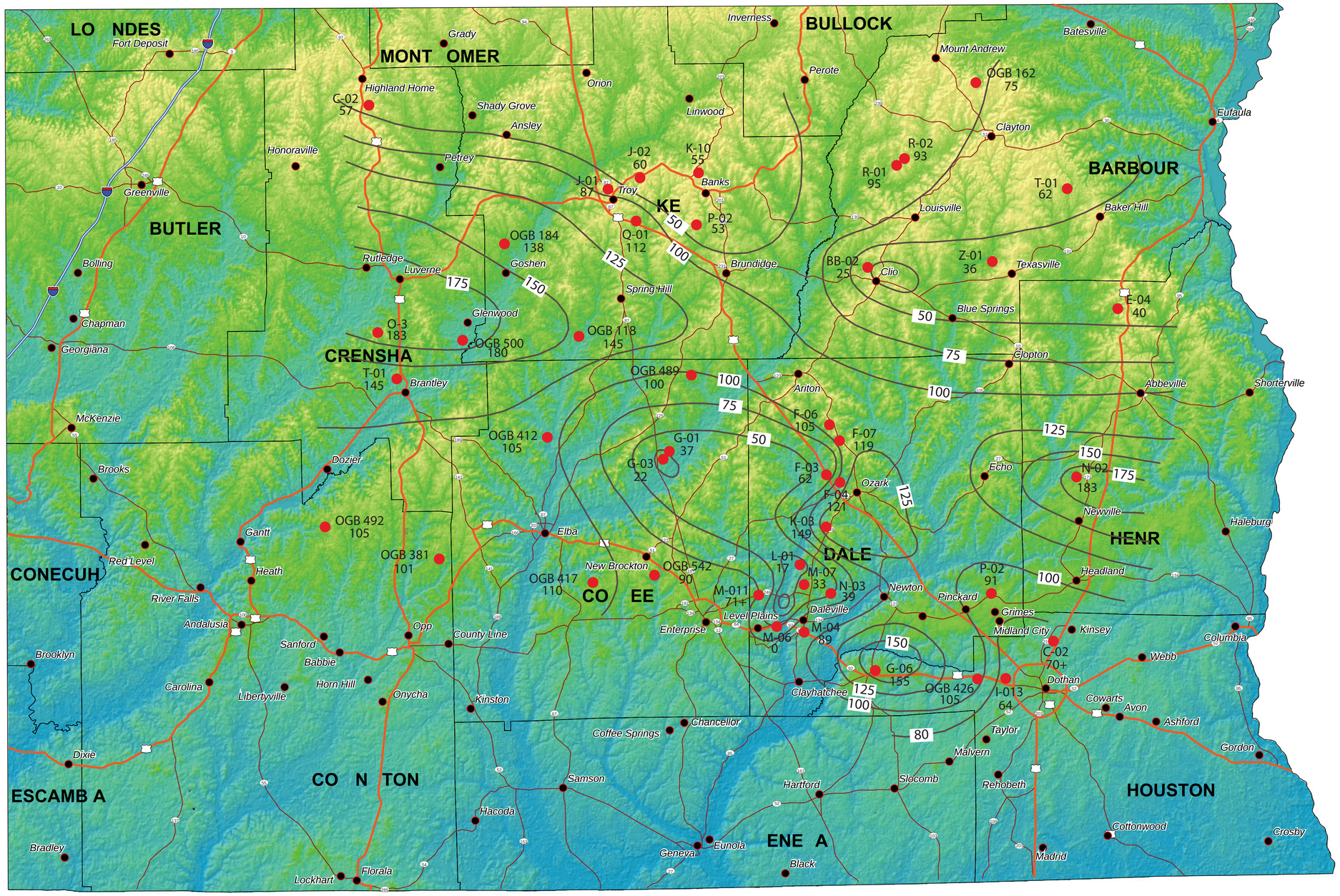

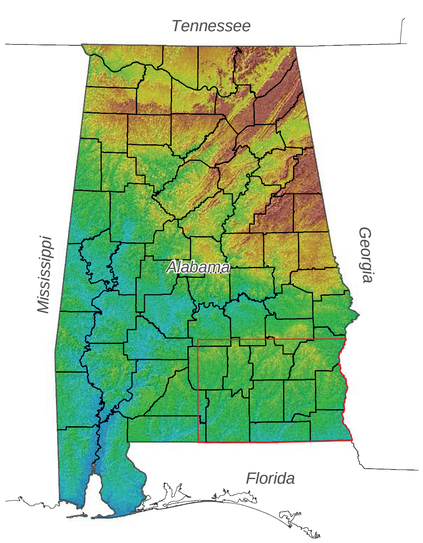

Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

N-02 183 Ripley well and net sand value (ft.)

Limited access interstate

Highway

Major road

Ripley line of equal net sand (contour interval 25 ft.)

Interstate highway

United States highway

State highway

Net Sand Map for the Ripley Aquifer in Southeast Alabama

By
Stephen P. Jennings and Marlon R. Cook

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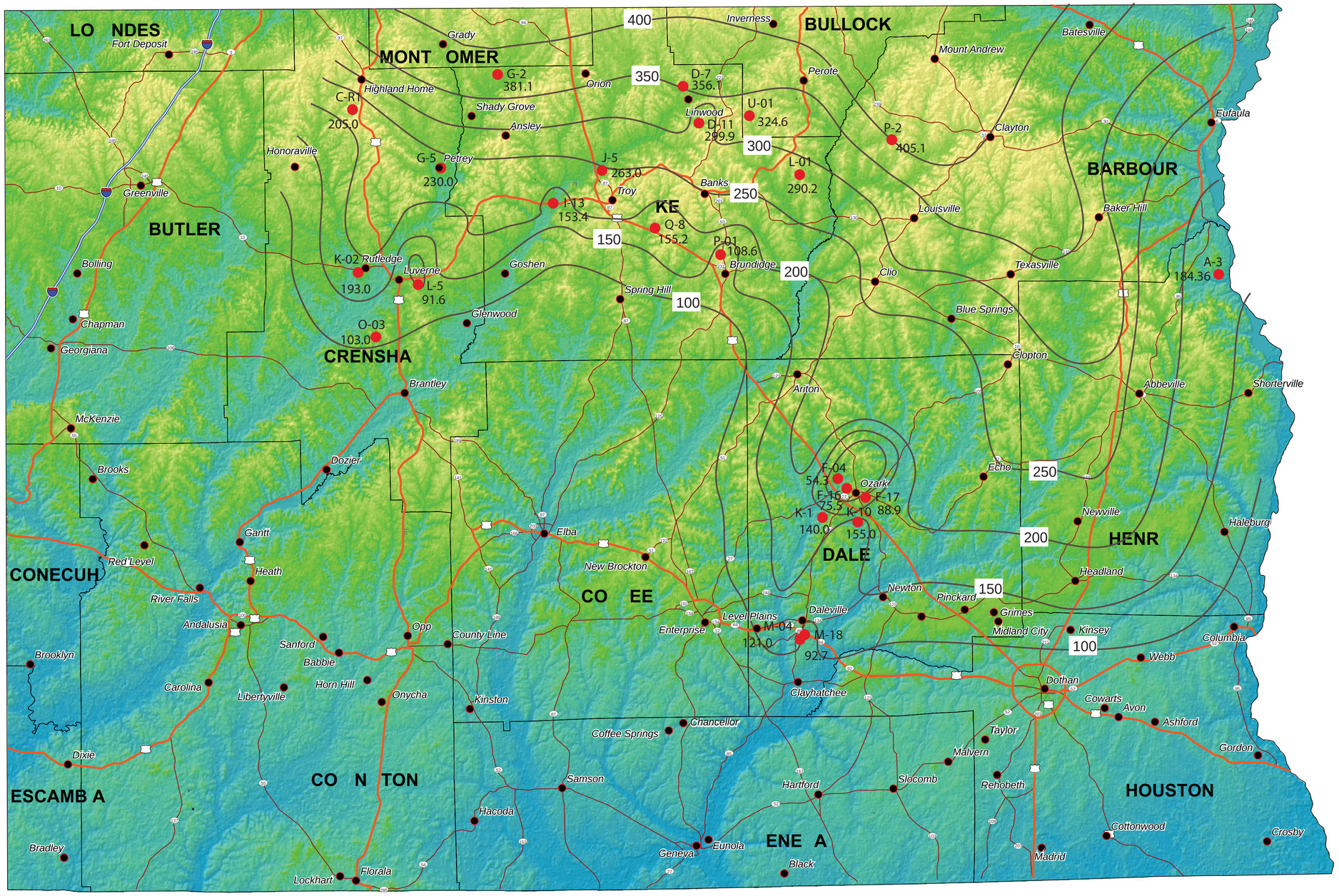

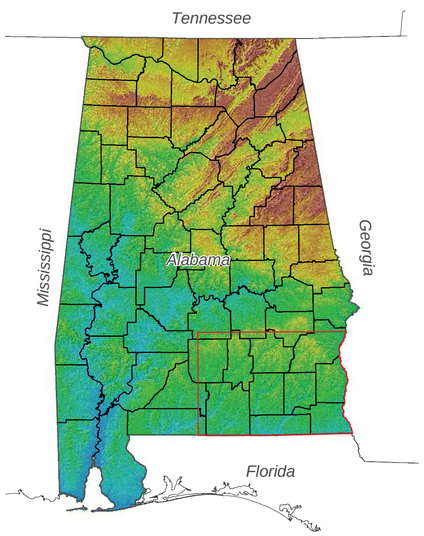

Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

K-10
155.0
Well and water level elevation (ft. MSL)

Interstate highway

United States highway

State highway

Line of equal water level elevation (ft. MSL) (contour interval 50 ft.)

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Potentiometric Surface for the Ripley Aquifer in Southeast Alabama

By
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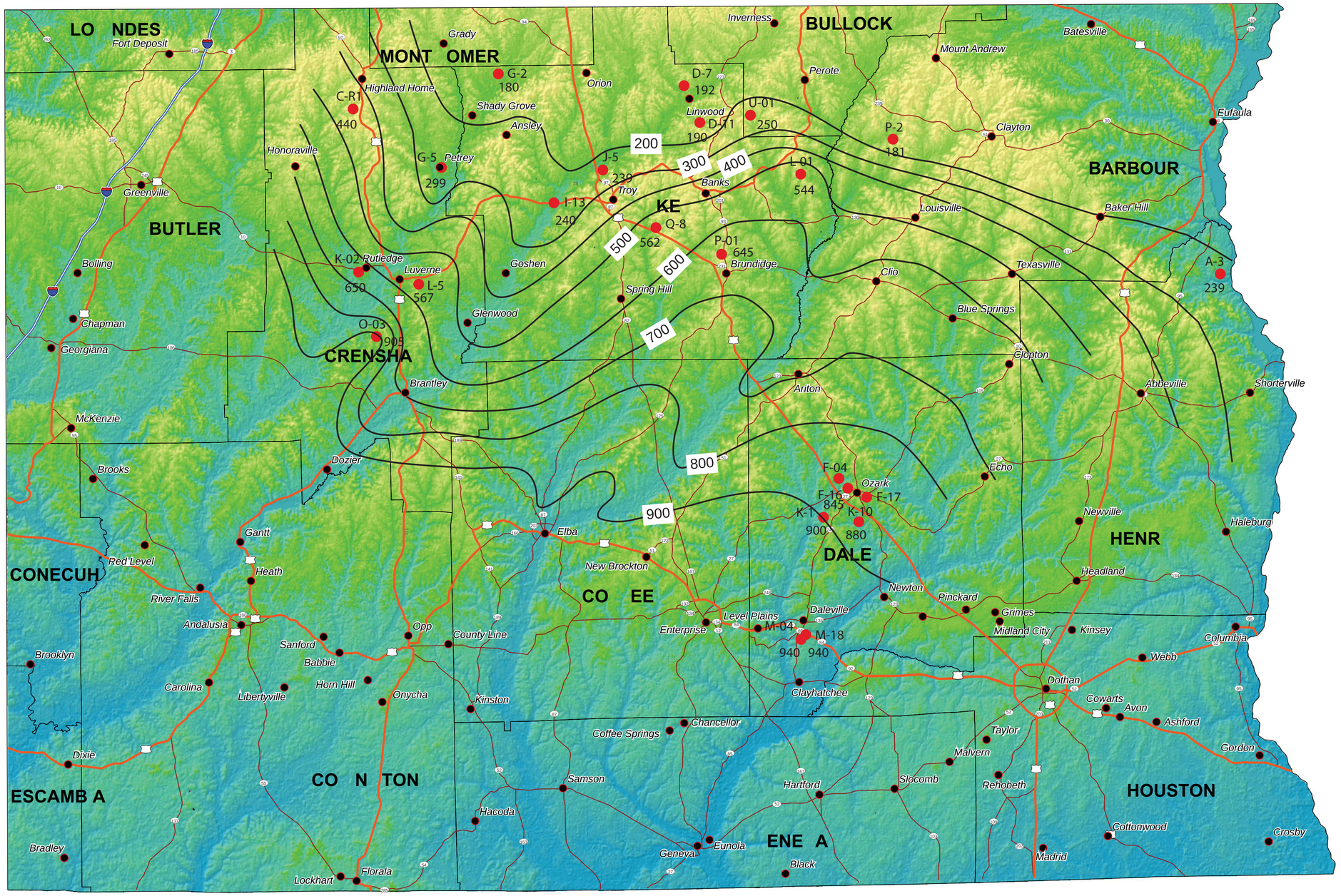

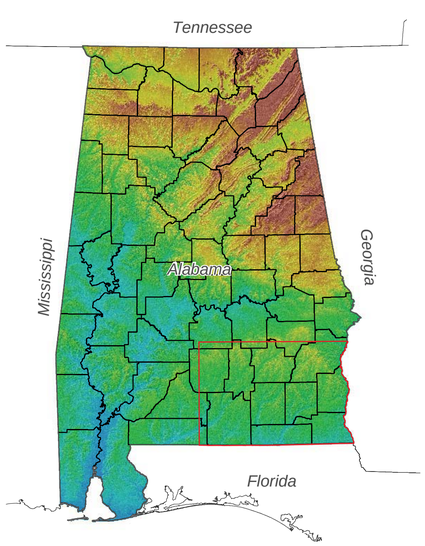

Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

K-10
880
Well and depth (ft.)

Interstate highway

United States highway

State highway

Line of equal well depth (contour interval 50 ft.)

GEOLOGICAL SURVEY OF ALABAMA
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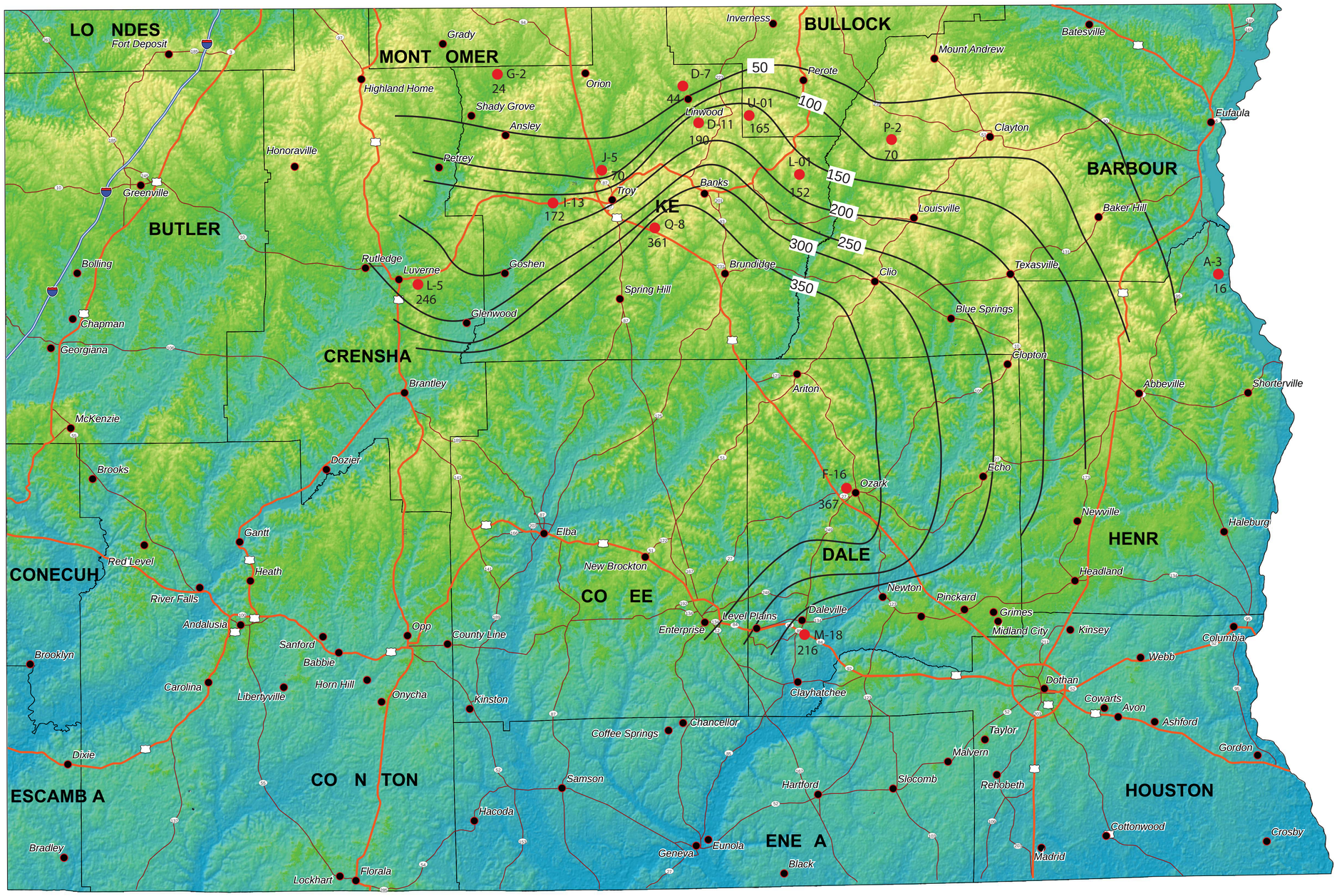
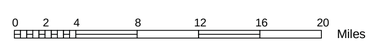
State Geologist

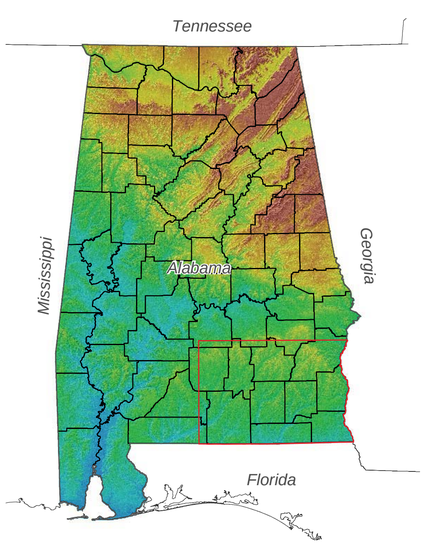
Depth of Selected Wells Constructed in the Ripley Aquifer in Southeast Alabama

By
Marlon R. Cook

2011







Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

F-16
367
Well and depth to water (ft.)

Interstate highway

United States highway

State highway

Line of equal depth to water (contour interval 50 ft.)

Depth to Groundwater in Selected Wells Constructed in the Ripley Aquifer in Southeast Alabama

By
Marlon R. Cook

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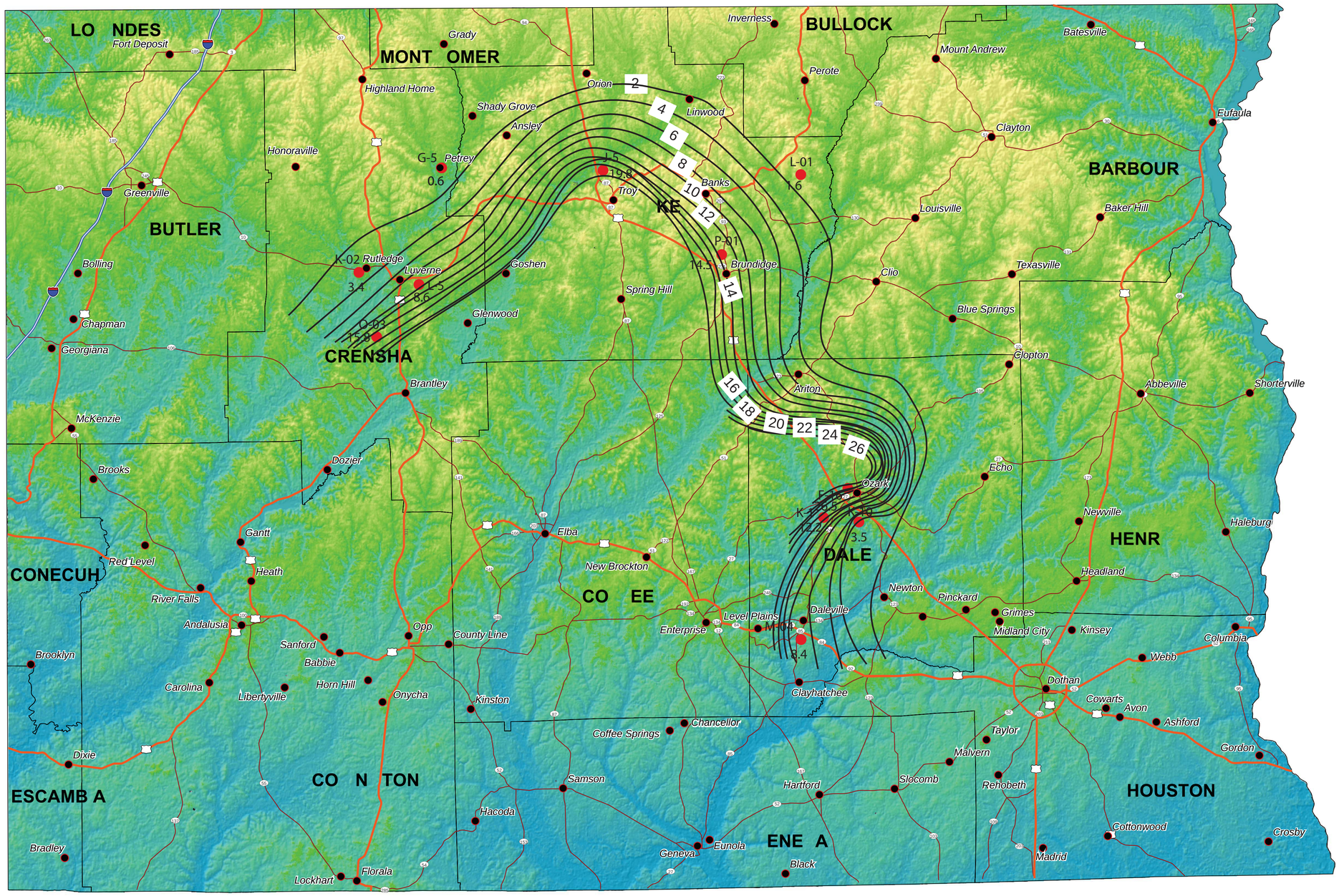
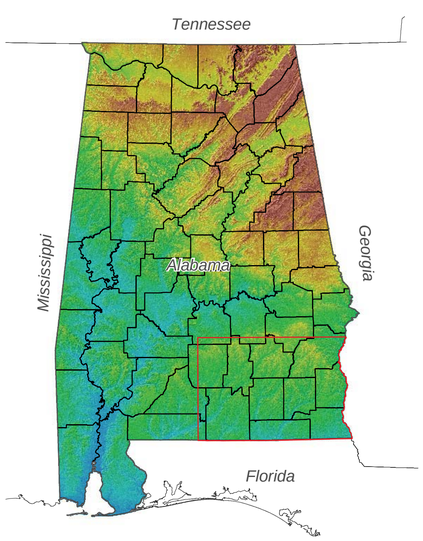
State Geologist





Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

K-10
3.5
Well and specific capacity (g/ft. drawdown)

Interstate highway

United States highway

State highway

Line of equal specific capacity (contour interval 2 g/ft. drawdown)

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Specific Capacities in Selected Wells Constructed in the Ripley Aquifer in Southeast Alabama

By
Marlon R. Cook

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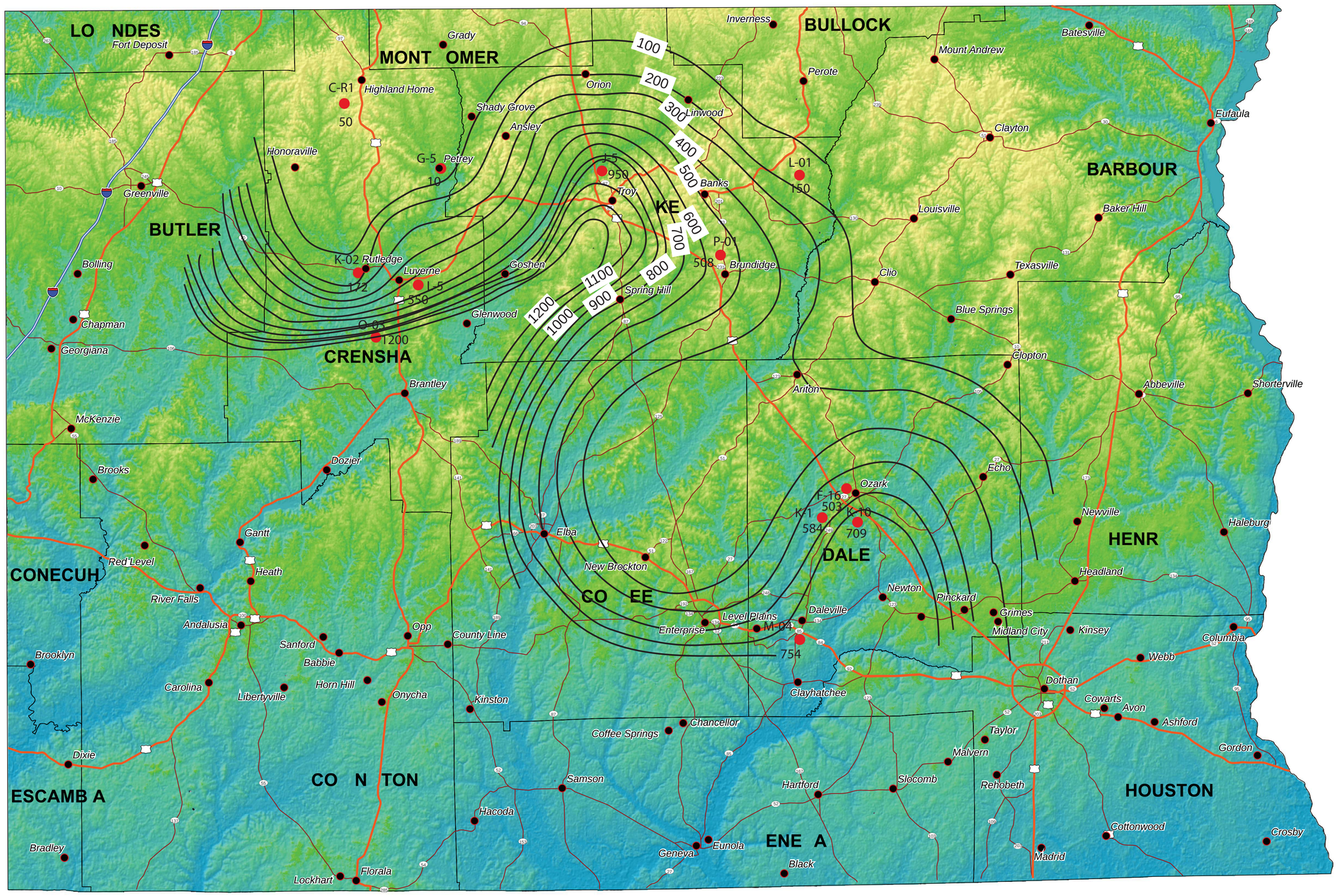

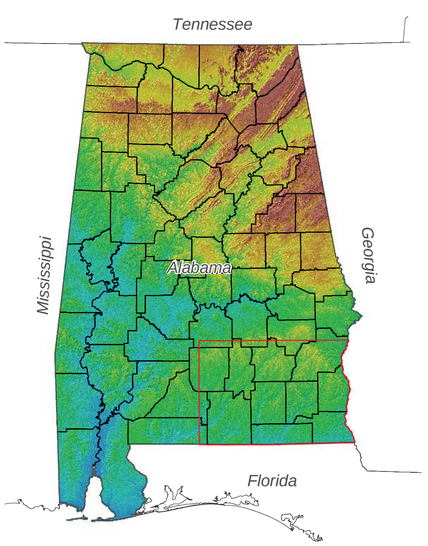

Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

K-10
709
Well and pumping rate (gpm)

Interstate highway

United States highway

State highway

Line of equal pumping rate (contour interval 100 gpm)

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State Geologist

Pumping Rates in Selected Wells Constructed in the Ripley Aquifer in Southeast Alabama

By
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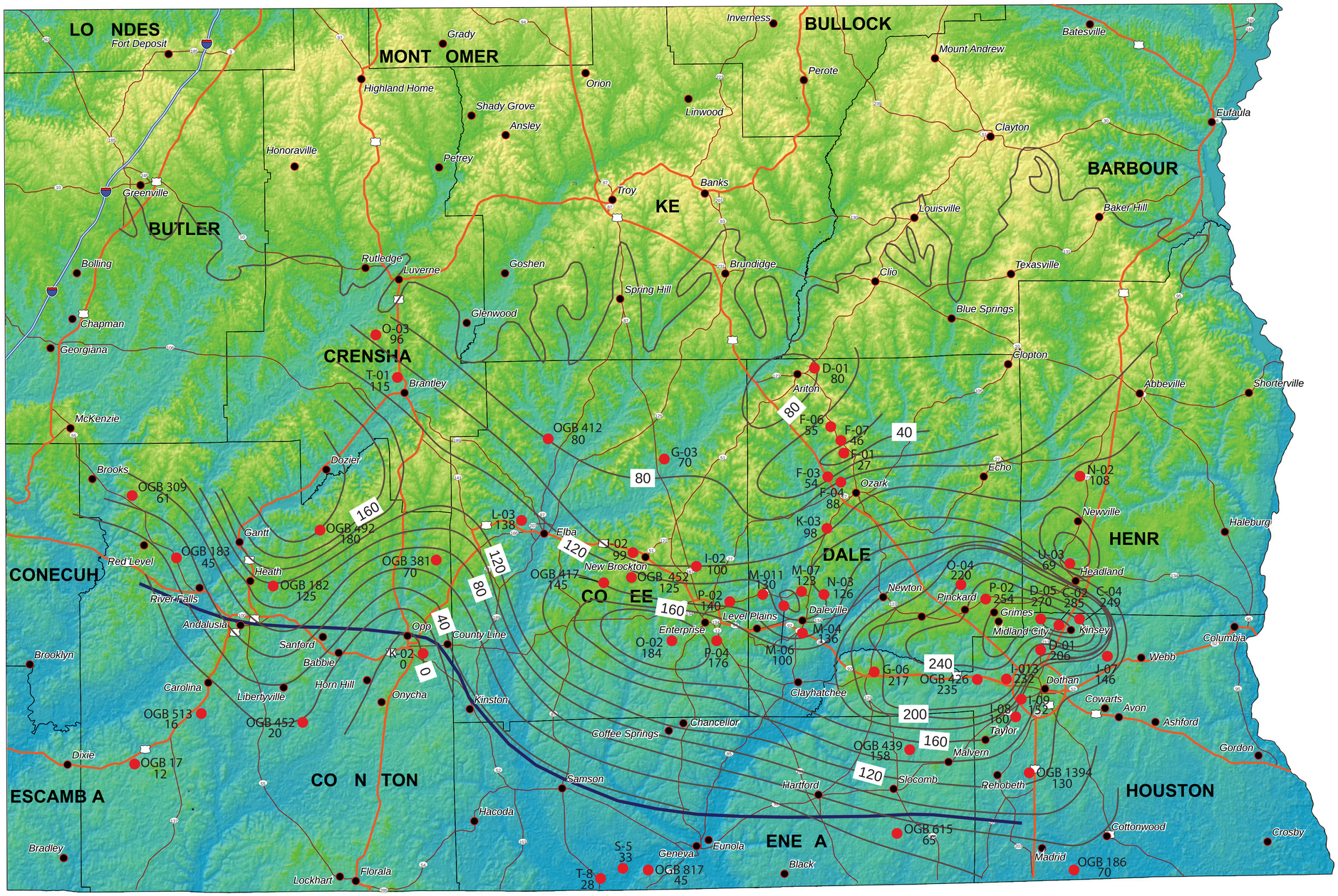

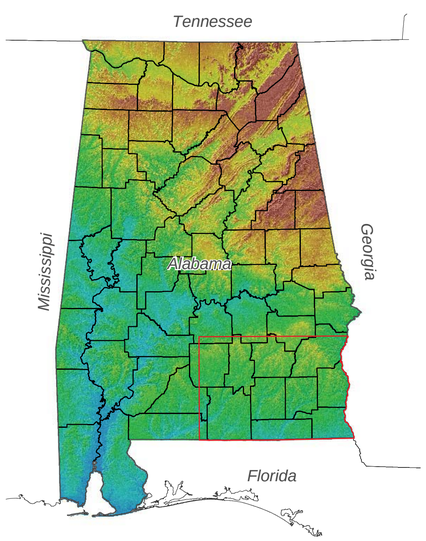

Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Downdip limit of fresh water in the Clayton aquifer

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Clayton well and net sand value (ft.)

Limited access interstate

Highway

Major road

Clayton line of equal net sand (contour interval 20 ft.)

Interstate highway

United States highway

State highway

Net Sand Map for the Clayton Aquifer in Southeast Alabama

By
Stephen P. Jennings and Marlon R. Cook
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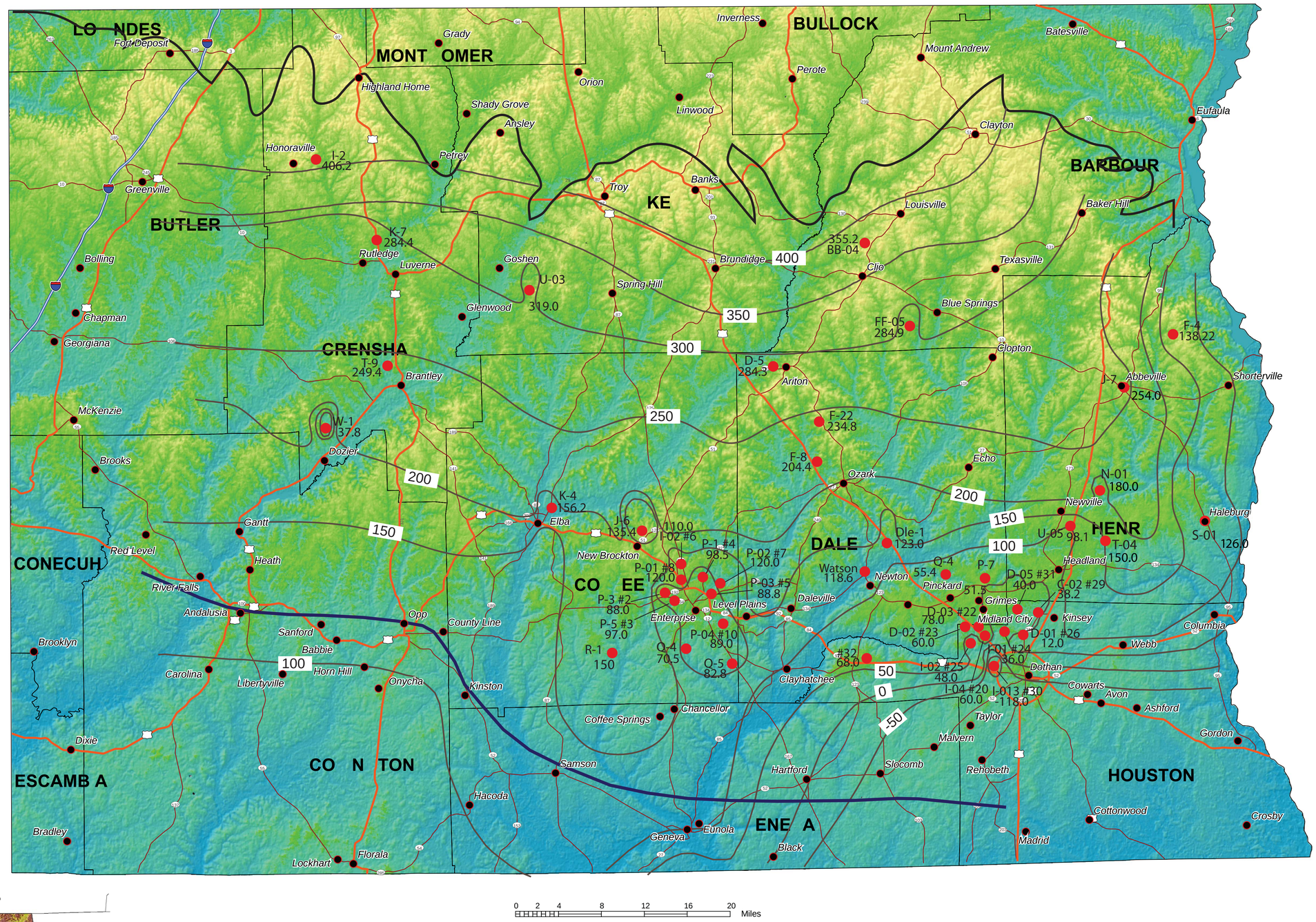

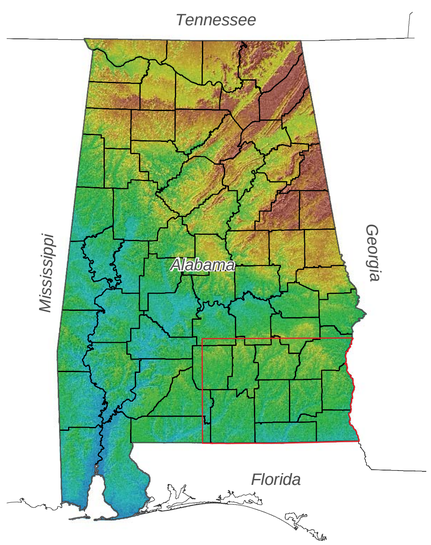

Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Downdip limit of fresh water in the Clayton aquifer

Limited access interstate

Highway

Major road

F-8 204.4 Well and water level elevation (ft. MSL)

Interstate highway

United States highway

State highway

Line of equal water level elevation (ft. MSL) (contour interval 50 ft.)

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Potentiometric Surface for the Clayton Aquifer in Southeast Alabama

By
Marlon R. Cook

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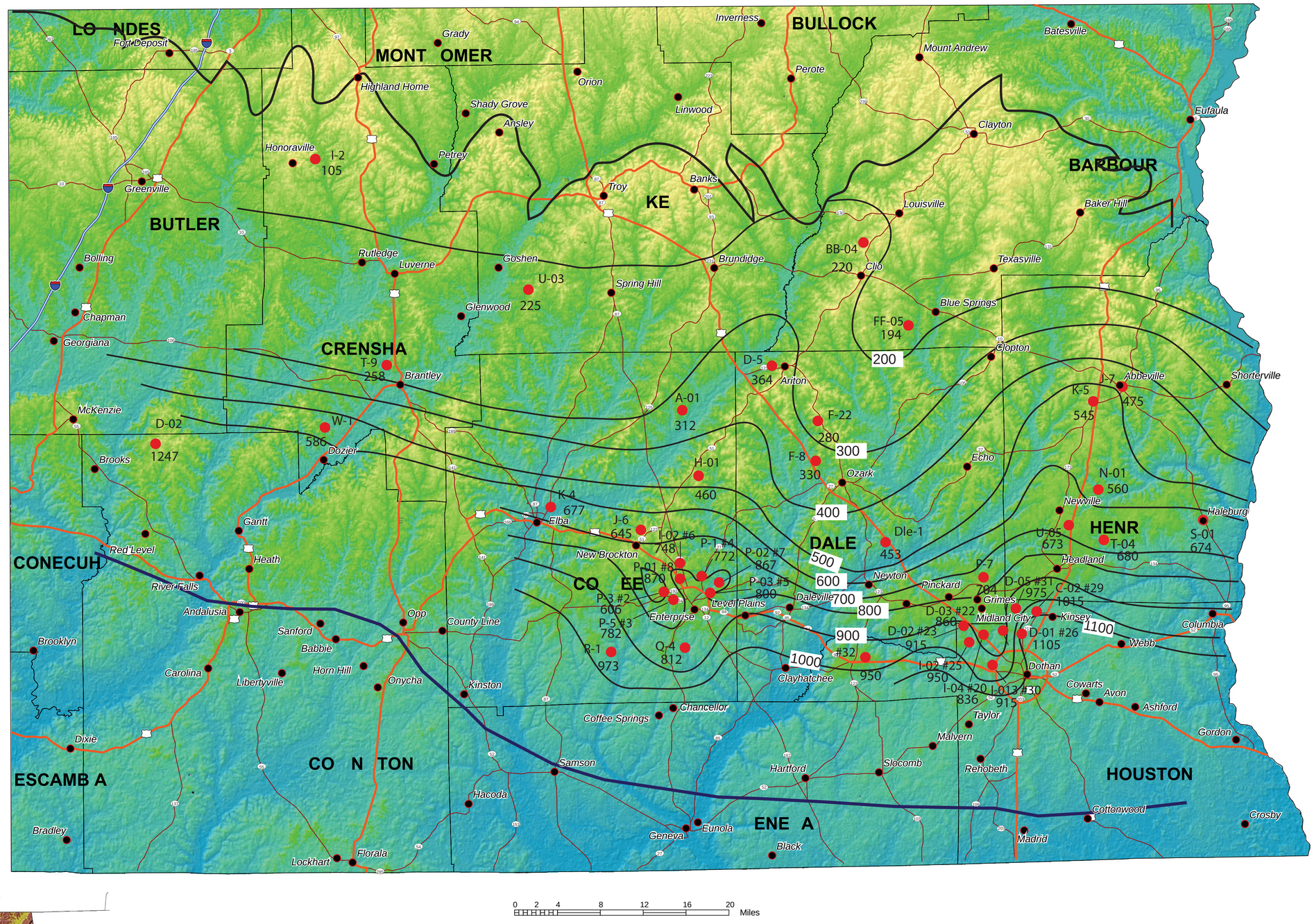
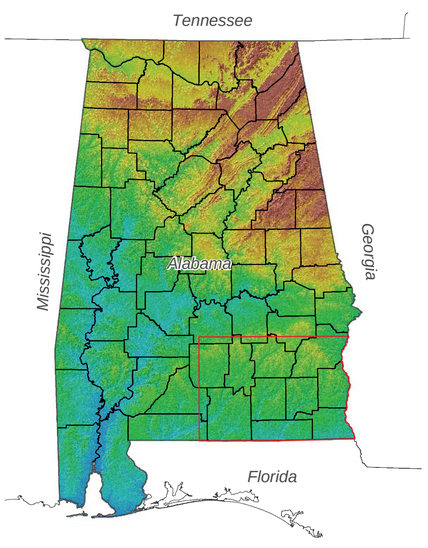


0 2 4 8 12 16 20 Miles



Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Downdip limit of fresh water in the Clayton aquifer

Limited access interstate

Highway

Major road

R-1 973 Well and depth (ft.)

Interstate highway

United States highway

State highway

Line of equal well depth (contour interval 100 ft.)

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State Geologist

Depth of Selected Wells Constructed in the Clayton Aquifer in Southeast Alabama

By
Marlon R. Cook

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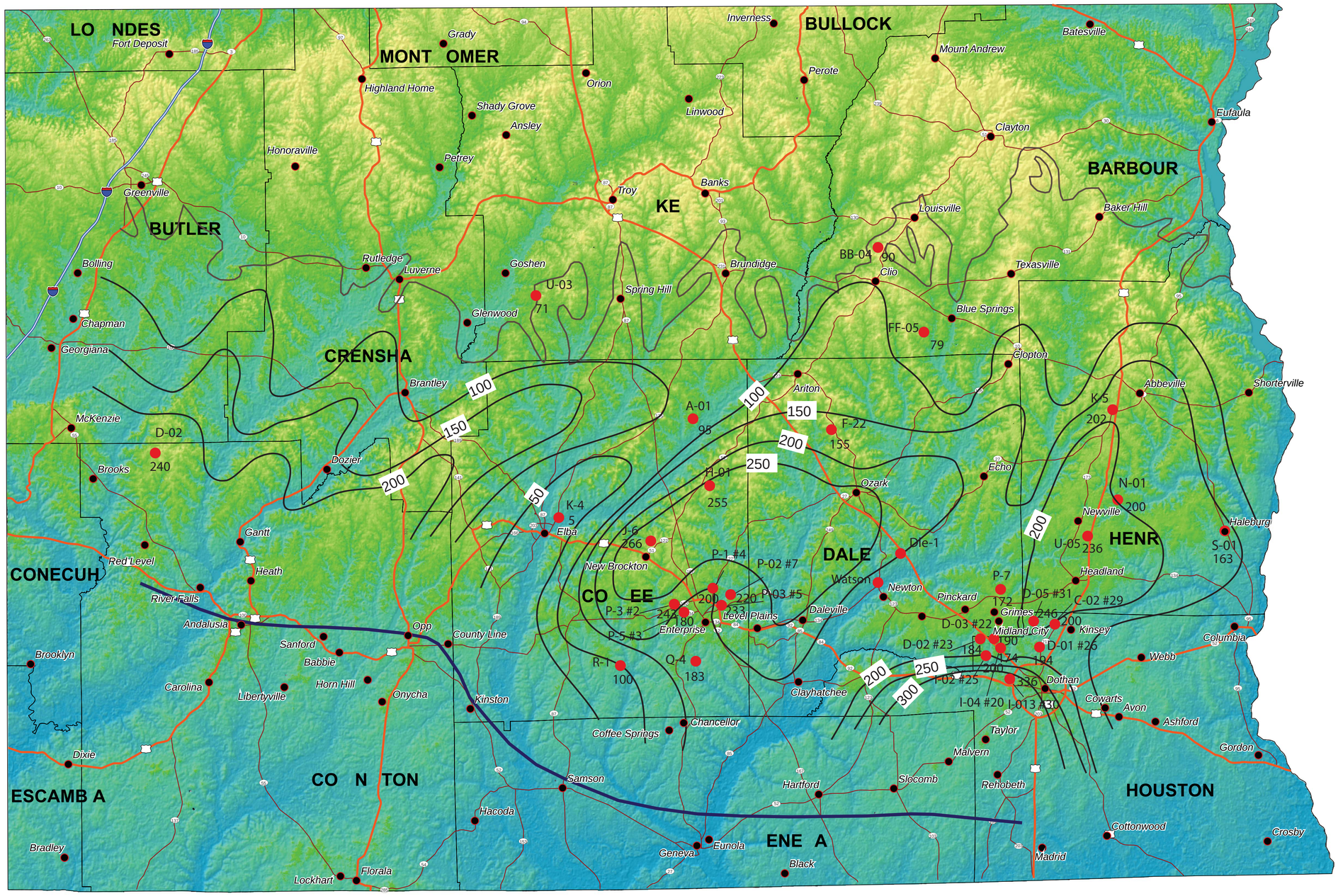
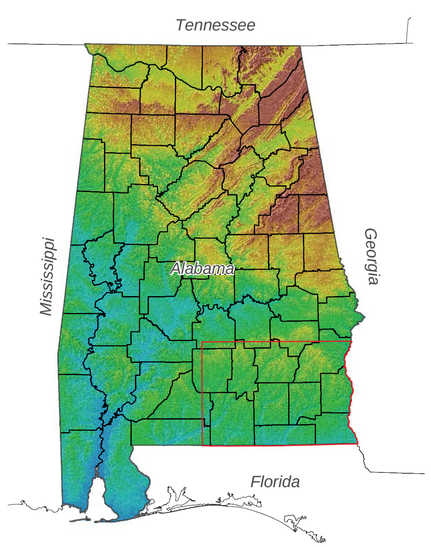




Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Downdip limit of fresh water in the Clayton aquifer

Limited access interstate

Highway

Major road

Q-4
183
Well and depth to water (ft.)

Interstate highway

United States highway

State highway

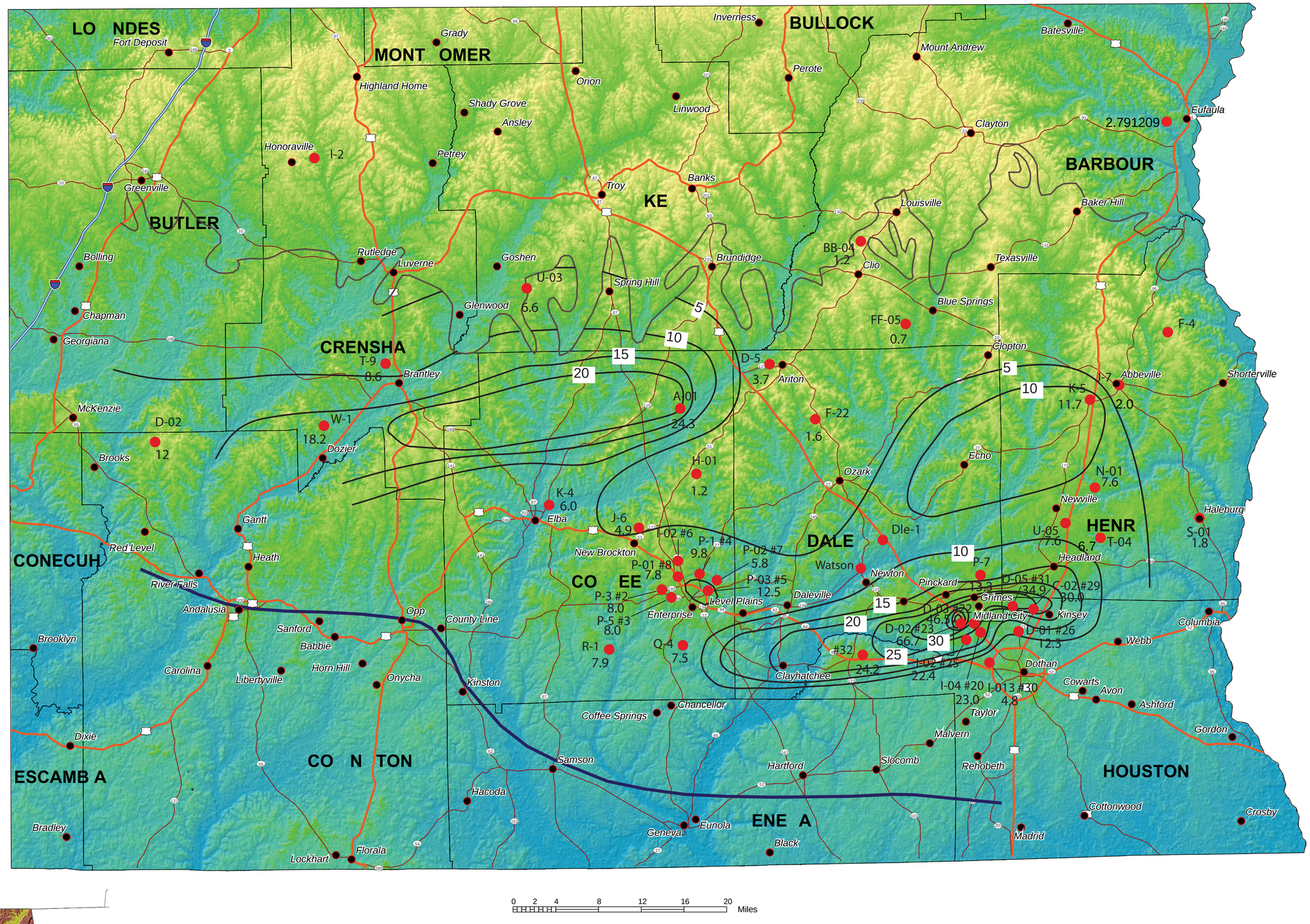
Line of equal depth to water (contour interval 50 ft.)

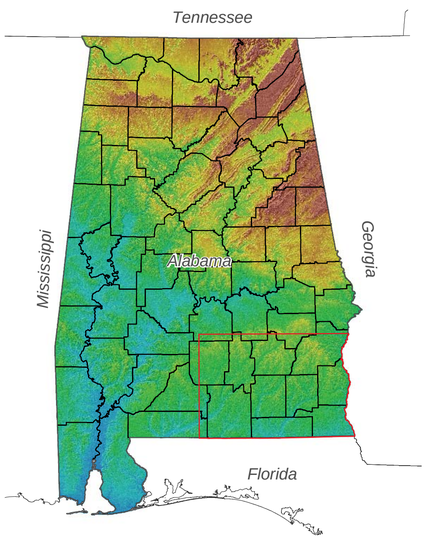
Berry H. (Nick) Tew, Jr.
State Geologist

Depth to Groundwater in Selected Wells Constructed in the Clayton Aquifer in Southeast Alabama

By
Marlon R. Cook

2011





Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Downdip limit of fresh water in the Clayton aquifer

Limited access interstate

Highway

Major road

Q-4 7.5 Well and specific capacity (gpm/ft. drawdown)

Interstate highway

United States highway

State highway

Line of equal specific capacity (contour interval 5 gpm/ft. drawdown)

Specific Capacities in Selected Wells Constructed in the Clayton Aquifer in Southeast Alabama

By
Marlon R. Cook

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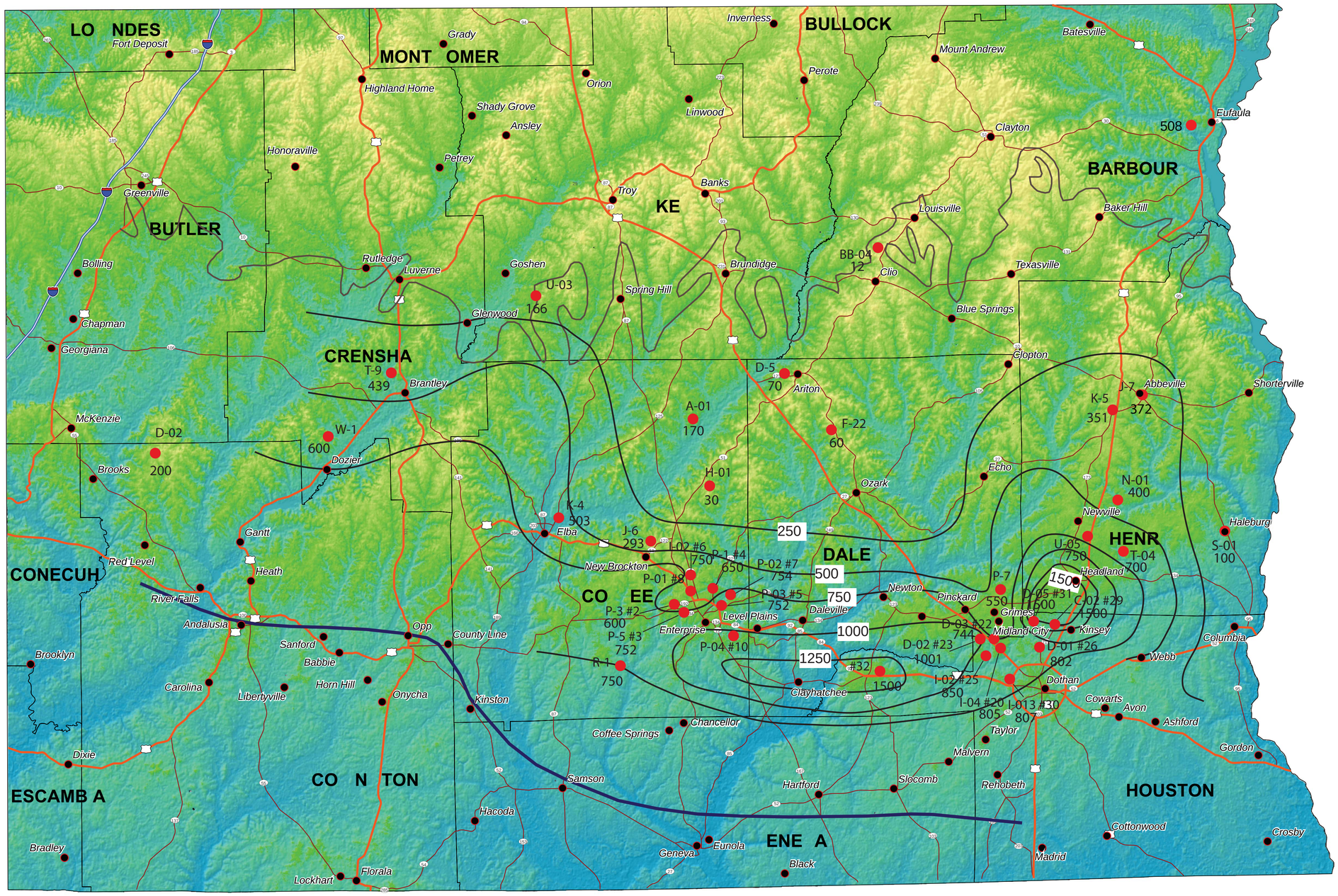
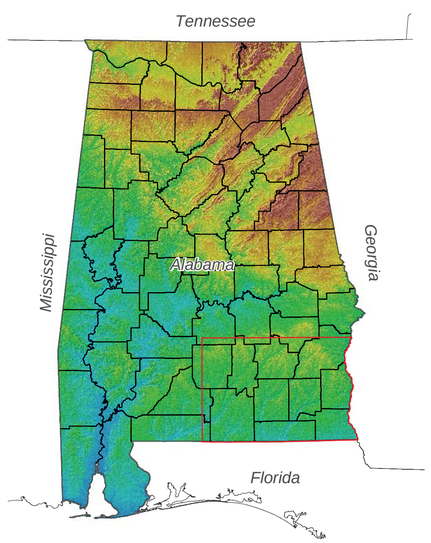
State Geologist



0 2 4 8 12 16 20 Miles



Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Downdip limit of fresh water in the Clayton aquifer

Limited access interstate

Highway

Major road

N-01 400 Well and pumping rate (gpm)

Interstate highway

United States highway

State highway

Line of equal pumping rate (contour interval 250 gpm)

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State Geologist

Pumping Rates in Selected Wells Constructed in the Clayton Aquifer in Southeast Alabama

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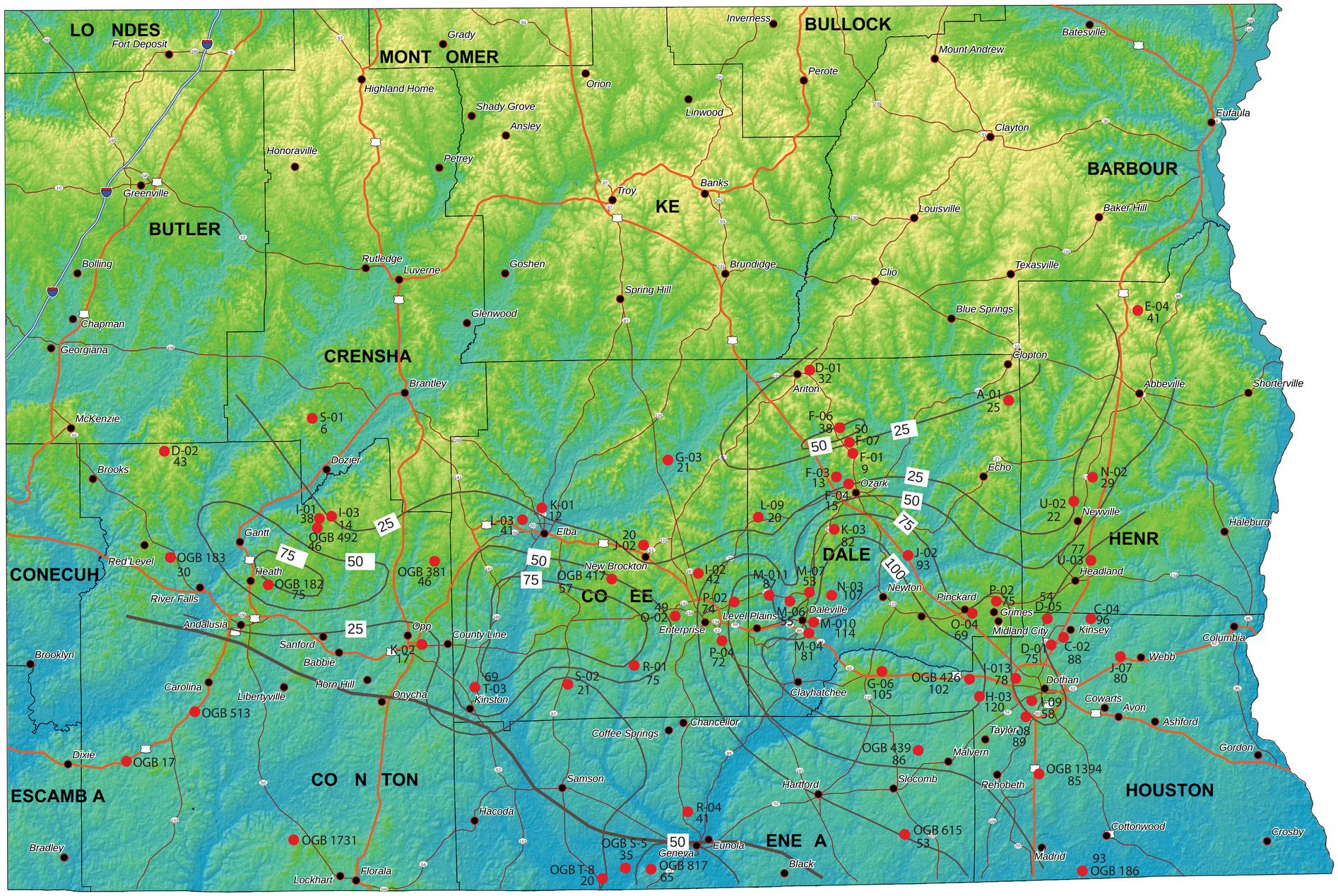

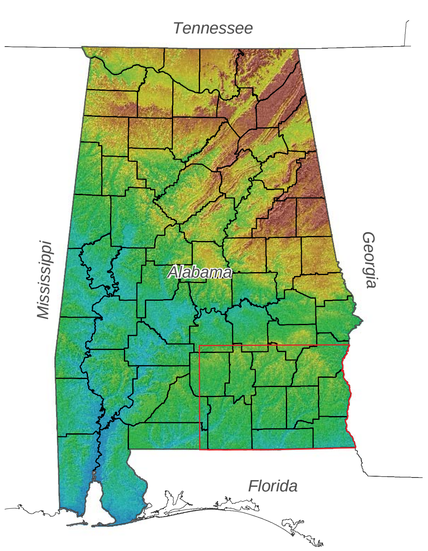

Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Downdip limit of fresh water in the Clayton aquifer

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

R-01 75 Nanafalia well and net productive interval value (ft.)

Limited access interstate

Highway

Major road

Nanafalia line of equal net productive interval (contour interval 25 ft.)

Interstate highway

United States highway

State highway

Net Productive Interval Map for the Nanafalia Aquifer in Southeast Alabama

By
Stephen P. Jennings and Marlon R. Cook

2011

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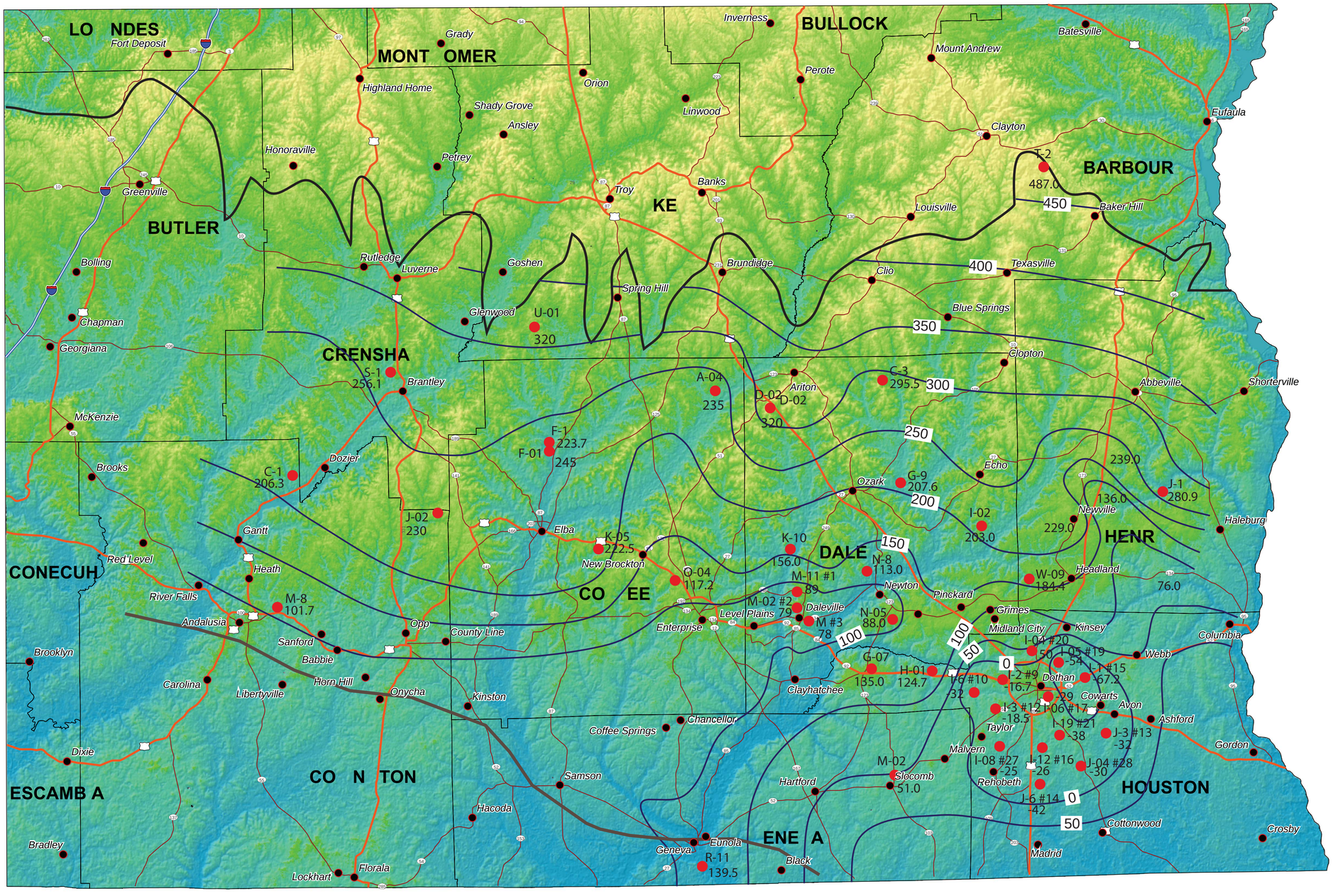
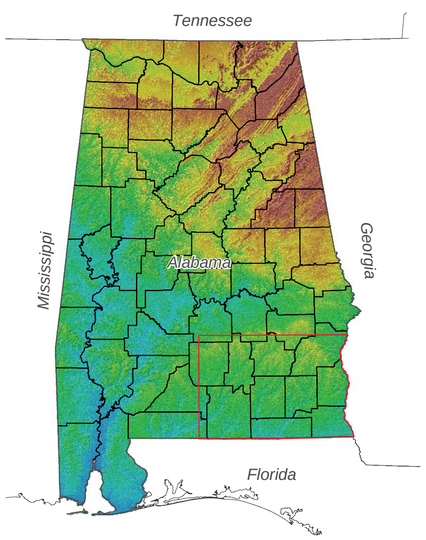
State Geologist





Explanation

Elevation in feet above NGVD 1929
- High : 715
- Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Downdip limit of fresh water in the Nanafalia aquifer

Limited access interstate

Highway

Major road

R-11 139.5 Well and water level elevation (ft. MSL)

Interstate highway

United States highway

State highway

Line of equal water level elevation (ft. MSL) (contour interval 50 ft.)

Potentiometric Surface for the Nanafalia Aquifer in Southeast Alabama

By
Marlon R. Cook

2011

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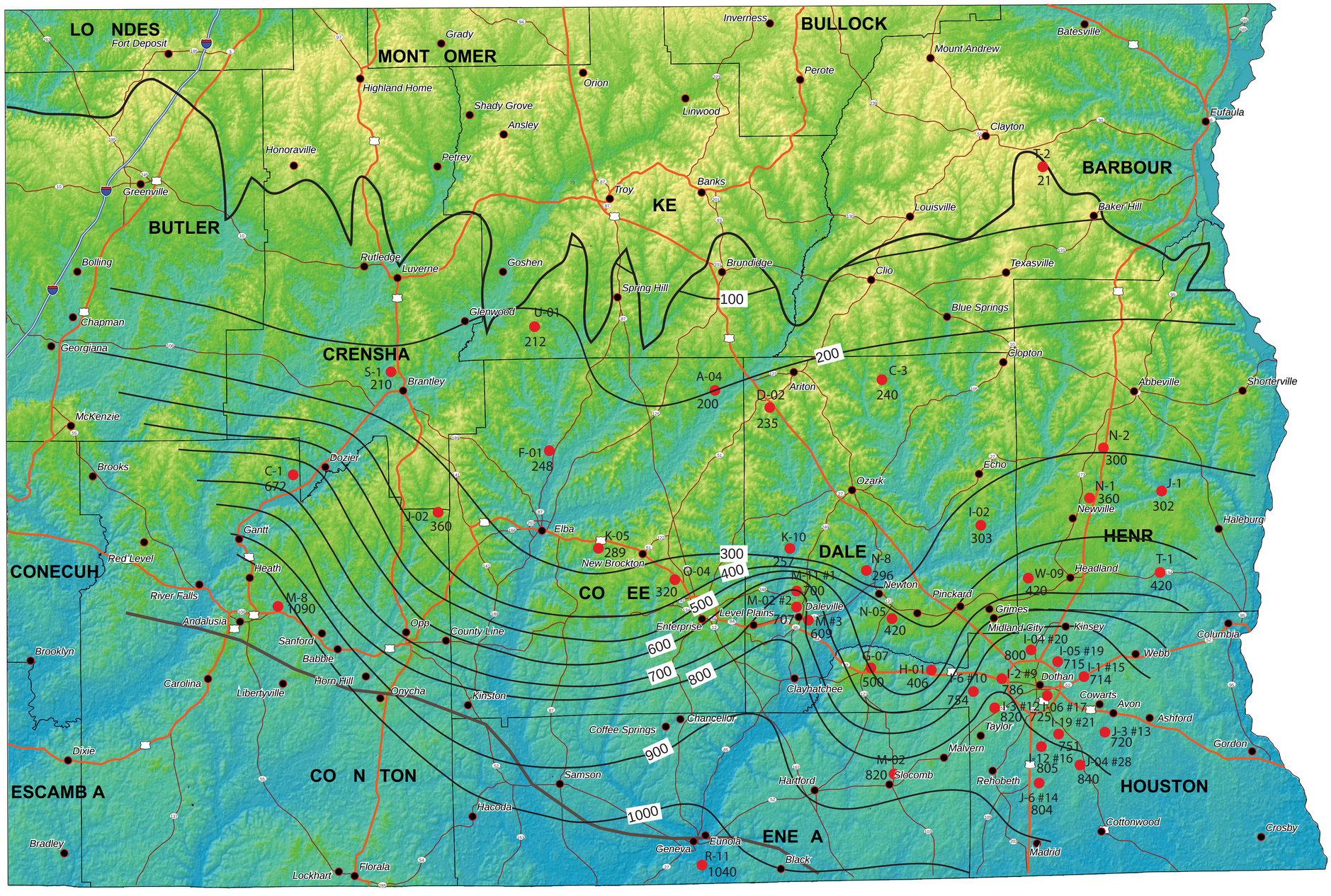
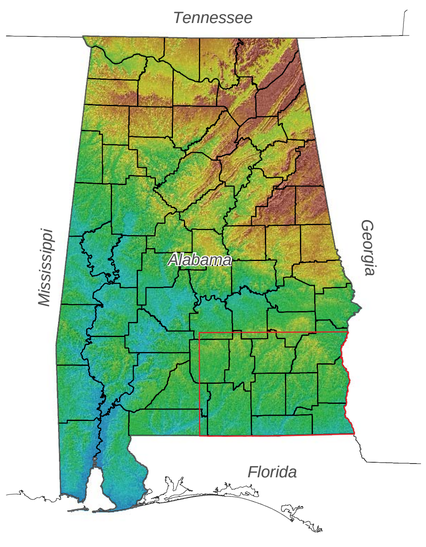
State Geologist





0 2 4 8 12 16 20 Miles

Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Downdip limit of fresh water in the Nanafalia aquifer

Limited access interstate

Highway

Major road

R-11 1040 Well and depth (ft.)

Interstate highway

United States highway

State highway

Line of equal well depth (contour interval 100 ft.)

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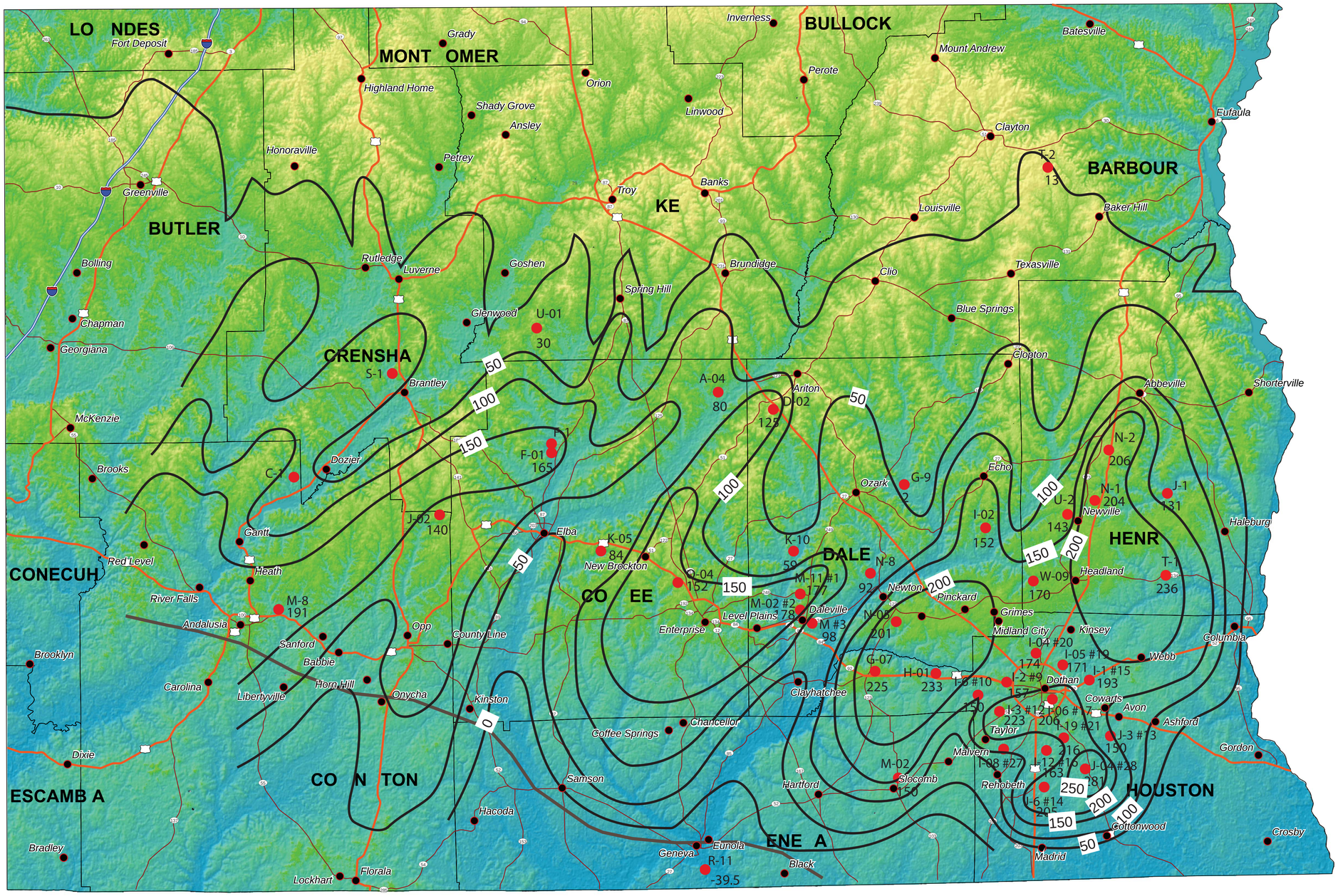
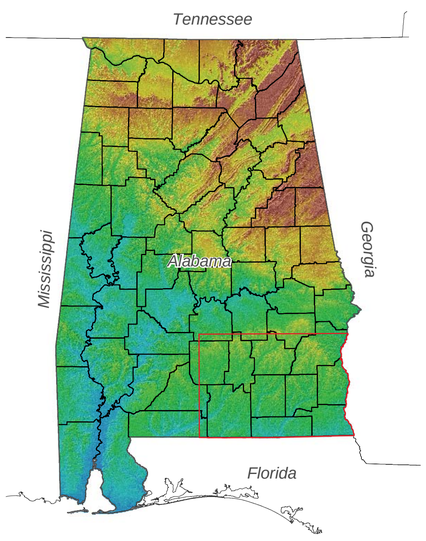
Berry H. (Nick) Tew, Jr.
State Geologist

Depth of Selected Wells Constructed in the Nanafalia Aquifer in Southeast Alabama

By
Marlon R. Cook
2011





Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Downdip limit of fresh water

Limited access interstate

Highway

Major road

I-02
152
Well and depth to water (ft.)

Interstate highway

United States highway

State highway

Line of equal depth to water (contour interval 50 ft.)

Depth to Groundwater in Selected Wells Constructed in the Nanafalia Aquifer in Southeast Alabama

By
Marlon R. Cook
2011

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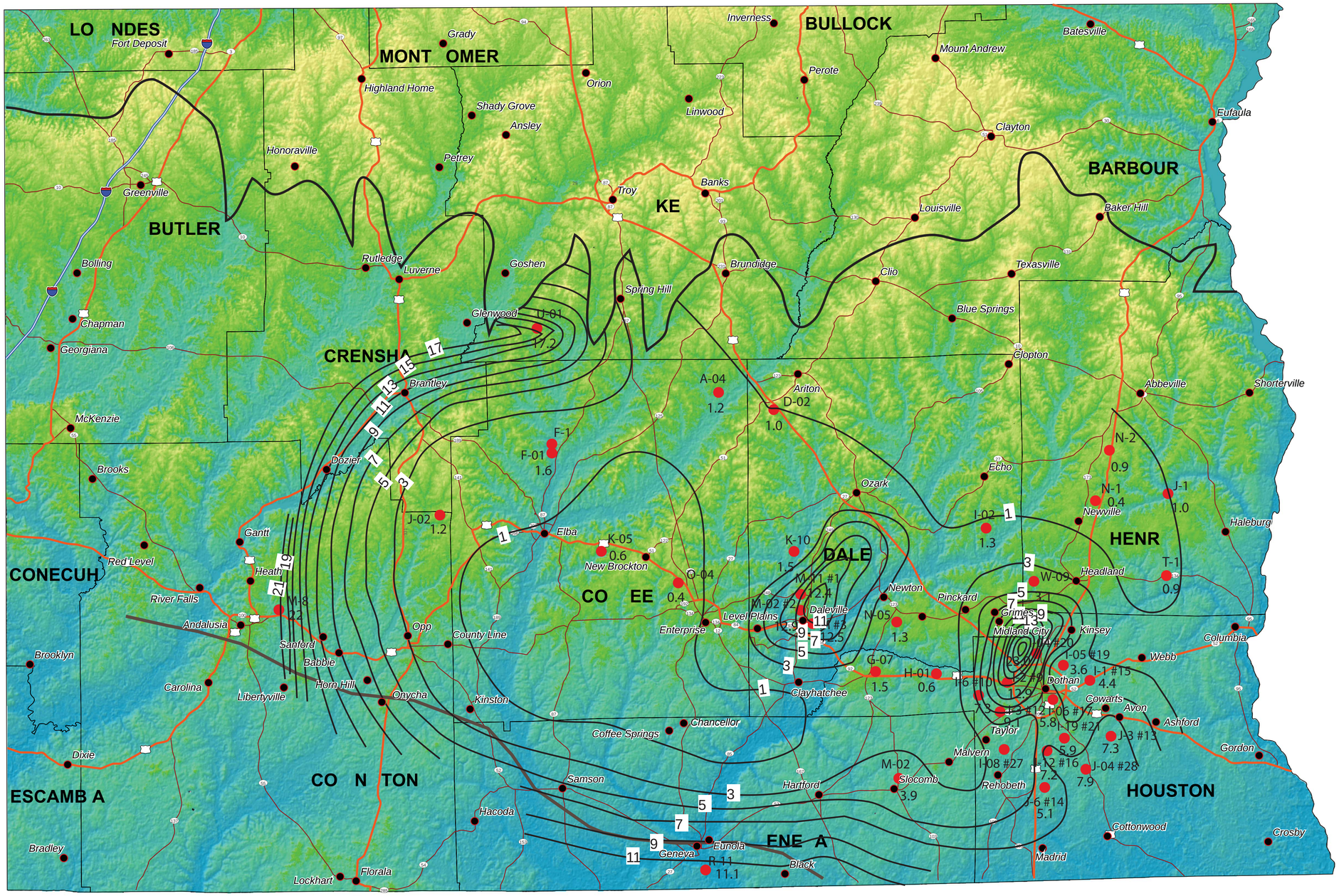
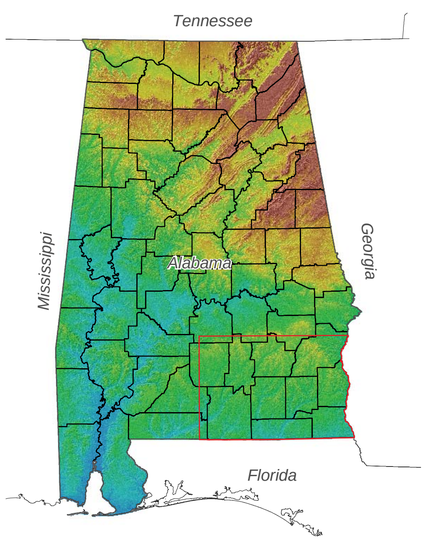
Founded 1848

Berry H. (Nick) Tew, Jr.
State Geologist





Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Downdip limit of fresh water in the Nanafalia aquifer

Limited access interstate

Highway

Major road

M-02
3.9
Well and specific capacity (gpm/ft. drawdown)

Interstate highway

United States highway

State highway

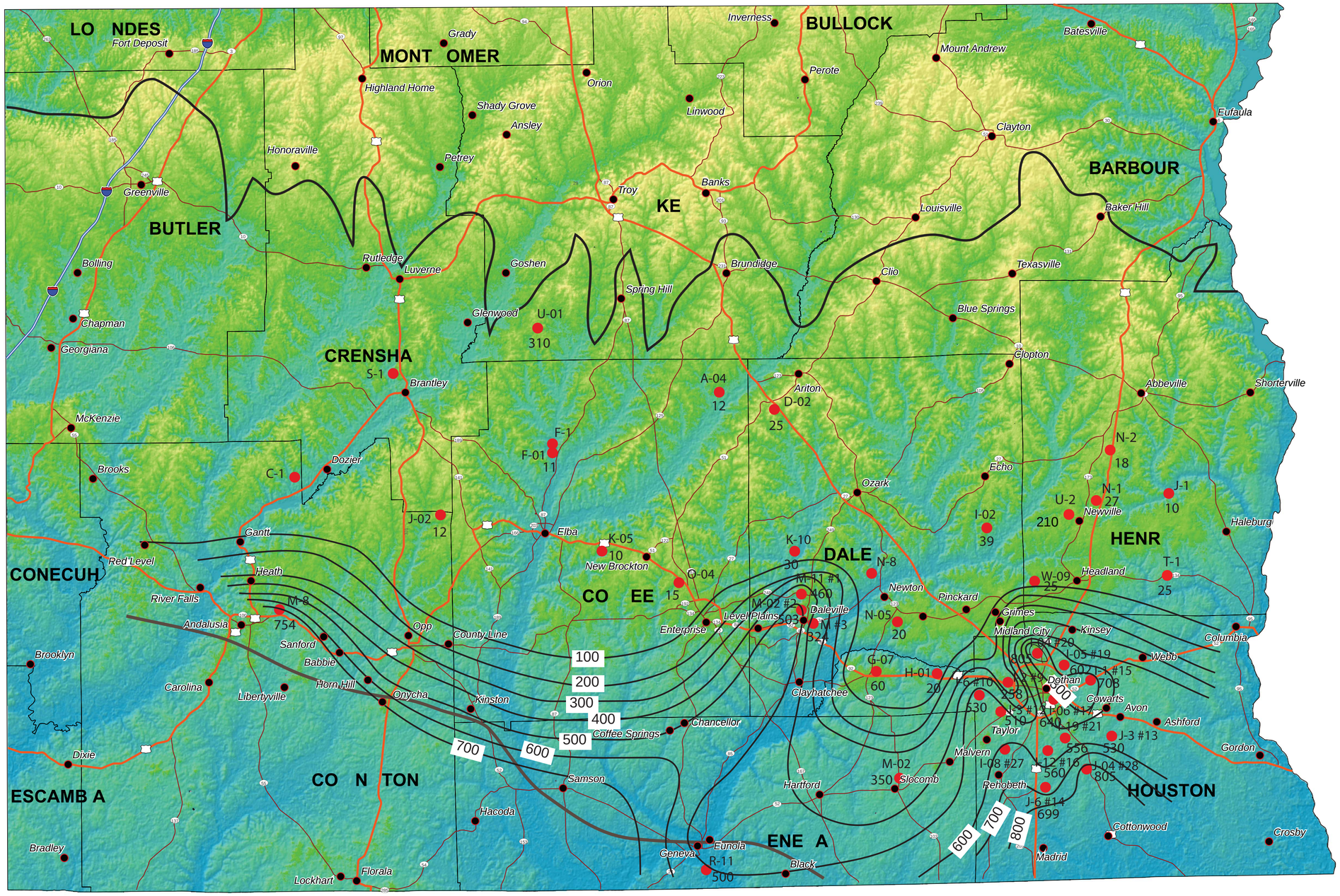
Line of equal specific capacity (contour interval 5 gpm/ft. drawdown)

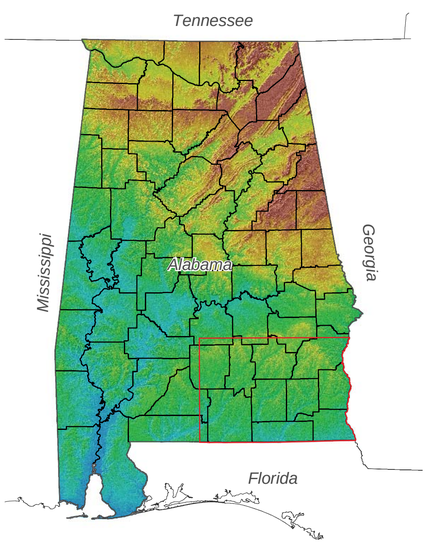
Berry H. (Nick) Tew, Jr.
State Geologist

Specific Capacities in Selected Wells Constructed in the Nanafalia Aquifer in Southeast Alabama

By
Marlon R. Cook

2011





Explanation

Elevation in feet above NGVD 1929
- High : 715
- Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Downdip limit of fresh water in the Nanafalia aquifer

Limited access interstate

Highway

Major road

R-11 500 Well and pumping rate (gpm)

Interstate highway

United States highway

State highway

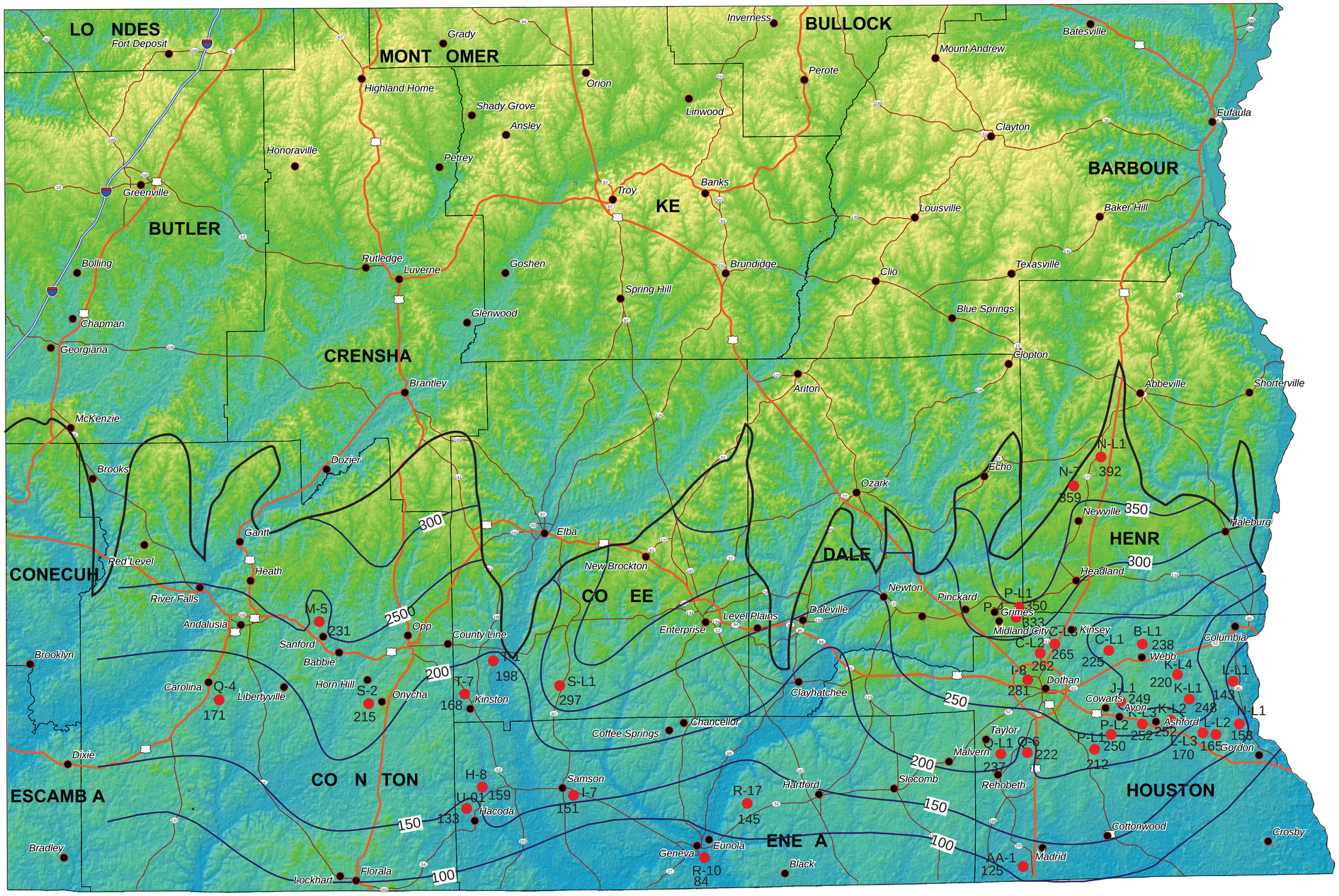
Line of equal pumping rate (contour interval 100 gpm)

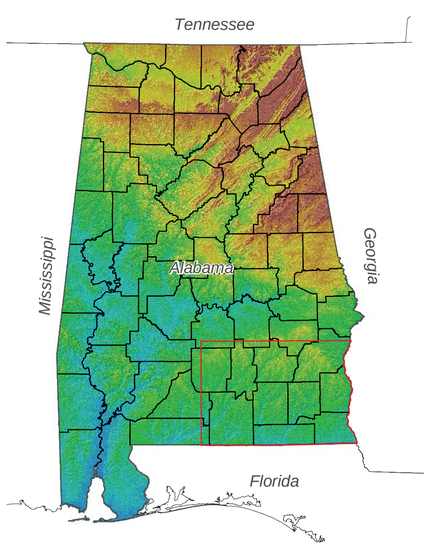
Pumping Rates in Selected Wells Constructed in the Nanafalia Aquifer in Southeast Alabama

By
Marlon R. Cook
2011

GEOLOGICAL SURVEY OF ALABAMA
Founded 1848

Berry H. (Nick) Tew, Jr.
State Geologist





Explanation

Elevation in feet above NGVD 1929
- High : 715
- Low : 0
- City

- Southeast Alabama groundwater irrigation assessment area
- County boundary
- Rivers

- Limited access interstate
- Highway
- Major road
- R-10 84 Well and water level elevation (ft. MSL)

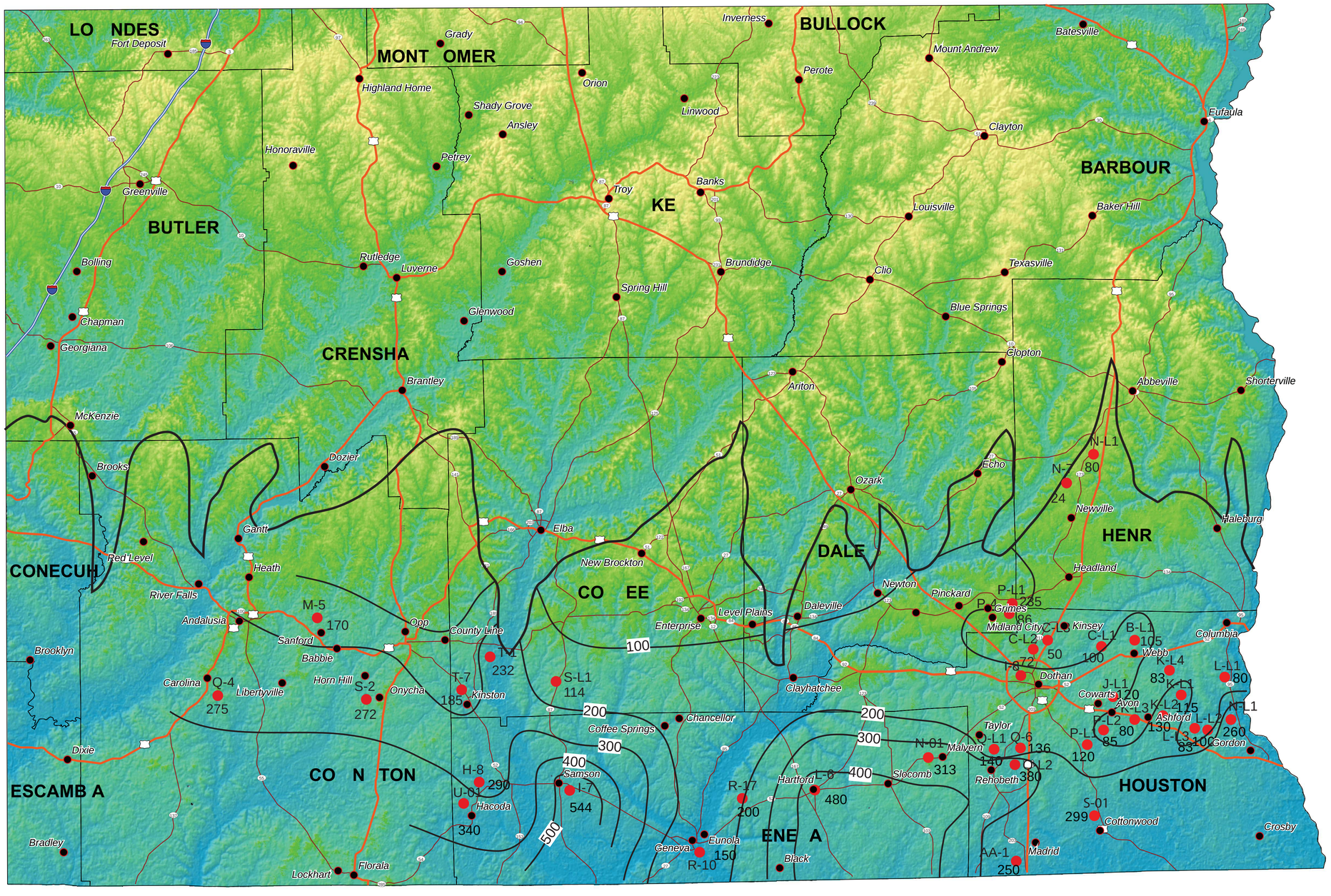
- Interstate highway
- United States highway
- State highway
- Line of equal water level elevation (ft. MSL) (contour interval 50 ft.)

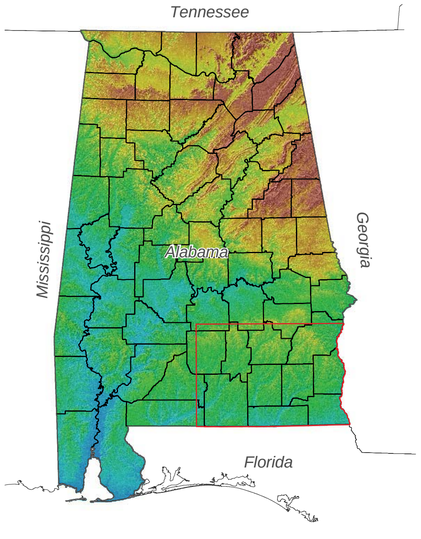
Potentiometric Surface for the Lisbon Aquifer in Southeast Alabama

By
Marlon R. Cook
2011

GEOLOGICAL SURVEY OF ALABAMA • Founded 1848

Berry H. (Nick) Tew, Jr.
State Geologist





0 2 4 8 12 16 20 Miles

Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

R-10 150 Well and depth (ft.)

Interstate highway

United States highway

State highway

Line of equal well depth (contour interval 100 ft.)

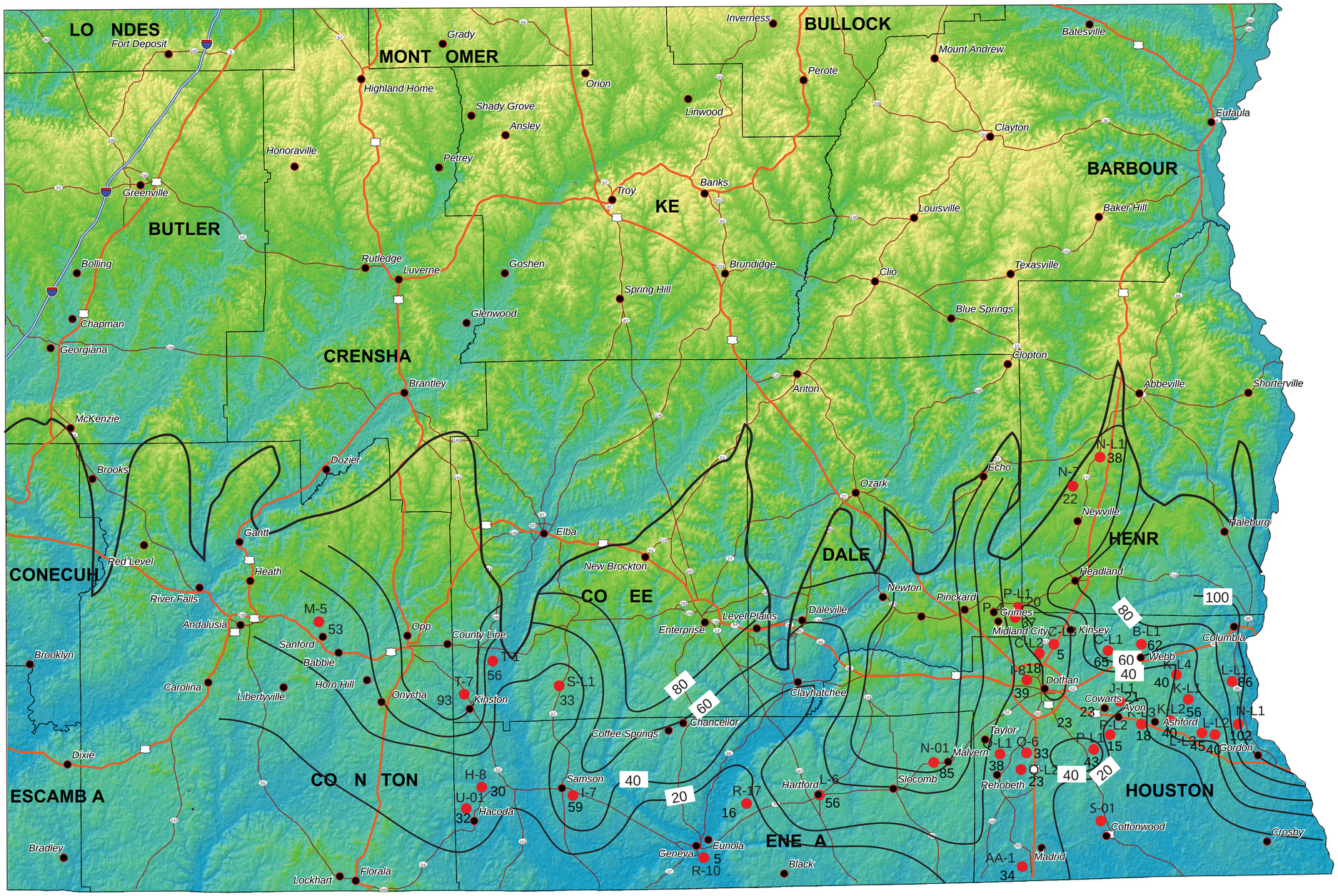
GEOLOGICAL SURVEY OF ALABAMA • Founded 1848 •

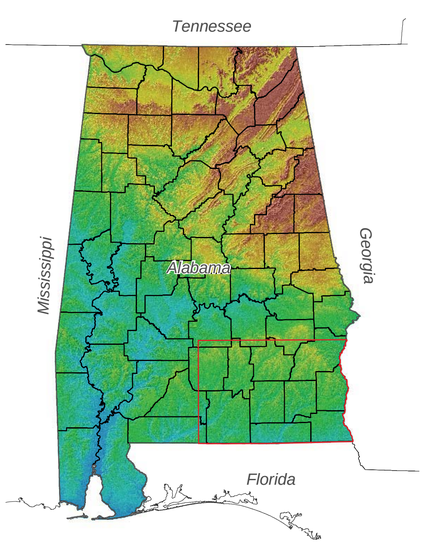
Berry H. (Nick) Tew, Jr.
State Geologist

Depth of Selected Wells Constructed in the Lisbon Aquifer in Southeast Alabama

By
Marlon R. Cook

2011





Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

R-10
5
Well and depth to water (ft.)

Interstate highway

United States highway

State highway

Line of equal depth to water (contour interval 20 ft.)

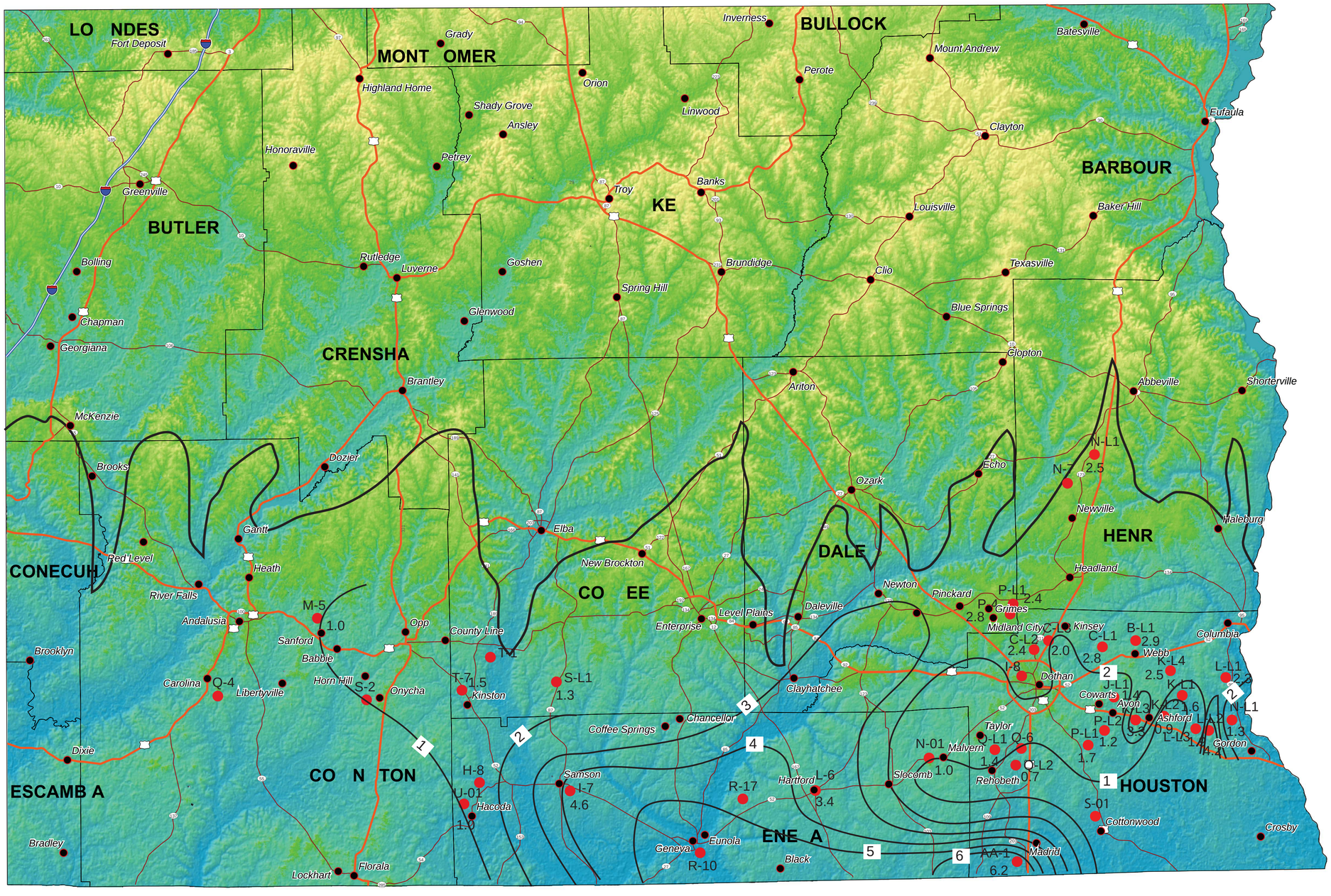
GEOLOGICAL SURVEY OF ALABAMA
Founded 1848

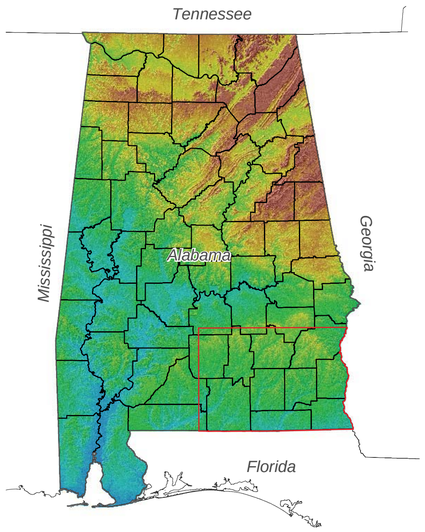
Berry H. (Nick) Tew, Jr.
State Geologist

Depth to Groundwater in Selected Wells Constructed in the Lisbon Aquifer in Southeast Alabama

By
Marlon R. Cook

2011





Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

I-7 4.6 Well and specific capacity (gpm/ft. drawdown)

Interstate highway

United States highway

State highway

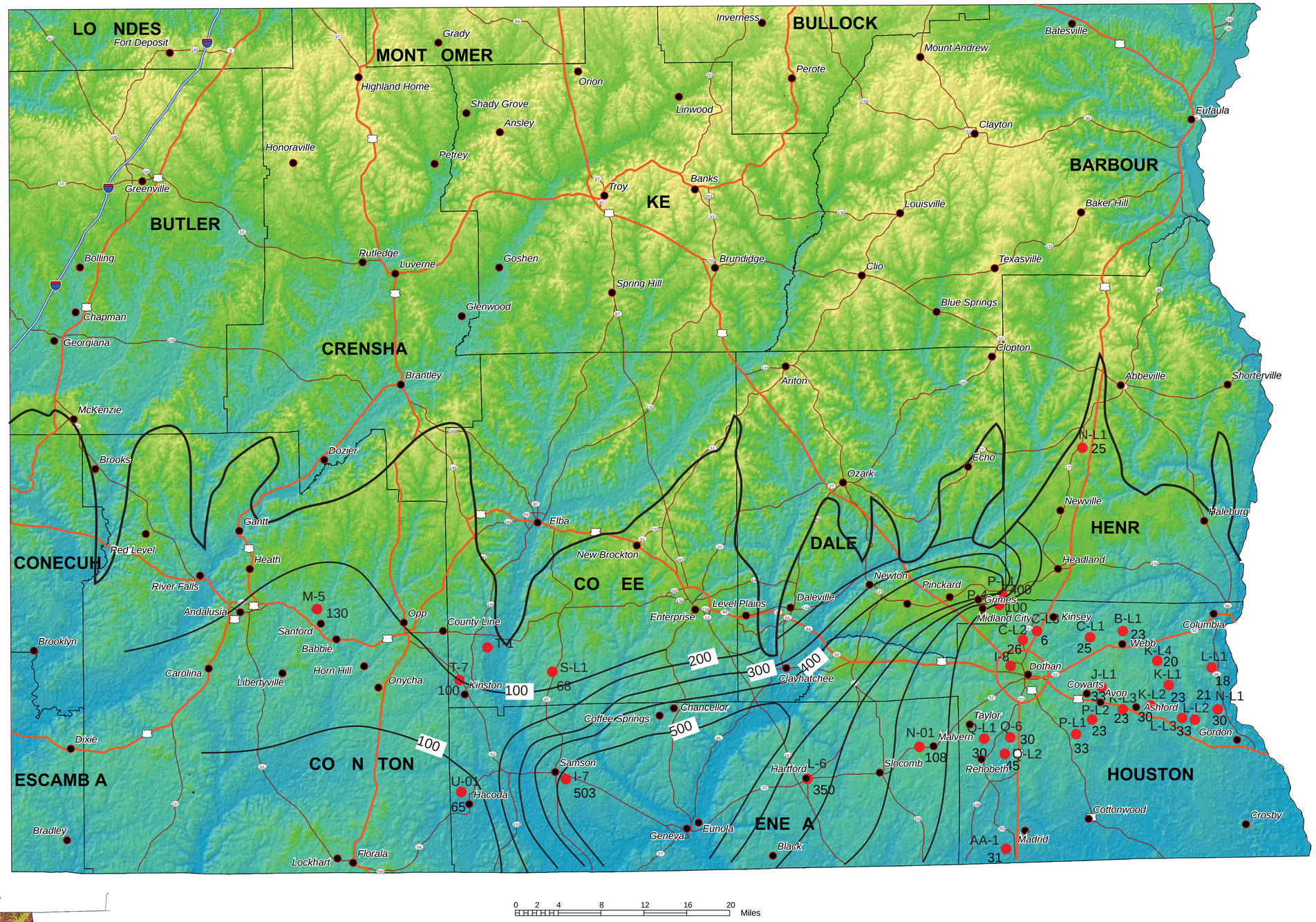
Line of equal specific capacity (contour interval 1 gpm/ft. drawdown)

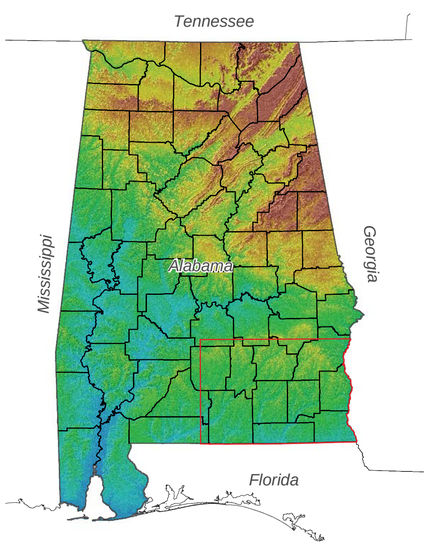
Berry H. (Nick) Tew, Jr.
State Geologist

Specific Capacities in Selected Wells Constructed in the Lisbon Aquifer in Southeast Alabama

By
Marlon R. Cook

2011





Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

L-6
350
Well and pumping rate (gpm)

Interstate highway

United States highway

State highway

Line of equal pumping rate (contour interval 100 gpm)

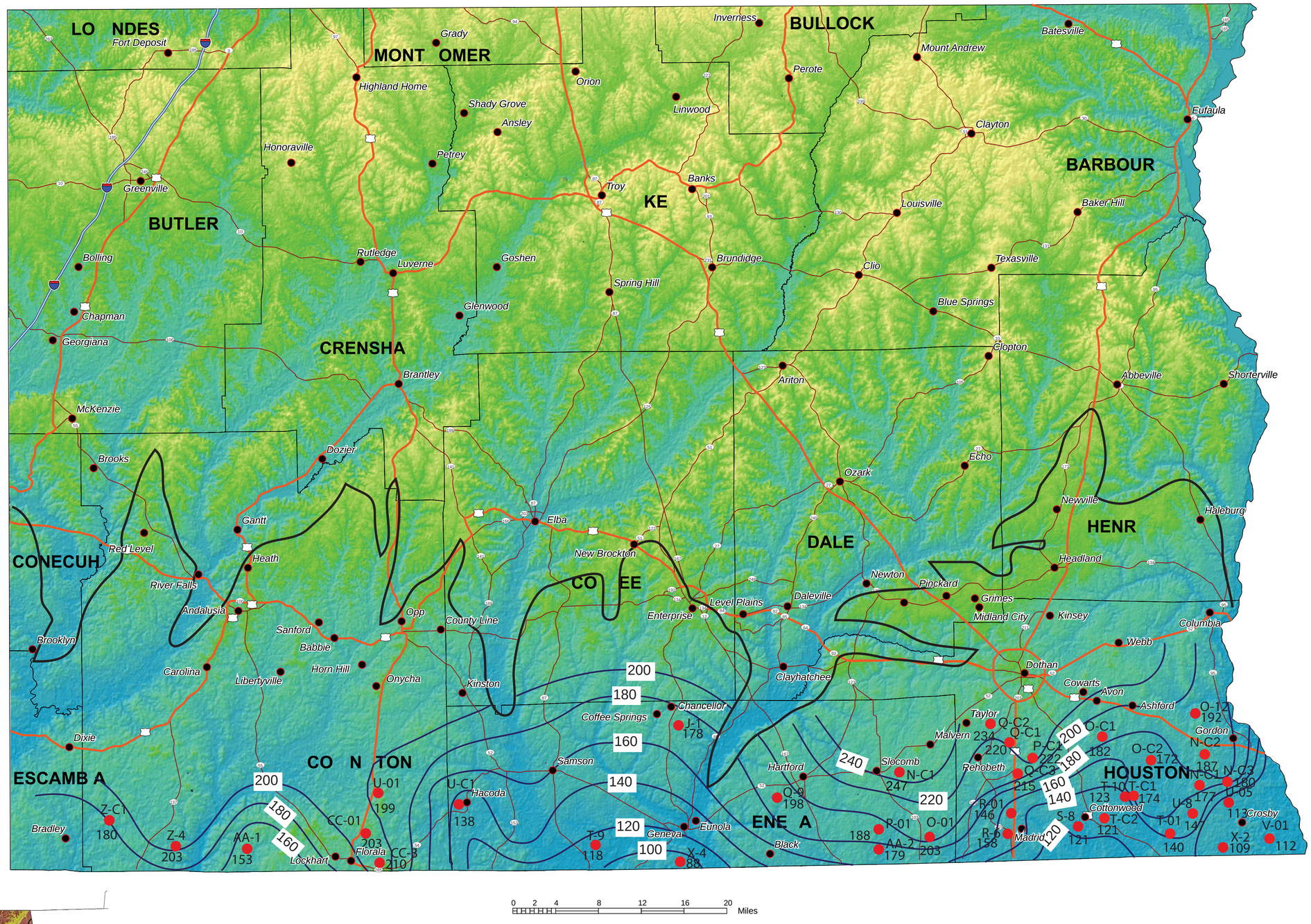
GEOLOGICAL SURVEY OF ALABAMA
Founded 1848

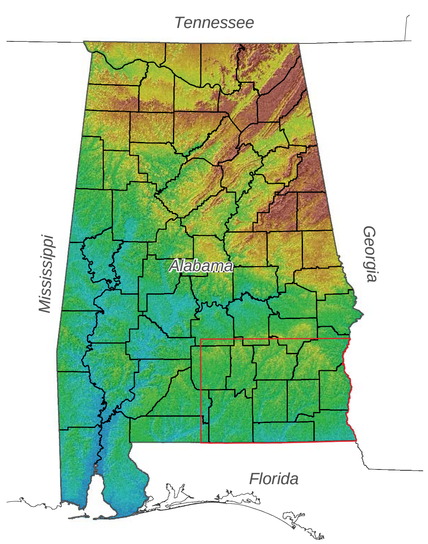
Berry H. (Nick) Tew, Jr.
State Geologist

Pumping Rates in Selected Wells Constructed in the Lisbon Aquifer in Southeast Alabama

By
Marlon R. Cook

2011





Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

T-9 118 Well and water level elevation (ft. MSL)

Interstate highway

United States highway

State highway

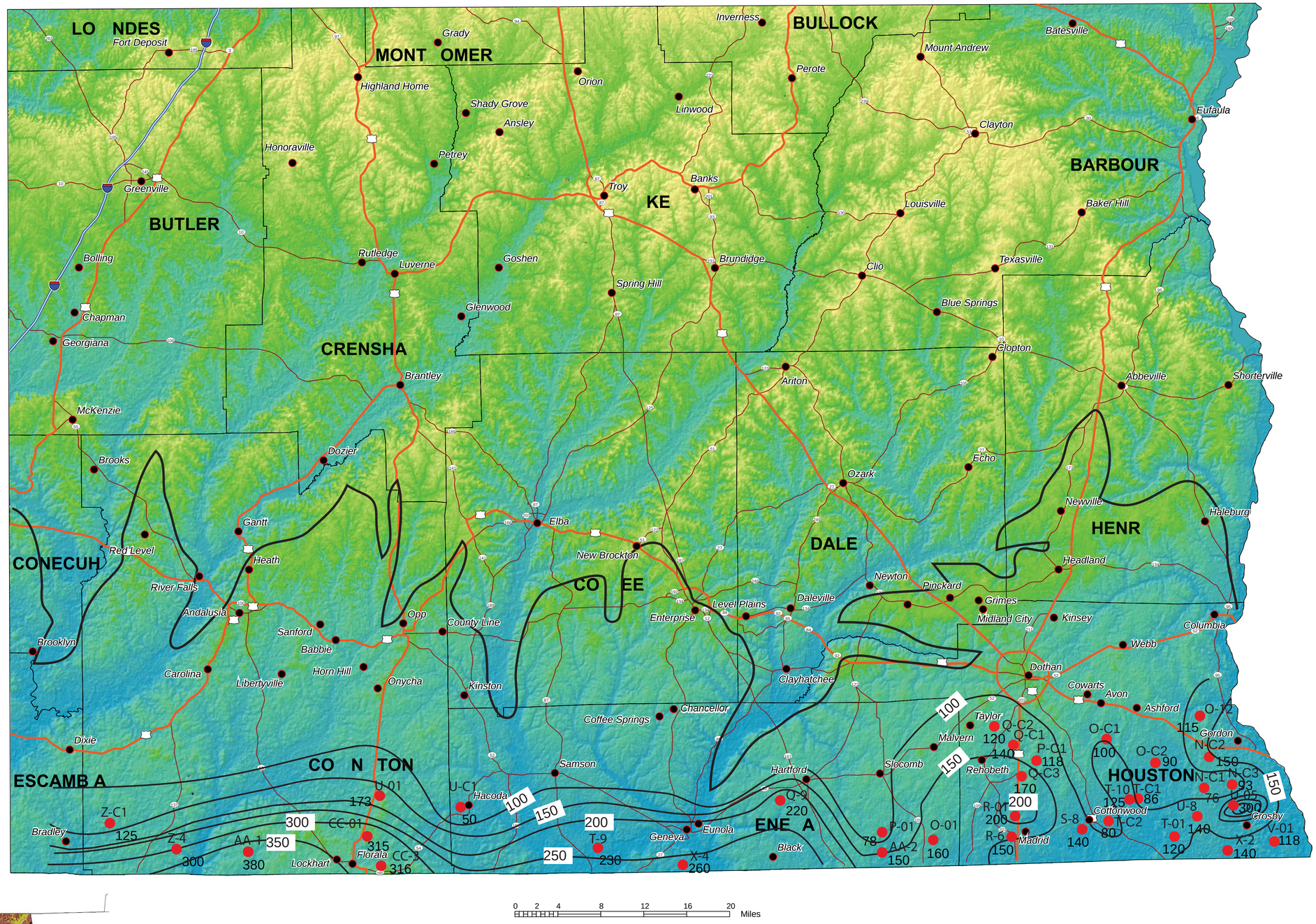
Line of equal water level elevation (ft. MSL) (contour interval 20 ft.)

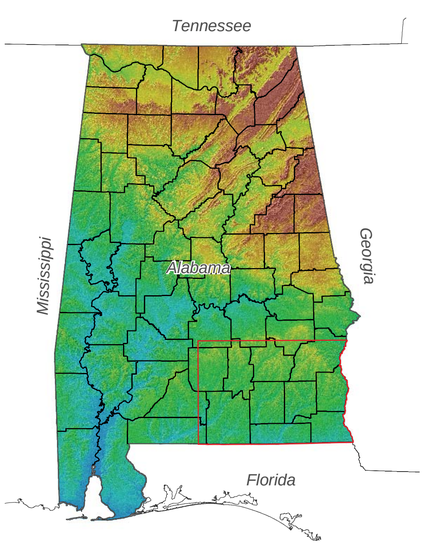
Berry H. (Nick) Tew, Jr.
State Geologist

Potentiometric Surface for the Crystal River Aquifer in Southeast Alabama

By
Marlon R. Cook

2011





Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

X-4 260 Well and depth (ft.)

Interstate highway

United States highway

State highway

Line of equal well depth (contour interval 50 ft.)

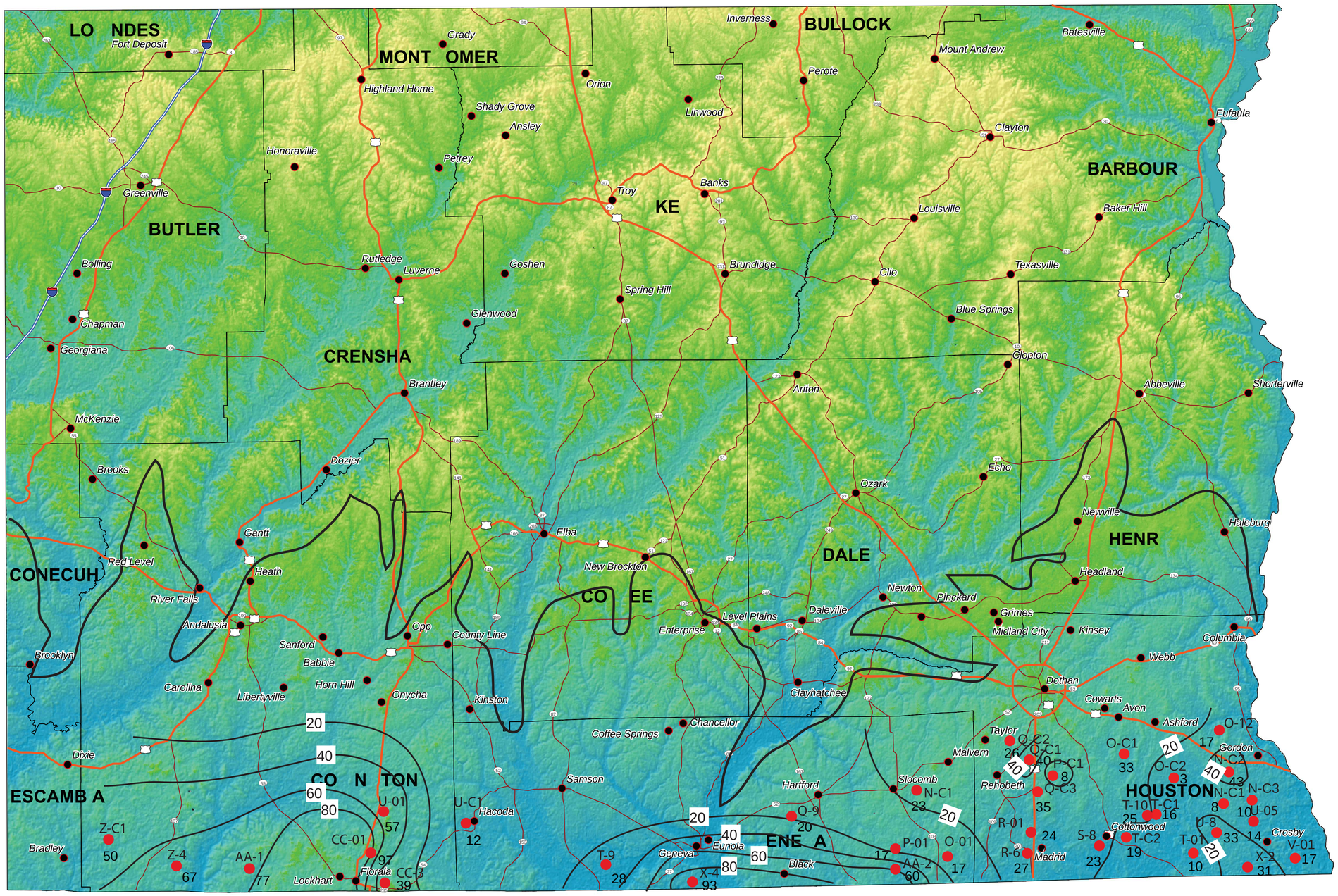
GEOLOGICAL SURVEY OF ALABAMA • Founded 1848 •

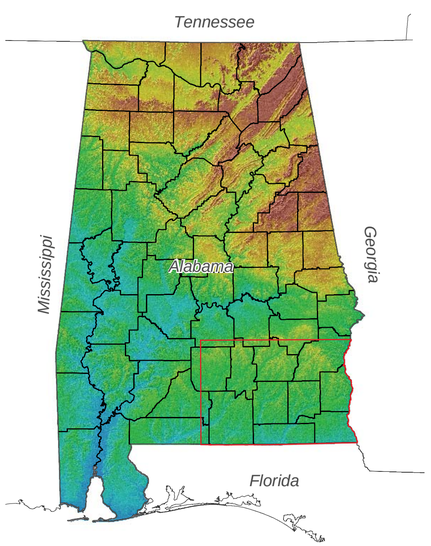
Berry H. (Nick) Tew, Jr.
State Geologist

Depth of Selected Wells Constructed in the Crystal River Aquifer in Southeast Alabama

By
Marlon R. Cook

2011





Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

O-C1
33
Well and depth to water (ft.)

Interstate highway

United States highway

State highway

Line of equal depth to water (contour interval 20 ft.)

Depth to Groundwater in Selected Wells Constructed in the Crystal River Aquifer in Southeast Alabama

By
Marlon R. Cook

2011

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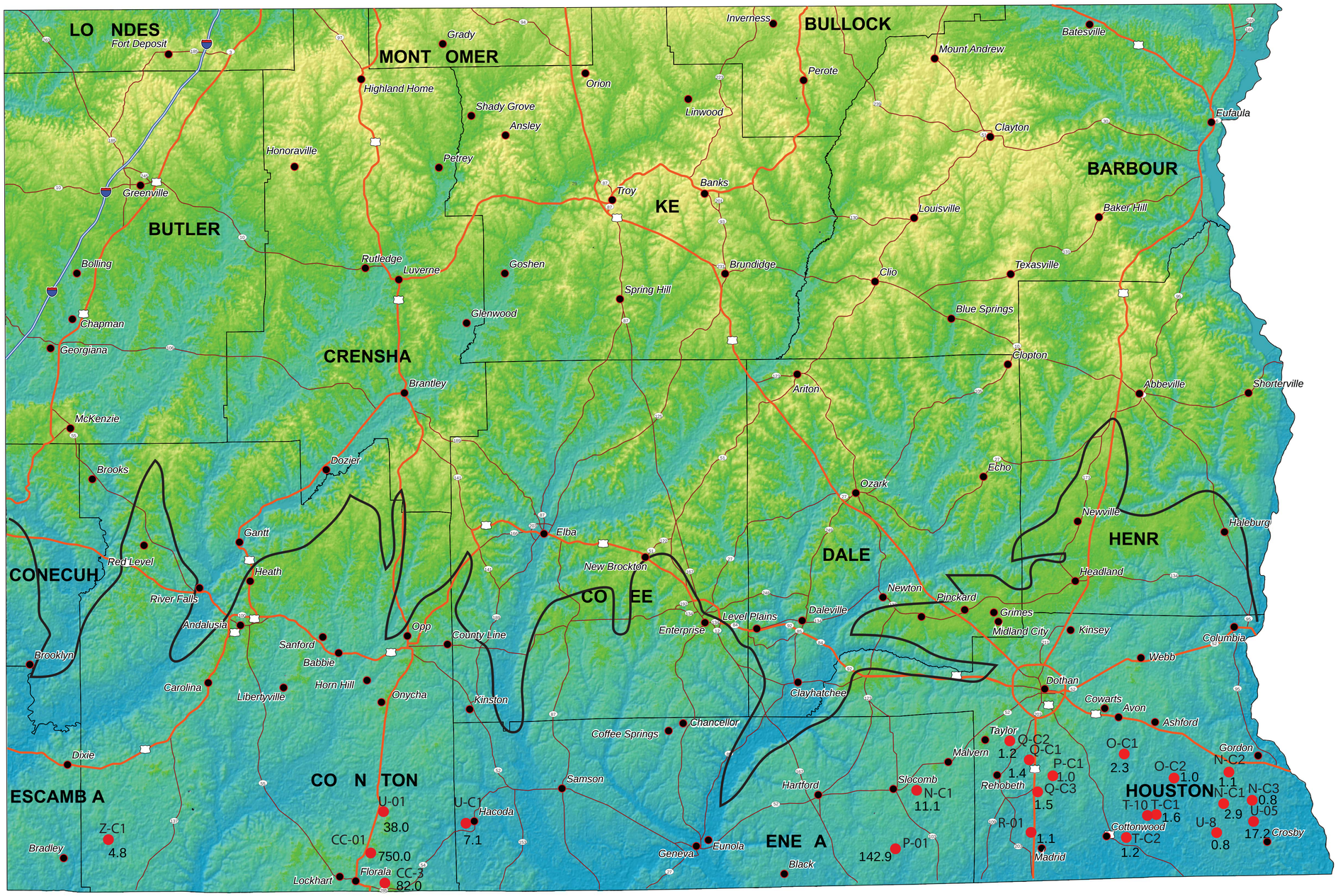
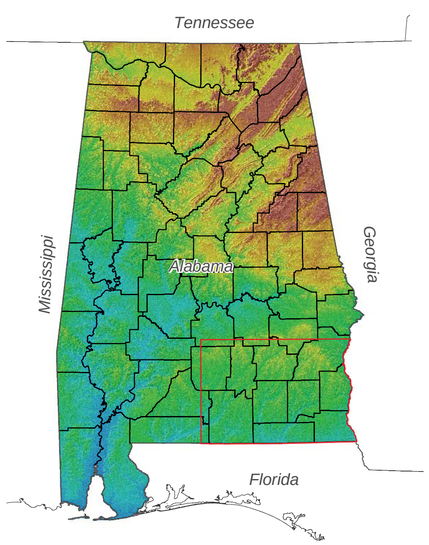
Founded 1848

Berry H. (Nick) Tew, Jr.
State Geologist





Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

N-C1
11.1
Well and specific capacity (gpm/ft. drawdown)

Interstate highway

United States highway

State highway

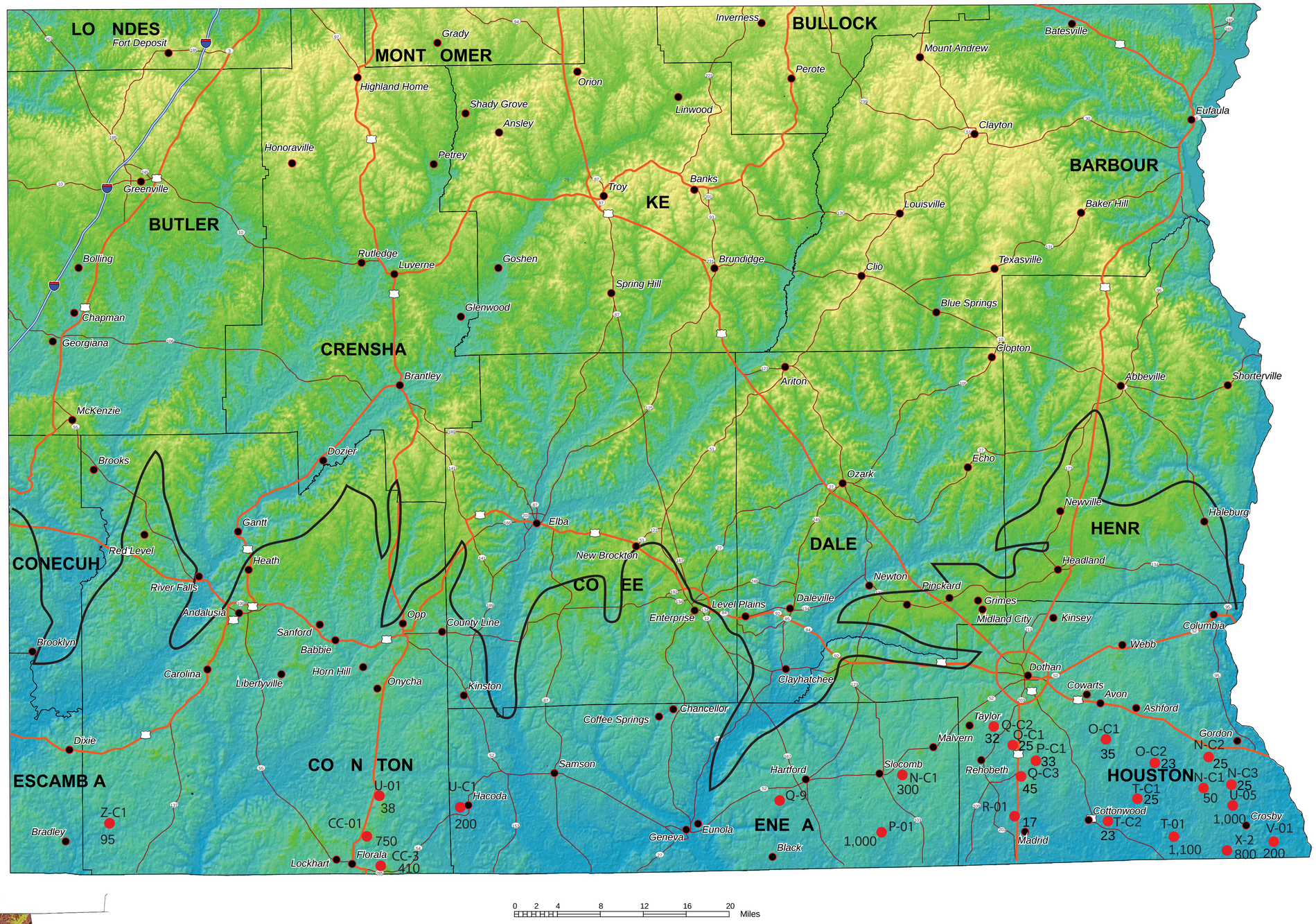
GEOLOGICAL SURVEY OF ALABAMA
Founded 1848

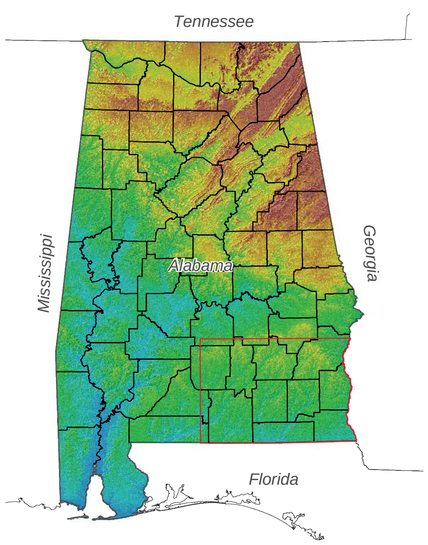
Berry H. (Nick) Tew, Jr.
State Geologist

Specific Capacities in Selected Wells Constructed in the Crystal River Aquifer in Southeast Alabama

By
Marlon R. Cook

2011





Explanation

Elevation in feet above NGVD 1929
High : 715
Low : 0

City

Southeast Alabama groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

O-C1
35
Well and pumping rate (gpm)

Interstate highway

United States highway

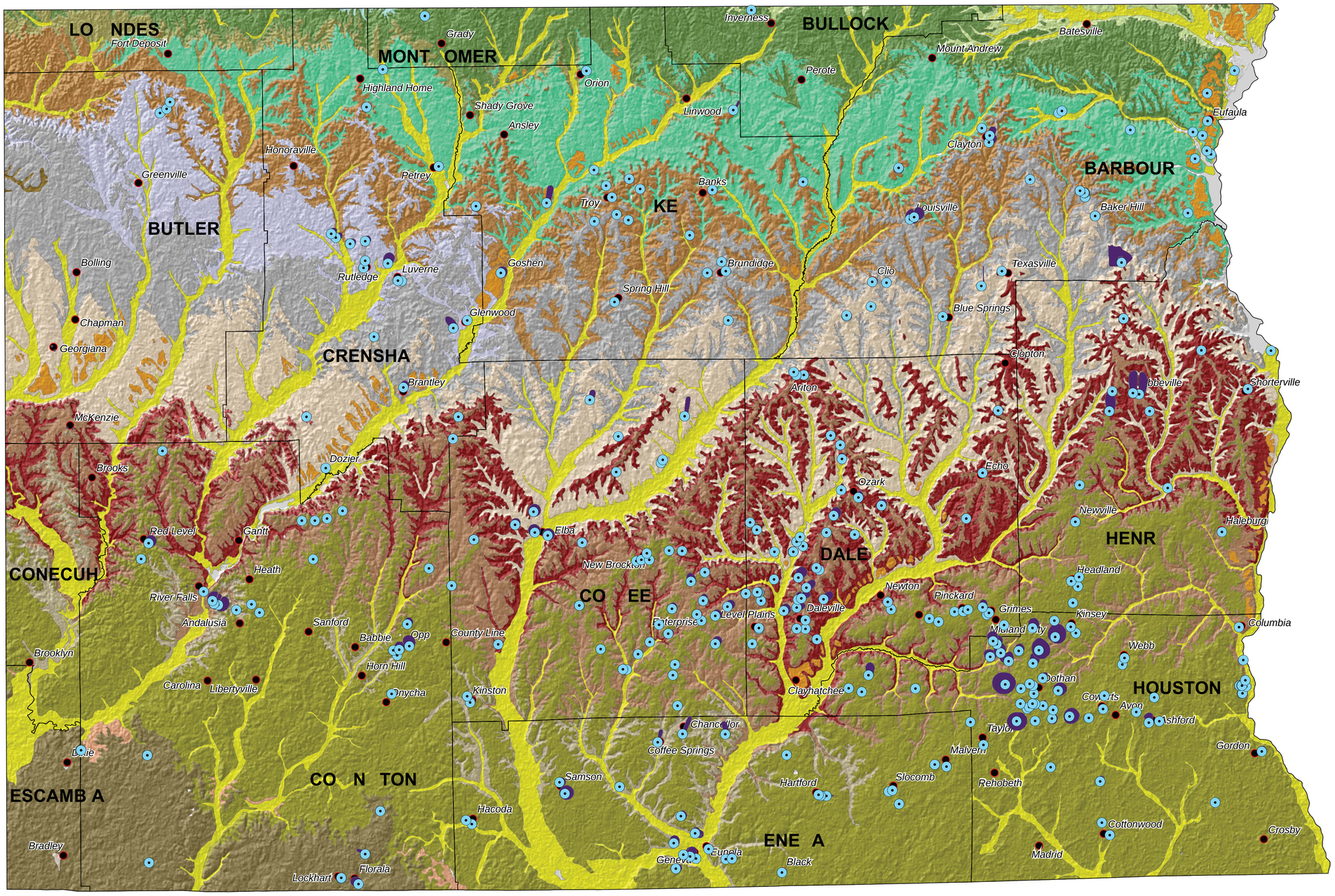
State highway

Pumping Rates in Selected Wells Constructed in the Crystal River Aquifer in Southeast Alabama

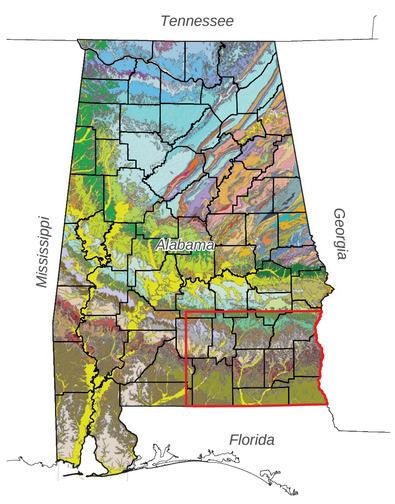
By
Marlon R. Cook
2011

GEOLOGICAL SURVEY OF ALABAMA
Founded 1848

Berry H. (Nick) Tew, Jr.
State Geologist



0 2 4 8 12 16 20 Miles



Explanation

Eocene
- Jackson Group undifferentiated
- Lisbon Formation
- Tallahatta Formation
- Hatchetigbee Formation

Paleocene
- Tuscahoma Sand
- Nanafalia Formation
- Naheola Formation
- Porters Creek Formation
- Clayton Formation

Quaternary
- Alluvial, coastal, and low terrace
- High terrace deposits
- Citronelle Formation

Tertiary
- Miocene Series undifferentiated

Oligocene
- Oligocene Series undifferentiated

Eocene-Oligocene
- Residuum

Cretaceous
- Prairie Bluff Chalk
- Providence Sand
- Ripley Formation
- Demopolis Chalk
- Cusseta Sand Member of the Ripley Formation
- Blufftown Formation

Other Symbols
- Water
- Southeast Alabama groundwater irrigation assessment area
- County boundary
- City
- Public water supply well
- Source water assessment area

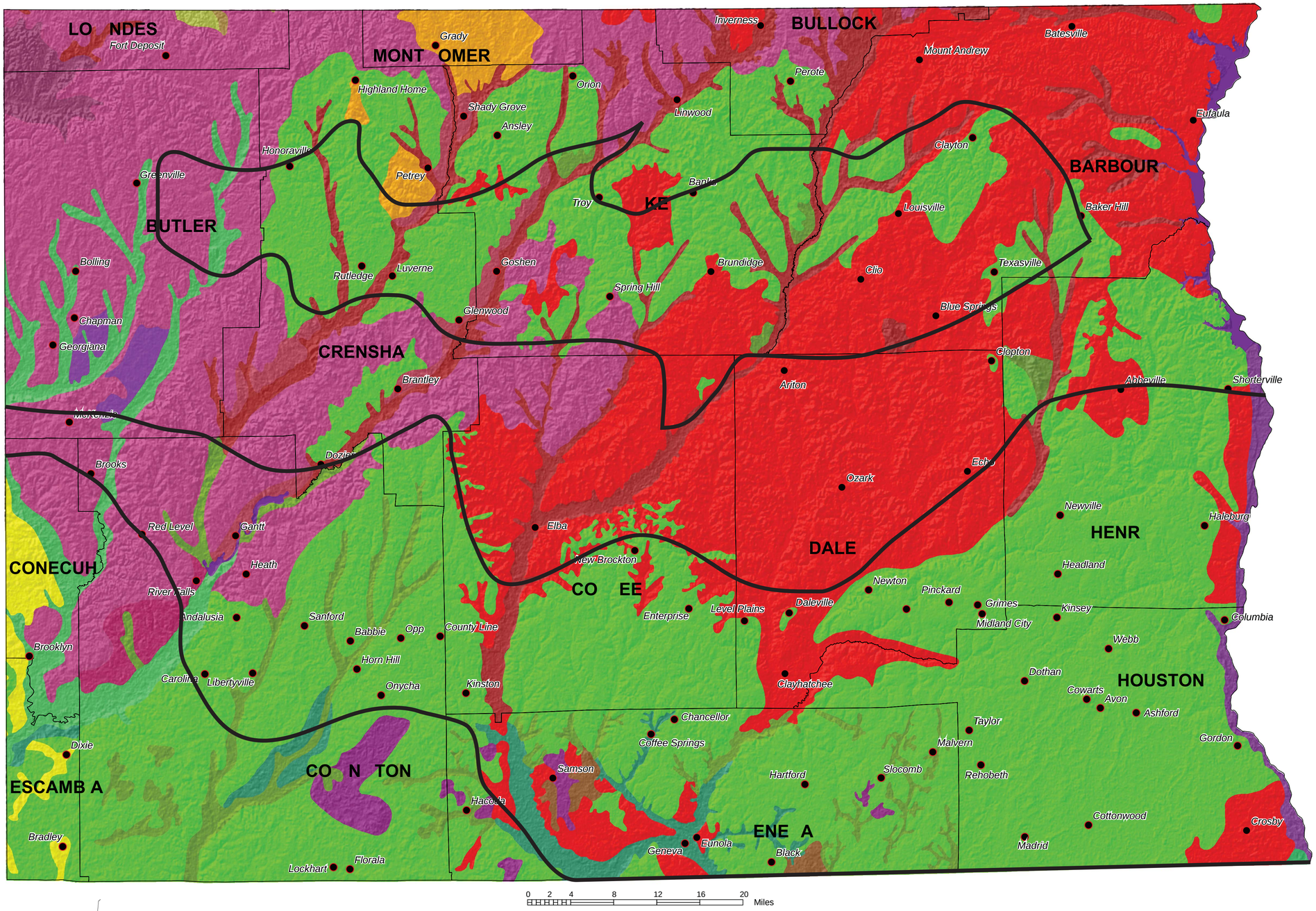
GEOLOGIC MAP AND LOCATION OF PUBLIC WATER SUPPLY WELLS AND SOURCE WATER ASSESSMENT AREAS FOR THE SOUTHEAST ALABAMA GROUNDWATER IRRIGATION ASSESSMENT AREA

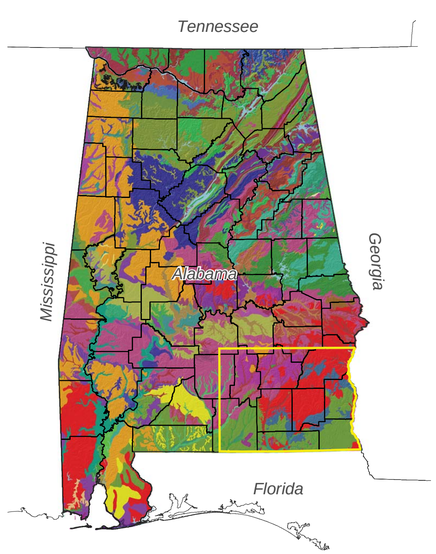
(Geology from Geological Survey of Alabama, 2006)

By
Alana Rogers
2011

GEOLOGICAL SURVEY OF ALABAMA
Founded 1848

Berry H. (Nick) Tew, Jr.
State Geologist





Explanation

Alfisols
- Fine, mixed, active, thermic
- Fine, mixed, semiactive, thermic

Histosols
- Dysic, thermic

Inceptisol
- Fine-loamy, siliceous, active, acid, thermic
- Fine-silty, carbonatic, thermic

Ultisols
- Coarse-loamy, siliceous, semiactive, thermic
- Coarse-loamy, siliceous, subactive, thermic
- Fine, mixed, semiactive, thermic
- Fine, smectitic, thermic
- Fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic
- Fine-loamy, kaolinitic, thermic
- Fine-loamy, mixed, active, thermic
- Fine-loamy, siliceous, semiactive, thermic
- Fine-loamy, siliceous, subactive, thermic
- Loamy, kaolinitic, thermic
- Loamy, siliceous, semiactive, thermic
- Loamy, siliceous, subactive, thermic
- Fine, kaolinitic, thermic
- Southeast Alabama groundwater irrigation assessment area
- County boundary
- City
- Area dominated by agricultural land use

Soil Order and Taxonomic Classification for the South East Alabama Groundwater Irrigation Assessment Area

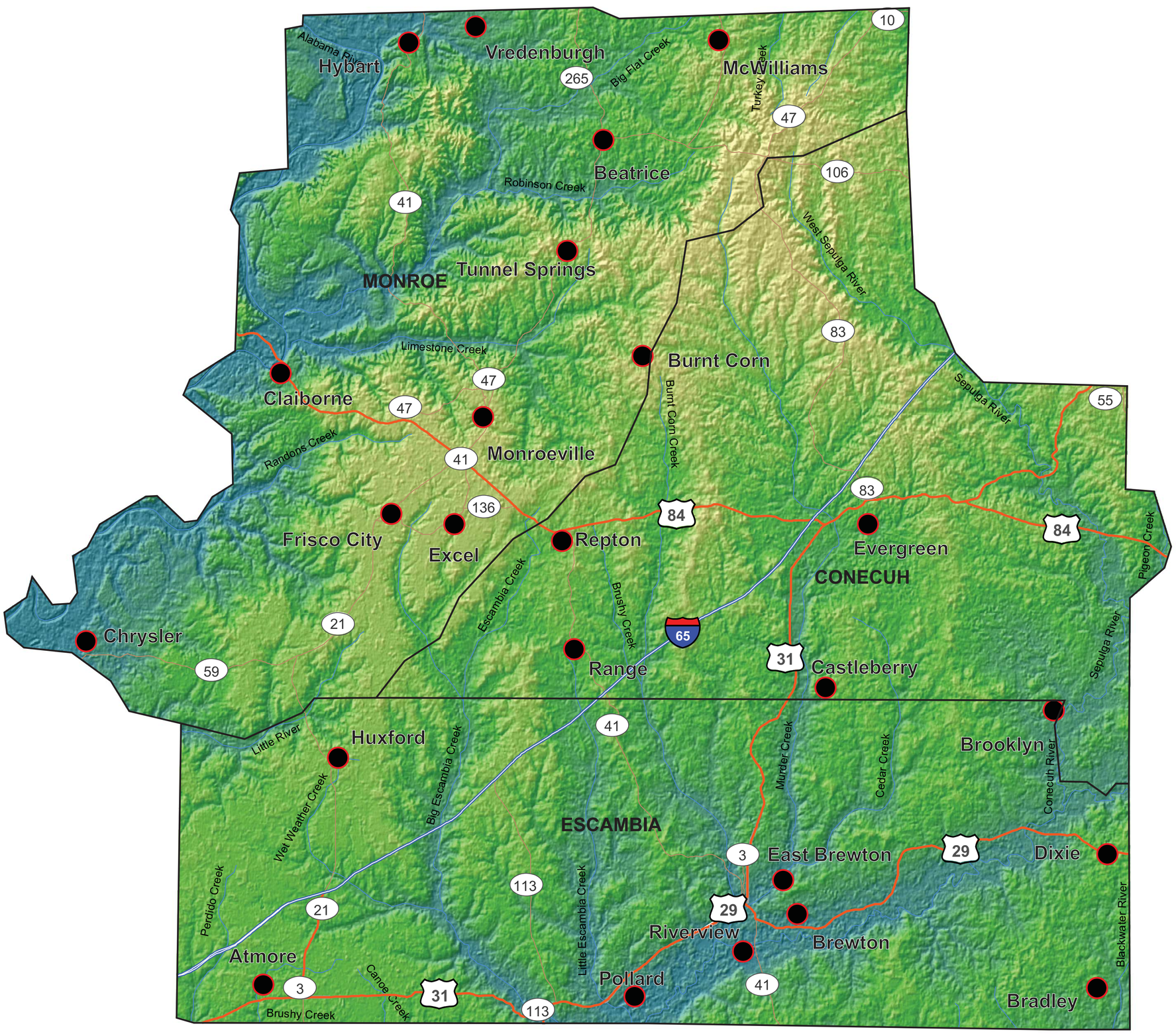
(modified from USDA-NRCS: Web Soil Survey, 2009)

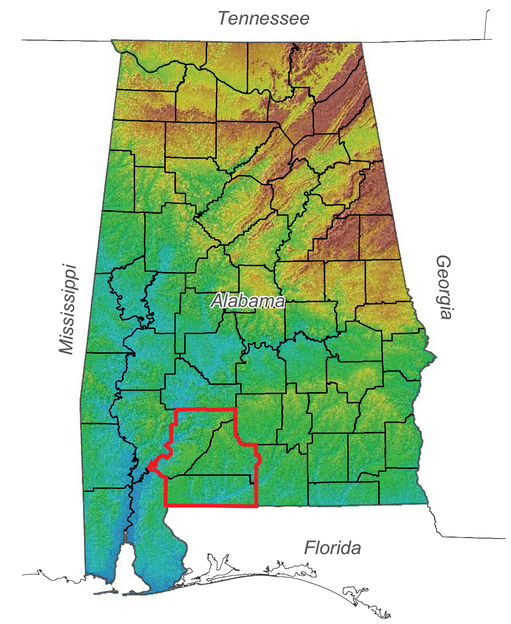
By
Alana Rogers and Marlon Cook

2011

GEOLOGICAL SURVEY OF ALABAMA
Founded 1848

Berry H. (Nick) Tew, Jr.
State Geologist





Explanation

Elevation in feet above NGVD 1929

High : 614

Low : 13

City

South-central Alabama groundwater irrigation assessment area

County boundary

Rivers

Limited access interstate

Highway

Major road

Interstate highway

United States highway

State highway

LOCATION MAP OF THE SOUTH-CENTRAL ALABAMA GROUNDWATER IRRIGATION ASSESSMENT AREA

By
Blakeney Gillett
2011

Berry H. (Nick) Tew, Jr.
State Geologist

Explanation

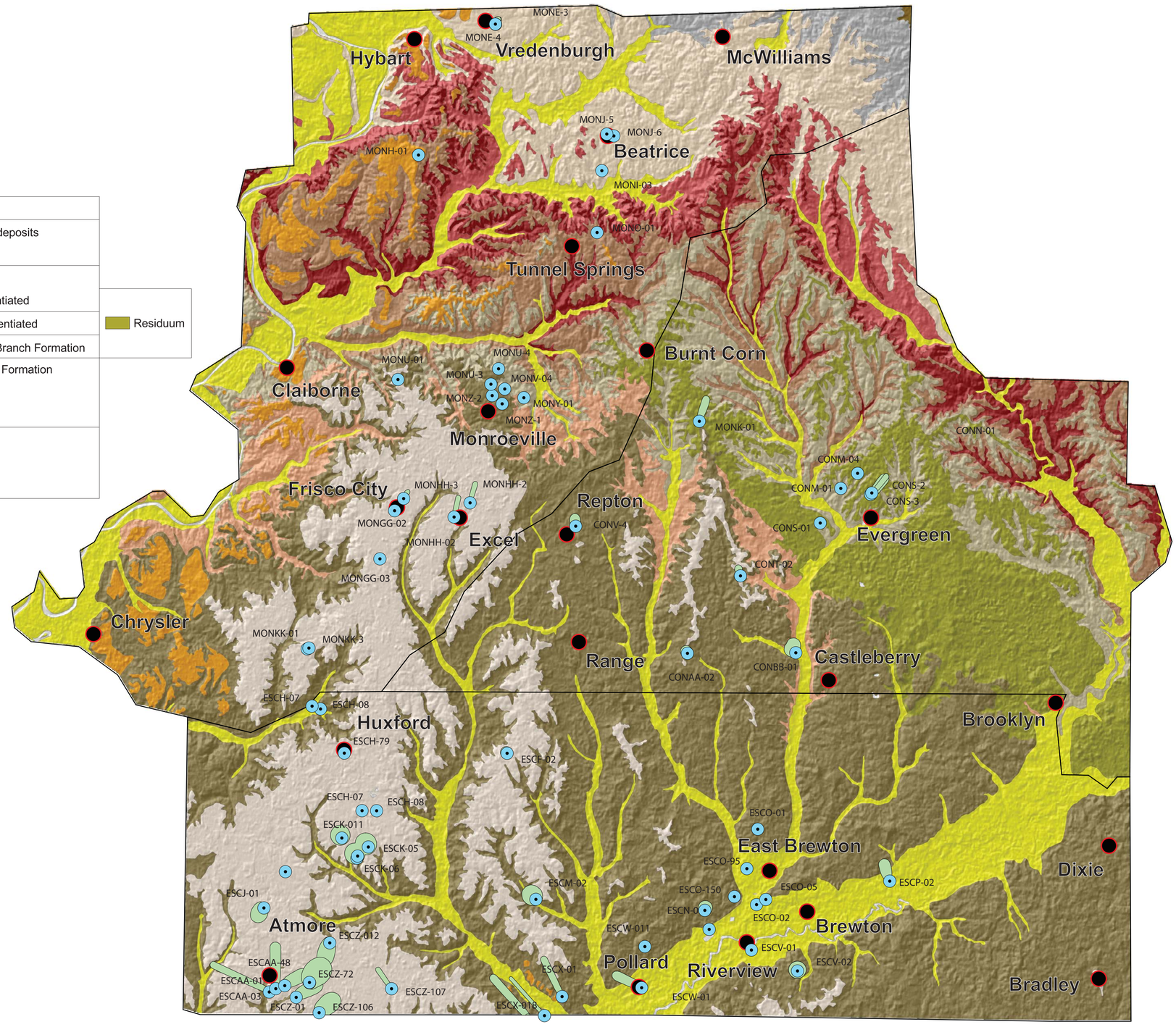
County boundary

City

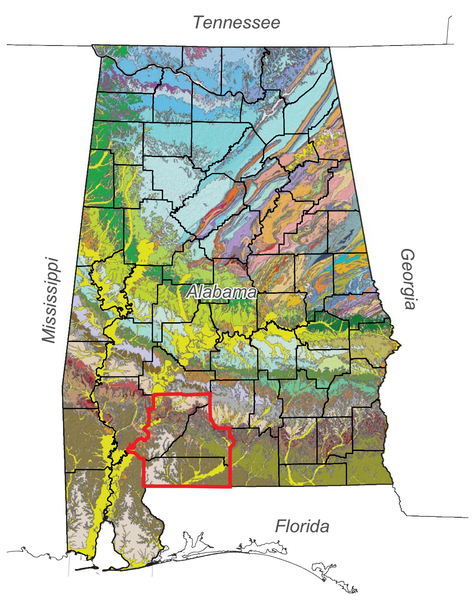
Public water supply well, SWAA, and GSA well number

SYSTEM	SERIES	GROUP	GEOLOGIC UNIT
Quaternary	Holocene and Pleistocene		Alluvium and low terrace deposits
			High terrace deposits
Tertiary	Pliocene and Miocene		Citronelle Formation
			Miocene Series undifferentiated
	Oligocene	Vicksburg	Oligocene Series undifferentiated
	Eocene	Jackson	Yazoo Clay and Moodys Branch Formation
		Claiborne	Gosport Sand and Lisbon Formation
			Lisbon Formation
			Tallahatta Formation
		Wilcox	Hatchetigbee Formation
			Tuscahoma Sand
	Paleocene		Nanafalia Formation

Residuum



0 2 4 8 12 16 20 Miles

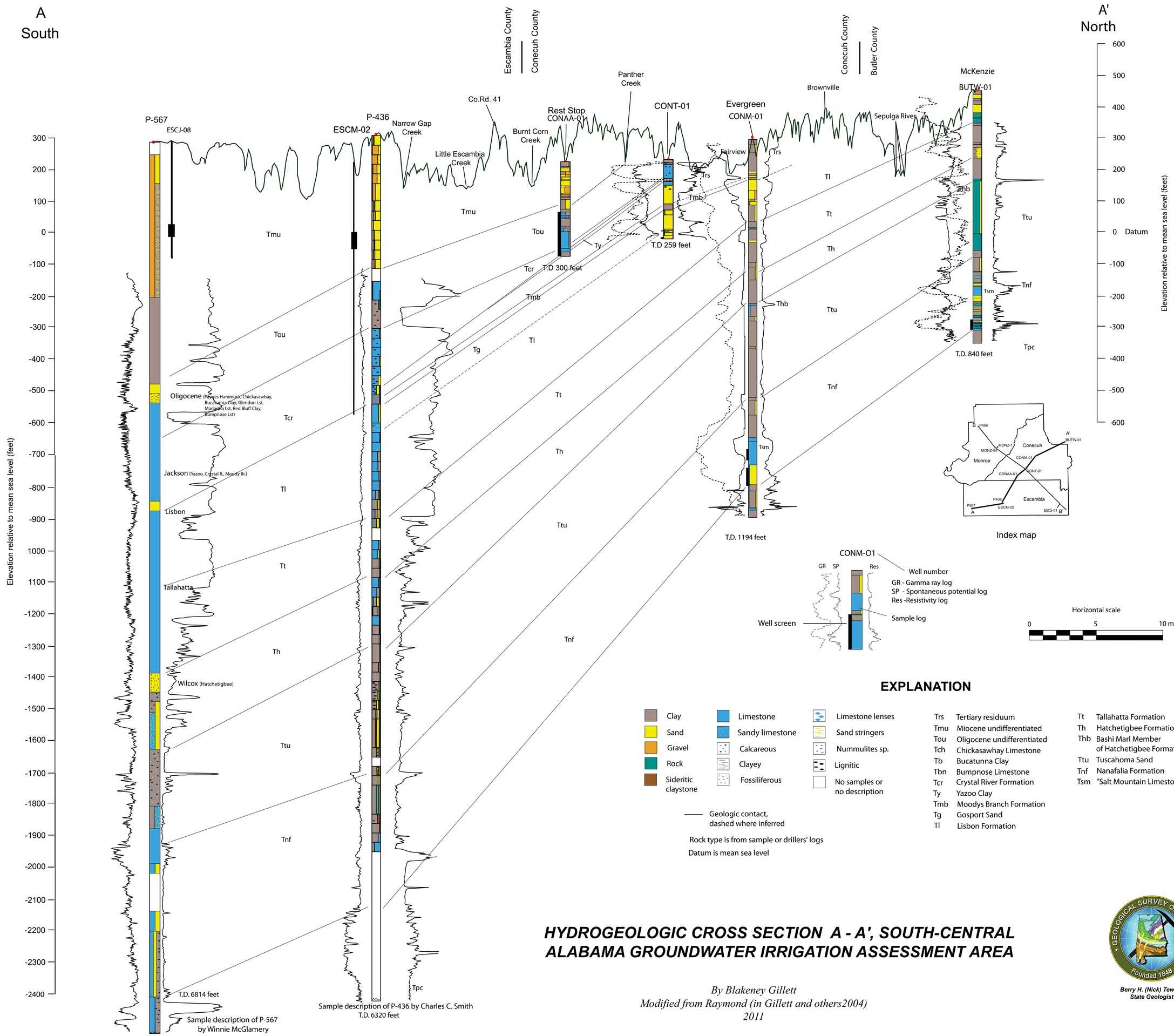


GEOLOGIC MAP, LOCATION OF PUBLIC WATER SUPPLY WELLS, AND SOURCE WATER ASSESSMENT AREAS FOR THE SOUTH-CENTRAL ALABAMA GROUNDWATER IRRIGATION ASSESSMENT AREA

(from Geological Survey of Alabama, 2006)

By
Blakeney Gillett
2011

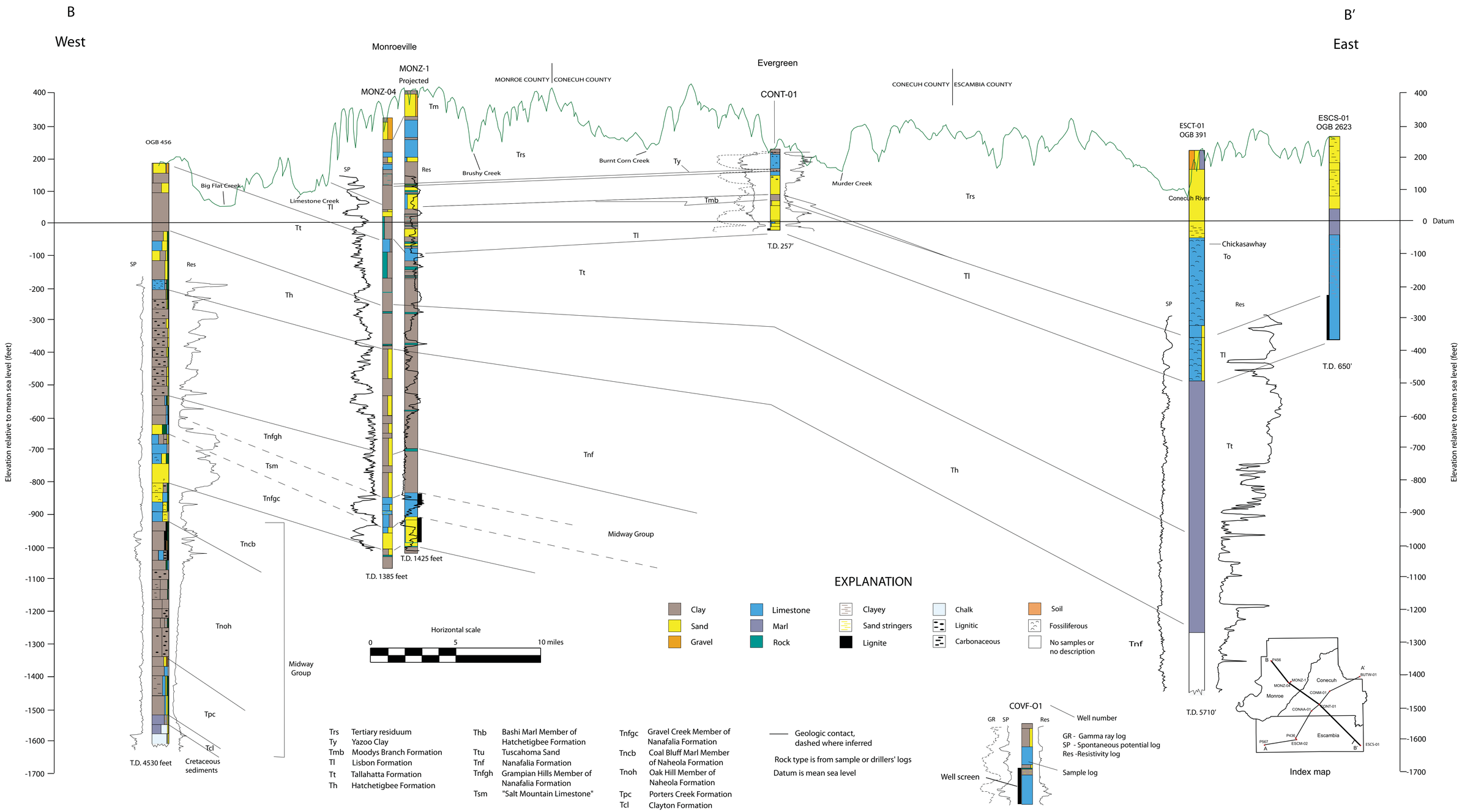
Berry H. (Nick) Tew, Jr.
State Geologist



HYDROGEOLOGIC CROSS SECTION A - A', SOUTH-CENTRAL ALABAMA GROUNDWATER IRRIGATION ASSESSMENT AREA

By Blakeney Gillett
Modified from Raymond (in Gillett and others2004)
2011

Berry H. (Nick) Tew, Jr.
State Geologist



HYDROGEOLOGIC CROSS SECTION B- B',
SOUTH-CENTRAL ALABAMA GROUNDWATER IRRIGATION ASSESSMENT AREA

By Blakeney Gillett
Modified from Raymond (in Gillett and others2004)
2011

BERRY H. (NICK) TEW, JR.
State Geologist

Explanation

County boundary

City

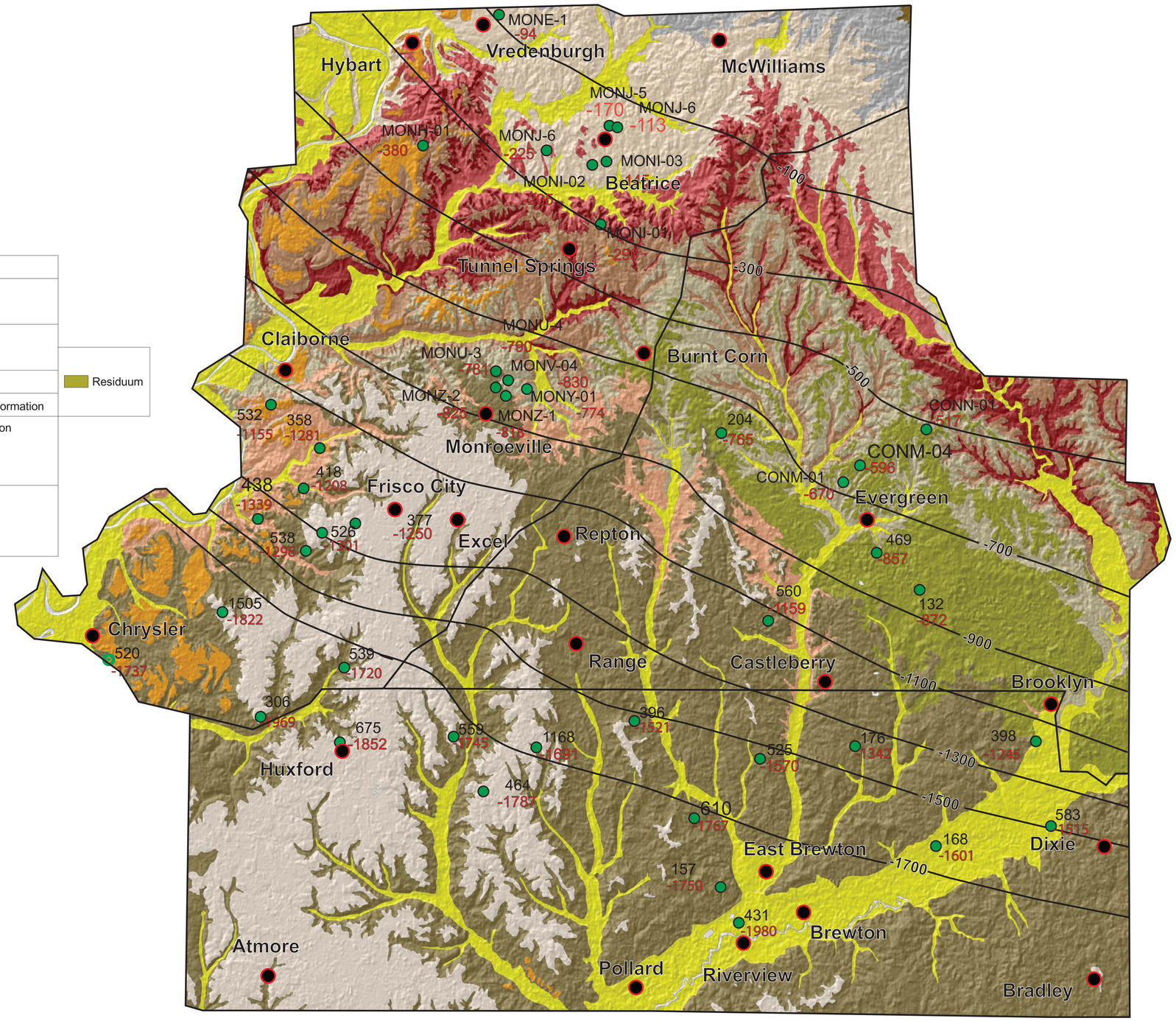
-600 Contour interval: 200 feet. Datum sea level.

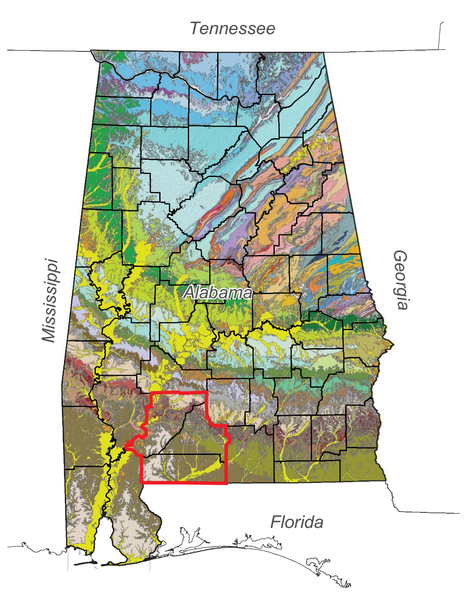
157 Oil and gas test well and State Oil and Gas Board Permit Number or GSA identifiers

-1750 Elevation, in feet relative to mean sea level, of top of Selma Group

SYSTEM	SERIES	GROUP	GEOLOGIC UNIT
Quaternary	Holocene and Pleistocene		Alluvium and low terrace deposits
			High terrace deposits
Tertiary	Pliocene and Miocene		Citronelle Formation
			Miocene Series undifferentiated
	Oligocene	Vicksburg	Oligocene Series undifferentiated
	Eocene	Jackson	Yazoo Clay and Moodys Branch Formation
		Claiborne	Gosport Sand and Lisbon Formation
			Lisbon Formation
			Tallahatta Formation
		Wilcox	Hatchetigbee Formation
			Tuscahoma Sand
	Paleocene		Nanafalia Formation

Residuum





CONFIGURATION OF THE TOP OF THE NANAFALIA FORMATION IN THE SOUTH-CENTRAL ALABAMA GROUNDWATER IRRIGATION ASSESSMENT AREA

(from Geological Survey of Alabama, 2006)

By
Blakeney Gillett
2011

Berry H. (Nick) Tew, Jr.
State Geologist

Explanation

County boundary

City

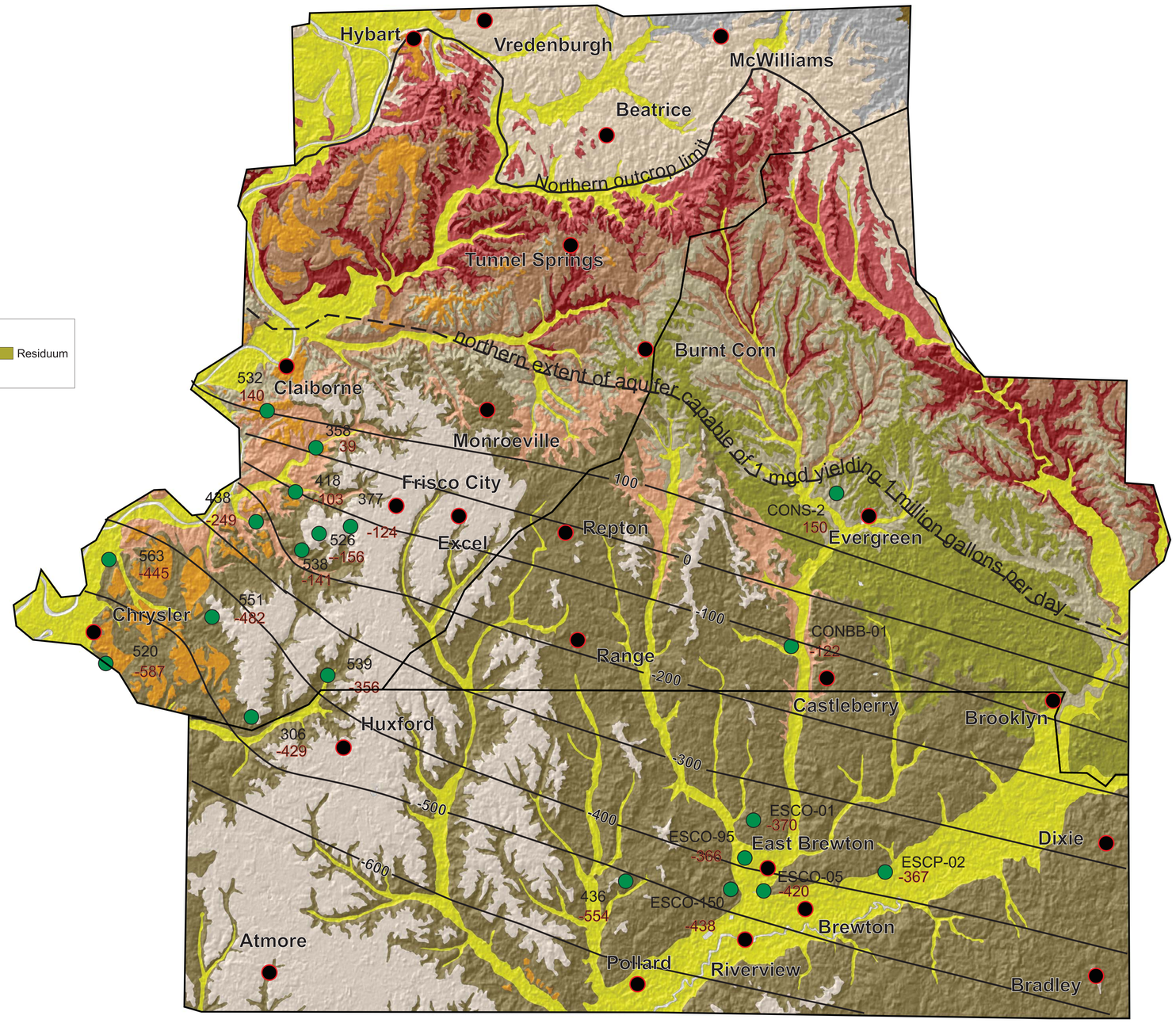
-600 Contour interval: 200 feet. Datum sea level.

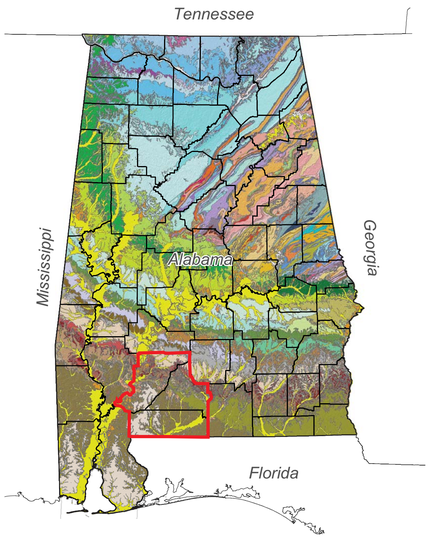
157 -1750 Oil and gas test well and State Oil and Gas Board Permit Number or GSA identifiers

Elevation, in feet relative to mean sea level, of top of Selma Group

SYSTEM	SERIES	GROUP	GEOLOGIC UNIT
Quaternary	Holocene and Pleistocene		Alluvium and low terrace deposits
			High terrace deposits
Tertiary	Pliocene and Miocene		Citronelle Formation
			Miocene Series undifferentiated
	Oligocene	Vicksburg	Oligocene Series undifferentiated
	Eocene	Jackson	Yazoo Clay and Moodys Branch Formation
		Claiborne	Gosport Sand and Lisbon Formation
			Lisbon Formation
			Tallahatta Formation
		Wilcox	Hatchetigbee Formation
			Tuscahoma Sand
	Paleocene		Nanafalia Formation

Residuum



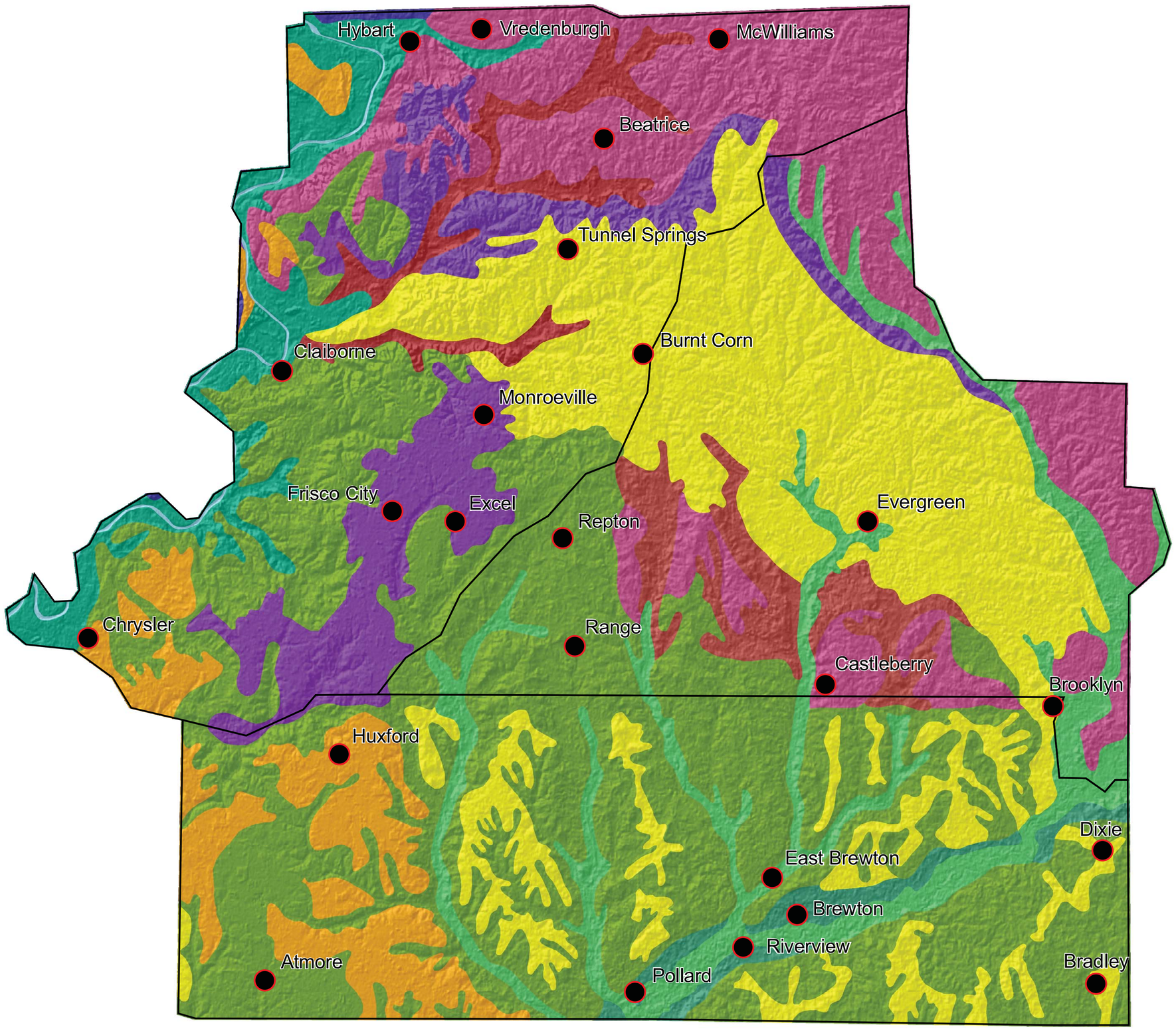


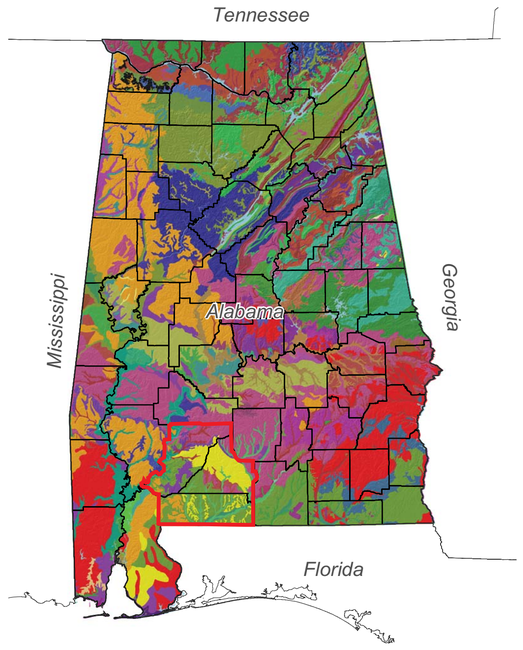
CONFIGURATION OF THE TOP OF THE SOUTH-CENTRAL ALABAMA GROUNDWATER IRRIGATION ASSESSMENT AREA

(from Geological Survey of Alabama, 2006)

By
Blakeney Gillett
2011

Berry H. (Nick) Tew, Jr.
State Geologist





0 2 4 8 12 16 20 Miles

Explanation

Ultisols
- Fine, kaolinitic, thermic Rhodic Kandiudults
- Fine-loamy, siliceous, thermic Typic Hapludults and Paleudults
- Fine-loamy over sandy or sandy-skeletal, siliceous, thermic Typic
- Fine-loamy, kaolinitic, thermic Plinthic Kandiudults
- Fine-loamy, siliceous, subactive, thermic Rhodic Paleudults
- Fine, smectitic, thermic Typic Hapludults
- Fine, mixed, semiactive, thermic Typic Hapludults

Inceptisols
- Fine, mixed, active, acid, thermic Vertic Epiaquepts
- Fine-loamy, mixed, active, thermic Fluvaquentic Dystrudepts
- Fine-loamy, siliceous, active, acid, thermic Aeric Endoaquepts

Vertisols
- Very-fine, smectitic, thermic Chromic Dystruderts

South-central groundwater irrigation assessment area

County boundary

City

SOIL ORDER AND TAXONOMIC CLASSIFICATION FOR THE THE SOUTH-CENTRAL ALABAMA GROUNDWATER IRRIGATION ASSESSMENT AREA

(modified from USDA-Cropland Data Layer for Southeastern States, 2010)

By
Blakeney Gillett
2011

Berry H. (Nick) Tew, Jr.
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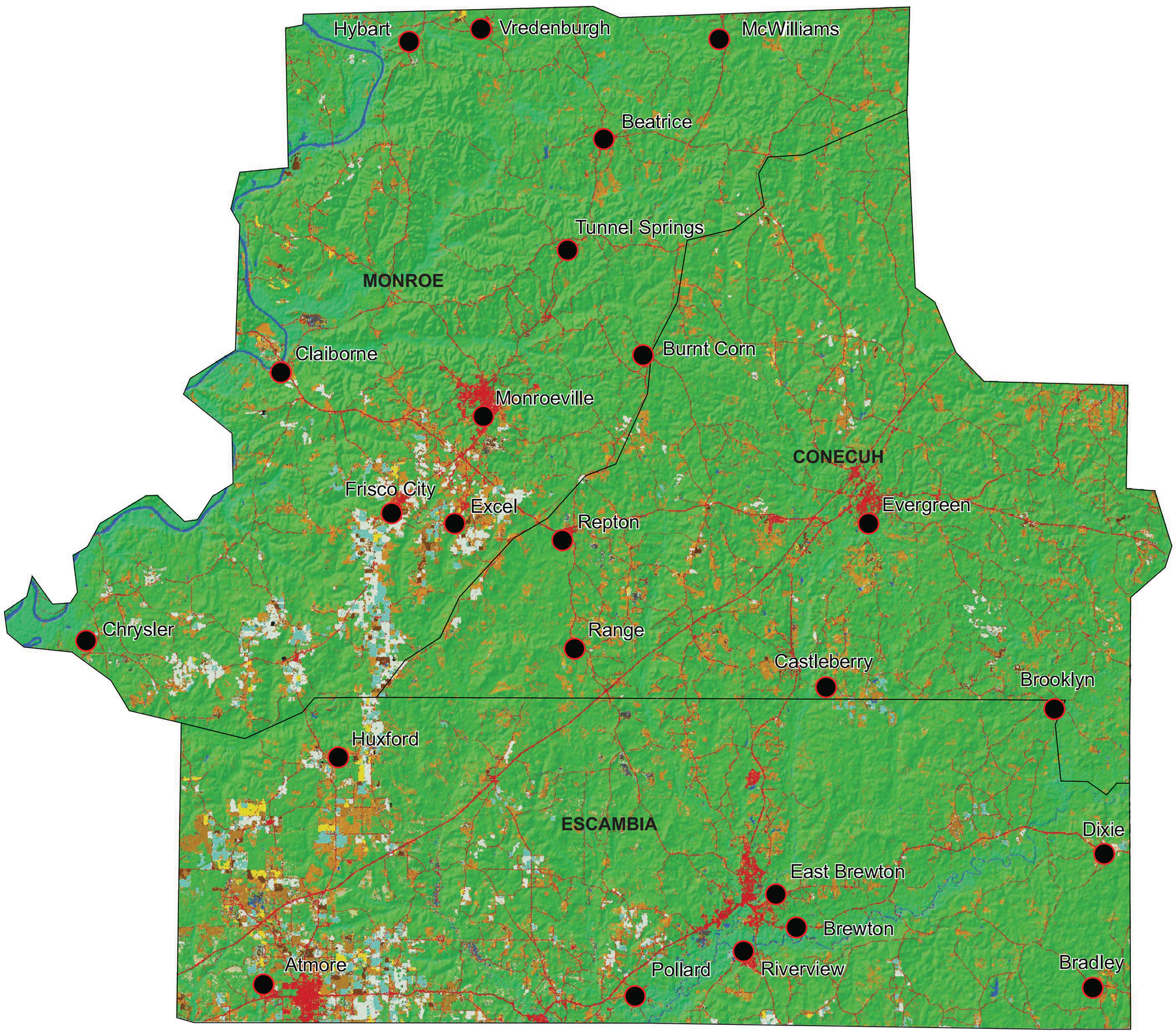
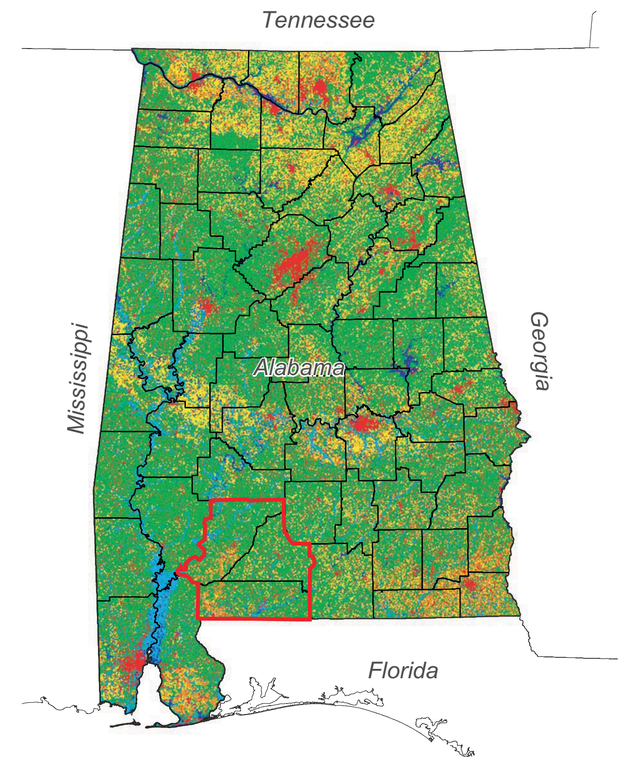




Explanation

LULC Classification

- Corn
- Cotton
- Other Crops
- Soybeans
- Seed/Sod Grass
- Pasture/Hay
- Forest
- Pecans
- Aquaculture
- Open Water
- Developed
- Barren
- Grassland Herbaceous
- Wetlands
- Peanuts

Other Symbols

- County boundary
- City

LAND-USE/LAND-COVER CLASSIFICATION FOR THE SOUTH-CENTRAL ALABAMA GROUNDWATER IRRIGATION ASSESSMENT AREA

(LULC- modified from the USDA-Cropland Data Layer for Southeastern States, 2010)

By
Blakeney Gillett
2011

Berry H. (Nick) Tew, Jr.
State Geologist

Explanation

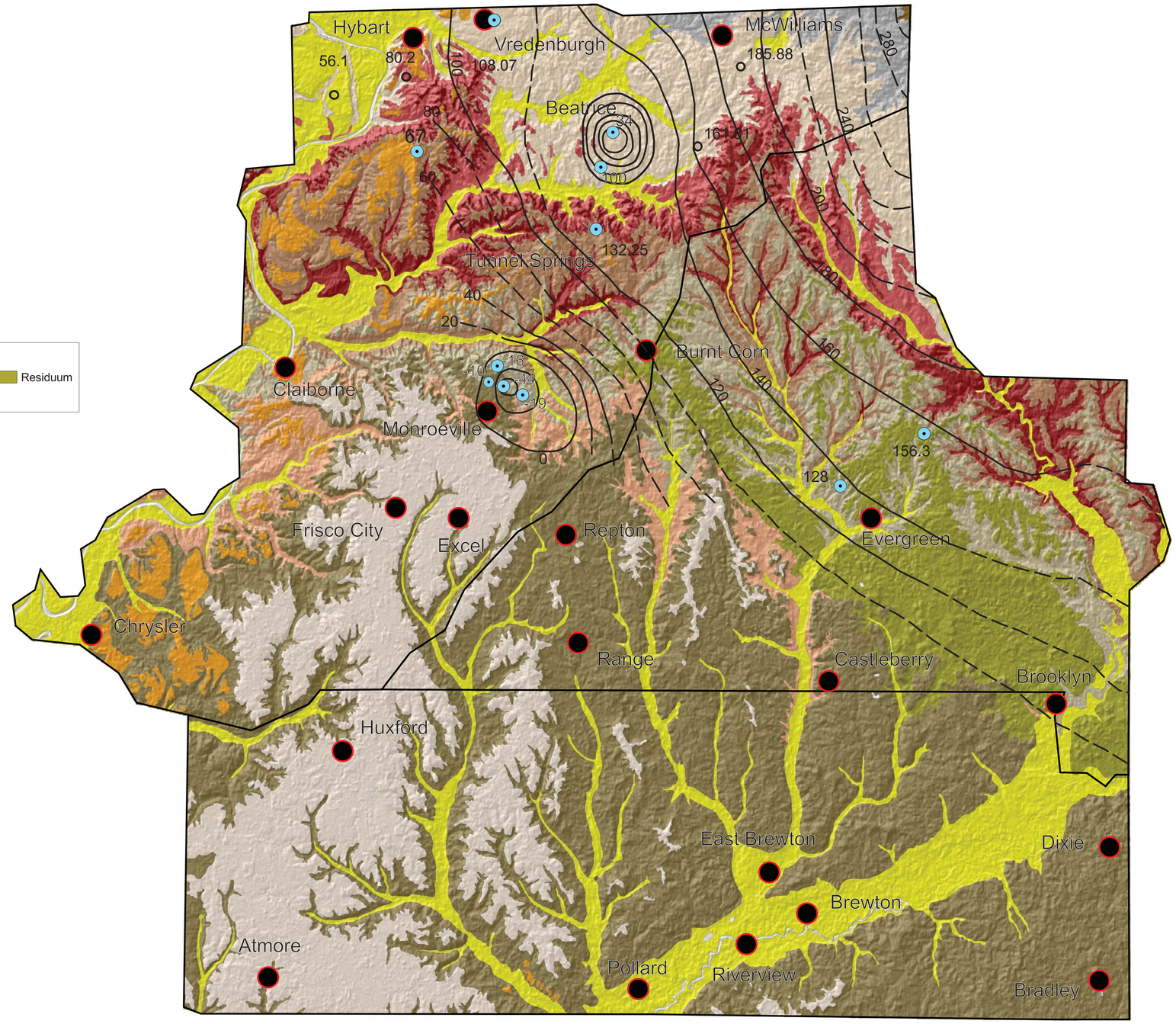
County boundary

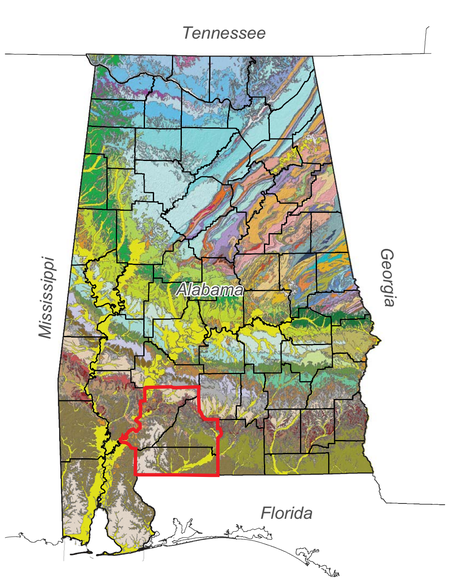
City

67 Public water supply well and water level in feet above mean sea level

156 Well location and water level in feet below mean sea level

SYSTEM	SERIES	GROUP	GEOLOGIC UNIT	
Quaternary	Holocene and Pleistocene		Alluvium and low terrace deposits	
			High terrace deposits	
Tertiary	Pliocene and Miocene		Citronelle Formation	
			Miocene Series undifferentiated	Residuum
	Oligocene	Vicksburg	Oligocene Series undifferentiated	
	Eocene	Jackson	Yazoo Clay and Moodys Branch Formation	
		Claiborne	Gosport Sand and Lisbon Formation	
			Lisbon Formation	
			Tallahatta Formation	
		Wilcox	Hatchetigbee Formation	
			Tuscahoma Sand	
	Paleocene		Nanafalia Formation	





CONFIGURATION OF THE POTENTIOMETRIC SURFACE OF THE NANAFALIA AQUIFER IN THE SOUTH-CENTRAL ALABAMA GROUNDWATER IRRIGATION ASSESSMENT AREA

(from Geological Survey of Alabama, 2006)

By
Blakeney Gillett
2011

Berry H. (Nick) Tew, Jr.
State Geologist

Explanation

County boundary

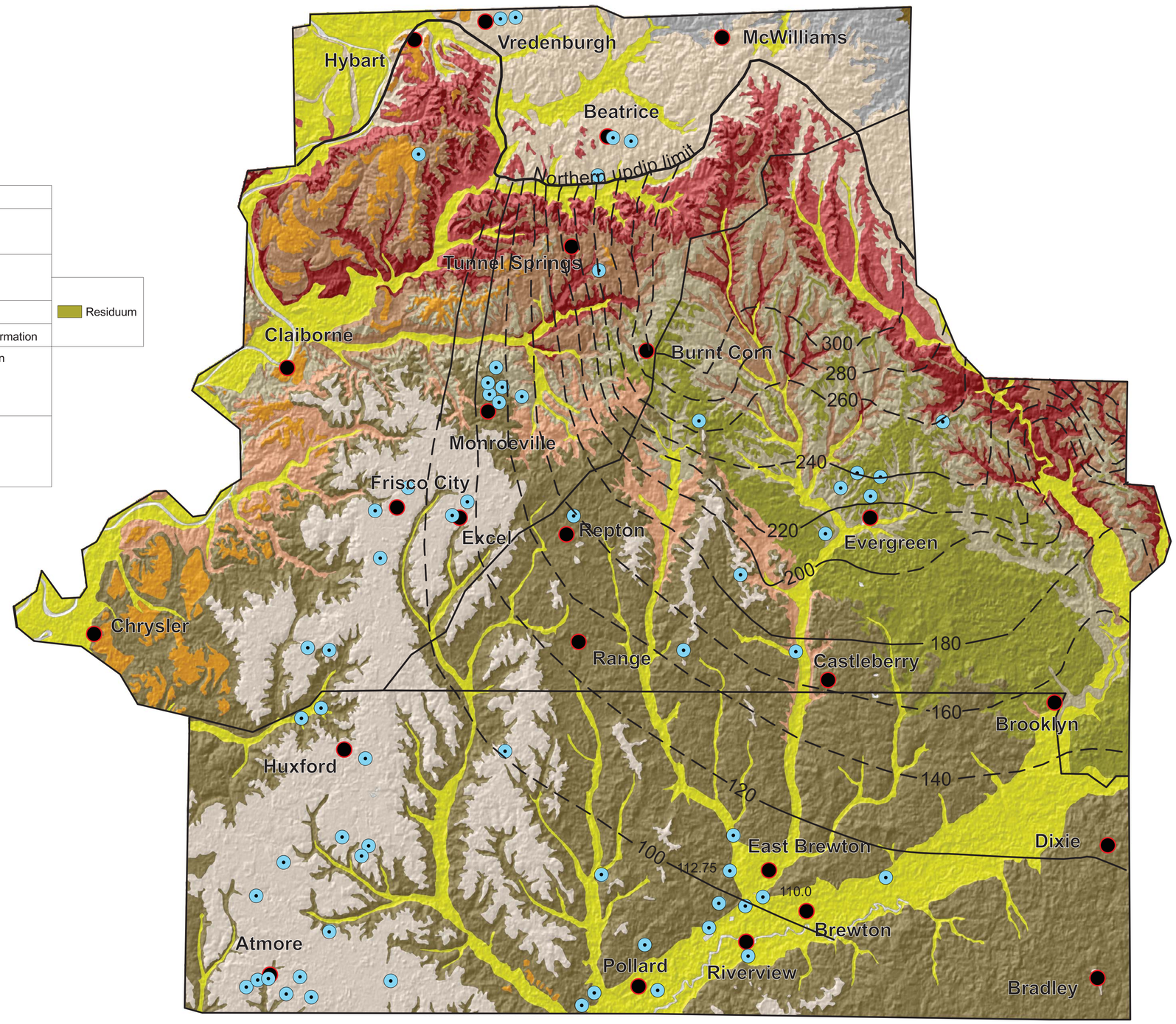
City

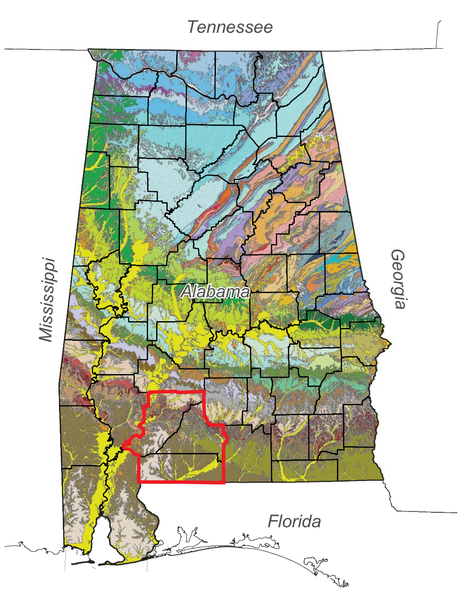
-200 Potentiometric contour, dashed where inferred. Datum is mean sea level. Contour interval is 20 feet.

156 Well location and water level in feet below mean sea level

SYSTEM	SERIES	GROUP	GEOLOGIC UNIT
Quaternary	Holocene and Pleistocene		Alluvium and low terrace deposits
			High terrace deposits
Tertiary	Pliocene and Miocene		Citronelle Formation
			Miocene Series undifferentiated
	Oligocene	Vicksburg	Oligocene Series undifferentiated
	Eocene	Jackson	Yazoo Clay and Moodys Branch Formation
		Claiborne	Gosport Sand and Lisbon Formation
			Lisbon Formation
			Tallahatta Formation
		Wilcox	Hatchetigbee Formation
			Tuscahoma Sand
	Paleocene		Nanafalia Formation

Residuum





CONFIGURATION OF THE POTENTIOMETRIC SURFACE OF THE LISBON AQUIFER IN THE SOUTH-CENTRAL ALABAMA GROUNDWATER IRRIGATION ASSESSMENT AREA

(from Geological Survey of Alabama, 2006)

By
Blakeney Gillett
2011

Berry H. (Nick) Tew, Jr.
State Geologist

Explanation

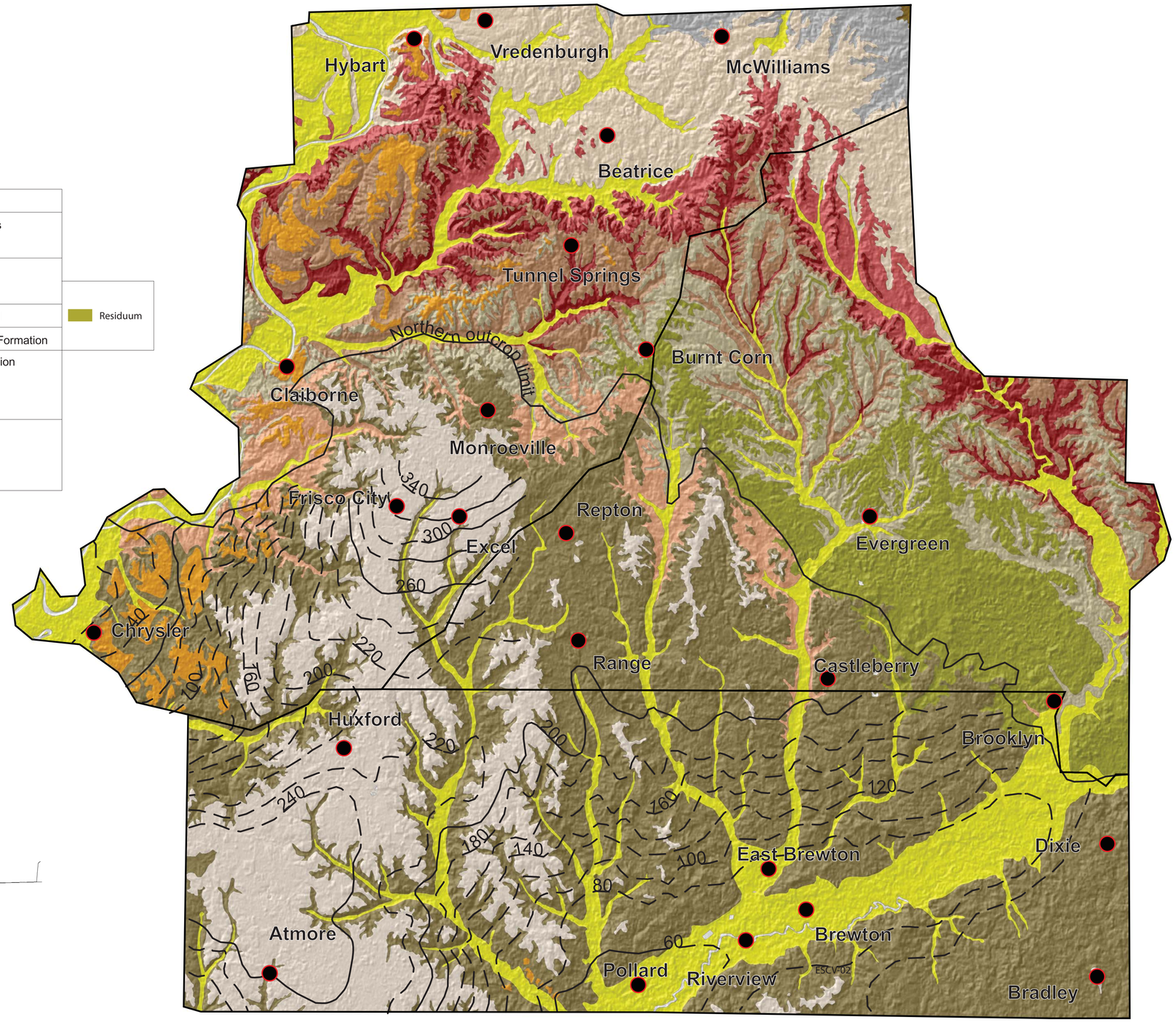
County boundary

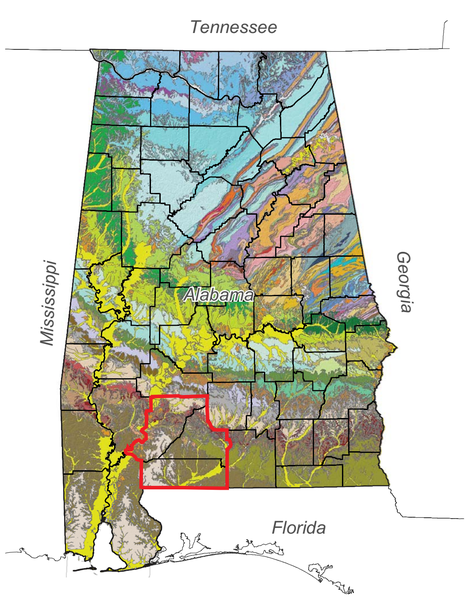
City

-200 Potentiometric contour, dashed where inferred. Datum is mean sea level. Contour interval is 20 feet.

SYSTEM	SERIES	GROUP	GEOLOGIC UNIT
Quaternary	Holocene and Pleistocene		Alluvium and low terrace deposits
			High terrace deposits
Tertiary	Pliocene and Miocene		Citronelle Formation
			Miocene Series undifferentiated
	Oligocene	Vicksburg	Oligocene Series undifferentiated
	Eocene	Jackson	Yazoo Clay and Moodys Branch Formation
		Claiborne	Gosport Sand and Lisbon Formation
			Lisbon Formation
			Tallahatta Formation
		Wilcox	Hatchetigbee Formation
			Tuscahoma Sand
	Paleocene		Nanafalia Formation

Residuum





CONFIGURATION OF THE POTENTIOMETRIC SURFACE OF THE MIOCENE AQUIFER IN THE SOUTH-CENTRAL ALABAMA GROUNDWATER IRRIGATION ASSESSMENT AREA

(from Geological Survey of Alabama, 2006)

By
Blakeney Gillett
2011

Berry H. (Nick) Tew, Jr.
State Geologist

Explanation

Elevation in feet above NGVD 1929

High : 394

Low : 0

County boundary

City

River and stream

Limited access interstate

Highway

Major road

Interstate highway

United States highway

State highway

Water body

Southwest groundwater irrigation assessment area

LOCATION MAP FOR THE SOUTHWEST GROUNDWATER IRRIGATION ASSESSMENT AREA

By
Dorina Murgulet

2010

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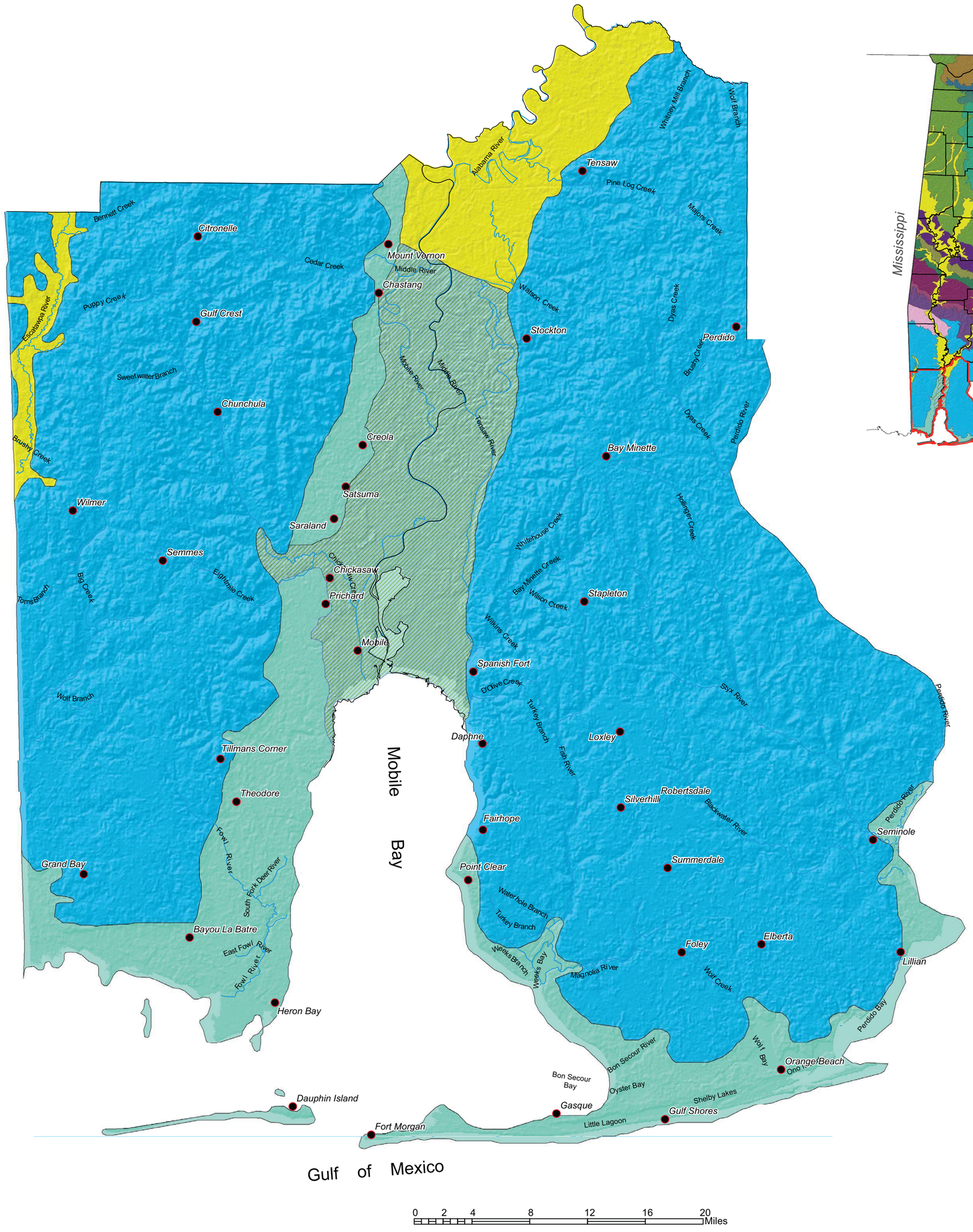


Explanation

Physiographic Districts

- Alluvial
- Coastal Lowlands
- Alluvial Deltaic Plain
- Southern Pine Hills

Other symbols

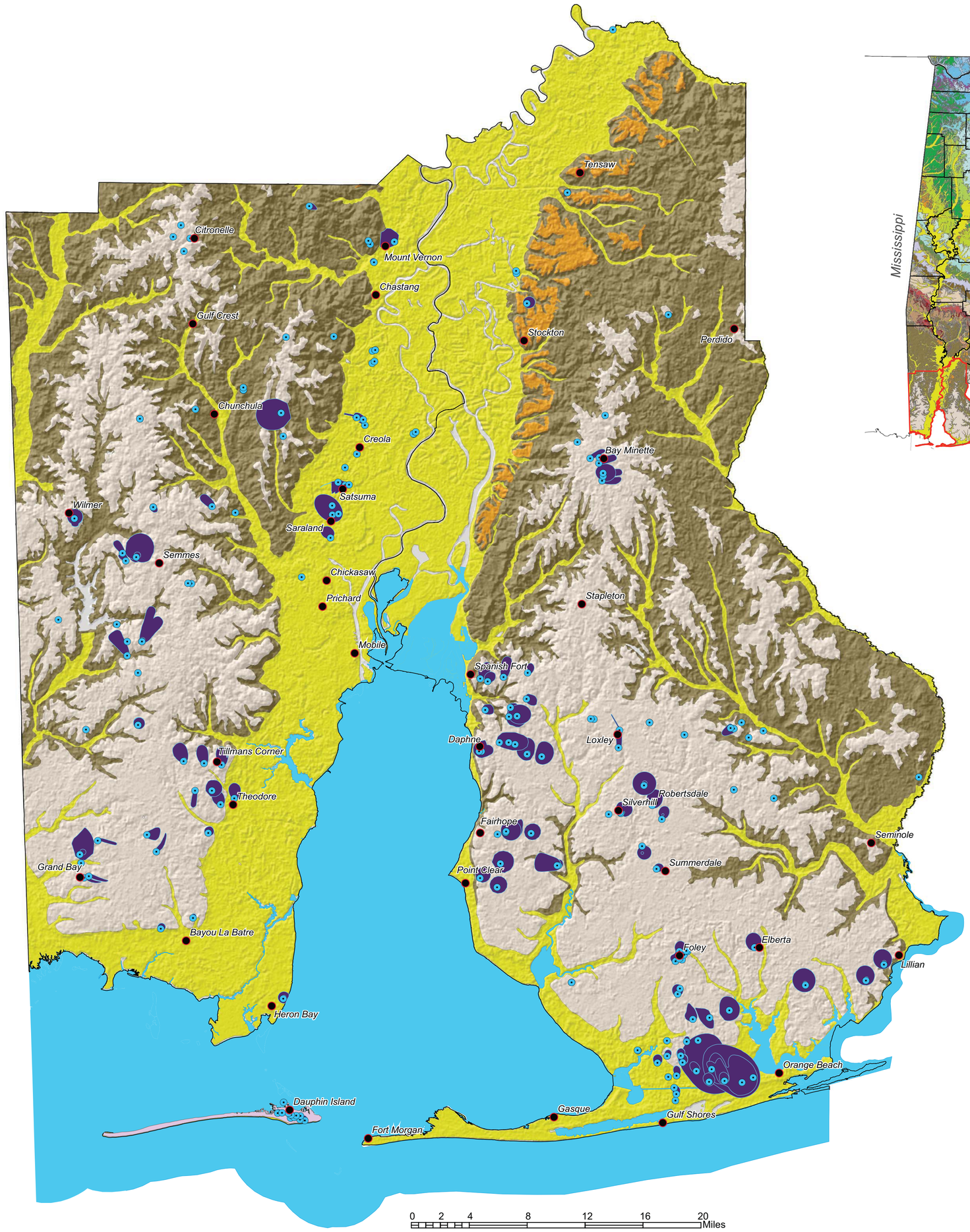
- Southwest groundwater irrigation assessment area
- County boundary
- City
- River and stream

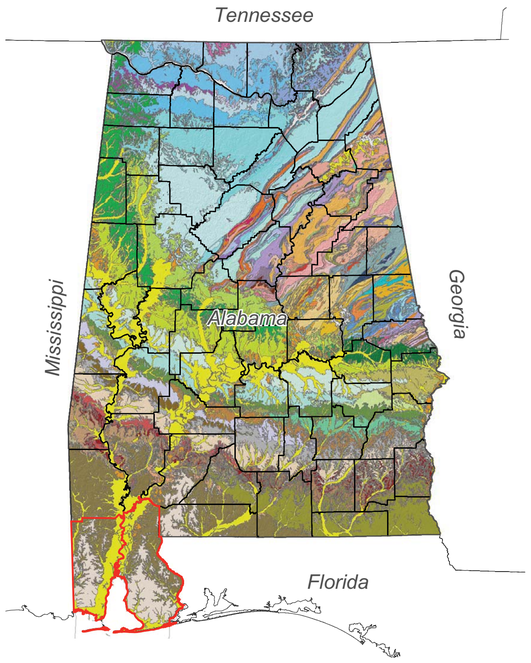
PHYSIOGRAPHIC REGIONS FOR THE SOUTHWEST GROUNDWATER IRRIGATION ASSESSMENT AREA

(modified from Sapp and Emplaincourt, 1975)

By
Dorina Murgulet
2011

Berry H. (Nick) Tew, Jr.
State Geologist





Explanation

Geology

Quaternary

- Alluvial, coastal, and low terrace
- High terrace deposits

Tertiary

- Citronelle Formation
- Miocene Series undifferentiated

Other symbols

- Water body
- Southwest groundwater irrigation assessment area
- County boundary
- City
- Public water supply well
- Source water assessment area

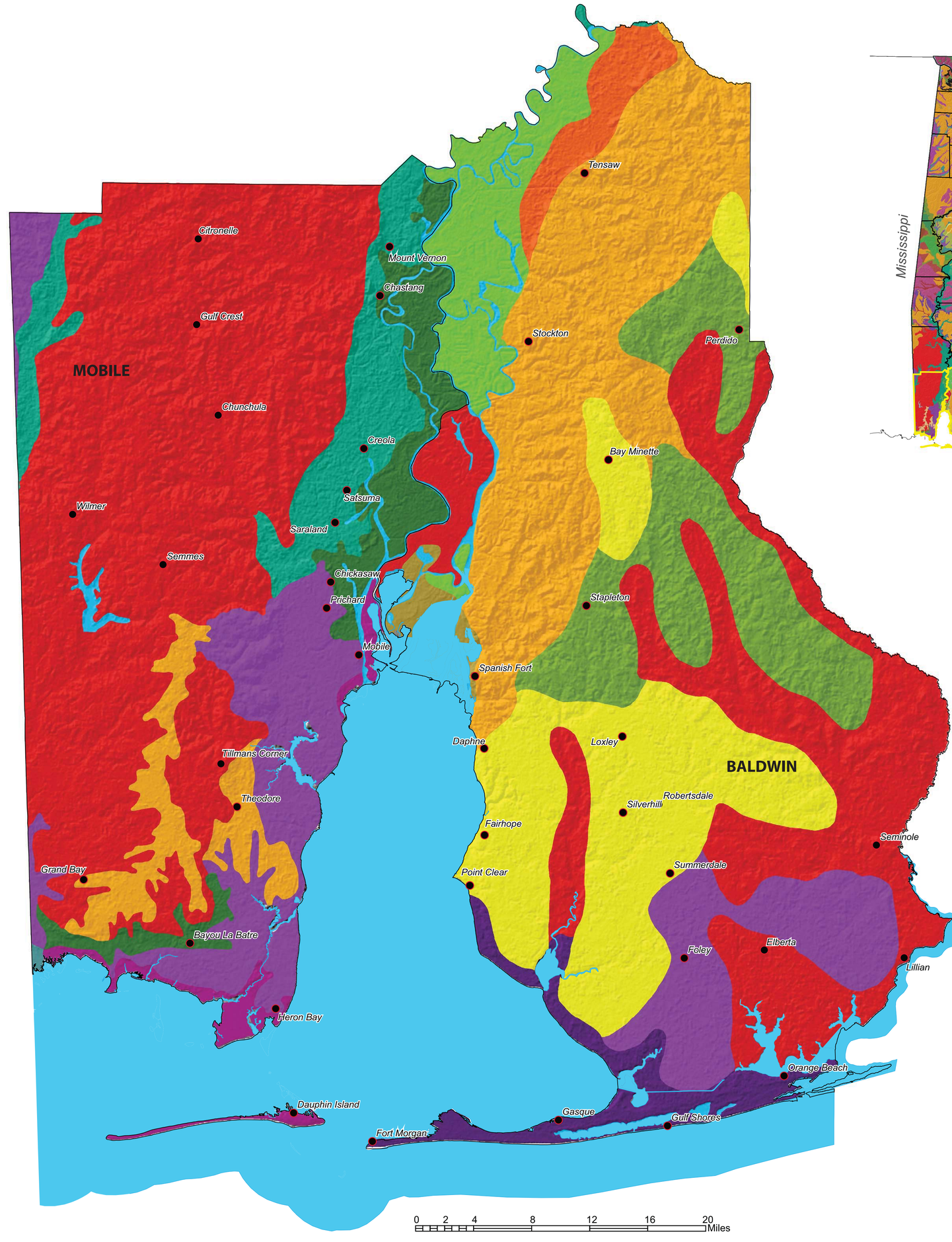
GEOLOGY, PUBLIC WATER SUPPLY WELLS, AND SOURCE WATER ASSESSMENT AREAS FOR THE SOUTHWEST GROUNDWATER IRRIGATION ASSESSMENT AREA

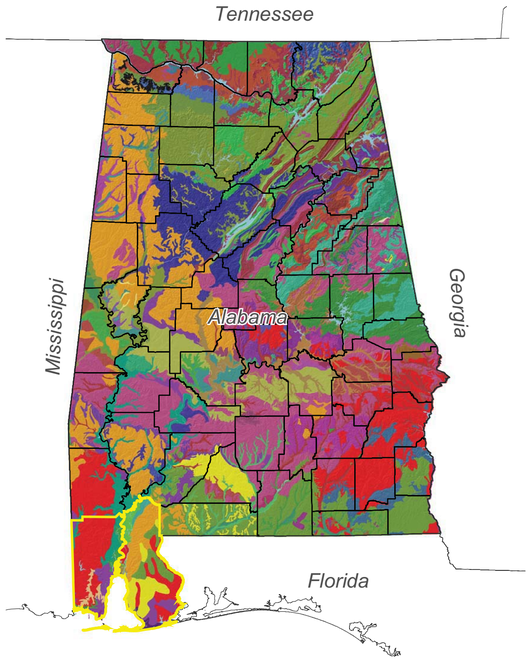
(Geology from Geological Survey of Alabama, 2006)

By
Dorina Murgulet
2010

GEOLOGICAL SURVEY OF ALABAMA • Founded 1848 •

Berry H. (Nick) Tew, Jr.
State Geologist





Explanation

Soil classification

Entisols

- Coarse-loamy, mixed, superactive, nonacid, thermic
- Fine, mixed, semiactive, thermic
- Fine, mixed, superactive, nonacid, thermic
- Thermic, uncoated

Ultisols

- Coarse-loamy, siliceous, semiactive, thermic
- Fine, kaolinitic, thermic
- Fine, mixed, semiactive, thermic
- Fine-loamy, kaolinitic, thermic
- Fine-loamy, siliceous, subactive, thermic
- Loamy, kaolinitic, thermic

Histosols

- Dysic, thermic
- Euic, hyperthermic

Inceptisols

- Fine, mixed, active, thermic

Other symbols

- Water body
- Southwest groundwater irrigation assessment area
- County boundary
- City

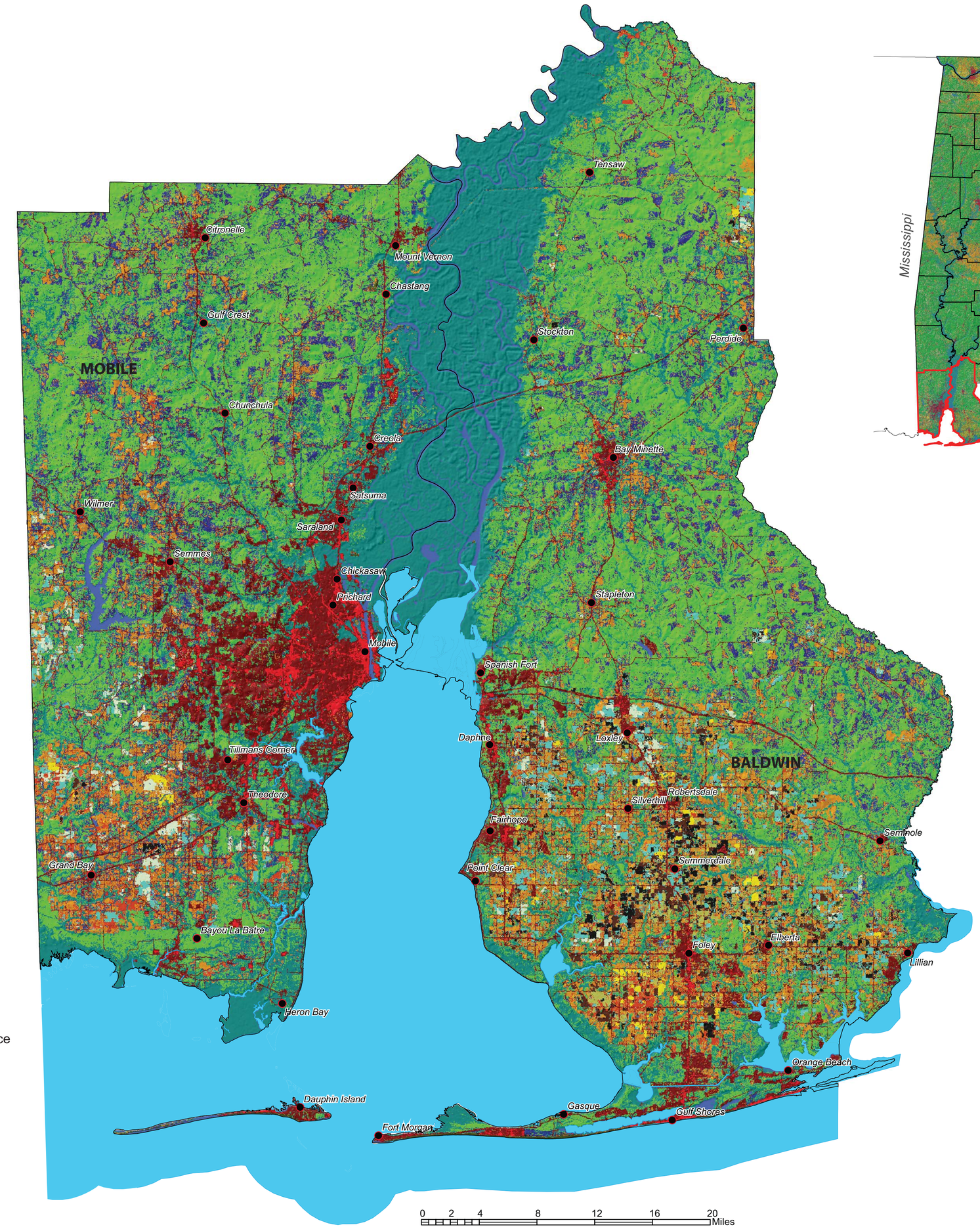
SOIL ORDER AND TAXONOMIC CLASSIFICATION FOR THE SOUTHWEST GROUNDWATER IRRIGATION ASSESSMENT AREA

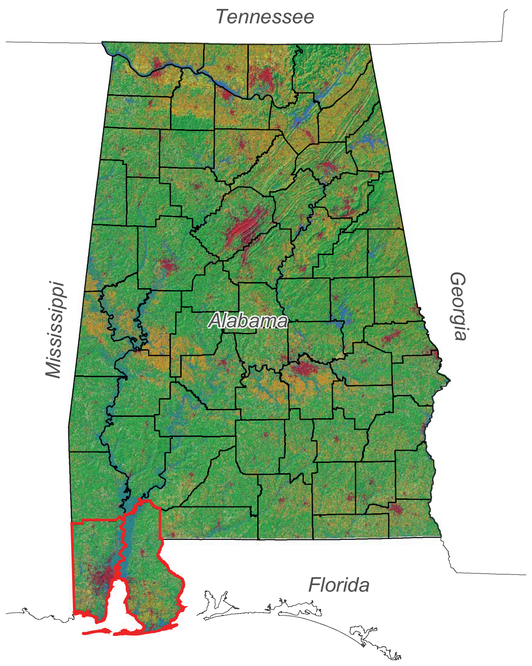
(modified from USDA-NRCS: Web Soil Survey, 2009)

By
Dorina Murgulet

2011

Berry H. (Nick) Tew, Jr.
State Geologist





Explanation

LULC Classification

Agricultural

- Corn
- Cotton
- Other Crops
- Soybeans
- Peanuts/Pecans
- Double Crop/Cotton, Soybeans, Oats, and Winter Wheat
- Pasture/Hay/Grass
- Seed/Sod Grass
- Fallow/Idle Cropland

Nonagricultural

- Open Water
- Developed/Low Intensity and Open Space
- Developed/Medium and High Intensity
- Barren
- Forest
- Shrubland
- Wetlands

Other Symbols

- Water Body
- Southwest groundwater irrigation assessment area
- County boundary
- City

LAND-USE/LAND-COVER CLASSIFICATION FOR THE SOUTHWEST GROUNDWATER IRRIGATION ASSESSMENT AREA

(modified from the USDA-Cropland Data Layer for the Southeast States, 2010)

By
Dorina Murgulet

2011

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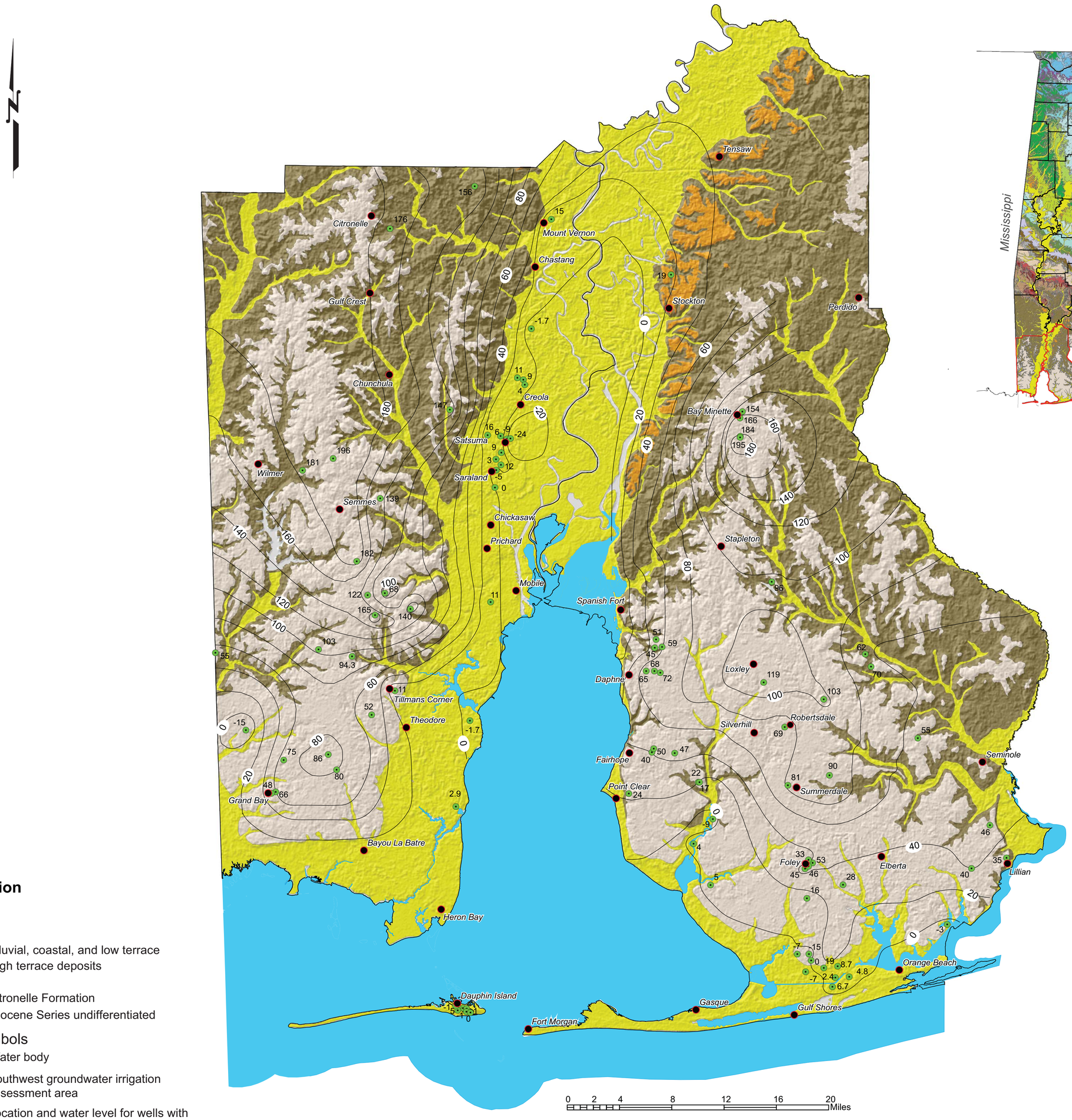
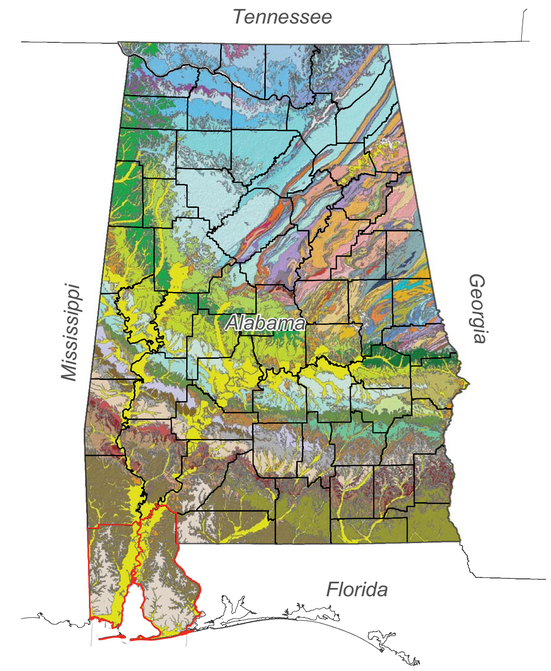
State Geologist





Explanation

Geology

Quaternary

- Alluvial, coastal, and low terrace
- High terrace deposits

Tertiary

- Citronelle Formation
- Miocene Series undifferentiated

Other symbols

- Water body
- Southwest groundwater irrigation assessment area
- 66 Location and water level for wells with screens ranging between 47 and 220 feet below land surface
- 20 Potentiometric contours (feet, datum mean sea level; contour interval 10 feet)
- County boundary
- City

GROUNDWATER POTENTIOMETRIC SURFACE OF AQUIFERS AT DEPTHS RANGING FROM 47 TO 220 FEET FOR SOUTHWEST GROUNDWATER IRRIGATION ASSESSMENT AREA

By
Dorina Murgulet
2011

BERRY H. (NICK) TEW, JR.
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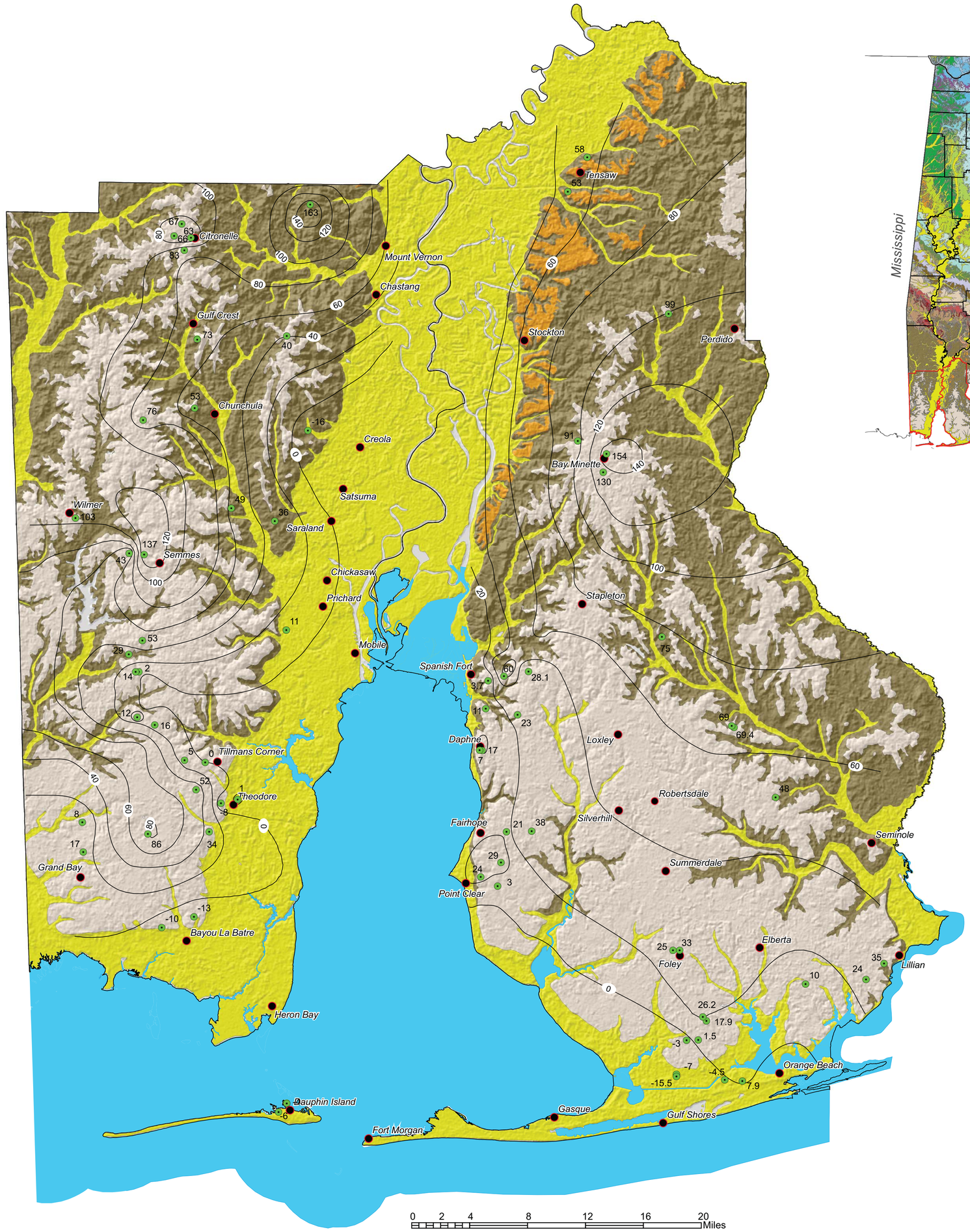

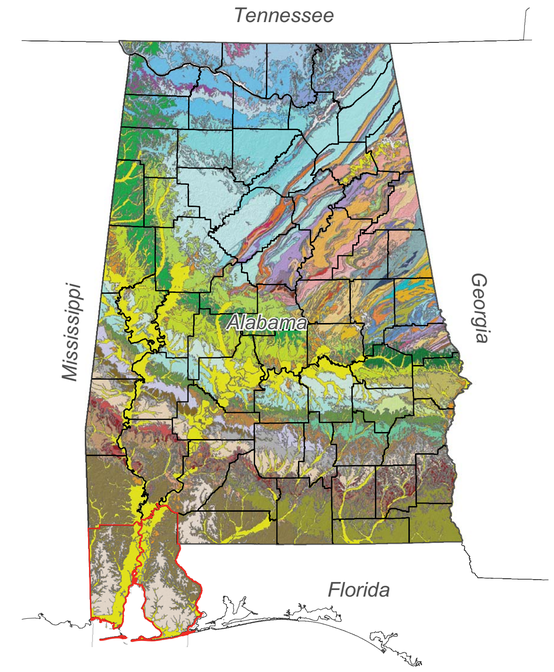

Explanation

Geology

Quaternary

- Alluvial, coastal, and low terrace
- High terrace deposits

Tertiary

- Citronelle Formation
- Miocene Series undifferentiated

Other symbols

- Water body
- Southwest groundwater irrigation assessment area
- 66 Location and water level for wells with screens ranging between 200 and 1,000 feet below land surface
- Potentiometric contours (feet, datum mean sea level; contour interval 10 feet)
- County boundary
- City

GROUNDWATER POTENTIOMETRIC SURFACE OF AQUIFERS AT DEPTHS RANGING FROM 200 TO 1,000 FEET FOR THE SOUTHWEST GROUNDWATER IRRIGATION ASSESSMENT AREA

By
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2011

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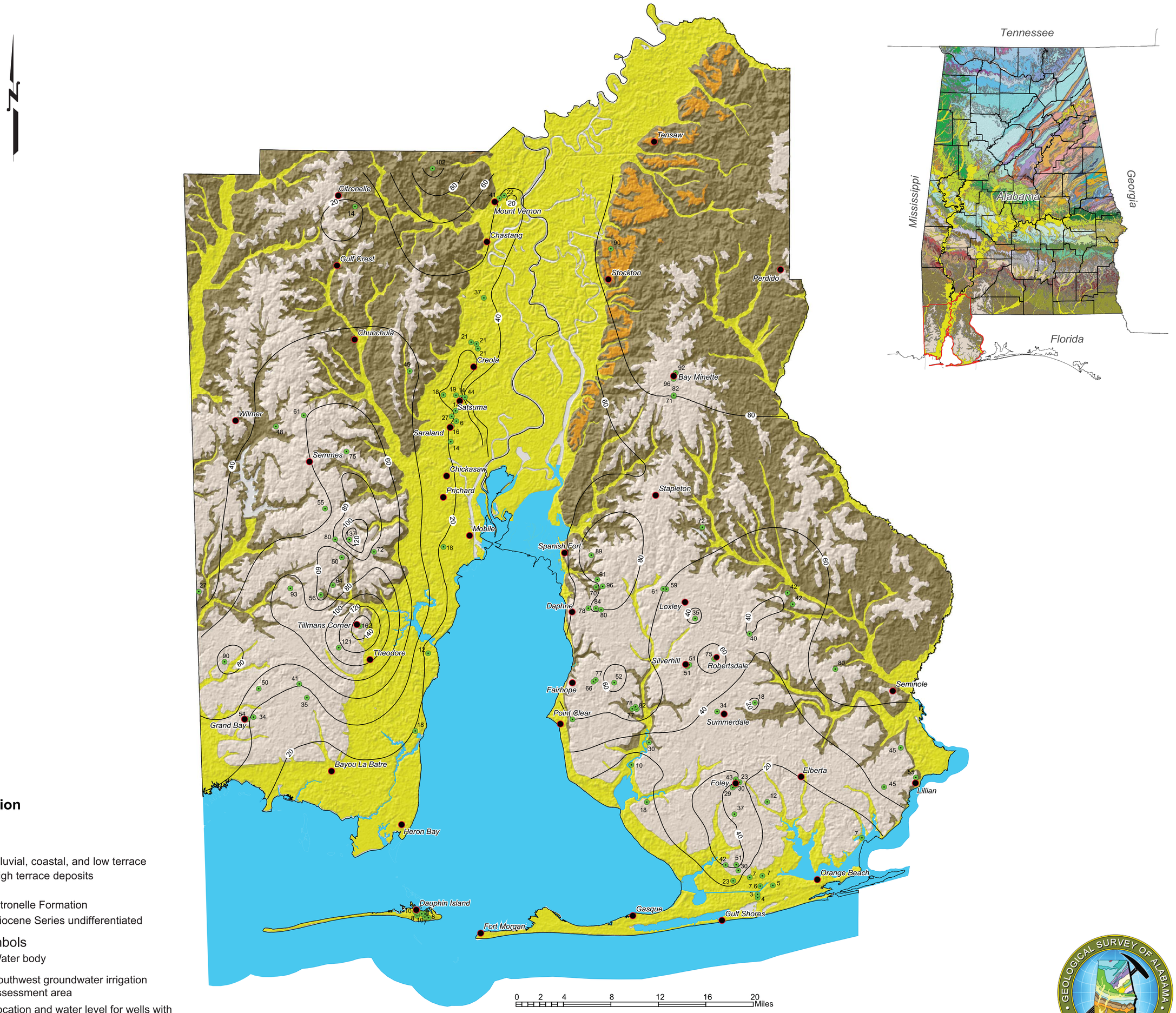

Explanation

Geology

Quaternary

- Alluvial, coastal, and low terrace
- High terrace deposits

Tertiary

- Citronelle Formation
- Miocene Series undifferentiated

Other symbols

- Water body
- Southwest groundwater irrigation assessment area
- 35 Location and water level for wells with screens ranging between 47 and 220 feet below land surface
- Potentiometric contours (feet, datum mean sea level; contour interval 20 feet)
- County boundary
- City

DEPTH TO WATER FOR AQUIFERS AT DEPTHS RANGING FROM 47 TO 220 FEET FOR THE SOUTHWEST GROUNDWATER IRRIGATION ASSESSMENT AREA

By
Dorina Murgulet
2011

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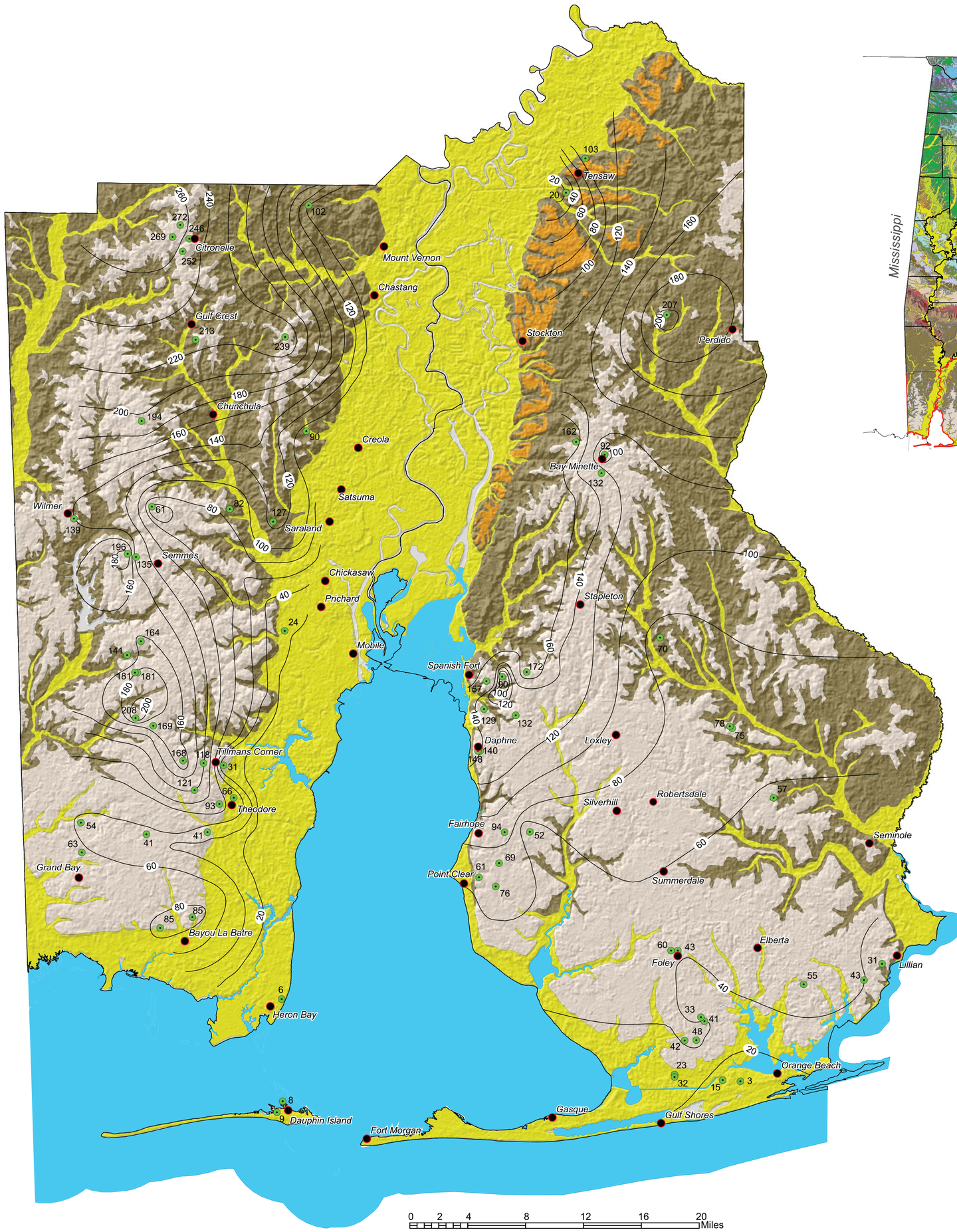

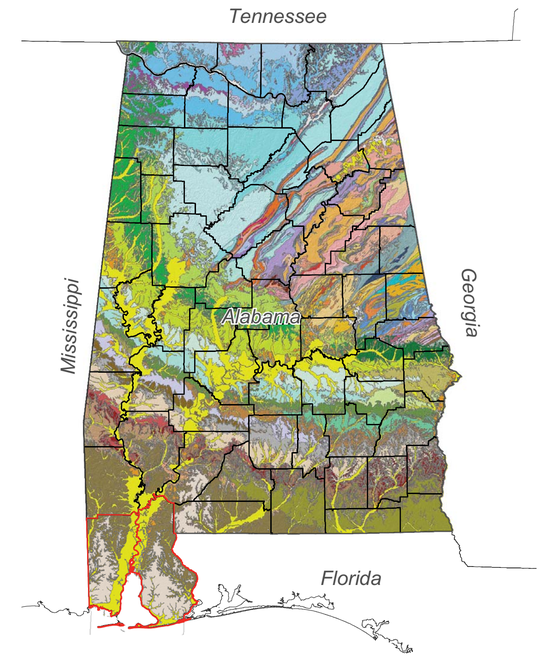

Explanation

Geology

Quaternary

- Alluvial, coastal, and low terrace
- High terrace deposits

Tertiary

- Citronelle Formation
- Miocene Series undifferentiated

Other symbols

- Water body
- Southwest groundwater irrigation assessment area
- 66 Location and water level for wells with screens ranging between 200 and 1,000 feet below land surface
- 60 Potentiometric contours (feet, datum mean sea level; contour interval 20 feet)
- County boundary
- City

DEPTH TO WATER FOR AQUIFERS AT DEPTHS RANGING FROM 200 TO 1,000 FEET FOR THE SOUTHWEST GROUNDWATER IRRIGATION ASSESSMENT AREA

By
Dorina Murgulet
2011

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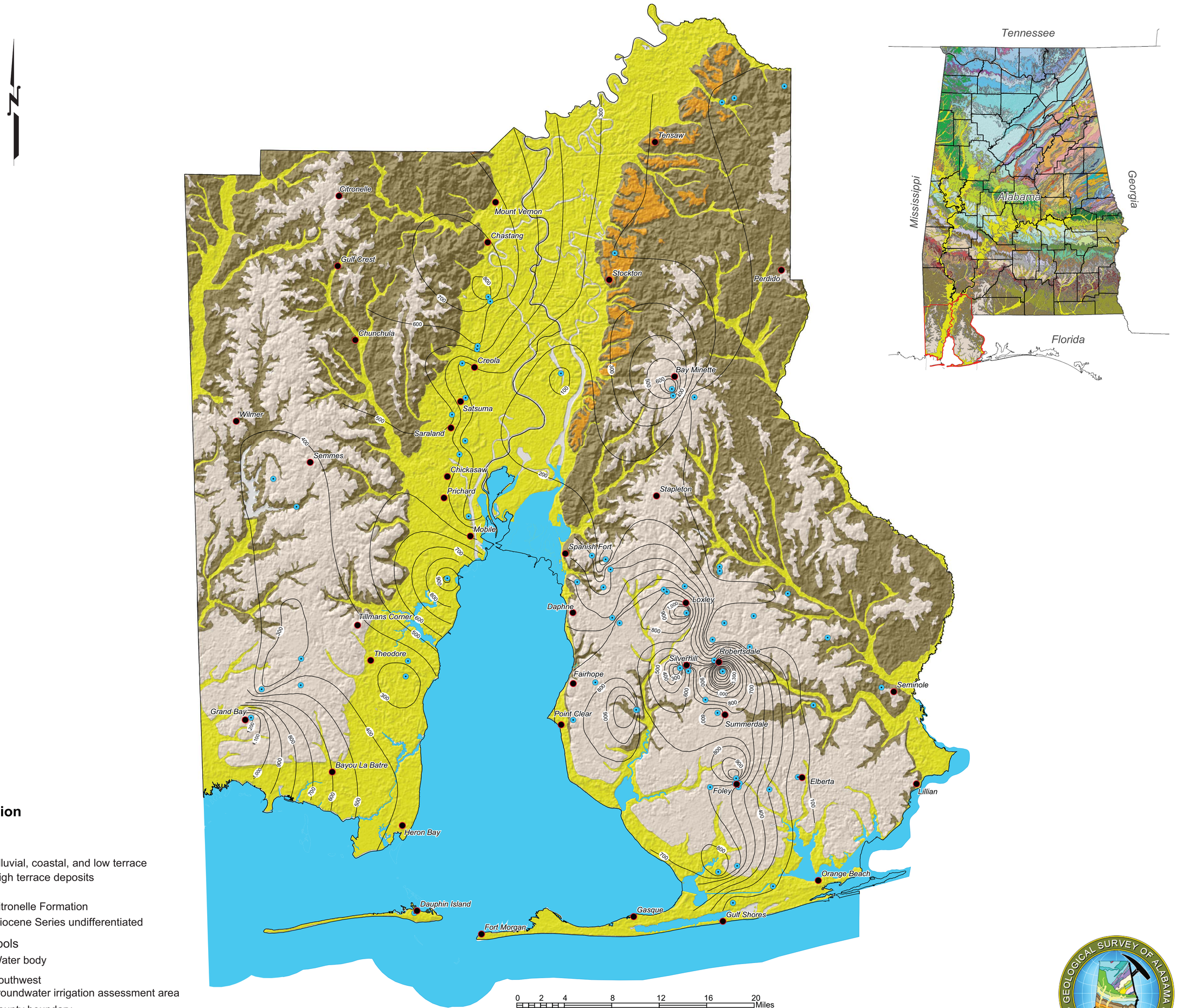

Explanation

Geology

Quaternary

- Alluvial, coastal, and low terrace
- High terrace deposits

Tertiary

- Citronelle Formation
- Miocene Series undifferentiated

Other symbols

- Water body
- Southwest groundwater irrigation assessment area
- County boundary
- Line of equal pumping rate (contour interval 100 gpm)
- City
- Water wells with screens ranging between 47 and 220 feet below land surface

PUMPING RATES FOR AQUIFERS AT DEPTHS RANGING FROM 47 to 220 FEET FOR THE SOUTHWEST GROUNDWATER IRRIGATION ASSESSMENT AREA

By
Dorina Murgulet
2011

GEOLOGICAL SURVEY OF ALABAMA
Founded 1848

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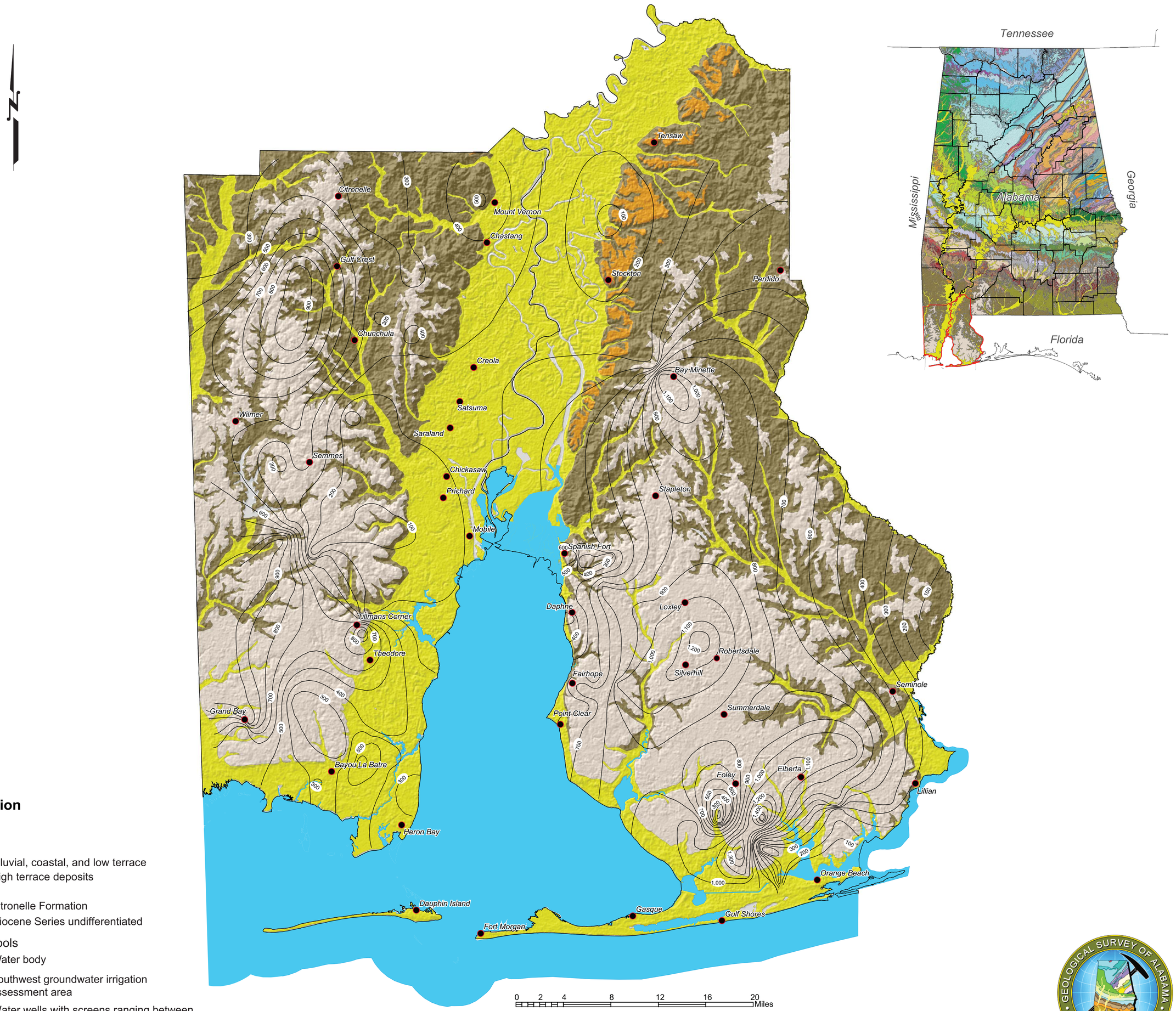

Explanation

Geology

Quaternary

- Alluvial, coastal, and low terrace
- High terrace deposits

Tertiary

- Citronelle Formation
- Miocene Series undifferentiated

Other symbols

- Water body
- Southwest groundwater irrigation assessment area
- Water wells with screens ranging between 200 and 935 feet below land surface
- Line of equal pumping rate (contour interval 100 gpm)
- County boundary
- City

PUMPING RATES FOR AQUIFERS AT DEPTHS RANGING FROM 200 TO 935 FEET FOR THE SOUTHWEST GROUNDWATER IRRIGATION ASSESSMENT AREA

By
Dorina Murgulet
2011

GEOLOGICAL SURVEY OF ALABAMA
Founded 1848

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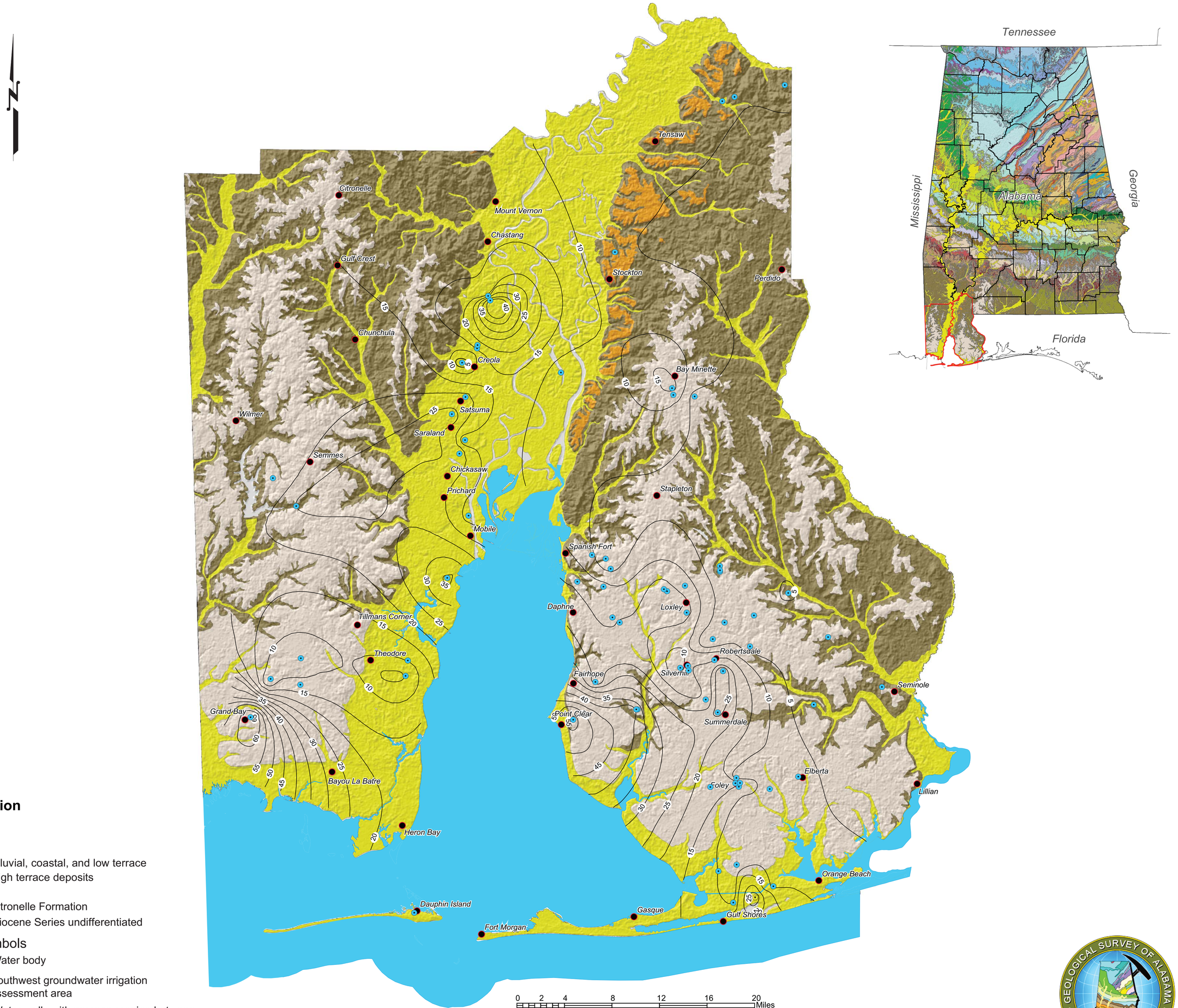

Explanation

Geology

Quaternary

- Alluvial, coastal, and low terrace
- High terrace deposits

Tertiary

- Citronelle Formation
- Miocene Series undifferentiated

Other symbols

- Water body
- Southwest groundwater irrigation assessment area
- Water wells with screens ranging between 47 and 220 feet below land surface
- Line of equal specific capacity (contour interval 5 gpm/ft)
- County boundary
- City

SPECIFIC CAPACITY FOR AQUIFERS AT DEPTHS RANGING FROM 47 TO 220 FEET FOR THE SOUTHWEST GROUNDWATER IRRIGATION ASSESSMENT AREA

By
Dorina Murgulet
2011

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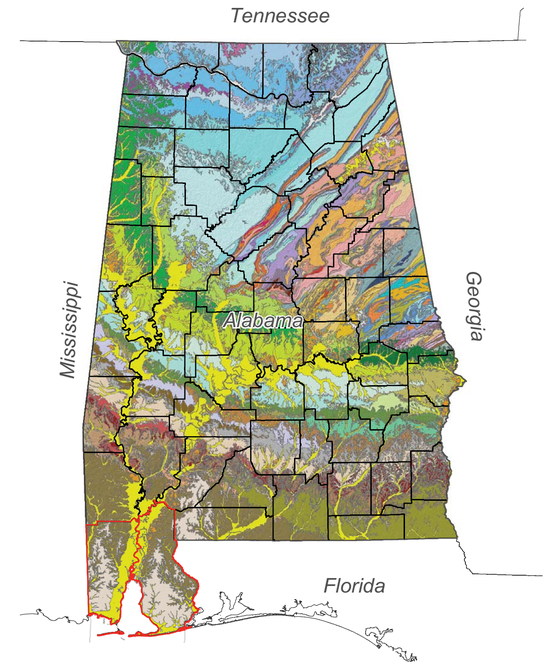

Explanation

Geology

Quaternary

- Alluvial, coastal, and low terrace
- High terrace deposits

Tertiary

- Citronelle Formation
- Miocene Series undifferentiated

Other symbols

- Water body
- Southwest groundwater irrigation assessment area
- Water wells with screens ranging between 200 and 935 feet below land surface
- Line of equal specific capacity (contour interval 5 gpm/ft)
- County boundary
- City

SPECIFIC CAPACITY FOR AQUIFERS AT DEPTHS RANGING FROM 200 TO 935 FEET FOR THE SOUTHWEST GROUNDWATER IRRIGATION ASSESSMENT AREA

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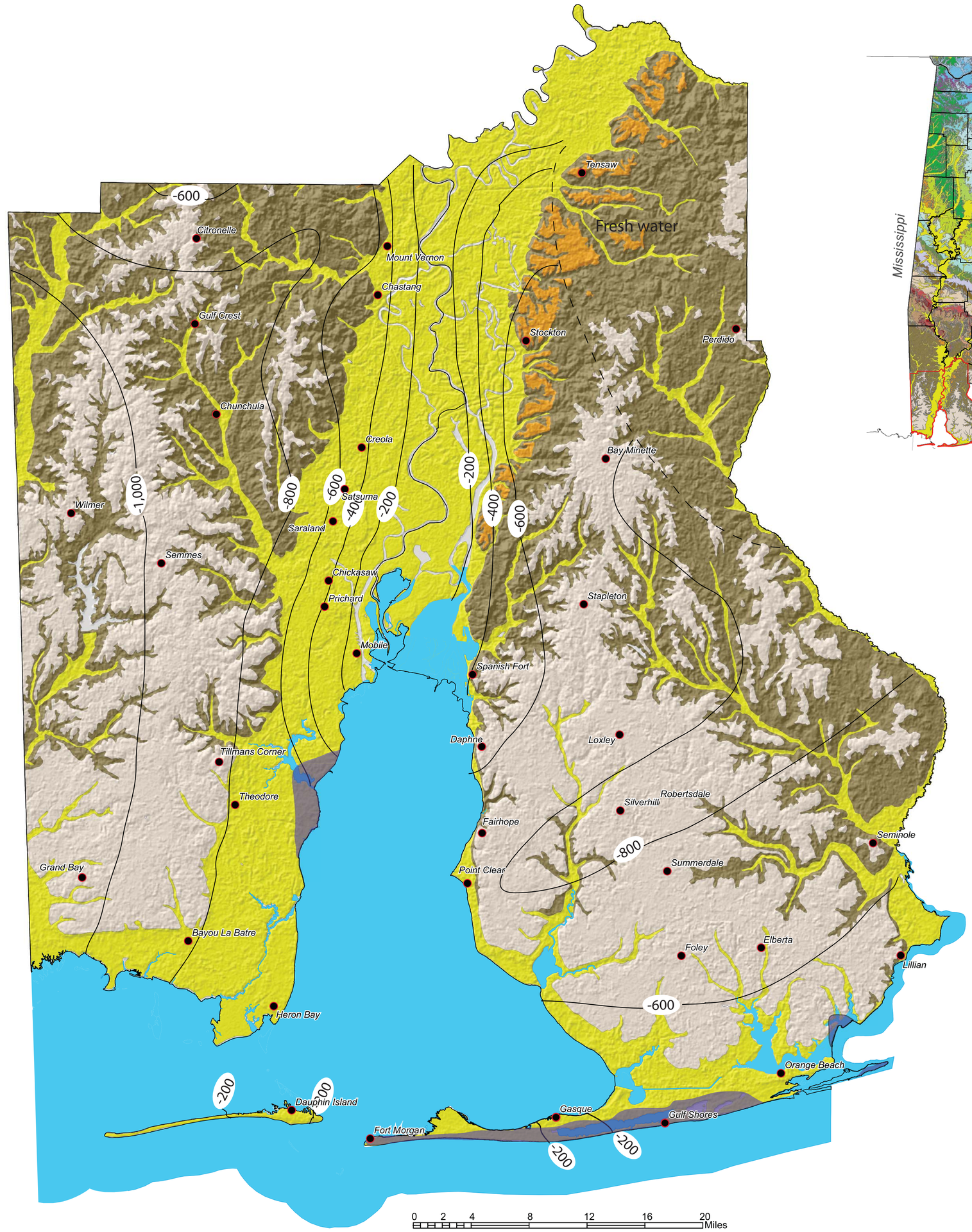

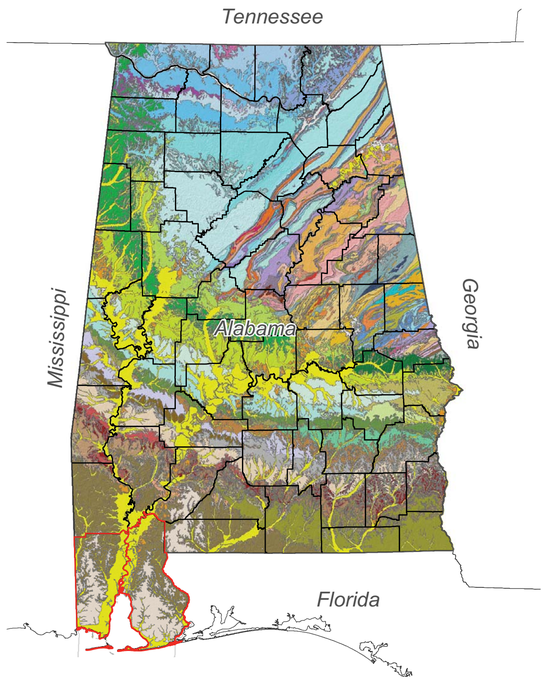

Explanation

Geology

Quaternary

- Alluvial, coastal, and low terrace
- High terrace deposits

Tertiary

- Citronelle Formation
- Miocene Series undifferentiated

Other symbols

- Water body
- Southwest groundwater irrigation assessment area
- County boundary
- City
- Chloride concentrations > 50 mg/L
- -700 Depth in feet (below msl) to groundwater with approximately 1,000 mg/L TDS as NaCl at 25°C (contour interval 200 ft)

DEPTH TO GROUNDWATER WITH APPROXIMATELY 1,000 mg/L OF TOTAL DISSOLVED SOLIDS (modified from Moser and Chermock, 1978) AND CHLORIDE CONCENTRATIONS IN WATER FROM SELECTED WELLS CONSTRUCTED AT DEPTHS RANGING FROM 47 TO 220 FEET (modified from Murgulet and Tick, 2007) FOR THE SOUTHWEST GROUNDWATER IRRIGATION ASSESSMENT AREA

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