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

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

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By

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

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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. The Geological Survey of Alabama was tasked with investigating the potential for large-scale irrigation from groundwater sources in the state. The initial investigation contained in this report is focused on the Black Belt area of central Alabama where increased agricultural production and diversity 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 1), comprising an area of approximately 3,745 square miles (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 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 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 feet (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 feet (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 feet.

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 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 feet per mile (Cook, 1993a, 2002) and vary in thickness from a few feet along the area’s northern boundary to more than 3,000 feet 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 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 3). All other Tertiary and Paleozoic strata are designated as Tertiary formations and Paleozoic formations, respectively (plate 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 feet in western Alabama (updip Tuscaloosa Group) to 300 feet 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 feet. 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 feet 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 feet along the northern limit of the outcrop (Cook, 1993a) to 350 and 400 feet in outcrop in western and central Alabama and thins eastward to 100 to 150 feet (easternmost Alabama) (Raymond and others, 1988). Downdip, the formation has a maximum thickness of 500 feet, but generally is about 400 feet 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 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 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 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 feet in west Alabama to 600 feet in Montgomery County and thins to 100 feet in southern Macon County, grading into other Cretaceous formations in Bullock and Russell Counties (Raymond and others, 1988).

SOILS

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). There are six soil orders present in the Cretaceous aquifer recharge areas (plate 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). 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, 2009). 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, 2009). 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 U.S. Department of Agriculture (USDA) - Natural Resources Conservation Service (NRCS) (2007) 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, 2007). Major soil series and their taxonomic characteristics for the potential large-scale agricultural irrigation area are tabulated in table 1 and depicted in plate 4. All other series are referred to as "all other" orders in table 1.

Table 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

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. A landscape pattern is 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. The 2001 USGS Land Use/Land Cover data (Homer and others, 2004) were used in delineating land use/land cover (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 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 5). Most of the recharge area is dominated by forest with lesser agriculture (plate 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 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 3), soil types (plate 4), and the distribution of cultivated areas (plate 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 3, 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, 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 2 and indicate three major classes of LULC: agriculture, forest, and other land uses.

Table 2.—Classes, area, and proportion of land use/land cover 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 2). However, it should be noted that scattered agricultural fields are also present within the recharge area (plate 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 5), which, in large part, are pasture and hay with only limited amounts of row crop agriculture (table 2).

HYDROGEOLOGY

The Eutaw and Tuscaloosa Group aquifers are the major water bearing units in the area of investigation (plate 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 (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 million gallons per day (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

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.

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 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 feet above mean sea level along the upgradient margin of the Coker aquifer (plate 6). The hydraulic gradient in the recharge areas of the subject aquifers is southwestward at about 12 feet per mile in the western and central parts of the area and southward at about 17 feet per mile in the eastern part of the area (plate 6). The hydraulic gradient generally flattens to about 3 feet per mile in much of the western and central parts of the area of potential agricultural groundwater irrigation and about 9 feet per mile in the eastern part of the area (plate 6). The change in gradient is primarily caused by the influence of the Tombigbee, Black Warrior, Alabama, and Tallapoosa Rivers (plate 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 feet above mean sea level (plate 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 6).

DEPTH TO WATER

The depth to water map (plate 7) is similar to the potentiometric surface map except the depth to water surface is measured by the number of feet below land surface. This map 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 feet, hydraulic head causes the depth to water from these aquifers to range from 0 to 240 feet below land surface (plate 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 7). The deepest water levels (100 to 240 feet below land surface) 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. These data can be used to calculate specific capacity: the yield of a well, determined from a pumping test, divided by the water-level drawdown for a specified period (Fetter, 1994) and is expressed in gallons per minute per foot (gpm/ft) of drawdown.

One of the exploration techniques that utilize 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. 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 feet (67 wells) and wells drilled to depths greater than 500 feet (87 wells).

Plate 8 shows the specific capacity for well depths ranging from 60 to 500 feet. Specific capacities varied from less than 1 to more than 10 gpm/ft of drawdown. Plate 9 shows the specific capacity for wells with depths greater than 500 feet. 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 gallons per minute (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 10 shows the pumping rates for wells with depths from 60 to 500 feet. 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 11 shows the pumping rates for wells greater than 500 feet. 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

Waters from lakes, streams, and aquifers represent the source water for a large variety of uses, most importantly, the source of public drinking water. Assessment and protection of land areas contributing source water is essential in decreasing the potential for contamination, costs of treatment, and risks to public health. Consequently, 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 aids the protection of drinking water supply source waters by analyzing existing and potential threats throughout the state. SWAP is a process through which each state delineates the land area contributing water to each public water system and identifies potential contamination sources.

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 3). However, public supply wells are dispersed within most of the investigated area accompanied by small source water assessment areas for some of these wells (plate 3). Nevertheless, a large part of the investigated area remains outside of source water assessment areas and have no public supply wells (plate 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 (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 chloride. 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 chloride is unacceptable for human consumption or agriculture. The maximum contaminant level (MCL) for chloride 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 Mississippi State University Extension Service has also established guidelines for the hazard to crops related to chloride 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 12, 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 chloride concentration that exceeds crop hazard guidelines and drinking water standards (plates 12, 13).

Two areas of groundwater with excessive chloride 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 12, 13). Groundwater with excessive chlorides 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 chloride-rich water from underlying Paleozoic rocks and from the overlying Eutaw Formation. Groundwater with elevated chloride in the Eutaw aquifer underlies most of Lowndes County and extends upgradient well beyond the high chloride water in the underlying Gordo aquifer (plates 12, 13). Cook (1993b) suggested that water with excessive chloride 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 chloride ratio for this water was almost identical to the sodium to chloride 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-chloride 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 chloride 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 chloride 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 feet: 950 feet of 10.75 inch diameter steel casing, and 50 feet 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 feet below ground surface, capable of delivering 300 gpm at 300 feet total dynamic head with a pumping level of 210 feet 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 chloride 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.

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GEOLOGICAL SURVEY OF ALABAMA
P.O. Box 869999
420 Hackberry Lane
Tuscaloosa, Alabama 35486-6999
205/349-2852

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

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ATTACHMENT 4-1

REPORT OF INVENTIONS AND SUBCONTRACTS

(Pursuant to "Patent Rights" Contract Clause)(See Instructions on Reverse Side.)

FORM APPROVED
OMB NO. 0704-0016

1a. NAME OF CONTRACTOR/SUBCONTRACTOR Geological Survey of Alabama	c. CONTRACT NUMBER SUB2008-243	2a. NAME OF GOVERNMENT PRIME CONTRACTOR The University of Alabama in Huntsville	c. CONTRACT NUMBER NA06NES4400015	3. TYPE OF REPORT *(check one)* ☐ INTERIM ☒ FINAL
b. ADDRESS *(include Zip Code)* 420 Hackberry Lane Tuscaloosa, AL 35486-6999	d. AWARD DATE *(YYMMDD)*	b. ADDRESS *(include Zip Code)* Huntsville, AL 35899	d. AWARD DATE *(YYMMDD)* 7/1/06	4. REPORTING PERIOD *(YYMMDD)* FROM: 08/06/01 TO: 09/05/31

SECTION I - SUBJECT INVENTIONS

5. "SUBJECT INVENTIONS" REQUIRED TO BE REPORTED BY CONTRACTOR/SUBCONTRACTOR *(If "None," so state)*

a. NAME OF INVENTOR (S) *(Last, First, M.I.)*	b. TITLE OF INVENTION (S)	c. DISCLOSURE NO., PATENT APPLICATION SERIAL NO. OR PATENT NO.	d. ELECTION TO FILE PATENT APPLICATIONS				e. CONFIRMATORY INSTRUMENT OR ASSIGNMENT FORWARDED TO CONTRACTING OFFICER	
			UNITED STATES		FOREIGN			
			YES	NO	YES	NO	YES	NO

f. EMPLOYER OF INVENTOR (S) NOT EMPLOYED BY CONTRACTOR/SUBCONTRACTOR.		g. ELECTED FOREIGN COUNTRIES IN, WHICH A PATENT APPLICATION WILL BE FILED.	
i. NAME OF INVENTOR *(Last, First, M.I.)*	i. NAME OF INVENTOR *(Last, First, M.I.)*	i. TITLE OF INVENTION	ii. FOREIGN COUNTRIES OF PATENT APPLICATION
ii. NAME OF EMPLOYER	ii. NAME OF EMPLOYER		
iii. ADDRESS OF EMPLOYER *(include Zip Code)*	iii. ADDRESS OF EMPLOYER *(include Zip Code)*		

SECTION II - SUBCONTRACTS *(Containing a "Patent Rights" clause)*

6. SUBCONTRACTS AWARDED BY CONTRACTOR/SUBCONTRACTOR *(If "None," so state)*

a. NAME OF SUBCONTRACTOR (S)	b. ADDRESS *(include Zip Code)*	c. SUBCONTRACTOR NO.(S)	d. DAR "PATENT RIGHTS"		e. DESCRIPTION OF WORK TO BE PERFORMED UNDER SUBCONTRACT (S)	f. SUBCONTRACT DATES *(YYMMDD)*	
			CLAUSE NO.	DATE *(YYMM)*		AWARD	ESTIMATED COMPLETION

SECTION III - CERTIFICATION

7. CERTIFICATION OF REPORT BY CONTRACTOR/SUBCONTRACTOR. *(Not required if ☐ Small Business or ☐ Non-Profit organization.)(Check appropriate box)*

a. NAME OR AUTHORIZED CONTRACTOR/SUBCONTRACTOR OFFICIAL *(Last, First, M.I.)*

b. TITLE

c. I certify that the reporting party has procedures for prompt identification and timely disclosure of "Subject Inventions," that such procedures have been followed and that all "Subject Inventions" have been reported.

SIGNATURE OF AUTHORIZED CONTRACTOR/SUBCONTRACTOR OFFICIAL

DATE *(YYMMDD)*