GROUNDWATER ASSESSMENT OF THE CENTRAL ELMORE WATER AND SEWER AUTHORITY SERVICE AREA, ELMORE COUNTY, ALABAMA

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INTRODUCTION

The Central Elmore Water and Sewer Authority (CEWSA) distribution system serves the major portion of Elmore County and consists of an extensive system of water treatment, transmission lines, and storage facilities in nine pressure zones (plate 1). The principal water supply for CEWSA is Lake Martin, with additional supply from Montgomery to the south and emergency supply from Alexander City to the north. CEWSA also sells water to the systems of Wetumpka, Friendship (Tallassee), and Eclectic in Elmore County and Rockford in Coosa County. Concerns regarding the availability of water to meet projected long-term demand for public water supplies, coupled with the current lack of sources for back-up supply for portions of existing service areas, resulted in the need for CEWSA to assess potential groundwater resources within its distribution area. CEWSA approached the Geological Survey of Alabama (GSA) in 2011 for assistance in evaluating options for developing potential groundwater supplies within the CEWSA service area to augment its current surface water supplies.

Numerous small-capacity wells in central Elmore County currently provide water for domestic (home) uses and relatively small irrigation systems, but there has been little effort to develop groundwater sources for public water supplies in recent decades. Prior to the construction of the CEWSA large-capacity surface water treatment and distribution system, groundwater provided a much higher proportion of water supply in the area, including modest public-supply systems in the Blue Ridge-Redland area and at Eclectic (Lines, 1975; Gillett, 1991). Groundwater is the principal supply source for southwestern Elmore County (Gillett, 1991; Jennings and Cook, 2008).

PROJECT AREA AND SCOPE OF WORK

The CEWSA groundwater assessment area includes the water distribution area for CEWSA plus the surrounding areas of Elmore, Coosa, and Tallapoosa Counties. Analysis of data for the project extended to areas beyond the CEWSA service area in order to adequately evaluate the service area within the context of the geologic, hydrologic, and geochemical setting and to provide a more comprehensive study. Data from surrounding wells and geologic outcrops are significant in the assessment process and in making recommendations concerning the development of additional groundwater sources. Greater effort was made by GSA in this assessment, however, in the Buyck, Madix, and Seman pressure zones due to the lack of emergency supply sources in those areas and in the Redland and Blue Ridge pressure zones (plate 1) due to their higher density of connections and history of faster growth of demand.

GSA conducted analyses of available geologic data from wells and outcrops, water quality data, water level data, and high altitude aerial photographic imagery, resulting in interpretations of the subsurface geology and groundwater hydrology. This study relied heavily on water well drillers' logs and other well data on file at GSA and field work conducted by the authors in 2012. This report summarizes the hydrogeology of the assessment area, followed by presentation and discussion of recommended prospective areas for drilling and groundwater supply development, with emphasis on consideration of the above-mentioned CEWSA concerns and priorities.

HYDROGEOLOGY

GENERAL PHYSIOGRAPHIC AND GEOLOGIC SETTING

Elmore County is located along the boundary of the Coastal Plain and Piedmont physiographic provinces—the Fall Line. The large distribution area of CEWSA encompasses a significant variety of physiographic, geologic, and hydrologic settings. The southern portions of the assessment area lie in the Alluvial and Fall Line Hills regions, and the northern portions of the area are part of the Piedmont Uplands regions (plate 2). Ground elevations in the floodplains of the

Coosa and Tallapoosa Rivers in the southern portions of the area are generally below 200 feet above mean sea level, whereas elevations in some areas in the north-central part of the assessment area exceed 700 feet above sea level (plate 3). Drainage in the assessment area is generally away from north-central Elmore County toward the Coosa and Tallapoosa Rivers. The uplands of the Piedmont region are characterized by low-relief hills and valleys, displaying subtle northeast-southwest orientation over most of the primary area of investigation. Drainage in the northwestern part of the assessment area is generally southwest toward the Coosa River and Lake Jordan, which abruptly demarcate the southwestern boundary of the area of interest. The Fall Line Hills region in the assessment area is characterized by several large, relatively flat-topped highland areas, 250-300 feet above the Coosa and Tallapoosa floodplains, composed of sedimentary strata, and separated from each other by southerly-flowing creeks that have cut steep-sided valleys (plate 3). Interrupting and in contrast to this topographic and physiographic pattern, east and southeast of Wetumpka, is a roughly circular area, approximately 4 miles in diameter, of higher elevation and relief that occurs along the Coastal Plain-Piedmont boundary. This feature has been interpreted to be the site of a meteor impact that occurred approximately 84 million years ago (Neathery and others, 1976; King and others, 2011). The geology and hydrology of the Wetumpka impact structure is very complex, and, despite more than a century of study, is far from being well understood (Smith and others, 1894; Petruny and others, 2012; Tabares Rodenas and others, 2012).

South and southwest of the Coastal Plain-Piedmont boundary, loosely consolidated sediments of Cretaceous and younger age unconformably overlie much older Paleozoic metamorphic and igneous (crystalline) rocks (fig. 1, plate 4). North of the boundary, Paleozoic crystalline rocks are exposed where younger sediments were not deposited or where post-depositional erosion removed the sedimentary cover. Cretaceous units, from oldest to youngest, are the Coker, Gordo and Eutaw Formations. Terrace deposits of Pleistocene age cap many of the higher elevations in the southern and western parts of the assessment area, and younger (Holocene) fluvial sediments deposited by the Tallapoosa and Coosa Rivers and their tributaries occur at the surface in the lower elevations, primarily in the southern part of the area.

Cretaceous and younger Coastal Plain sediments generally strike west- northwest and thicken to the south, whereas metamorphic and igneous rocks of the Piedmont Province generally strike northeast.

Delineation of aquifers and development of groundwater resources along the Coastal Plain-Piedmont boundary in Elmore County is challenging because the thickness of the stratigraphic section containing water-bearing sands and gravels, where present, is less than 500 feet in most places. Development of large-capacity wells in the Coastal Plain sediment aquifers in the CEWSA assessment area is limited, therefore, due to relatively thin sediments and shallow well depth. As will be discussed later, the southern portions of the Redland and Blue Ridge pressure zones are the most prospective areas for locating and developing groundwater supplies from the Cretaceous and younger sedimentary aquifers. Sand and gravel deposits within the Coker Formation constitute the principal aquifers in the Coastal Plain stratigraphic section, with gravel and sand intervals in the Gordo and Eutaw Formations and Quaternary deposits providing groundwater to some shallow wells.

Paleozoic metamorphic and igneous rocks also constitute potential aquifers that locally provide significant quantities of groundwater to wells. For the most part, however, Paleozoic crystalline rocks in the area are generally devoid of porosity and permeability, except where they have been significantly weathered and/or fractured. Pertinent geological, geophysical, and hydrological data is generally unavailable to adequately detect and delineate fracture systems in the Paleozoic rocks.

PALEOZOIC ROCKS

Paleozoic metamorphic and igneous rocks, ranging from metasediments to gneiss and granite, occur at the surface across much of the northern part of the assessment area. The principal Paleozoic units in the assessment area are rocks of the Emuckfaw Group, Wedowee Group, Kowaliga Gneiss, Zana Granite, and Elkhatchee Quartz Diorite Gneiss (fig. 1), with additional units occurring north and east of the main area of interest (plate 4). The Paleozoic rocks generally strike northeast, dip to the southeast at steep angles (60 to 80 degrees), and have been complexly folded and faulted. Large-scale thrust faults, some extending along strike many miles, have been mapped in the area (Osborne and others, 1988; Geological Survey of Alabama, 2006). Paleozoic crystalline rocks extend to the south and southwest beneath the Coastal Plain sediments (Dean, 1990). The ancient erosional surface of the top of the Paleozoic rocks generally slopes to the south at about 40 to 100 feet per mile, with the steepest slope along the southern part of the assessment area (plate 5). Only a generalized structural contour map can be constructed from the widely spaced subsurface well data, but localized relief on the Paleozoic-Cretaceous (or Tertiary) unconformity can be seen or inferred from outcrop data. Local relief on the unconformity, probably resulting from differential weathering and erosion of the various metamorphic and igneous rock types, was documented by Jennings and Cook (2008) in the subsurface in southwestern Elmore County and likely occurs in the subsurface in the CEWSA assessment area as well. A significant anomaly in the regional structural trend is located in and near the Wetumpka impact structure (plate 5), indicating that the meteor impact affected the Cretaceous sedimentary section as well as the underlying Paleozoic rocks.

Because the Buyck, Madix and Seman pressure zones are predominantly underlain by Paleozoic metamorphic and igneous rocks, with only scattered outliers of thin Coastal Plain sediments, important hydrogeologic factors to consider in selection of areas for test well drilling in those pressure zones include the potential for aquifer development in weathered rocks and/or fractures. The mineral composition of crystalline rocks is important in weathering rates and products. For example, feldspars, common in granites and gneisses, are much more susceptible to the chemical and physical processes of weathering than quartz and muscovite mica. Many of the outcrops of Paleozoic rocks examined during this investigation are extremely weathered, with some rocks having been broken down by physical and chemical processes to a mixture of clay, sand, and rock, only exhibiting remnant evidence of bedding or foliation.

Examination of outcrops of metamorphic and igneous rocks in the course of this investigation also revealed the presence of joints, fractures, and faults. Paleozoic units composed primarily of granitic and gneissic rocks, such as the Zana Granite, are commonly more brittle than schists and phyllites of other units, and are, therefore, more likely to be susceptible to fracturing during folding and faulting. A positive relationship between higher yielding wells and regional fracture systems has been indicated by Guthrie and others (1994) in a study of Alabama Piedmont wells.

COKER FORMATION

The Coker Formation, the lowermost Cretaceous geologic unit in the project area, unconformably overlies Paleozoic crystalline rocks. Sand intervals in the Coker Formation form the principal aquifers in the Redland and Blue Ridge pressure zone areas. Thin outliers of Coker Formation sediments locally overlie Paleozoic rocks in the more northern and northwestern pressure zones. As illustrated by a structure map of the top of Paleozoic rock in the southern part of the assessment area (plate 5) and geologic cross section A-A' (plate 6), the base of the Coker Formation ranges in elevation from about 300 feet above sea level to the north to about 250 feet below sea level to the south, indicating an average dip rate of about 50 feet per mile. The dip rate is higher (> 100 feet per mile) across the southern part of the assessment area and appears to be accompanied by a slight thickening of the Coker Formation southward. The full thickness of the Coker is present in the upland areas of the Fall Line Hills region between the generally south-flowing Harwell Mill, Chubbehatchee, Goodwater, and Tumkeehatchee Creeks (plates 5, 6, 7) and on the south side of the Wetumpka impact structure (plates 8, 9). In those areas the thickness of the Coker ranges from about 220 feet to about 270 feet. Neathery and others (1976) reported a thickness of the Coker in excess of 230 feet penetrated in a water well in the northwestern part of the central area of the Wetumpka impact structure.

Coker Formation sediments were deposited in fluvial to shallow marine environments that varied spatially and temporally across the project area. At an outcrop in northeastern Autauga County, Tew (1988) described and characterized approximately 48 feet of the lower Coker Formation as a sequence of marine sands, silts, and clays that grade upward into marginal marine sands, silts, clays, and lignite beds. Furthermore, the upper Coker there was described as consisting of approximately 18 feet of cross-bedded sands of fluvial origin that sharply overly the lower Coker. Both fine-grained, well-sorted sand intervals interbedded with thin clay beds and coarse-grained, poorly-sorted sand and gravel deposits are present in outcrops of the Coker Formation in Elmore County (fig's. 2, 3). Moreover, drillers' logs in the CEWSA assessment area indicate Coker sands are generally fine grained with some intervals of medium- to coarse-grained sands in a few wells. Data are insufficient, however, to correlate and map individual sand and gravel intervals in the Coker.

Outcrops of the Coker Formation in the northern parts of the project area constitute the principal recharge areas for the Coker aquifer. Recharge also likely occurs where sand and gravel beds of the overlying Gordo Formation and/or younger sand and gravel deposits are hydraulically connected to the Coker. Outliers of the Coker crop out in central Elmore County, but those outcrops are not physically or likely hydraulically connected to the main body of the Coker Formation to the south and southwest and are not considered part of the general recharge area for the Coker aquifer sands. Sands and gravel beds of those outliers locally serve as groundwater sources to very shallow wells and likely provide recharge to underlying Paleozoic rocks.

The Coker aquifer provides groundwater supplies for numerous small-capacity private wells in the CEWSA assessment area, primarily in the Redland and Blue Ridge pressure zone areas. Casing size for these wells ranges from 1 to 6 inches in diameter, with 4-inch diameter the most commonly used size. The largest capacity well noted from the available driller's logs is 300 gallons per minute (gpm) (well V-Hickory Bend Farm, plates 7, 10). The only Coker aquifer public water supply well in the assessment area is GSA well number U-8, a standby well owned by CEWSA in the Blue Ridge Estates area (plate 8, 9). This well, drilled and completed in 1964, tested 225 gpm with a water level drawdown of 36 feet in 2 hours. Other wells in the Blue Ridge area have apparently served in the past as relatively small-capacity public supply wells, but they are now mostly abandoned and/or destroyed. The Coker aquifer is, however, the principal water source for public water systems in the southwestern part of Elmore County (Gillett, 1991; Jennings and Cook, 2008). Data from pumping tests of six wells screened in Coker sands in southwestern Elmore County indicate well specific capacities range from 2.2 to 6.7 gallons per minute per foot of drawdown (gpm/ft) (Jennings and Cook, 2008). Specific capacities from Coker aquifer wells in the CEWSA assessment area could only be determined from three wells: well U-8, 6.25 gpm/ft; well U-11, 6.52 gpm/ft; well P-Scott, 0.8 gpm/ft.

Total (net) sand thicknesses were estimated from 9 wells (drillers' logs) interpreted to have penetrated the full thickness of Coker Formation in the Redland and Blue Ridge pressure zones; these data indicate net sand thickness ranges from 49 to 119 feet, with a median value of 83 feet. Four additional wells, however, penetrated estimated total sand thicknesses of ranging from 125 to143 feet without reaching Paleozoic rock, though it is interpreted from the general thickness of the Coker and the top of Paleozoic structure map that these wells likely reached the lowermost beds just above the "basement" rock. Intervals of sand can occur in any part of the formation, but are generally more abundant in the middle to lower part of the formation across the area. Whereas thicknesses of individual intervals of sand in the Coker noted by drillers ranged from 2 feet thick to 86 feet, sand intervals are most commonly about 10 to 40 feet thick. Difficult to assess are intervals described by drillers as "clayey sand" or "sand clay", especially in those wells in which portions of such described intervals were apparently screened. Coker aquifer sands that are screened are typically described by drillers as white, tan, and/ or yellow, with grain size and consolidation commonly noted as "coarse" and "loose", respectively. As shown above (fig. 2), outcrops of outliers of the lower part of the Coker present in the northern and northwestern part of the assessment area include very coarse sand and gravel sized material, but there are no indications of grain size grater than "coarse" in drill cuttings of Coker in the Redland and Blue Ridge areas, as described by drillers. No well cuttings were available for examination by the authors.

GORDO AND EUTAW FORMATIONS

The Gordo Formation overlies the Coker Formation and constitutes the upper part of the Tuscaloosa Group (fig. 1). The formation occurs in the southern part of the assessment area where it crops out or in the subsurface beneath the Eutaw Formation. The Gordo is composed of loosely consolidated sand and gravel beds as well as clay intervals. Deposited in nonmarine conditions, Gordo sediments are commonly more variable in thickness and grain size, both laterally and vertically, than those of the Coker Formation. This characteristic indicates that aquifer storage and transmissivity of the Gordo can vary significantly over relatively short distances, increasing risk for exploration of water-productive intervals. In addition, the base of the Gordo Formation is less than 200 feet deep in most areas. The Gordo is recharged primarily from rainfall in its outcrop area and from water moving through the overlying thin Eutaw Formation and/or overlying or adjacent terrace or alluvial deposits. In those areas where thick clay beds do not occur between Gordo sand and gravel deposits and sand intervals of the Coker Formation, the two aquifers are likely in hydraulic communication.

Sand and gravel beds in the Gordo Formation constitute a significant aquifer in southwestern Elmore County and have been screened in several major water-supply wells in the Elmore Water Authority and Millbrook service areas (Jennings and Cook, 2008). In the CEWSA distribution area, however, Gordo aquifer intervals are generally too shallow to be considered a major groundwater source due to limited available drawdown and/or limited recharge area. In spite of its limitations for use in the project area as a major potential water source, the Gordo aquifer is screened in some private wells and likely provides groundwater storage for recharge to the underlying Coker aquifer.

Overlying the Gordo, the Eutaw Formation is an interval of fine- to medium-grained sand interbedded with clay (fig. 4). The formation locally contains marine fossils and glauconite, both indicators of its marine environment of deposition. The Gordo and Eutaw Formations, though stratigraphically distinct and of different depositional origins, are shown undifferentiated on geologic cross sections presented in this report (plates 6, 7, 8), because aquifer intervals in these two units are generally too thin and/or shallow for consideration as major targets for large-capacity public water supply wells. They do, however, comprise important components in the overall hydrogeologic system, primarily as recharge sources for underlying aquifers or, conversely, to serve as hydrologic confinement for those deeper aquifers.

QUATERNARY TERRACE AND ALLUVIAL DEPOSITS

Quaternary terrace deposits, primarily composed of poorly-sorted sand and gravel, locally cap the Cretaceous sedimentary sequence at higher elevations (fig. 5) or occur above Paleozoic crystalline rocks. Locally, terrace deposits do occur at significantly lower elevations, however. Terrace deposits, like the Eutaw and Gordo Formations, are generally too thin to be of significance for water supply purposes over most of the assessment area except to serve as sources of groundwater recharge for underlying and/or topographically adjacent Cretaceous or Paleozoic aquifers. Similar conclusions can generally be drawn regarding Quaternary alluvial deposits in stream valleys in the assessment area. In the floodplain of the Tallapoosa River, however, the thickness of Quaternary alluvium is significantly greater, locally exceeding 50 feet, and prospects for constructing large-capacity wells in alluvial sand and gravels are increased.

AQUIFER WATER LEVEL DATA

A potentiometric water level is the elevation to which water rises in a well that penetrates a confined aquifer. A potentiometric surface (relative to sea level) represents the sum of the elevation head and confined pressure (hydrostatic head) throughout all or part of a confined aquifer at a particular time and is useful in determining directions of groundwater flow, hydraulic gradients, and depths from which water can be pumped at particular locations. When water is removed from the aquifer by pumping, the potentiometric surface will decline (drawdown), especially near pumped wells, but the surface commonly rebounds when pumping ceases. As long as the potentiometric surface remains above the stratigraphic top of the aquifer, the aquifer media remains saturated, and declining water levels only represent a decrease in hydrostatic pressure. If the water level declines below the stratigraphic top of the aquifer, the aquifer becomes unconfined. An aquifer that is unconfined or is partially confined exhibits water table conditions in which little or no pressure head is present (atmospheric pressure). Therefore, water surfaces in wells completed in an unconfined aquifer indicate the top of the saturated zone in the aquifer. The water table surface is influenced by and typically somewhat mimics topography. An aquifer may be confined in part of its area of extent and unconfined in other areas (e.g., where it crops out or due to pressure declines as explained above). Fluctuations in water level measurements in a confined aquifer are commonly greater in magnitude than those in an unconfined aquifer (or portion of the same aquifer), because no actual dewatering of the confined aquifer's storage space occurs unless groundwater withdrawal declines the pressure head to atmospheric pressure.

Static water level data from drillers' logs and other well records from wells screened in aquifer sands in the Coker Formation in southern Elmore County are shown on plate 5. These available data, though limited in geographic extent and measured over a wide range in years, are useful in providing an estimate of overall hydraulic gradient in the Coker aquifer and indicating the general direction of groundwater flow in the aquifer, assuming that the various screened Coker sands in the wells that are the sources of the data are hydraulically connected. As might be expected, regional groundwater flow in the Coker aquifer is generally from north to south. Groundwater flow in the Coker aquifer in the southern part of the assessment area is also likely influenced by the fact that the Coker is exposed along the valleys of the streams that dissect the area (plate 5). Though not measured and documented in this investigation, some portion of groundwater flow through the Coker is postulated to discharge to those streams, through direct hydraulic connection with stream beds, indirectly through hydraulic connection of Coker aquifer sands with adjacent alluvial valley fill, or possibly through connection with overlying lower Gordo aquifer sand beds that are in hydraulic connection with streams or alluvium.

Important in planning for groundwater development for public supply are natural fluctuations and/or long-term trends in static water levels in potential target aquifers. GSA has measured static water levels in 4 wells in the assessment area since the early 1980's. Static water levels measured in well P-3 (sec. 32, T. 18 N., R. 19 E.) (plates 8, 9, 10) have shown a variation of about 21 feet from 1982 to 2010, with a mean water level of 143.6 feet below land surface (approximately 349 feet above mean sea level). The well is screened in the Coker aquifer from 335 to 355 feet, but was also completed as open hole in Paleozoic rock from 355 to 421 feet (total depth). Static water levels in well U-14 (sec. 15, T. 17 N., R. 19 E.), measured during the same years as well P-3, exhibited a variation of 9.26 feet, with a mean water level of 8.6 feet below land surface (approximately 161 feet above mean sea level). Well U-14 is 135 feet deep and is screened in the Coker aquifer. Water levels in well N-2, a Gordo aquifer well (total depth 88 feet) located in sec. 19, T. 18 N., R. 21 E., have shown a fluctuation of approximately 8.4 feet from 1982 to 2010 and a mean of approximately 26 feet below land surface (429 feet above mean sea level). Well J-6, located in Eclectic, (sec. 14, T. 19 N, R. 20 E.), has shown a much grater range in water level measurements—approximately 56 feet—due to the well's periodic use to irrigate nearby athletic fields (several measurements known to have been affected by recent pumpage were omitted). The well depth of J-6 is 402 feet, and it is productive from Paleozoic metamorphic rock (Kowaliga gneiss). The average water level is about 16 feet below land surface, but GSA water level data from1984 to 2010 indicate that the aquifer is slow to recover from pumpage (estimated at 15 gpm) that has been demonstrated to lower water levels more than 150 feet.

GROUNDWATER QUALITY

Groundwater quality in central Elmore County is generally good with the exception of locally elevated concentrations of iron above the recommended limit of 0.3 milligrams per liter (mg/L) for drinking water (Table 1). The data suggest that iron concentration in the Coastal Plain aquifers (Coker, Gordo, and Quaternary alluvium) and in the Paleozoic rock aquifers is generally inversely related to depth (figs. 6,7), a finding not unexpected, in consideration of the oxidation-reduction state of iron minerals in relatively shallow aquifers within the range of measured pH values (Hem, 1985; Jennings and Cook, 2008). Relatively high concentrations of manganese are locally present in groundwater in the Coker and Gordo aquifers in southwestern Elmore County (Jennings and Cook, 2008), but there is insufficient data to determine that this problem occurs in the CEWSA assessment area.

DISCUSSION AND RECOMMENDATIONS

From a hydrogeological and groundwater exploration and development standpoint and in consideration of the infrastructure and principal needs of CEWSA outlined above, the assessment area can be subdivided into three general areas summarized and discussed below. Within each general hydrogeological area, more specific areas recommended for further investigation and consideration for test well drilling are also presented and discussed. Plate 10 illustrates the general hydrogeologic areas, recommended areas of interest for locating possible drill sites, and serves as an index map for outcrops and wells utilized in this investigation.

The first area, here termed the southern Coastal Plain area, makes up the Montgomery pressure zone and most of the Redland pressure zone and lies principally in the Fall Line Hills and Alluvial Plain physiographic regions. In this area, the principal target is the Coker aquifer, with secondary aquifer sands potentially present in the overlying undifferentiated Gordo and Eutaw interval. At lower elevations in the southernmost part of the area, alluvial sand and gravel beds lie directly above the Coker or locally above thin remnants of the Gordo Formation. There, alluvial aquifers likely serve as part of the recharge to the Coker aquifer. Although the alluvial sand and gravel deposits likely store and transmit significant quantities of groundwater, the shallow depths and general lack of confinement (sealing clay beds) render these aquifer intervals unsuitable for conventional water well development for public water supply. Moreover, unacceptable concentrations of iron can be expected in the shallow alluvial sand and gravel aquifers (Table 1). The Coker aquifer is largely untested for large-capacity public supply wells, and the overall rural to suburban setting appears to be conducive to locating suitable test well drilling sites. Recommended areas of interest for locating drill sites are located south of Redland Road and at surface elevations above about 425 feet above sea level, primarily on sites comprised of Quaternary terrace materials (plates 5, 10). In these areas, drill depths are anticipated to be less than 500 feet to penetrate the Coker aquifer interval and reach total depth in Paleozoic crystalline rock. Overall, it is expected that water wells drilled and completed in the area would be similar in construction and yield to those in southwestern Elmore County. Anticipated water quality is generally good, but objectionable levels of iron (and possibly manganese) may occur locally.

Metamorphic and igneous rocks of Paleozoic age are considered here to be probable but, as yet, mostly untested sources of ground water in the southern area beneath the Coastal Plain sediments. A long and complex geologic history that includes folding, faulting, prolonged weathering, and the formation of joints and fractures indicates that groundwater of suitable quantity and quality is likely present in the crystalline rocks in the area. Although it is well known that Paleozoic rocks and faults extend southwestward beneath Coastal Plain sediments in the area, available data are not sufficient to accurately map specific water-bearing discontinuities such as fractures or fault planes. Under favorable conditions, especially where discontinuities in the crystalline rocks, both lithologic and structural, allow groundwater recharge from the overlying Cretaceous and younger sediments, Paleozoic rocks should be capable of producing groundwater at relatively high flow rates. Though little data is available to assess the aquifer potential of the Paleozoic rocks in the area due to very few penetrations of more than a few feet of the rock units, consideration should be given to drilling into the upper part of the Paleozoic section at least 100 feet.

Screening a high percentage of the net sand thickness has proven elsewhere to be an effective means of increasing well yields. Although the cost of well construction is increased by setting more and/or longer screens, the long-term benefits of higher yields over the lifetime of the well make this a cost-effective measure. Knowledge of appropriate intervals to screen is a very important factor in well construction and development, but the common practice of relying solely on the driller's observations and logs is generally insufficient to detect relatively thin sand beds. Supplementing the driller's observations with geophysical well logs is a time- and experience-proven method of increasing knowledge of the intervals penetrated by drilling and therefore can greatly aid in deciding which intervals to screen and test. It is recommended that these measures be employed in future drilling and groundwater resource development projects in the project area.

The second hydrogeologic area is the Wetumpka meteor impact structure (plate 9). This area lies within the Blue Ridge pressure zone and the northwestern part of the Redland pressure zone. Though geologic complexity of the area suggests complex groundwater hydrology, the overall groundwater flow regime is likely from uplifted and topographically high areas to lower areas. Available static water level data from wells screened in the Coker aquifer on the southern part of the structure suggest southerly, downdip groundwater flow in that area (plate 5). Several springs are located within or on the flanks of the impact structure.

The geology in and around the site of the Wetumpka meteor impact has been investigated by the scientific community for many years, but there are no known published investigations focusing on groundwater. Eight test holes were drilled across the structure between 1998 and 2009 for scientific purposes (King and others, 2011), but the cores and other data obtained, if available, were not studied in the course of this investigation for their hydrogeological significance. Data from the test holes and years of scientific studies and publications by others have produced a clearer understanding of the structure, rock and sediment types, and provenance of the impact site's features. King and others (2011) have subdivided the impact structure into three surficial terrains: (1) *crystalline rim*, composed of schistose-gneissic bedrock and coarse breccias with foliation and dips away from the center of the structure; (2) *interior*, composed primarily of large blocks of disturbed Cretaceous formations and mixed provenance sediments and polymict breccias; and (3) *exterior*, comprised of structurally disturbed Cretaceous sedimentary units, including Coker, Gordo, and Eutaw Formations and Mooreville Chalk, which are largely intact but locally faulted and tilted. Potential aquifer materials interpreted here from their studies include locally faulted or slumped Coker Formation and other sandy Cretaceous units; polymict impact breccias, where they are composed of coarse-grained mixtures of rock fragments and sediments; sands embedded with large blocks of Cretaceous sediments resulting from the impact, and; deformed Paleozoic crystalline rocks. The hydrogeologic significance of faults that have been mapped in and around the impact structure (Neathery and others, 1976; Osborne and others, 1988, Tabares Rodenas and others, 2012) is unknown.

Recommended potential drill site areas are primarily located on the southern side of the impact structure (plate 10), in the *exterior* terrain of King and others (2011), where the likelihood of penetrating a relatively thick section of Cretaceous sediments is greatest and where previous drilling efforts have resulted in development of groundwater supplies from some wells (plates 8, 9). Sand intervals in the Coker Formation are the most prospective aquifer intervals in the area.

Other potential (but not, as yet, recommended) drill sites in the impact structure area, however, could target breccia zones within and flanking the crater rim (plate 9) that may provide substantial groundwater storage and transmissivity. In addition, rock and sediments on the steeply dipping flanks of the crater rim may constitute suitable aquifers. In these areas, there is significant potential for relatively high hydraulic head resulting from higher elevations of the crater rim and therefore increased likelihood of groundwater flow to areas of lower elevation. In addition, because King and others (2011) estimate wells and test holes to have penetrated only the upper 15 to 20 percent of the interior of the Wetumpka structure, drilling deeper in the central area could prove productive. Further investigation of the hydrogeology of the Wetumpka structure is needed to more fully evaluate the water supply potential of this complex feature.

The third general area is to the north and northwest where Paleozoic metamorphic and igneous rocks predominate, with only thin outliers of Coker Formation and/or Quaternary sediments locally present. Porous and permeable sand and gravel intervals in the Coker along with local occurrences of terrace and alluvial sand and gravel deposits likely serve to retain some precipitation which may then recharge underlying crystalline rocks. Because there is a general absence of porosity and permeability in the crystalline rocks, discontinuities, such as lithologic boundaries, fractures, and faults, likely provide the few potential locations for groundwater storage and flow. Recommended potential drill site areas in this area (plate 10) are located along faults and other discontinuities in the Paleozoic rock section or where there are local areas of Coker and/or Quaternary terrace deposits overlying crystalline rocks.

Evident from satellite imagery, topography, and field mapping (Lines, 1972), a significant discontinuity (possible fracture zone or shear zone) within the Elkhatchee Quartz Diorite Gneiss trends approximately N 45° E from the valley of Weoka Creek in sec. 20, T. 20 N., R. 18 E. across Buyck Road to sec. 10, T. 20 N, R.

18 E. Well E-02, drilled in 1987 to a depth of 196.5 feet near this discontinuity, was noted by the driller to have a yield exceeding 100 gpm through 4 inch diameter casing.

Another area of interest lies along the northeast-southwest oriented contact of the Zana Granite with the Wedowee Group, particularly in the western part of T. 20 N., R. 18 E. and the southeast part of T. 20 N, R. 18 E. This contact has been mapped as a steeply dipping fault (Osborne and others, 1988), where more competent granitic rocks comprise the hanging wall, juxtaposed to less competent schists of the Wedowee. Fractures in Zana Granite can be seen in some outcrops of the unit.

Southwest of that area, along and west of U. S. Highway 231, two prospective areas in the southern part of T. 20 N., R. 18 E. (plate 10) are located where sand and gravel beds of the Coker Formation and Quaternary terrace gravel beds lie above rocks of the Wedowee Group and Elkhatchee Quartz Diorite Gneiss. Field mapping by the authors suggests that the thickness of the Coker and terrace deposits may locally exceed 100 feet in the southeastern part of section 34. Projection of the regionally extensive Alexander City fault beneath terrace gravel deposits (and possible thin Coker Formation) defines an area of interest in the SE¼ of section 27.

West of Titus in sec. 14, T 20 N., R. 17 E., Elkhatchee Quartz Diorite Gneiss, overlain by terrace gravel and cross bedded Coker gravelly sand, constitute another prospective area. Nearby, just above the shore of Lake Jordan, a well constructed in 1984 to a depth of 125 feet into rock of the Elkhatchee yielded 60 gpm.

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STRATIGRAPHIC COLUMN				
SYSTEM/ ERATHEM	SERIES	GROUP	GEOLOGIC UNIT	LITHOLOGY
Quaternary	Holocene		Alluvial Deposits	Gravel, sand, and clay
	Pleistocene		Terrace Deposits	Gravel, sand, and clay
Cretaceous	Upper Cretaceous		Eutaw Formation	Sand, clay, and minor gravel
		Tuscaloosa Group	Gordo Formation	Sand, gravel, and clay
			Coker Formation	Sand and clay
Paleozoic			Elkhatchee Quartz Diorite Gneiss	Quartz diorite, gneiss (intrudes the Wedowee Group)
			Zana Granite	Granite, grano-diorite (intrudes the Emuckfaw Group)
			Kowaliga Gneiss	Granodiorite, monzonite
		Wedowee Group		Schist, phyllite, and gneiss
		Emuckfaw Group		Schist and metasediments

Figure 1.—Generalized stratigraphic column of the principal portion of the Central Elmore Water and Sewer Authority groundwater assessment area, Elmore County, Alabama.

Figure 2.—Contact (red line) of highly weathered Paleozoic Kowaliga Gneiss with overlying sand and gravel of the Cretaceous Coker Formation (outcrop 19, NW¼, sec. 6, T. 19 N., R. 20 E., Elmore County, Alabama).

Figure 3.—Fine-grained sand with thin clay laminae of the Coker Formation (outcrop 7, SW¼, sec. 16, T. 18 N., R. 18 E., Elmore County, Alabama).

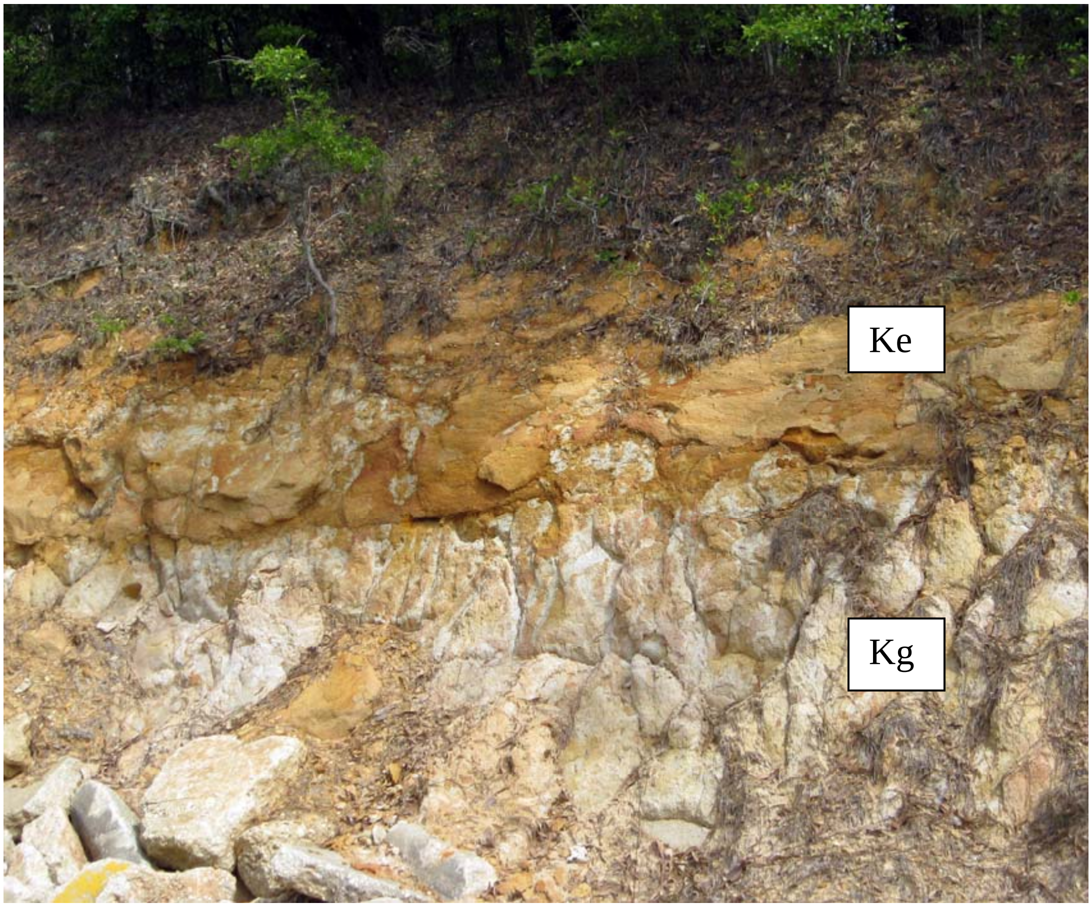

Figure 4.—Sand beds of the Eutaw Formation (Ke) overlying sandy clay of the Gordo Formation (Kg) (outcrop 15, NE¼ sec. 14, T. 17 N, R. 19 E., Elmore County, Alabama).

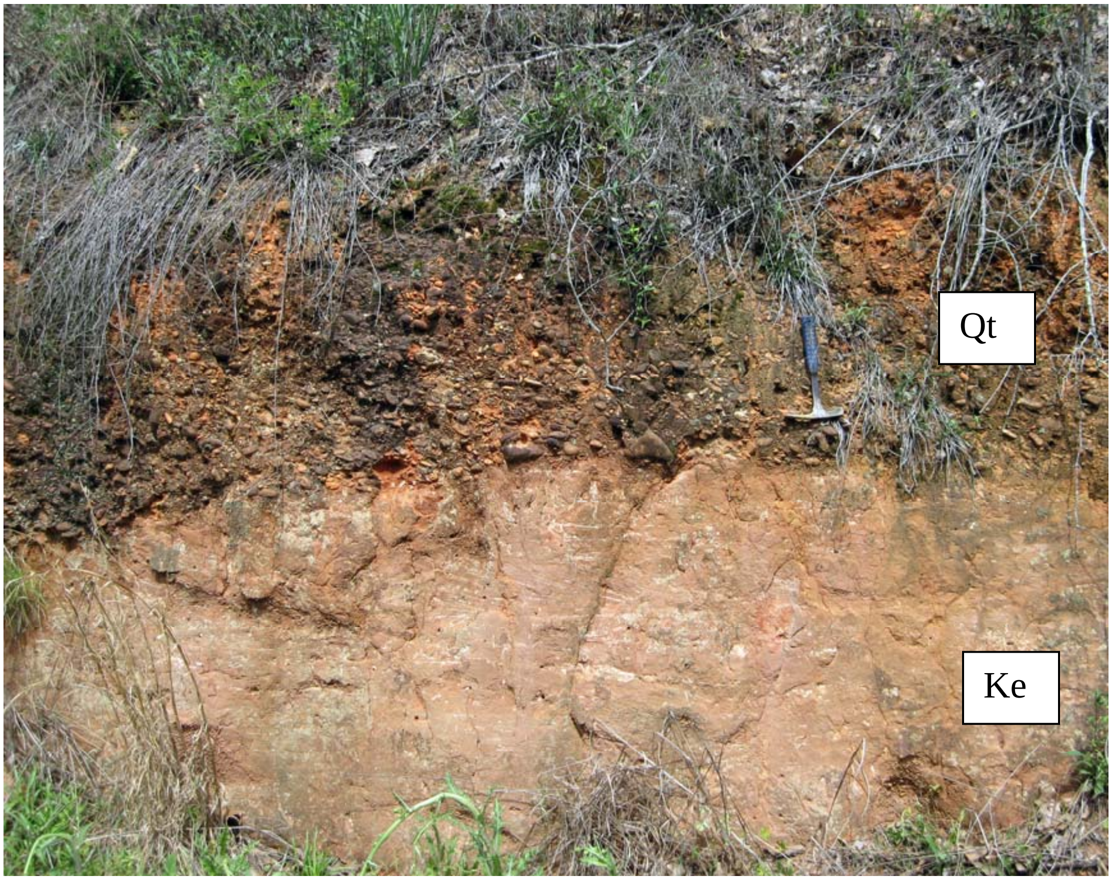

Figure 5.—Quaternary terrace sand and gravel (Qt) overlying Eutaw Formation (Ke) sand (outcrop 13, NE¼ sec. 35, T. 18 N. R. 19 E., Elmore County, Alabama).

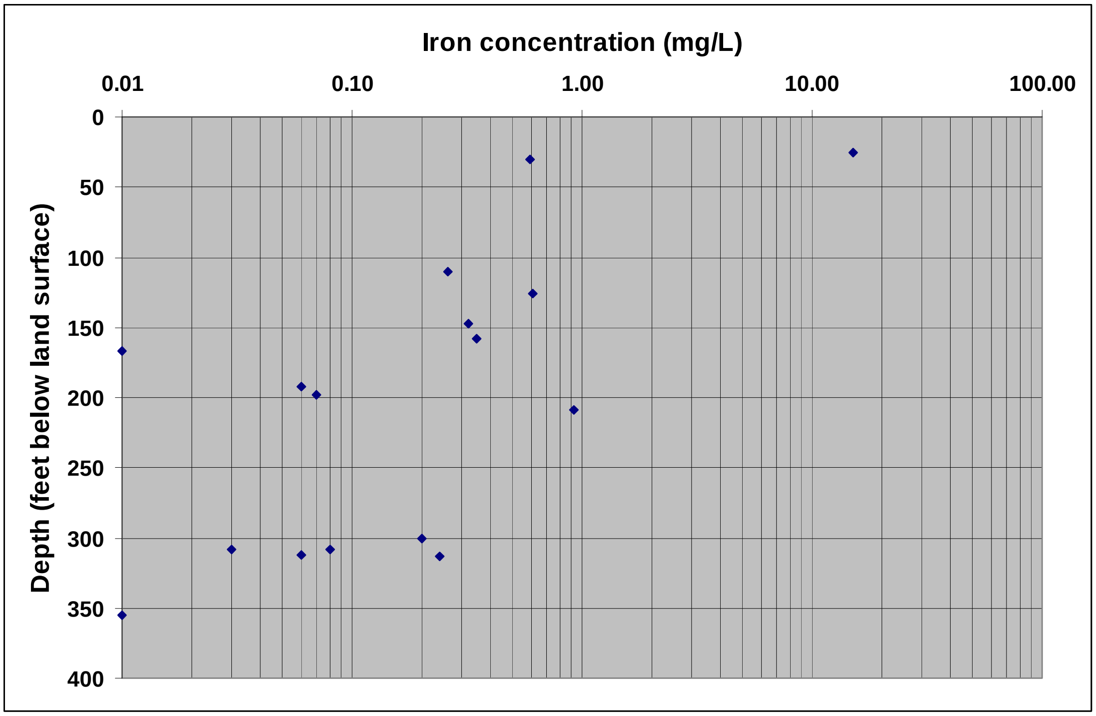

Figure 6.—Concentration of iron with depth, groundwater samples from Coker aquifer wells, southern Elmore County, Alabama (see Table 1 for data).

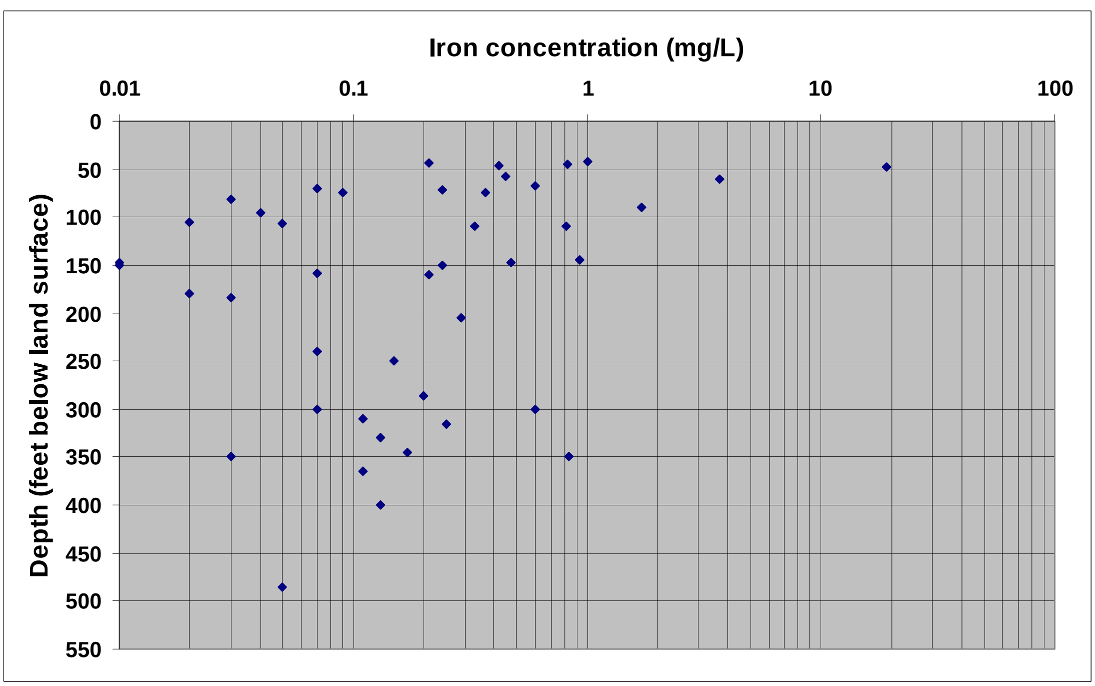

Figure 7.—Concentration of iron with depth, groundwater samples from Paleozoic aquifer wells, northern Elmore County (see Table 1 for data).