GROUNDWATER HYDROGEOLOGY, RECHARGE, AND WATER AVAILABILITY IN THE TENNESSEE RIVER WATERSHED OF ALABAMA

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GROUNDWATER HYDROGEOLOGY, RECHARGE, AND WATER AVAILABILITY IN THE TENNESSEE RIVER WATERSHED OF ALABAMA

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By

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EXECUTIVE SUMMARY

The Tennessee River watershed includes all or part of 15 counties in north Alabama and is contained in the Cumberland Plateau, Highland Rim, and East Gulf Coastal Plain physiographic sections. The area is underlain by clastic and carbonate geologic units ranging in age from Cambrian to Cretaceous. Topographic, hydrologic, and soil characteristics of the area are controlled, in large part, by the local and regional geologic structure and stratigraphy.

The Tennessee River watershed was divided into six geologic areas based on common stratigraphy, geologic structure, and hydrogeology. Geologic area 1 lies along the western margin of the Tennessee River watershed, including parts of Marion, Winston, Franklin, Colbert, and Lauderdale Counties. Geologic area 2 includes parts of Morgan, Lawrence, Franklin, Colbert, and Lauderdale Counties. Geologic area 3 includes Limestone County and parts of Madison, Morgan, Lawrence, Lauderdale, and Colbert Counties. Geologic area 4 includes parts of Jackson, Madison, and Marshall Counties. Geologic area 5 includes parts of Jackson, Marshall, and Blount Counties. The easternmost geologic area, area 6, includes parts of Jackson, DeKalb, Marshall, and Etowah Counties.

The source of groundwater and surface water in the Tennessee River watershed is precipitation, which averages about 56 inches per year. The surface hydrology of the project area is dominated by the Tennessee River and tributaries characterized by flashy runoff over relatively impermeable Paleozoic rocks. The groundwater system is characterized by relatively shallow, fractured, Paleozoic clastic and carbonate aquifers with widespread karst development in the north-central part of the area and coarse-grained Cretaceous sediment cover in the western part of the area.

Groundwater recharge in much of the Tennessee River watershed is local. Recharge rates are controlled by a number of factors, including porosity and permeability, which in Paleozoic aquifers in the project area are enhanced by leached fossils, fractures, and solution development. Estimates of recharge can be useful in determining available groundwater, impacts of disturbances in recharge areas, and water budgets for water resource development and protection. Numerous methods have been used for estimating recharge, including development of water budgets, measurement of

seasonal changes in groundwater levels, and flow velocities. However, equating average annual baseflow of streams to groundwater recharge is the most widely accepted method.

Separating runoff and baseflow from total stream discharge can be accomplished by several methods including (1) recession analysis, (2) graphical hydrograph separation, and (3) partitioning of stream flow using daily rainfall and stream discharge. More recently, a number of computer models have automated hydrograph separation techniques. Discharge data for 20 streams in the Tennessee River watershed with current or discontinued U.S. Geological Survey (USGS) discharge measurement stations were used to evaluate recharge. Discharge data for each stream were analyzed using the PART and WHAT automated hydrograph separation programs and the Meyboom manual recession analysis method. When runoff and baseflow discharge results from PART were compared to results obtained from the Meyboom method, there was poor agreement. However, much better correlations were observed between results from the WHAT and Meyboom methods. Therefore, based on the general agreement between the Meyboom method and the WHAT program, values of baseflow estimated by the WHAT program were used to estimate volumes of groundwater recharge.

Previous investigators in north Alabama estimated that annual recharge to sandstone aquifers is 2 to 3 inches and recharge to carbonate aquifers may be more than 11 inches. Results obtained during this study from the Meyboom recession analysis method and the WHAT program were 5.3 and 6.1 inches for geologic area 1, 2.3 and 3.4 inches for geologic area 2, 7.5 and 7.8 inches for geologic area 3, 4.6 and 6.7 inches for geologic area 4, and 4.8 and 6.4 inches for geologic area 6. Due to the relatively small size of area 5, discharge data were unavailable. However, all Paleozoic units in the other five geologic areas outcrop in geologic area 5. Therefore, the average of recharge values for the other five areas was assigned to area 5 (4.9 and 6.1 inches).

Groundwater availability in the Tennessee River watershed is generally defined as the total amount of groundwater of adequate quality stored in the subsurface. Large quantities of groundwater in excess of 1 million gallons per day can be obtained from wells constructed in the Tuscumbia Limestone/Fort Payne Chert aquifer if sufficient water-filled cavities are encountered. However, the non-uniform distribution of fractures and/or solution channels and cavities makes the prediction of groundwater movement and occurrence difficult. For the purpose of this assessment, volumes of groundwater recharge estimated for the Tennessee River watershed were assumed to be the amount of available groundwater. The smallest amount of available groundwater in the Tennessee River watershed estimated from results of the WHAT program was 36.2 billion gallons per year (g/yr) in geologic area 5. The estimate for geologic area 2 was 53.8 billion g/yr, geologic area 6 was 85.5 billion g/yr, geologic area 1 was 108.9 billion g/yr, geologic area 4 was 129.7 billion g/yr, and the largest amount was 304.0 billion g/yr in geologic area 3. Total available groundwater in the Tennessee River watershed is more than 718 billion g/yr or about 2 billion gallons per day (g/d).

Surface water is composed of precipitation that falls and moves along the land surface as overland runoff, enters water bodies directly as direct flow, or infiltrates into the subsurface and returns to the surface as baseflow. The sum of all stream discharge in a specified area represents the total volume of available surface water (impounded waters were not considered in this assessment of surface-water availability). However, since direct measurements of discharge were not available for all streams in the project area, a method of estimation was used to indirectly determine surface-water availability. The method chosen for this assessment was the determination of a unit discharge (cubic feet per second per square mile of drainage area, cfs/s/mi^2) for gauged streams that was applied to ungauged streams in similar geographic and hydrogeologic areas. Unit discharges were determined for the same streams used for the estimation of recharge rates and available groundwater.

Average unit discharge in each geologic area was used to calculate available surface water. Total surface-water availability is the sum of volumes of the six geologic areas plus Tennessee River discharge entering Alabama at the Tennessee state line. Total surface water varied from 61.9 million cubic feet per day (ft^3/day) (0.5 billion g/d for geologic area 5 to 321.4 million ft^3/day (2.4 billion g/d) for geologic area 3. Total surface-water availability for the six geologic areas is 1.09 billion ft^3/d (8.2 billion g/d) and average discharge for the Tennessee River entering Alabama is 3.3 billion ft^3/d (24.4 billion g/d). Therefore, total surface-water availability for the Tennessee River watershed based on geologic areas is 4.4 billion ft^3/d (32.6 billion g/d).

Total available water in the Tennessee River watershed in Alabama is composed of 2 billion g/d of groundwater, 24.4 billion g/d of surface water flowing into the state in the Tennessee River, and 8.2 billion g/d of surface water flowing into the Tennessee River in Alabama from tributaries, most of which originate in the state. Therefore, total water availability for the Tennessee River watershed in Alabama is 34.6 billion gallons per day.

INTRODUCTION

The economic future and quality of life for Alabamians is dependent upon the availability and protection of the state’s natural resources. The most basic and essential of these are water resources. Planning for prudent development and protection of Alabama’s water resources requires comprehensive knowledge of factors such as the amount of water available, current water use, and projected future water demand. The following report is part of a regional assessment of available water and water use in the Tennessee River watershed of north Alabama (fig. 1) accomplished through a partnership with the Alabama Department of Economic and Community Affairs Office of Water Resources (OWR), U.S. Geological Survey (USGS), and the Geological Survey of Alabama (GSA).

Water resources in the Tennessee River watershed in Alabama include significant quantities of surface and groundwater. Surface-water resources are dominated by the Tennessee River that enters Alabama in the northeastern corner of the state (fig. 2). However, numerous tributaries with headwaters inside the state contribute significantly to the surface-water resources in north Alabama. Groundwater in the Tennessee River watershed occurs in clastic and carbonate rocks that vary in age from Cambrian to Pennsylvanian and in unconsolidated Cretaceous sediments. Much of the groundwater occurs at relatively shallow depths and readily interacts with the land surface through processes involved with recharge and baseflow. The purpose of this water availability assessment is to characterize the occurrence of groundwater and to quantify the amount of available groundwater and surface water in the Tennessee River watershed.

ACKNOWLEDGMENTS

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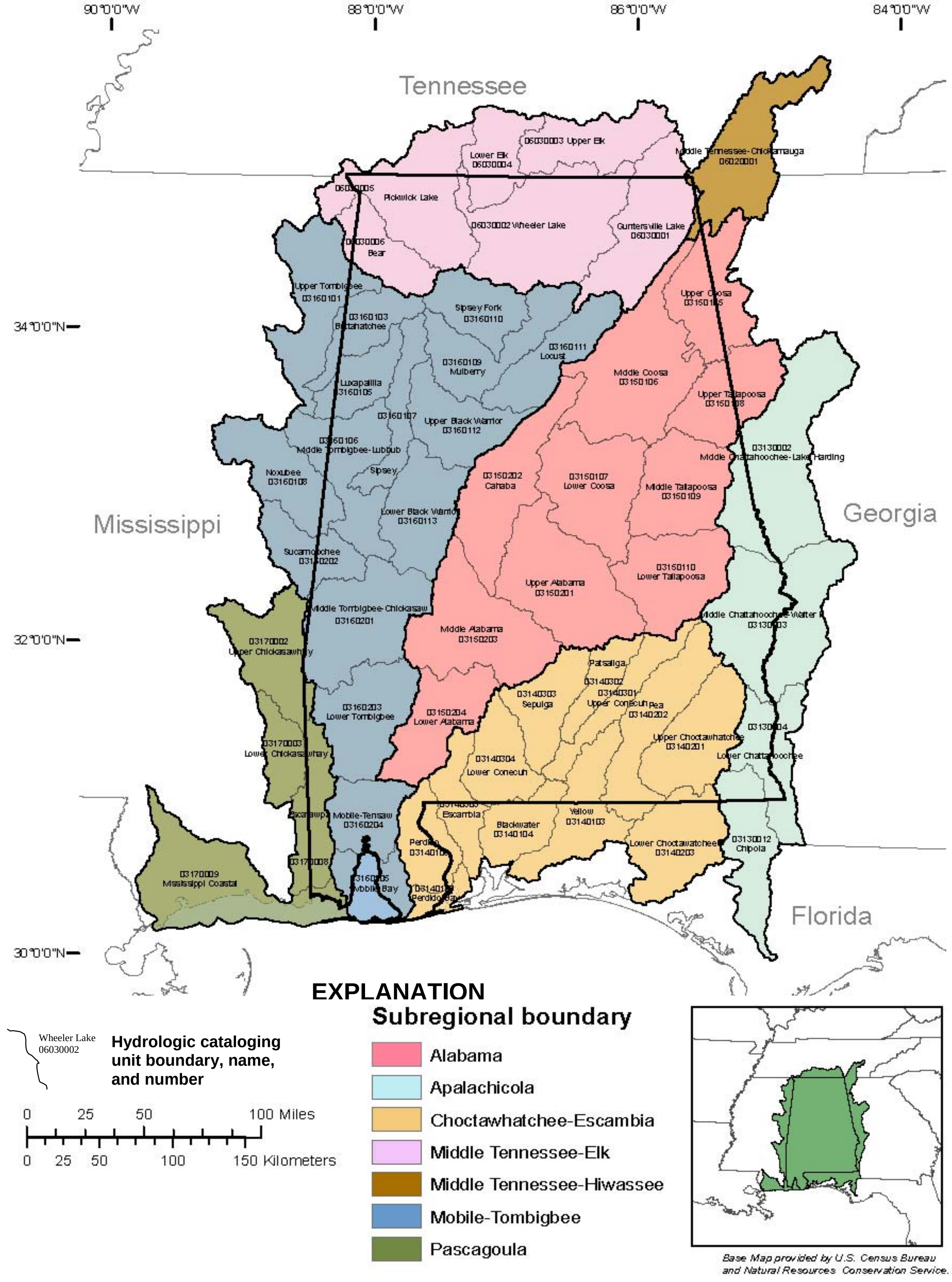


Map provided to GSA by the Alabama Office of Water Resources.

Figure 1.—Major watersheds in Alabama.

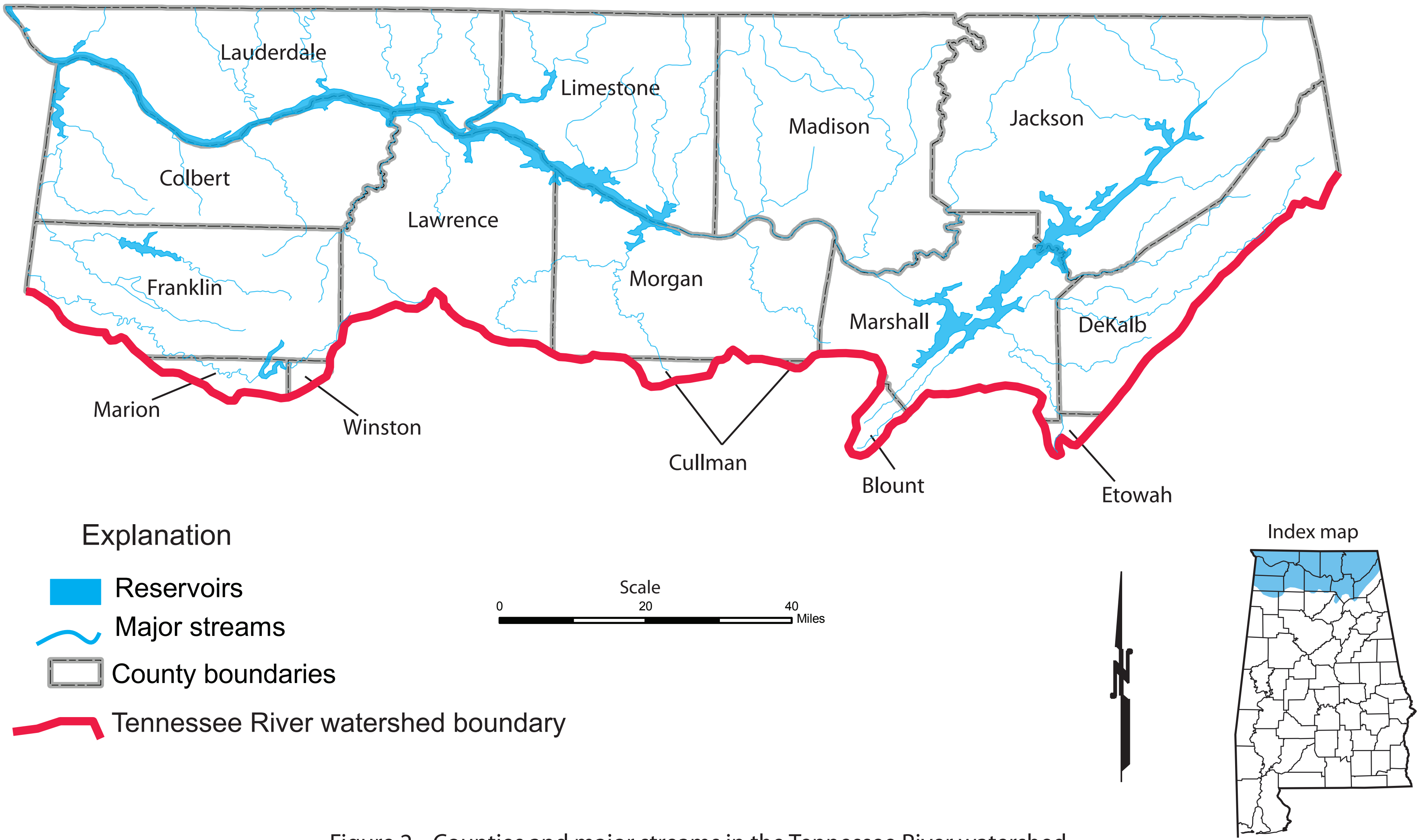


Figure 2.--Counties and major streams in the Tennessee River watershed.

PHYSIOGRAPHY

The Tennessee River watershed includes all or parts of 15 counties in north Alabama (fig. 2). It is contained in the Cumberland Plateau, Highland Rim, and East Gulf Coastal Plain physiographic sections (fig. 3) (Sapp and Emplaincourt, 1975).

The Cumberland Plateau section in the Tennessee watershed includes DeKalb, Marshall, and Jackson Counties, eastern Madison County, and parts of northern Cullman, Blount, Morgan, and Etowah Counties. It is divided into the Warrior Basin district, a synclinal dissected sandstone and shale plateau of moderate relief; Jackson County Mountains district, a high relief plateau composed of mesa-like sandstone remnants above a limestone lowland; Sand Mountain district, a sandstone and shale synclinal plateau of moderate relief; Sequatchie Valley district, an elongated anticlinal valley of moderate relief about 5 miles wide; and the Wills Valley district in northeastern DeKalb County, an elongated anticlinal valley of moderate relief (Sapp and Emplaincourt, 1975).

The Highland Rim section includes western Madison, Limestone, northern Morgan and Lawrence, northeastern Franklin, and eastern Colbert and Lauderdale Counties. It is divided into the Tennessee Valley district, comprising the northern 60 percent of the section, characterized by plateaus of moderate relief; Little Mountain district, a sandstone homoclinal ridge of moderate relief; and the Moulton Valley district, a homoclinal limestone valley of low relief (Sapp and Emplaincourt, 1975).

The East Gulf Coastal Plain section in the Tennessee watershed includes parts of northern Marion and Winston Counties, western Franklin, Colbert, and Lauderdale Counties. It consists of the Fall Line Hills district, a dissected upland of moderate relief with broad, flat ridges of Cretaceous gravel, sand, and clay overlying Paleozoic sandstone.

GEOLOGY

The Tennessee River watershed is underlain by clastic and carbonate geologic units ranging in age from Cambrian to Cretaceous (fig. 4). The watershed was divided into six areas based on common geologic structure and stratigraphy, which are major factors influencing topography, hydrology, and soil characteristics (fig. 5).

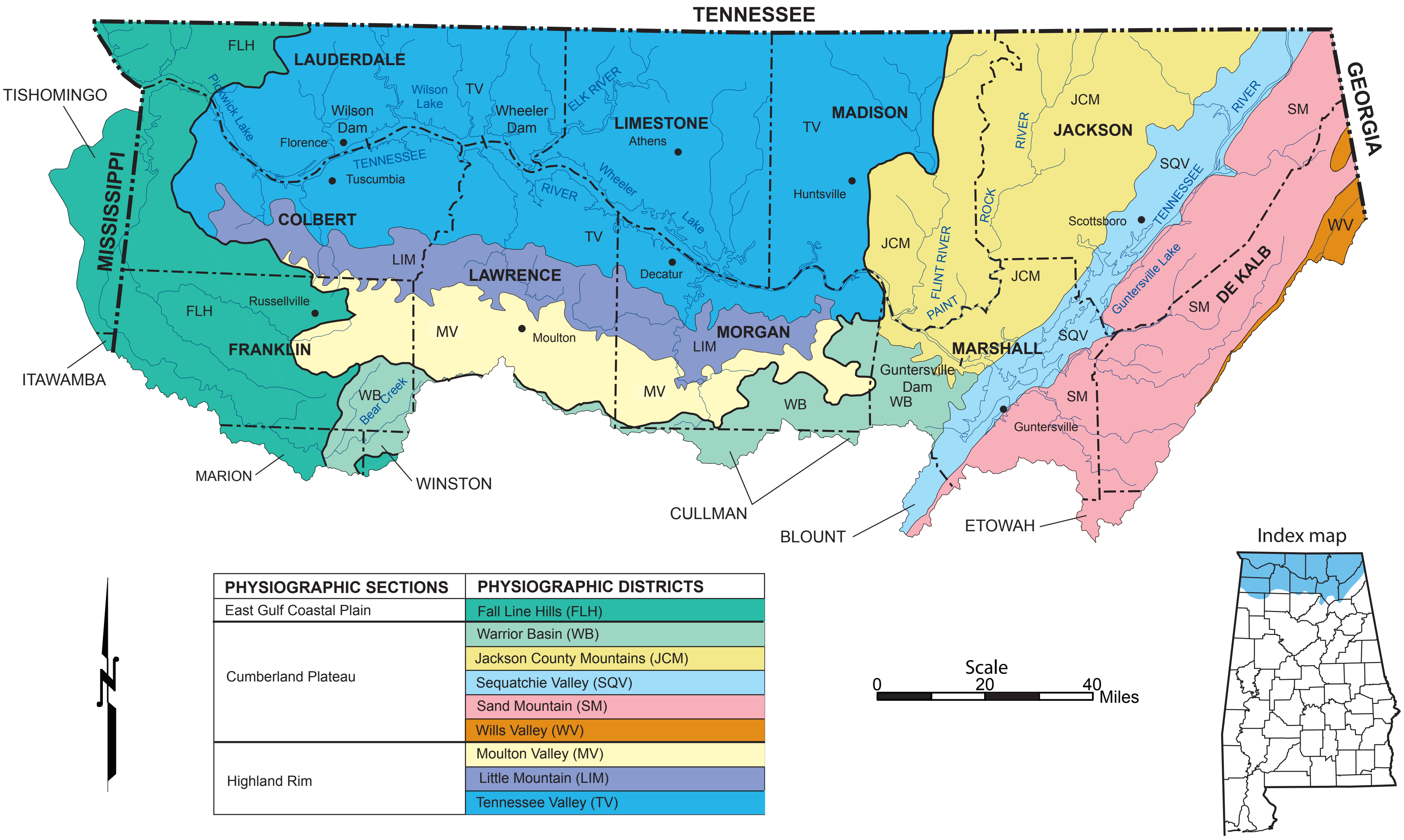


Figure 3.--Physiographic regions of the Tennessee River watershed (modified from Sapp and Emplaincourt, 1975).

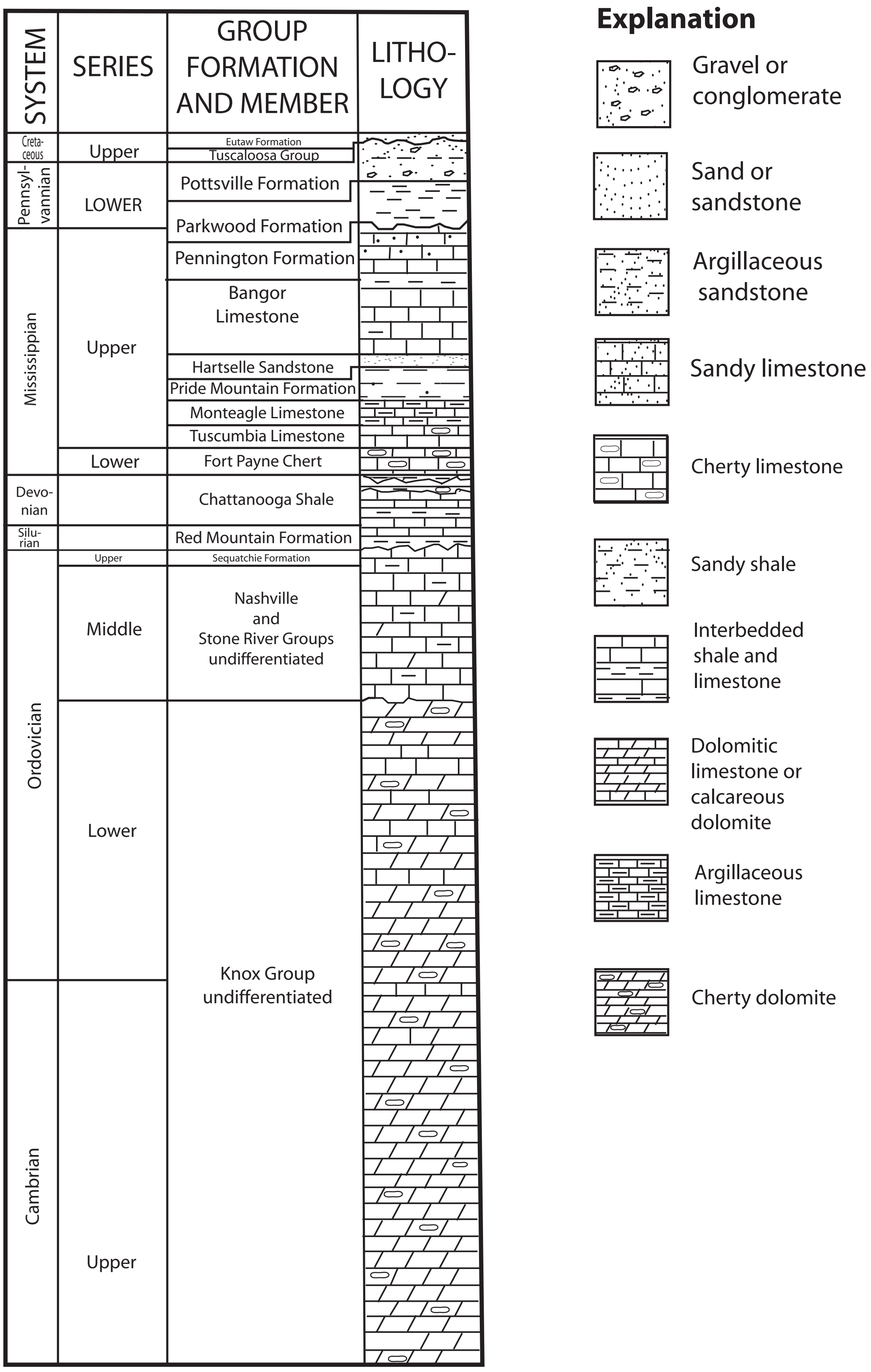


Figure 4.--Typical stratigraphyfor the Tennessee River watershed in Alabama.

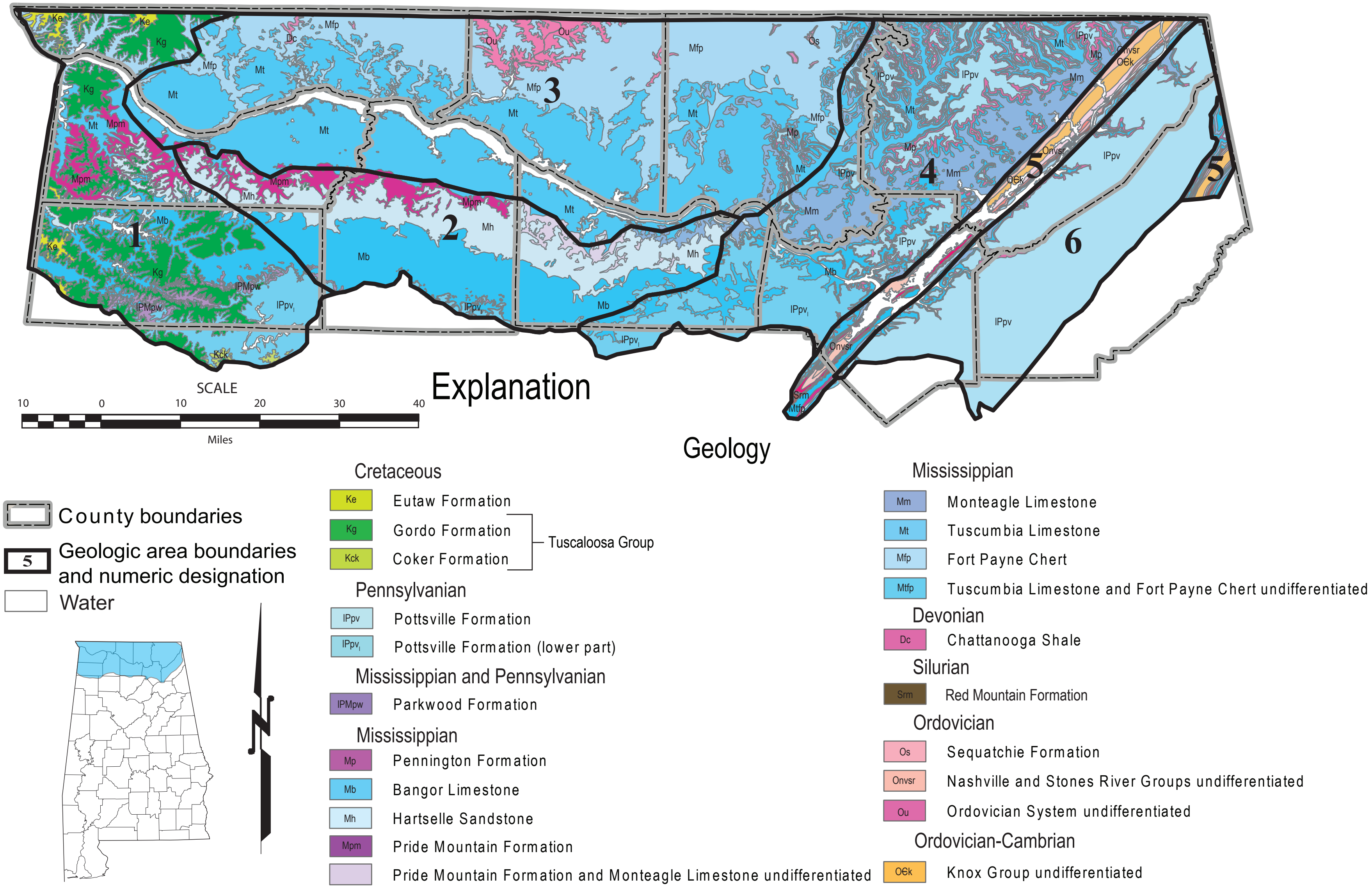


Figure 5.--Geology of the Tennessee River watershed (Geological Survey of Alabama, 2006).

STRUCTURE

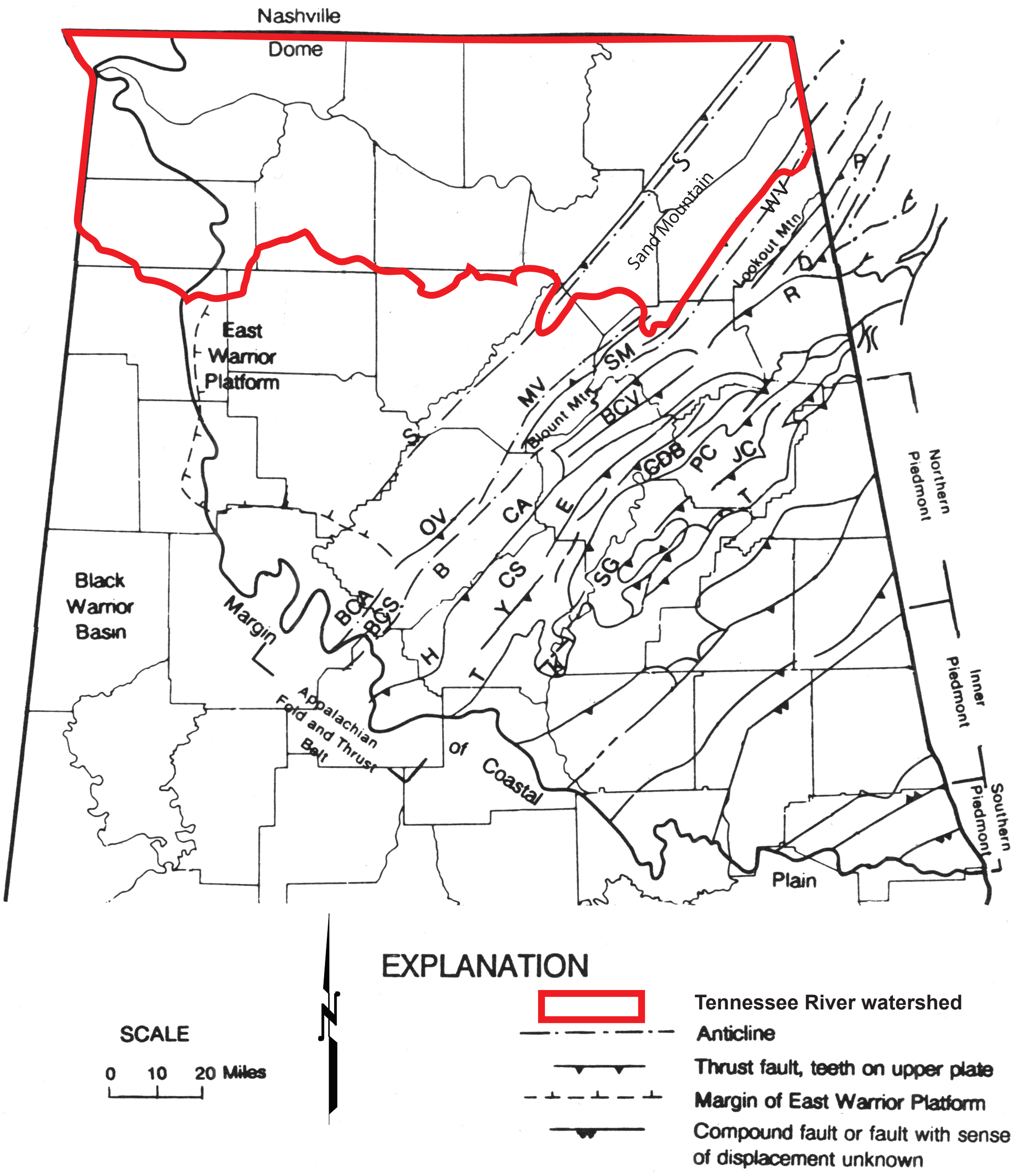
The Tennessee River watershed in Alabama is bordered by four prominent geologic structures that not only influence the exposure of geologic units in the watershed but also control the flow of ground and surface water, including the Tennessee River. The eastern part of the watershed is bordered by the Appalachian fold and thrust belt (fig. 6), consisting of Paleozoic sedimentary rocks that were deformed into a series of thrust sheets and thrust-related folds during the late Paleozoic Alleghanian orogeny (Osborne and Raymond, 1992). This part of the Tennessee River watershed is a series of broad synclinal mountains separated by narrow symmetrical to asymmetrical anticlinal valleys.

Geologic area 6 (figs. 5, 7) is formed by Sand Mountain, a northeast-trending synclinal mountain composed of Pottsville Sandstone that forms a broad plateau about 20 miles wide (fig. 7). Sand Mountain has about 700 feet of topographic relief and most surface water flows northwestward into the Tennessee River in streams that are incised deeply into the Pottsville Sandstone that caps the mountain.

Sand Mountain is bounded on the northwest and southeast by northeast-trending breached anticlinal structures that form geologic area 5. The northwestern bounding structure is the Sequatchie anticline, which is the northwesternmost large-scale structure in the Appalachian fold and thrust belt, and the southeast bounding structure is the Wills Valley anticline (figs. 5-7). The cores of the anticlines expose the oldest rocks in the Tennessee River watershed, forming carbonate-floored valleys in which the Tennessee River and its tributaries flow. The northwestern limbs of both structures are cut by thrust faults (Osborne and others, 1989).

The central part of the Tennessee River watershed in Alabama is underlain by a thick sequence of nearly flat-lying Paleozoic rocks, ranging in age from Middle Ordovician to Early Pennsylvanian. These rocks were less affected by the tectonic forces that formed the Appalachian fold and thrust belt. With the exception of a few minor folds, rocks generally dip south-southwest at 20 to 40 feet per mile (Osborne and Raymond, 1992; Jennings and Cook, 2008) in response to the position of the Tennessee River watershed on the southern flank of the Nashville Dome (figs. 6, 7).

Figure 6.--North Alabama geologic regions and features (modified from Osborne and Raymond, 1992).



B	Birmingham anticlinorium	MV	Murphrees Valley anticline
BCA	Blue Creek anticline	OV	Opossum Valley fault
BCS	Blue Creek syncline	P	Peavine anticline
BCV	Big Canoe Valley fault	PC	Pell City fault
CA	Cahaba synclinorium	R	Rome fault
CDB	Coosa deformed belt	S	Sequatchie anticline
CS	Coosa synclinorium	SG	Sleeping Giants klippe
D	Dirtseller Mountain syncline	SM	Straight Mountain fault
E	Eden fault	T	Talladega fault system
H	Helena fault	WV	Wills Valley anticline
JC	Jacksonville fault complex	Y	Yellowleaf fault
K	Kelley Mountain window		

Figure 7.--North Alabama major faults and geologic structures (modified from Osborne and Raymond, 1992).

The southern margin of the Tennessee River watershed borders the East Warrior Platform, a plateau formed by a thick sequence of clastic rocks of the Pottsville Formation (fig. 7). The western border of the watershed is formed by the Black Warrior Basin, a triangular shaped, southwestward dipping homocline in northwest Alabama and northeast Mississippi (Osborne and Raymond, 1992) (fig. 7).

JOINTS

Joints are characterized as brittle fractures in rock with no displacement, caused by accommodation to stress. In the Tennessee Valley, joints are generally the result of tension. Joints are of particular interest because they provide permeability for the movement of groundwater, especially in carbonate rocks where they may be enhanced by solution. An investigation of joint systems in the Tuscumbia Limestone and Fort Payne Chert in northern Madison County by Mann and others (1996) revealed that the most prominent joint strike directions were N. 30^o E., N. 60^o W., and N. 75^o W.

Mann and others (1996) also investigated the presence of lineaments in northern Madison County. Lineaments are linear features observed on aerial photographs or topographic maps that result from the alignment of stream channels, topographic relief, vegetation, or tonal anomalies. They are thought to be in part structurally controlled possibly by faults or zones of intense jointing and have been used to postulate the occurrence of groundwater. The investigation included analyses of high-altitude color-infrared photographs and identified dominant linear trends of N. 30^o E. and N. 60^o W., which agreed with the dominant trends of joints in the area.

STRATIGRAPHY

The geology of the Tennessee River watershed is characterized by outcropping units ranging in age from Cambrian to Cretaceous (fig. 5). Geologic area 1 lies along the western margin of the Tennessee River watershed and includes parts of Marion, Winston, Franklin, Colbert, and Lauderdale Counties and is characterized by Paleozoic rocks overlain by Cretaceous coastal plain sediments. Paleozoic rocks include Fort Payne Chert, Tuscumbia Limestone, Pride Mountain Formation, Hartselle Sandstone, Bangor Limestone, Parkwood Formation, and Pottsville Formation. The overlying Cretaceous sediments include the Coker and Gordo Formations of the Tuscaloosa Group, composed of unconsolidated sand, gravel, and clay that may be as much as 170 feet thick (Bossong and Harris, 1987) and small outcroppings of Eutaw Formation in the extreme southwestern part of the area, composed of silt, sand, and clay. Tuscaloosa Group and Eutaw Formation sediments are erosional remnants found at higher elevations dipping gently to the west and southwest.

Geologic area 2 includes parts of Morgan, Lawrence, Franklin, and Colbert Counties (fig. 5). The area is characterized by eastward-trending Lower Pennsylvanian and Upper Mississippian clastic and carbonate rocks that form the southern boundary of the Tennessee River watershed.

The Pride Mountain Formation crops out along the northern margin of the area (fig. 5). It is characterized as medium- to dark-gray shale with variable combinations of sandstone and limestone in the lower part (Osborne and others, 1989). The Pride Mountain is equivalent to the Monteagle Limestone in the eastern part of the area.

The Pride Mountain Formation is overlain by the Hartselle Sandstone, a light-colored, fine-grained, well-sorted, quartzose sandstone, locally crossbedded, and partly calcareous. It is generally thick bedded to massive and contains interbeds of clay or shale (Raymond and others, 1988).

The Bangor Limestone crops out in a broad east-west band across geologic area 2 and varies in thickness from 350 to 500 feet. It consists principally of bioclastic and oolitic limestone with minor amounts of clay and dolomitic limestone (Thomas, 1972) and grades southwestward into the Parkwood Formation.

The Parkwood Formation is Upper Mississippian-Lower Pennsylvanian and forms the southern boundary of the Tennessee River watershed (fig. 5). It consists of medium- to dark-gray silty clay or shale and mudstone, interbedded with light- to medium-gray very fine to fine-grained argillaceous, micaceous, and locally crossbedded and ripple-marked sandstone. Locally, it contains beds of medium- to dark-gray argillaceous, bioclastic, and cherty limestone (Raymond and others, 1988).

Geologic area 3 includes Limestone County and parts of Madison, Morgan, Lawrence, Lauderdale, and Colbert Counties (fig. 5). Relatively small, isolated outcrops of Ordovician, Silurian, and Devonian rocks are observed in Madison and Lauderdale Counties. The most prominent outcrops of Ordovician and Devonian units occur in northern Limestone County. The dominant stratigraphy in the area consists of Lower Mississippian Fort Payne Chert and Upper Mississippian Tuscumbia Limestone.

The Fort Payne Chert is composed of very light gray to light-gray, thin- to thick-bedded, fossiliferous or bioclastic limestone, siliceous and dolomitic limestone, and dolomite with abundant nodules, lenses, and beds of light- to dark-gray chert (Copeland and others, 1975; Szabo and others, 1988). Bedded chert is common throughout the unit but is more concentrated near the base. The percentage of chert in the formation is variable from 20 to 80 percent (Holler, 1975). In areas underlain by the Fort Payne Chert, bedrock exposures are rare and are usually covered with dark-yellowish-orange to dark-reddish-brown regolith containing abundant detrital blocky chert. The formation is exposed in the northern half of geologic area 3 and has an average thickness of about 160 feet.

The Tuscumbia Limestone overlies the Fort Payne Chert although in some areas it is lithologically indistinct. It is generally composed of a sequence of light-gray to light-brownish-gray coarse- to medium-grained bioclastic or micritic limestone, light-brownish-gray granular cherty calcareous dolomite, and randomly distributed light-gray and white nodular chert (Holler, 1975; Raymond and others, 1988). The Tuscumbia Limestone is exposed in the southern half of geologic area 3 and the average thickness of the unit is about 150 feet.

Geologic area 4 includes parts of Jackson, Madison, and Marshall, Blount, and Cullman Counties. It is characterized by narrow valleys underlain by Tuscumbia and Monteagle Limestone and narrow, high relief (more than 1,000 feet) ridges of Bangor Limestone and Pennington Formation, capped by the Pottsville Formation (fig. 5). These rocks dip regionally at about 20 to 30 feet per mile, influenced by the Nashville Dome.

The Tuscumbia Limestone is composed of massive to bedded micritic and bioclastic limestone, with chert beds and nodules. The formation thickness is about 200 feet with regolith accounting for as much as 100 feet of the formation in some areas. Many solutional features are present, and weathered exposures commonly show signs of vertically controlled solution (Bossong and Harris, 1987). The Monteagle Limestone in geologic area 4 is about 200 feet thick and grades laterally to the southwest into the Pride

Mountain Formation (Bossong and Harris, 1987). It is lithologically similar to the Tuscumbia Limestone.

The Bangor limestone consists of medium- to thick-bedded, primarily bioclastic and oolitic limestone, shaly argillaceous limestone, calcareous clay or shale, and dolomite. It varies in thickness from 350 to 500 feet and has a regolith thickness of about 20 feet where it crops out. The Pennington Formation in geologic area 4 may be as much as 400 feet thick and consists of shale, limestone, dolomite, argillaceous sandstone, and minor shaly coal with some limestone (Osborne and others, 1989).

Ridges in geologic area 4 are capped by as much as 800 feet of Pottsville Formation, consisting of tightly indurated and cemented sandstone, conglomerate, shale, and siltstone with thin beds of coal (Bossong, 1988).

Geologic area 5 consists of the Sequatchie and Wills Valley anticlines and includes parts of Jackson, Marshall, DeKalb, and Blount Counties. Most geologic units observed in the Tennessee River watershed are exposed in the Sequatchie anticline. These units include the Chepultepec Dolomite, Longview Limestone, and Newala Limestone (shown on fig. 4 as Upper Cambrian and Lower Ordovician Knox Group undifferentiated); Middle Ordovician Nashville and Stones River Groups undifferentiated (Sequatchie anticline) and Chickamauga Limestone (Wills Valley anticline); Upper Ordovician Sequatchie Formation and equivalent units; Silurian Red Mountain Formation; Devonian Chattanooga Shale; Lower Mississippian Fort Payne Chert; and Upper Mississippian Tuscumbia Limestone, Monteagle Limestone, Pride Mountain Formation, Hartselle Sandstone, Bangor Limestone, and Pennington Formation (Osborne and others, 1989) (fig. 5).

The Chepultepec Dolomite consists of medium- to thick-bedded dolomite with local lenses of limestone, which may be extremely cherty (Bossong, 1988). The Longview Limestone has an average thickness of 500 feet and is composed of cherty limestone, locally sandy and thick-bedded, with minor amounts of dolomite. The Newala Limestone consists primarily of textureless, thick-bedded micritic or peloidal limestone with only minor amounts of dolomite (Raymond and others, 1988).

The Stones River Group is composed of thick- to thin-bedded partly argillaceous and silty fine-grained limestone with locally abundant fossils. Near the top is a zone of bentonite and bentonitic shales. The upper part consists of brownish-gray to medium-gray occasionally fossiliferous and argillaceous, sometimes oolitic limestone with minor chert (Raymond and others, 1988). The Nashville Group consists of medium- to dark-gray fossiliferous limestone and minor gray shale (Raymond and others, 1988). The Sequatchie Formation is composed of siltstone, sandstone, and shale that is dusky red and olive gray in the lower part. The upper part is gray to grayish-green calcareous siltstone and dolomite (Raymond and others, 1988).

The Red Mountain Formation unconformably overlies the Sequatchie Formation and is composed of dark-reddish-brown to olive-gray siltstone, sandstone, and shale, and may also contain thin beds of limestone (Raymond and others, 1988).

The Chattanooga Shale is up to 50 feet thick and consists of brownish-black to grayish-black silty, organic shale and minor amounts of sandstone with pyrite and phosphatic inclusions (Bossong, 1988; Raymond and others, 1988).

The Fort Payne Chert is locally composed of highly fractured siliceous limestone and chert that weathers to grayish orange or light gray (Bossong, 1988; Raymond and others, 1988). The Tuscumbia Limestone, Fort Payne Chert, and Monteagle Limestone are lithologically similar consisting of massive to bedded micritic and bioclastic limestone, with chert beds and nodules. The Pride Mountain Formation is composed of shale containing abundant siderite nodules and pyrite, interbedded with mudstone, calcareous clay shale, and shaly argillaceous limestone (Raymond and others, 1988). The Hartselle Sandstone consists of light-colored, fine-grained quartzose sandstone.

The Bangor Limestone consists of medium- to thick-bedded, primarily bioclastic and oolitic limestone, shaly argillaceous limestone, calcareous clay shale, and dolomite. The Pennington Formation contains gray clay shale and interbeds of mudstone, bioclastic, micritic, and oolitic limestone, dolomite, argillaceous sandstone, and carbonaceous claystone and shaly coal (Raymond and others, 1988).

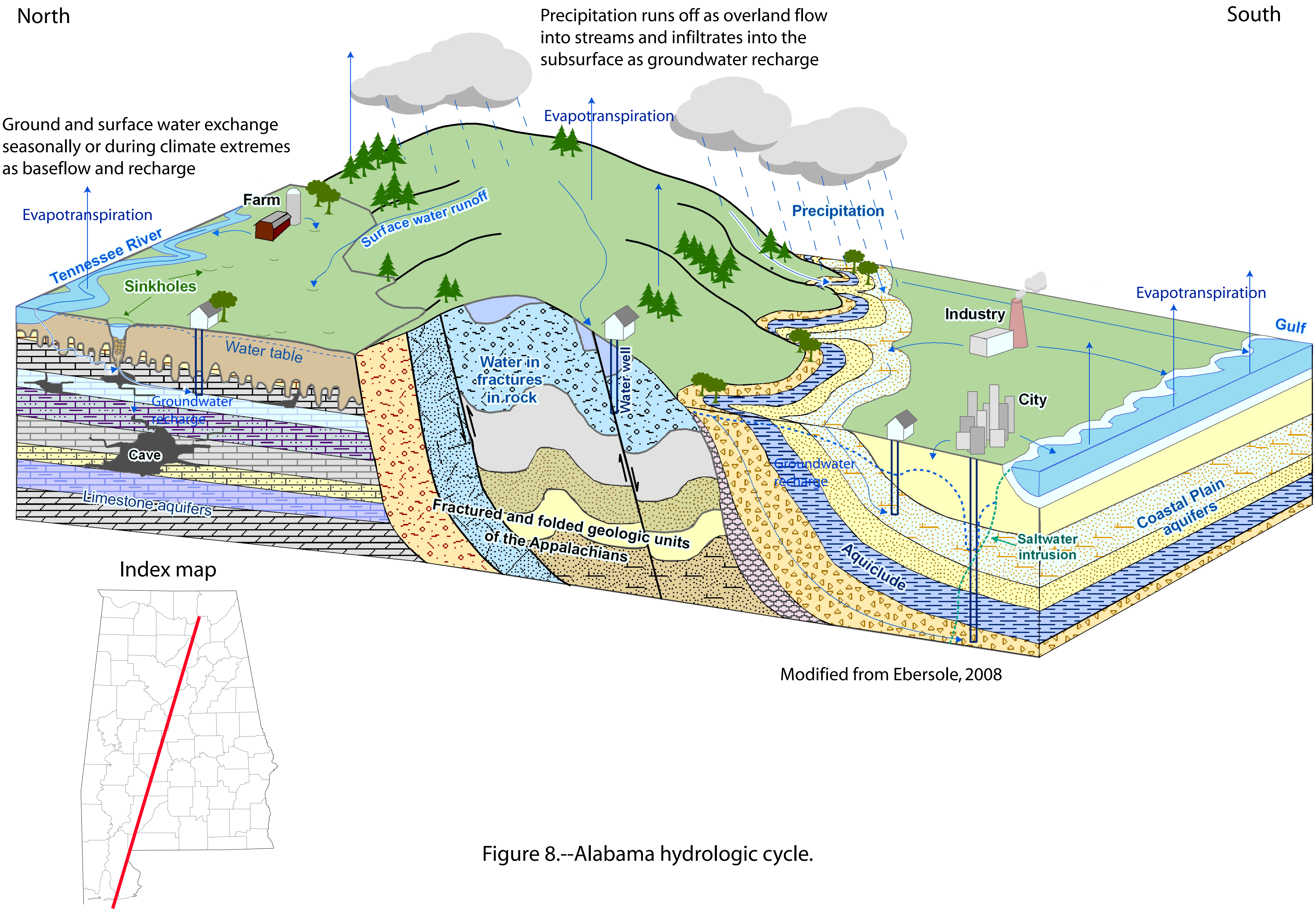
The easternmost geologic area, area 6, includes parts of Jackson, DeKalb, Marshall, and Etowah Counties and is dominated by Sand Mountain, a synclinal plateau about 20 miles wide, capped by the youngest formation of Paleozoic age in the Tennessee River watershed, the Lower Pennsylvanian Pottsville Formation (fig. 5). The Pottsville

Formation is as much as 800 feet thick and consists of tightly indurated and cemented sandstone, conglomerate, shale, and siltstone with thin beds of coal (Bossong, 1988).

HYDROGEOLOGY

The source of ground and surface water in the Tennessee River watershed is precipitation, which averages about 56 inches per year (Southeast Regional Climate Center, 2009). Availability and distribution of this water are controlled by processes illustrated in the hydrologic cycle (fig. 8), which includes overland flow into streams and lakes, evaporation into the atmosphere, transpiration by vegetation, and infiltration into the subsurface as groundwater recharge. The surface hydrology of the project area is dominated by the Tennessee River and tributaries characterized by flashy runoff over relatively impermeable Paleozoic rocks. The groundwater system is characterized as relatively shallow, fractured, Paleozoic clastic and carbonate aquifers with widespread karst development in the north-central part of the area, and coarse-grained Cretaceous sediment cover in the western part of the area. Groundwater yields are highly variable due to the diverse geology and locally variable porosity and permeability that affect the water-bearing characteristics of formations (fig. 9).

Aquifers in the Tennessee River watershed are semi-confined or unconfined due to shallow depths and absence of confining layers that isolate groundwater from the water table and the land surface. Therefore, groundwater movement in the project area is controlled by gravity as water moves from topographic highs to topographic lows where it discharges as springs or to surface-water bodies. Groundwater movement in Paleozoic aquifers is preferential with respect to direction and velocity, related to the geometry and connectivity of fracture systems. Investigations by the GSA found that groundwater flow velocities in the Tuscumbia Limestone/Fort Payne Chert aquifer in the Muscle Shoals area of Colbert County varied from 65 to 1,800 feet per hour (Chandler and Moore, 1991) and in the Huntsville area from 50 to 142 feet per hour (Baker, 2002). Directions of groundwater movement can be determined from contour maps of water level elevations. There are three types of water level maps: Water table maps, potentiometric maps, and hybrid water table-potentiometric maps. Water table maps show the configuration of groundwater under water table conditions (unconfined). Water levels used in the preparation of these maps can be from shallow wells, streams, springs, sink holes, and



Ground and surface water exchange seasonally or during climate extremes as baseflow and recharge

Precipitation runs off as overland flow into streams and infiltrates into the subsurface as groundwater recharge

Modified from Ebersole, 2008

Figure 8.--Alabama hydrologic cycle.

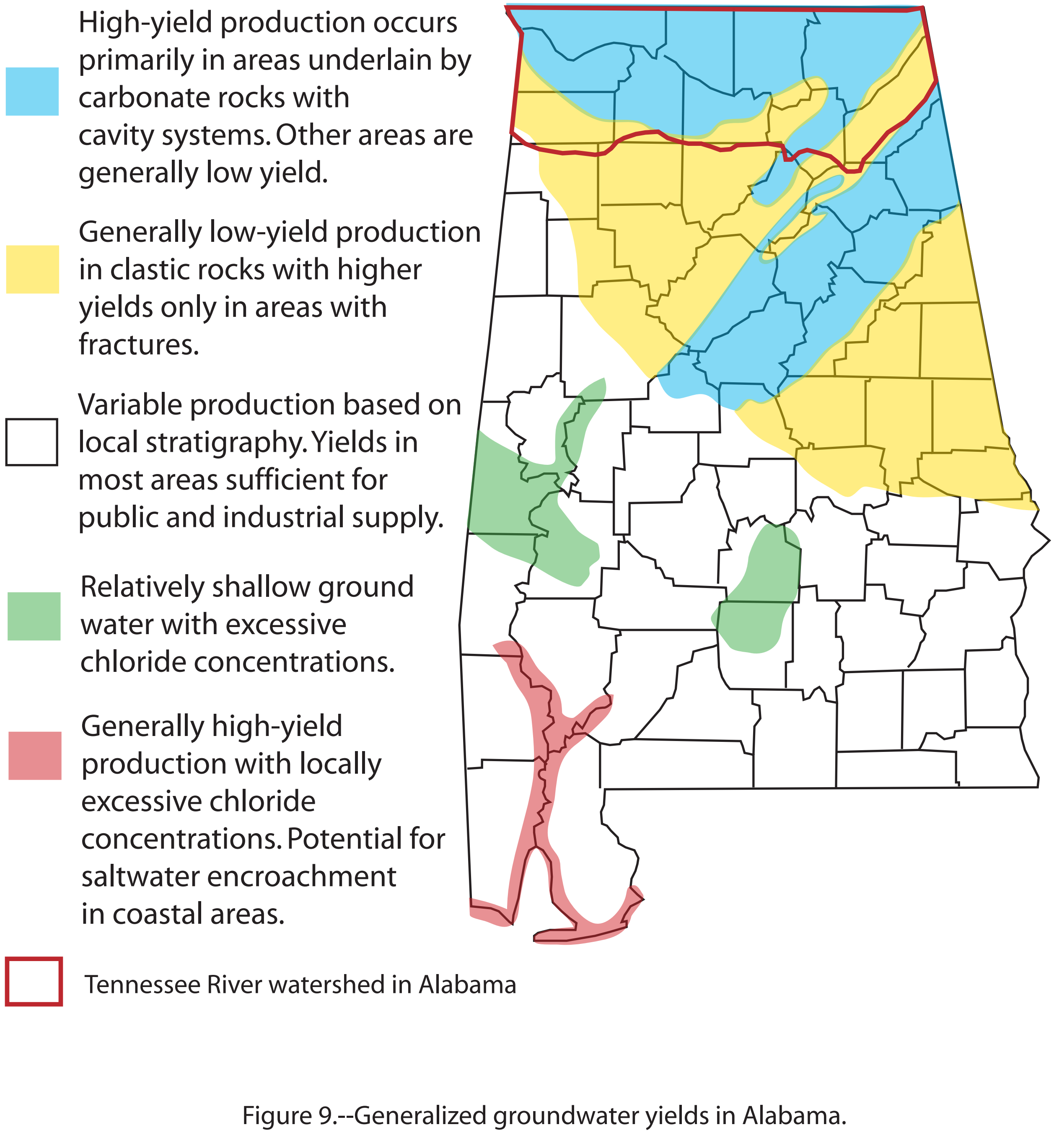


Figure 9.--Generalized groundwater yields in Alabama.

caves. Potentiometric maps represent groundwater levels in confined aquifers. Since confined groundwater is under hydraulic pressure, the elevation of the potentiometric surface is defined as the level that water rises in properly cased wells. The third type of water level map, common in the Tennessee River watershed, is a hybrid, composed of a mixture of water table, semi-confined, and/or confined water levels. Plate 1 is an example of a typical Tennessee River watershed groundwater level map in the Redstone Arsenal area of Madison County. The map shows that groundwater generally moves from higher to lower elevation and discharges into streams forming the baseflow component of surface-water flow.

GROUNDWATER RECHARGE

Unlike the Coastal Plain where groundwater can move long distances from recharge areas in aquifers that exceed depths of 2,500 feet (Cook, 2004) or the Valley and Ridge and Piedmont where large, complex faults create pathways for movement of recharge over long distances (Cook, 1997), groundwater recharge in much of the Tennessee River watershed is local. Recharge rates are controlled by a number of factors including porosity and permeability, which in Paleozoic aquifers are mainly secondary and are characterized by leached fossils, fractures, and solution development. Most carbonate rocks in the Tennessee River watershed are indurated and thoroughly cemented, resulting in limited intergranular porosity. Therefore, fractures provide much of the porosity and permeability for groundwater movement and storage. Fractures are characterized as stress-relief (vertical) and bedding-plane (horizontal) and are typically non-uniform and can vary significantly over short distances (Bossong and Harris, 1987). The principal constituent of these rocks is calcium carbonate ($CaCO_3$), a compound which is readily soluble by several dilute acids that are normally present in precipitation and runoff. However, the most significant process affecting solution development in these carbonate rocks is the production of carbonic acid by percolating groundwater. As water moves downward through the regolith, it encounters carbon dioxide (CO_2), which is produced by decay of organic matter (Freeze and Cherry, 1979). Water and CO_2 combine to form carbonic acid, which dissolves limestone and aids in development of solution-enlarged fractures and cavities (Mann and others, 1996).

Recharge, originating from precipitation, may also be influenced by drought (fig. 10), seasonal precipitation (fig. 11), land surface slope, surface drainage, and the character of surface material. If the topography is relatively flat and surface materials are permeable, more surface water will infiltrate into local aquifers. Recharge may also be greater where faults and fractures are common, subjected to solution enhancement, and extend to the surface where they connect surface water and aquifers (Bossong, 1988; Baker and others, 2005). Estimates of recharge can be useful in determining available groundwater, impacts of disturbances in recharge areas, and water budgets for water-resource development and protection. Numerous methods have been used for estimating recharge, including development of water budgets, measurement of seasonal changes in groundwater levels and flow velocities. However, equating average annual baseflow of streams to groundwater recharge is the most widely accepted method (Risser and others, 2005). Although it is desirable to assess recharge in watersheds with unregulated streams that are not subject to surface-water withdrawals, or discharges from wastewater treatment plants or industries, it is unrealistic to expect that no human impacts occur in any of the assessed watersheds.

As noted previously, average precipitation in the Tennessee River watershed is 56 inches per year. Precipitation is distributed as runoff, evapotranspiration, and groundwater recharge (fig. 8). Sellinger (1996) described the various pathways of precipitation movement that compose stream discharge and determine the shape of a stream hydrograph (fig. 12). However, for the purposes of this report, the pathways of precipitation movement shown in figure 12 are combined into 2 primary components, runoff and baseflow. Runoff is defined as the part of total stream discharge that enters the stream from the land surface. Bossong (1988) reported that runoff in the Tennessee River watershed varies from 20 to 30 inches per year, depending on the location of the subject watershed with respect to topography and geology. Baseflow is the part of stream flow supplied by groundwater, an essential component that sustains stream discharge during periods of drought and is equated to groundwater recharge.

Separating runoff and baseflow from total stream discharge can be accomplished by several methods (Sellinger, 1996; Risser and others, 2005) including (1) recession analysis (Nathan and McMayhon, 1990), (2) graphical hydrograph separation (Meyboom,

Figure 10.--Annual precipitation for the period 1980-2008 at the Huntsville Airport.

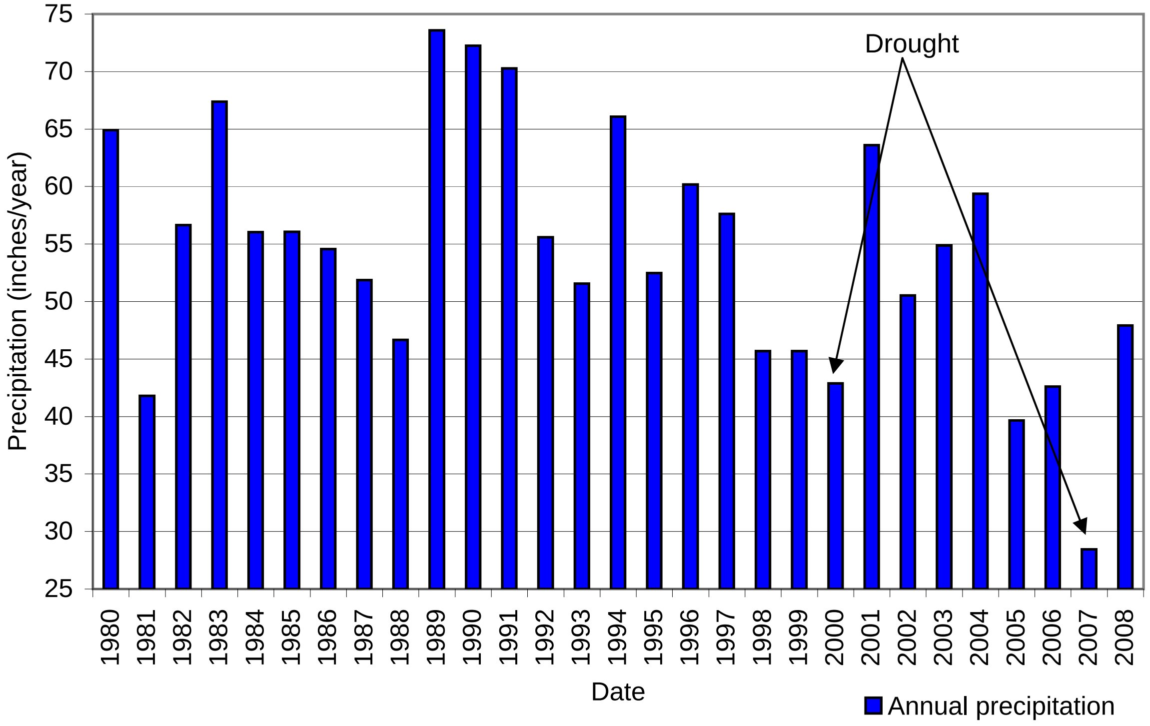
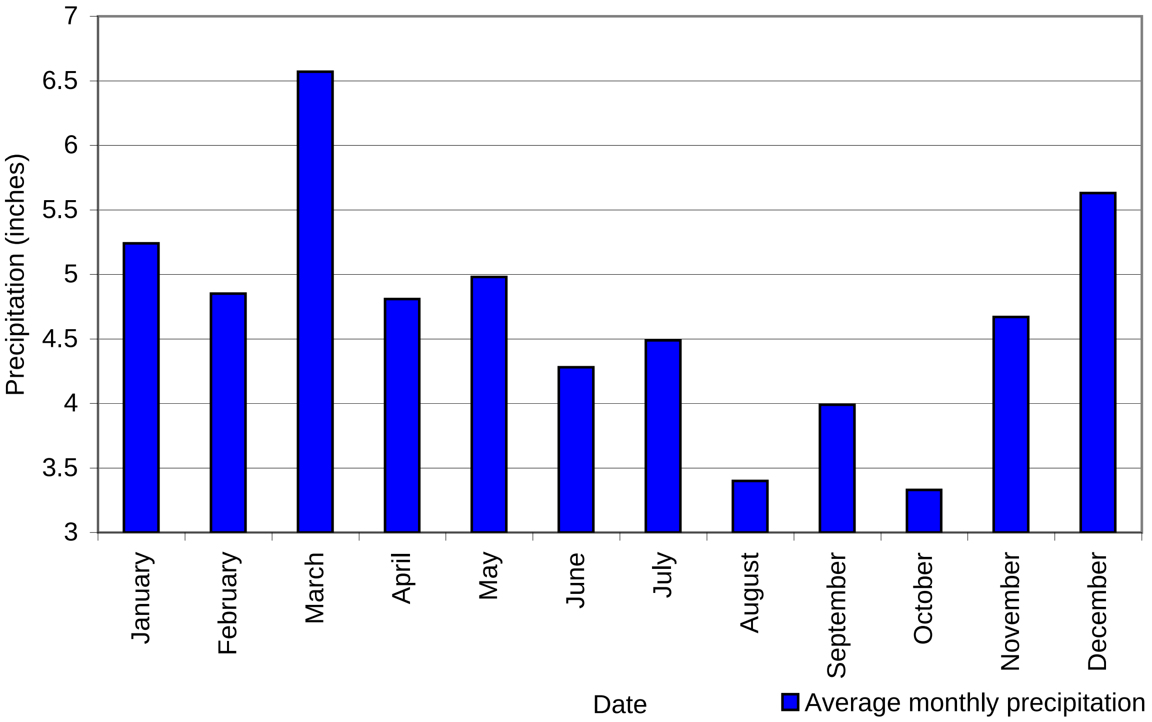
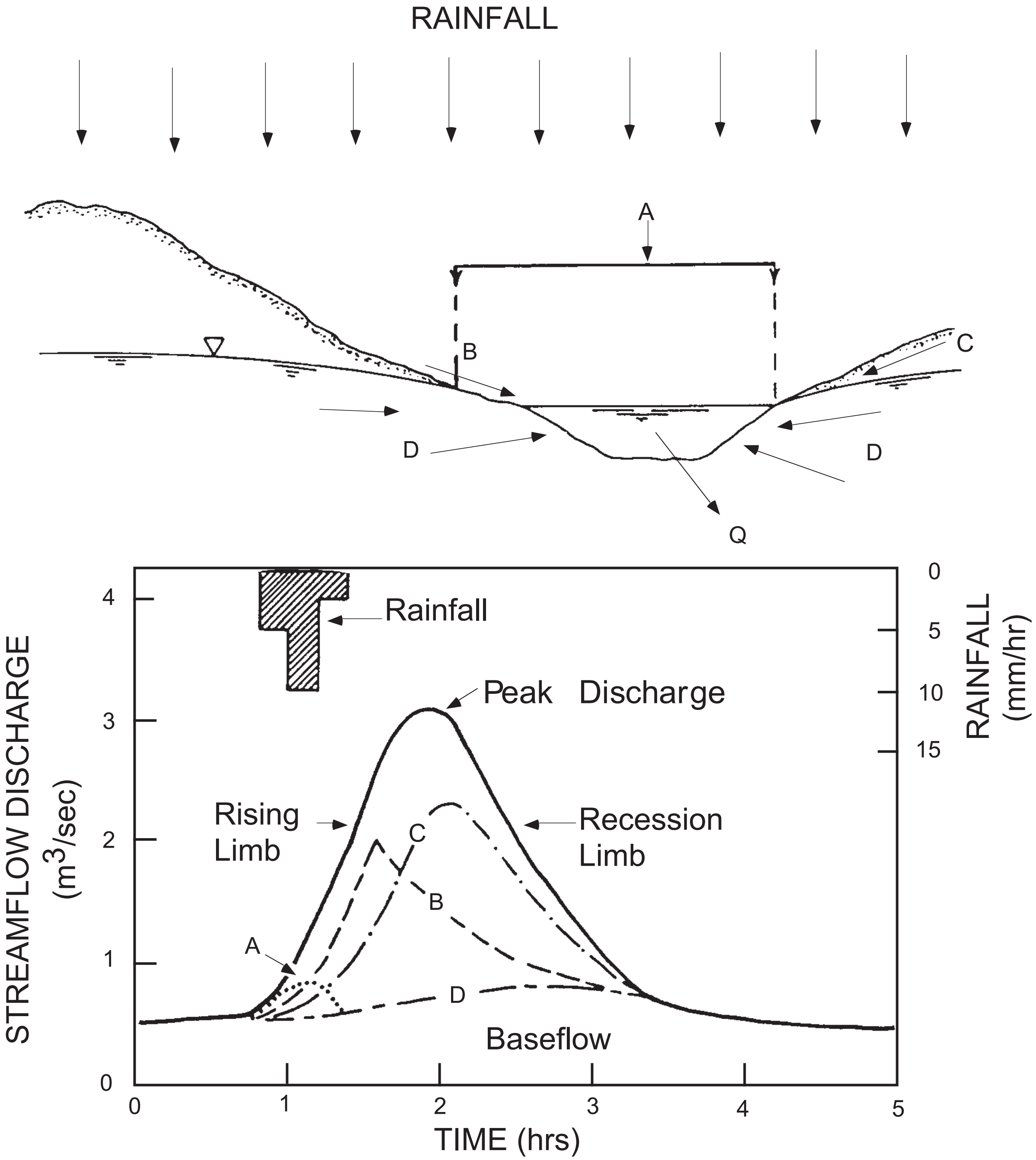


Figure 11.--Average monthly precipitation for the period 1908-2008 at the Huntsville Airport.





(A) Direct runoff (B) Runoff (C) Subsurface flow (D) Baseflow (Q) Total stream discharge

Figure 12. Graphic and stormflow hydrograph illustrating pathways of movement of rainfall into streams. (modified from Sellinger, 1996)

1961), and (3) partitioning of stream flow using daily rainfall and stream flow (Shirmohammadi and others, 1984). More recently, a number of computer models have automated hydrograph separation techniques (Risser and others, 2005; Lim and others, 2005).

The Meyboom method requires stream hydrograph data over two or more consecutive years. Baseflow is assumed to be entirely groundwater, discharged from unconfined aquifers. An annual recession is interpreted as the long-term decline during the dry season following the phase of rising stream flow during the wet season. The total potential groundwater discharge (V_{tp}) to the stream during this complete recession phase is derived as:

$$V_{tp} = \frac{Q_0 K}{2.3}$$

Where Q_0 is the baseflow at the start of the recession and K is the recession index, the time for baseflow to decline from Q_0 to $0.1Q_0$.

Discharge data for 20 streams in the Tennessee River watershed with current or discontinued USGS discharge measurement stations were used in the recharge evaluation (fig. 13, table 1). Discharge data for each stream were analyzed using the PART (Rutledge, 1998) automated hydrograph separation program (Johnston, 2008). When runoff and baseflow discharge results from PART were compared to results obtained from the recession analysis method developed by Meyboom (1961) for the same time periods, there was poor agreement. Baseflow averaged 51 percent of total discharge for watersheds analyzed using the PART program and 20 percent using the Meyboom method. Discharge data were then analyzed using the Web based Hydrograph Analysis Tool (WHAT) automated hydrograph separation program (Lim and others, 2005; Purdue University, 2004). When resulting runoff and base flow data from the WHAT model were compared to the results from the Meyboom method, a significantly better agreement was observed. Baseflow as a percentage of total discharge averaged 26 percent for watersheds analyzed using the WHAT program. Based on the general agreement between the Meyboom method and the WHAT program, values of baseflow estimated by the WHAT program were used to estimate recharge rates and to calculate volumes of groundwater recharge.

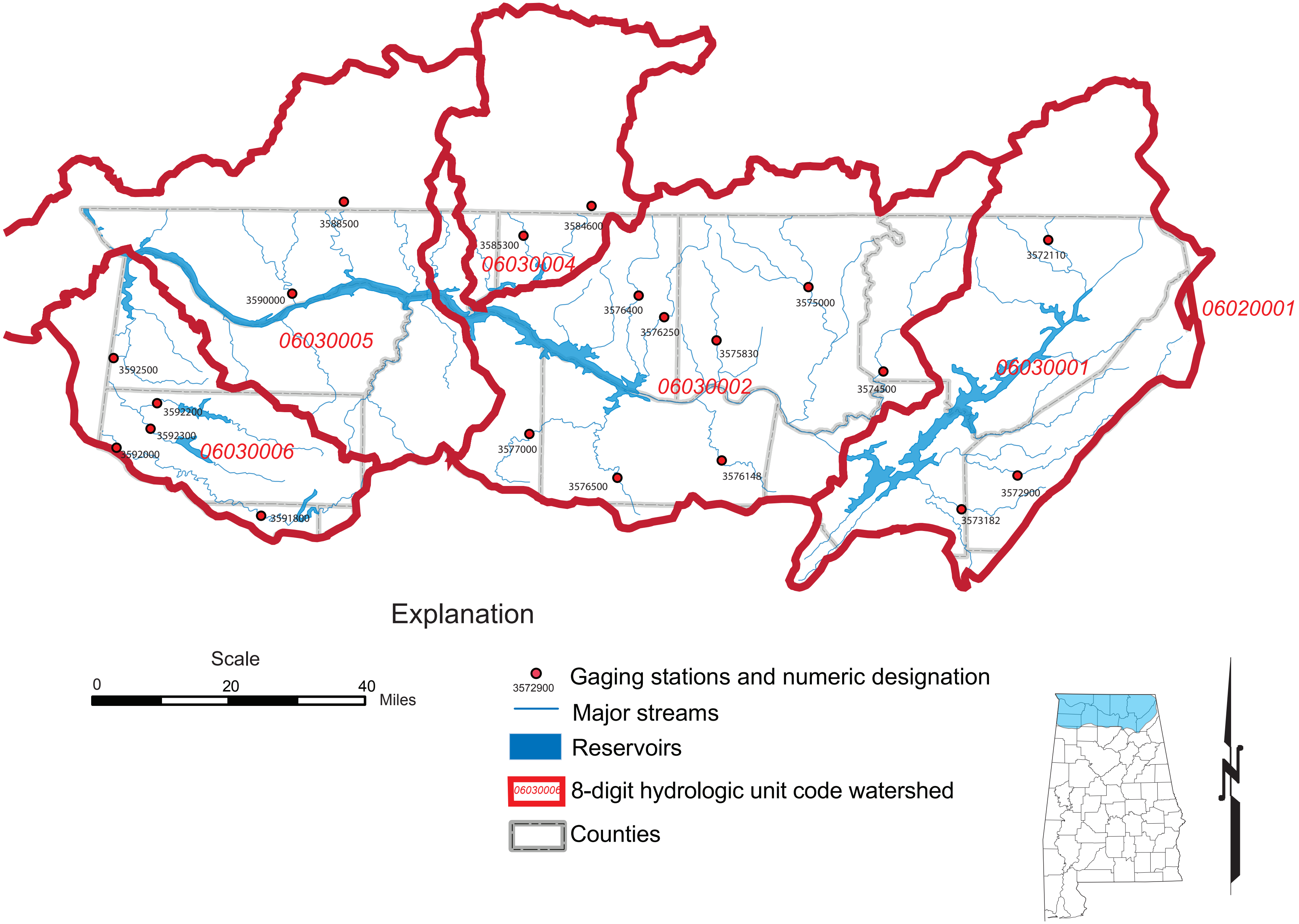


Figure 13.--Stream discharge measurement stations and 8-digit hydrologic unit code watersheds in the Tennessee River watershed.

Table 1—USGS discharge stations used for recharge estimates in the Tennessee River watershed.

Geologic area	8-digit HUC	USGS discharge station number	USGS discharge station name	Discharge period of record
1	06030006 (Bear)	03591800	Bear Creek near Hackleburg	1956-1979 1980-1981
1	06030006 (Bear)	03592000	Bear Creek near Red Bay	1913-1920 1958-1967 1969-1981
1	06030006 (Bear)	03592200	Cedar Creek near Pleasant Hill	1957-1977
1	06030006 (Bear)	03592300	Little Bear Creek near Halltown	1957-1977
1	06030006 (Bear)	03592500	Bear Creek near Bishop	1926-1928 1929-1932 1933-1979
2	06030002 (Wheeler Lake)	03577000	West Flint Creek near Oakville	1952-1998
2	06030002 (Wheeler Lake)	03576500	Flint Creek near Falkville	1952-1999
3	06030005 (Pickwick Lake)	03590000	Cypress Creek near Florence	1934-1953
3	06030005 (Pickwick Lake)	03588500	Shoal Creek at Iron City	1925-1994 2000-2008
3	06030002 (Wheeler Lake)	03575000	Flint River near Chase	1931-1993
3	06030002 (Wheeler Lake)	03576250	Limestone Creek near Athens	1939-2008
3	06030002 (Wheeler Lake)	03575830	Indian Creek near Madison	1959-2008
3	06030004 (Lower Elk)	03584600	Elk River at Prospect, Tennessee	1904-2008
3	06030002 (Wheeler Lake)	03576400	Piney Creek near Athens	1959-1968
3	06030002 (Wheeler Lake)	03585300	Sugar Creek near Good Springs	1957-1969
4	06030002 (Wheeler Lake)	03574500	Paint Rock River near Woodville	1937-2007
4	06030002 (Wheeler Lake)	03576148	Cotaco Creek at Florette	1966-1980
4	06030001 (Lake Guntersville)	03572110	Crow Creek at Bass	1975-1996
6	06030001 (Lake Guntersville)	03572900	Town Creek near Geraldine	1958-1979
6	06030001 (Lake Guntersville)	03573182	Scarham Creek near McVille	1998-2006

Kidd and Bossong (1987) estimated that annual recharge to the Pottsville Formation is 2 to 3 inches; Zurawski (1978) estimated that recharge to carbonate aquifers can be as much as 11 inches per year (in/yr); and Malmberg and Downing (1957) estimated that average recharge for limestone aquifers in Madison County is 11.4 in/yr.

Average results from the PART program obtained by Johnston (2008) were 13.4 in/yr for geologic area 1 (Cretaceous sediments overlying Paleozoic clastic and carbonate rocks), 6.6 in/yr for geologic area 2 (Paleozoic clastic and carbonate rocks), 10.3 in/yr for geologic area 3 (predominantly Tuscumbia Limestone and Fort Payne Chert), 14.2 in/yr for geologic area 4 (Mississippian and Pennsylvanian clastic and carbonate rocks capped by the Pottsville Formation), 12.6 in/yr for geologic area 5 (Paleozoic clastic and carbonate rocks), and 18.4 in/yr for geologic area 6 (Pottsville Formation) (table 2). Results obtained from the Meyboom recession analysis method and the WHAT program were 5.3 and 6.1 inches for geologic area 1, 2.3 and 3.4 inches for geologic area 2, 7.5 and 7.8 inches for geologic area 3, 4.6 and 6.7 inches for geologic area 4, and 4.8 and 6.4 inches for geologic area 6 (table 2). Due to the relatively small size of area 5, discharge data were unavailable. However, all Paleozoic units in the other five geologic areas outcrop in geologic area 5. Therefore, the average of recharge values for the other five areas was assigned to area 5 (4.9 and 6.1 inches).

Although precipitation in the Tennessee River watershed averages about 56 inches per year, precipitation varied from 28.46 to 73.58 inches per year for the period 1980 to 2008 (fig. 10), which had a profound affect on groundwater recharge. Recharge

Table 2.-- Comparisons of aquifer recharge estimated by multiple methods in geologic areas of the Tennessee River watershed.

Geologic area	Recharge estimation methods		
	PART (in/yr)	Meyboom (in/yr)	WHAT (in/yr)
1	13.4	5.3	6.1
2	6.6	2.3	3.4
3	10.3	7.5	7.8
4	14.2	4.6	6.7
5	12.6	4.9*	6.1*
6	18.4	4.8	6.4

*Discharge data not available; recharge values averaged from other five areas.

estimated for the Paint Rock River watershed, using the Meyboom method, was 5.4 in/yr during 1983 (a period of above average precipitation, 67.39 inches) and 2.2 in/yr during 2007 (a period of below normal precipitation, 28.46 inches) (fig. 10).

GROUNDWATER AVAILABILITY

Groundwater availability is generally defined as the total amount of groundwater of adequate quality stored in the subsurface. However, due to the inability to accurately predict the amount of water in subsurface storage, volumes of groundwater recharge estimated for the Tennessee River watershed were assumed to be the amount of available groundwater. Since aquifer recharge is a dynamic process, available groundwater is expressed in volume per unit time. Large quantities of groundwater, in excess of 1 million gallons per day (g/d), can be obtained from wells constructed in the Tuscumbia/Fort Payne aquifer if sufficient water-filled cavities are encountered (McGregor and others, 1997). However, the non-uniform distribution of fractures and/or solution channels and cavities makes the prediction of groundwater movement and occurrence extremely difficult.

The volume of available groundwater was calculated for each of the six geologic areas and for each 8-digit hydrologic unit code (HUC) area in the Tennessee River watershed. It was anticipated that unique lithologic and structural characteristics of each geologic area would influence the amount of recharge and ultimately the amount of available groundwater. Figure 14 shows the configuration of each geologic area, 8-digit HUC, assessed stream, and the location of each discharge monitoring station. The smallest amount of available groundwater in the Tennessee River watershed calculated from results of the WHAT program was 36.2 billion gallons per year (g/yr) (99.3 million g/d in geologic area 5 (fig. 14, table 3). Due to the relatively small size of area 5, discharge data were unavailable to estimate recharge or available groundwater. Therefore, average values from geologic areas 2, 3, 4, and 6 (areas with similar geologic formations) were assigned to area 5. Geologic area 2 has 53.8 billion g/yr (147.3 million g/d) (fig. 14, table 3). Geologic area 6 has 85.5 billion g/yr (234.1 million g/d) (fig. 14, table 3), geologic area 1 has 108.9 billion g/yr (298.4 million g/d) (fig. 14, table 3), geologic area 4 has 129.7 billion g/yr (355.4 million g/d) (fig. 14, table 3), and the largest amount was 304.0 billion g/yr (832.8 million g/d) in geologic area 3 (fig. 14, table 3).

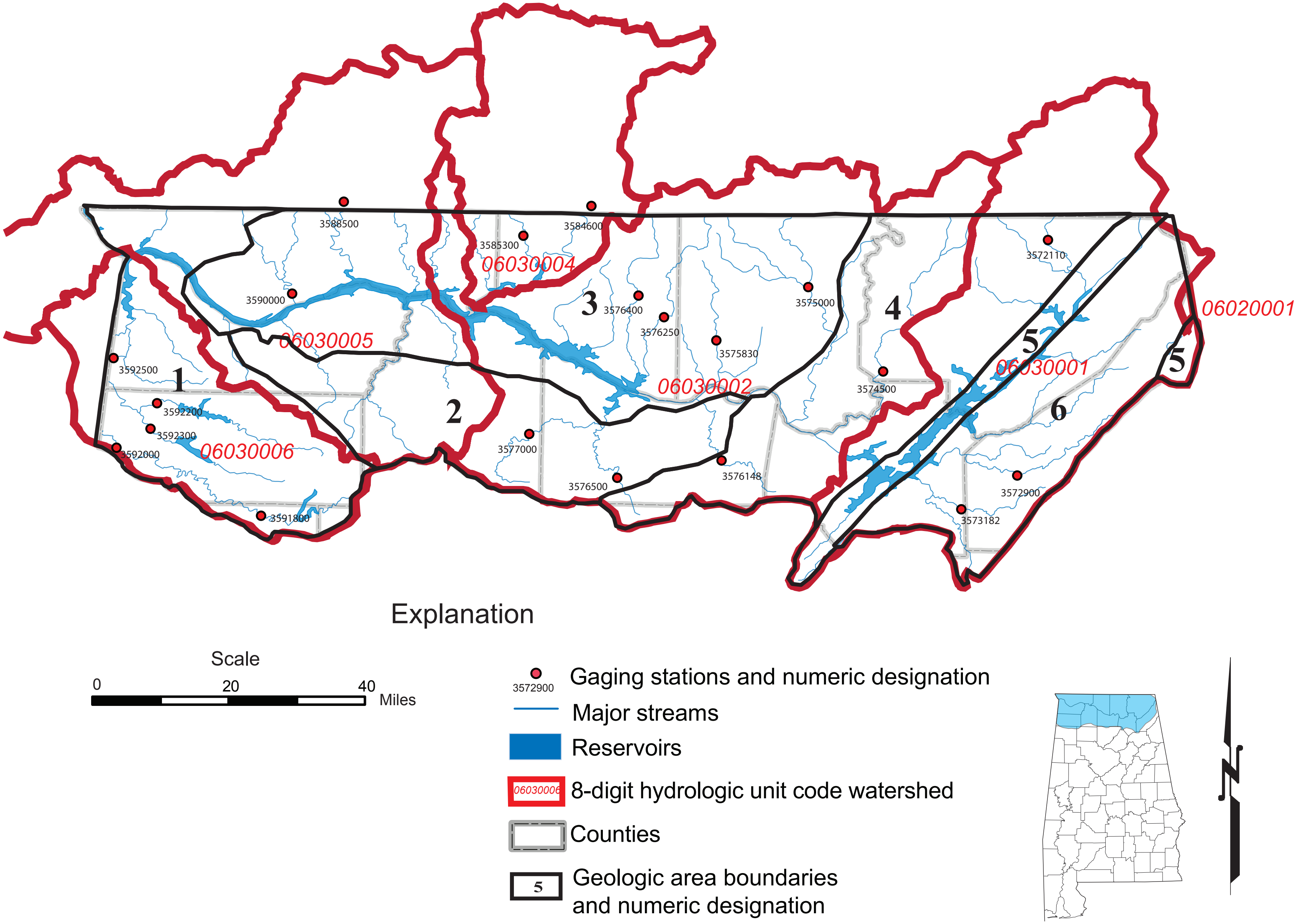


Figure 14.--Stream discharge measurement stations, 8-digit hydrologic unit code watersheds, and geologic areas in the Tennessee River watershed.

Table 3.—Available groundwater in the Tennessee River watershed.

Geologic area	Available groundwater			8-digit HUC	Available groundwater		
	Billion g/yr	Million g/d	Thousand g/d/mi^2		Billion g/yr	Million g/d	Thousand g/d/mi^2
1	108.9	298.4	265.2	06030001 (Lake Guntersville)	162.2	444.2	266.6
2	53.8	147.3	158.0	06030002 (Wheeler Lake)	233.6	639.9	240.9
3	304.0	832.8	376.2	06030004 (Lower Elk)	24.5	67.1	255.1
4	129.7	355.4	266.6	06030005 (Pickwick Lake)	154.2	422.4	296.6
5	36.2	99.3	262.0	06030006 (Bear)	75.4	206.6	265.2
6	85.5	234.1	266.6	06020001 (Middle Tennessee-Chickamauga)	4.8	13.1	267.4

Total groundwater available in the Tennessee River watershed based on geologic area is 718.1 billion g/yr (2.0 billion g/d). Available groundwater volumes estimated for 8-digit HUCs are shown in table 3. It should be noted that the estimate of total available groundwater based on geologic areas is about 8 percent larger than the estimate based on HUCs. This is due to groupings of gauged streams used to obtain average recharge values for geologic areas and for HUCs (fig. 14). The total groundwater availability for the Tennessee River watershed based on 8-digit HUCs is 654.6 billion g/yr (1.8 billion g/d). Normalization of data with respect to unit area in table 4 shows the significant variation of available groundwater caused by geology and topography (158,000 gallons per day per square mile (g/d/mi^2) for geologic area 2 to 376,200 g/d/mi^2 for geologic area 3) and the similarity of the data with respect to HUC that tends to negate the geologic impact (240,900 g/d/mi^2 for HUC 06030002 to 296,600 g/d/mi^2 for HUC 06030005).

As discussed previously, although the available groundwater volume estimated for the Tennessee River watershed is about 700 billion gallons per year (about 2.0 billion gallons per day), prediction of the location of this water in the subsurface with available hydrogeologic data and exploration techniques is difficult. There is a large body of information related to water well locations, driller's logs, geophysical logs, and well construction and testing data in the Tennessee River watershed. Although formal aquifer tests are usually not performed when production wells are installed, 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 (g/min/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 producibility. About 4,000 well records in the Tennessee River watershed were examined, of which 425 wells had adequate data to determine specific capacities (plate 2). Specific capacities varied from less than 1 to more than 1,000 g/min/ft of drawdown.

Plate 2 shows several trends related to the stratigraphy and geologic structure of the watershed. An eastward trend with a maximum specific capacity of more than 150 is observed along the Tennessee River in eastern Colbert, southern Lauderdale, and northern Morgan Counties (plate 2). Several northeast and southeast trends were observed in Limestone, Madison, and Morgan Counties with maximum specific capacities of more than 1,000 g/min/ft of drawdown (plate 2). These trends correlate with joint and fracture trends discussed previously in this report and may indicate areas for future test well drilling.

RECURRENCE INTERVAL ANALYSES OF GROUNDWATER RECHARGE

Calculations of recurrence intervals are used to evaluate the frequency of occurrence of many different events including flood, drought, and volumes of baseflow. Recurrence intervals are commonly referred to in terms of time as 2-, 5-,10-, 25-, 50-, or

100-year recurrence, which is interpreted as the occurrence of a particular magnitude event once every 2, 5, 10, 25, 50, or 100 years. However, a more accurate portrayal is by annual probability of occurrence, such as 50, 20, 10, 4, 2, or 1 percent chance that a particular magnitude event will occur in any year.

Figure 15 shows baseflow recurrence intervals for nine gauging stations in the Tennessee River watershed. Limited stream discharge data from gauging stations in the Tennessee River watershed prevented the determination of a 1 percent probability of occurrence and limited calculations of the 2 percent probability of occurrence to five stations. Recurrence interval analyses of baseflow data demonstrate impacts of climate on groundwater recharge (fig. 15). Baseflow volumes with a 2 percent chance of occurrence represent a dry year and with a 50 percent chance of occurrence represent a wet year. The average baseflow with a 2 percent chance of occurrence is 64 million g/d/mi^2, and the average baseflow with a 50 percent chance of occurrence is 162 million g/d/mi^2 (table 4, fig. 15).

SURFACE-WATER AVAILABILITY

Surface water is composed of precipitation that falls and moves along the land surface as overland runoff, enters water bodies directly as direct flow, or infiltrates into the subsurface and returns to the surface as baseflow (fig. 12). The volume of various surface-water sources is measured in streams as total discharge, which represents the total volume of available surface water (impounded waters were not considered in this assessment of surface-water availability). However, since direct measurements of discharge are not available for all streams in the project area, a method of estimation was selected to indirectly determine surface-water availability. The method chosen for this assessment was the unit discharge approach. Unit discharges for gauged streams were calculated as cubic feet per second per square mile of drainage area (cfs/mi^2) and applied to ungauged streams in areas of similar hydrogeology. Unit discharges were determined for the same streams used for the estimation of recharge rates and available groundwater (fig. 13). Unit discharge averages in each geologic area and HUC were used to calculate total surface-water availability (table 5). Total surface-water availability for the Tennessee River watershed is the sum of volumes of the six geologic areas plus Tennessee River discharge entering Alabama at the Tennessee state line (USGS gauging

Figure 15. --Baseflow recurrence curves for selected discharge measurement stations in theTennessee River watershed.

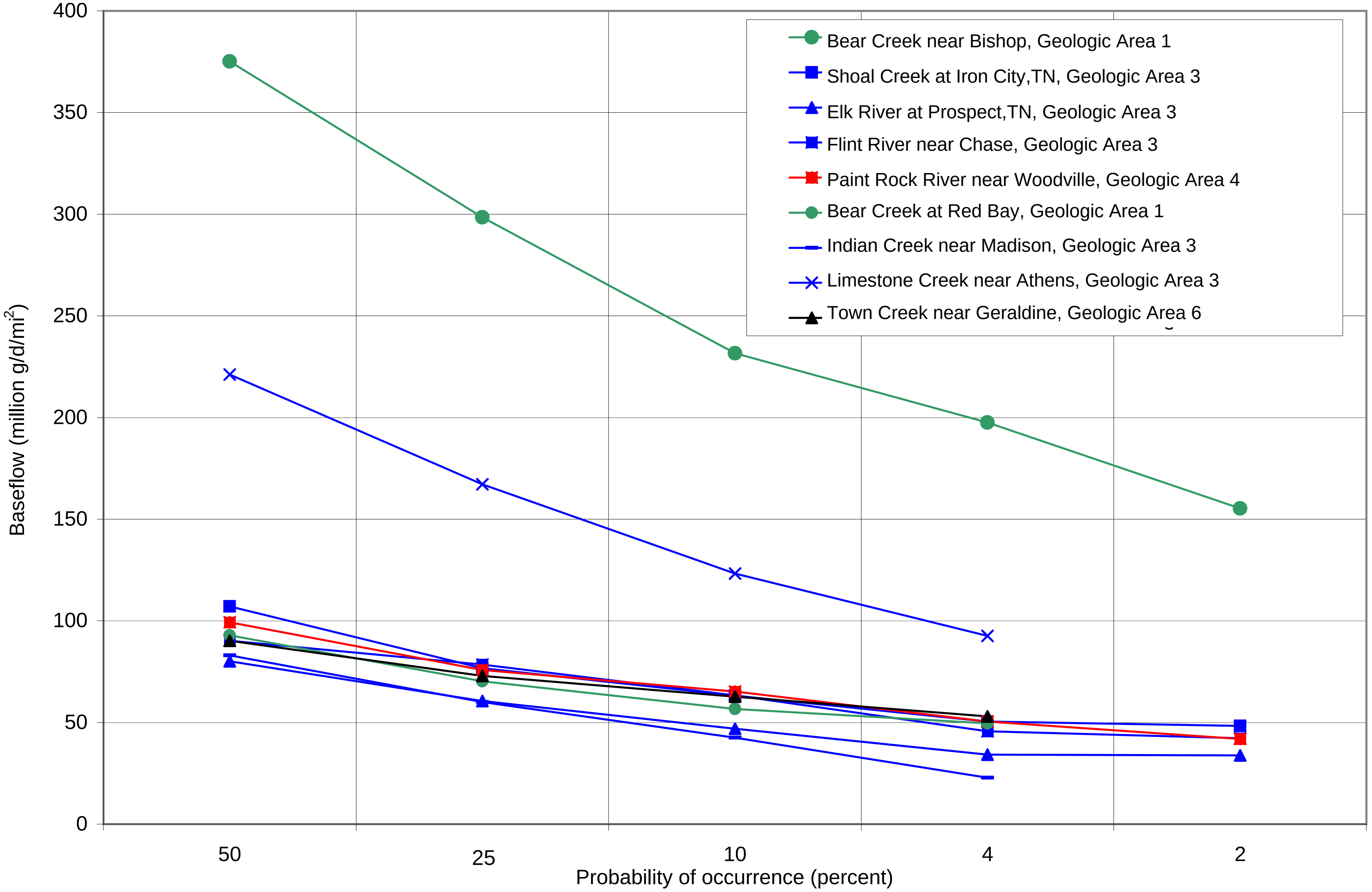


Table 4.—Probability of baseflow annual occurrence and volumes for evaluated sites in the Tennessee River watershed.

USGS discharge station name	Geologic area	Probability of annual occurrence (percent)				
		2	4	10	20	50
		Volume of baseflow (millions of g/d/mi^2)				
Bear Creek near Red Bay	1		50	57	70	93
Bear Creek near Bishop	1	155	198	232	299	375
Shoal Creek at Iron City	3	48	51	63	77	107
Flint River near Chase	3	42	46	63	78	90
Limestone Creek near Athens	3		93	123	167	221
Indian Creek near Madison	3		23	43	60	83
Elk River at Prospect, Tennessee	3	33	34	47	61	80
Paint Rock River near Woodville	4	42	51	65	76	88
Town Creek near Geraldine	6		53	63	73	90

station 03571850, Tennessee River at South Pittsburg, Tennessee). Daily discharge data were available for this site from 1930 to 1987 (USGS, 2008-2009).

Average unit discharges varied from 1.68 cfs/s/mi^2 for geologic area 3 to 2.08 cfs/mi^2 for geologic area 4 (table 5). Total surface water varied from 61.9 million cubic feet per day (ft^3/d) (0.5 billion g/d) for geologic area 5 to 321.4 million ft^3/d (2.4 billion g/d) for geologic area 3 (table 5). Due to the relatively small size of area 5, discharge data were unavailable. Therefore, the average discharge for the other five areas was assigned to area 5 (1.89 cfs/mi^2). Total surface-water availability for the six geologic areas is 1.09 billion ft^3/d (8.2 billion g/day) and average discharge for the Tennessee River entering Alabama is 3.3 billion ft^3/d (24.4 billion g/d). Therefore, total surface-water availability for the Tennessee River watershed based on geologic areas is 4.4 billion ft^3/d (32.6 billion g/d). The total surface-water availability for the Tennessee River watershed based on 8-digit HUCs is also 4.4 billion ft^3/d (32.6 billion g/d).

Table 5.—Available surface water in the Tennessee River watershed.

Geologic area	Unit discharge cfs/mi^2	Available surface water		8-digit HUC	Unit discharge cfs/mi^2	Available surface water	
		Million ft^3/d	Billion g/d			Million ft^3/d	Billion g/d
1	1.89	183.7	1.4	06030001 (Lake Guntersville)	1.96	282.1	2.1
2	1.72	134.8	1.0	06030002 (Wheeler Lake)	1.76	403.9	3.0
3	1.68	321.4	2.4	06030004 (Lower Elk)	1.68	38.2	0.3
4	2.08	239.6	1.8	06030005 (Pickwick Lake)	1.83	225.2	1.7
5	1.89	61.9	0.5	06030006 (Bear)	1.89	127.2	1.0
6	1.96	148.7	1.1	06020001 (Middle Tennessee-Chickamauga)	1.96	8.3	0.1

TOTAL WATER AVAILABILITY

Total average available water in the Tennessee River watershed in Alabama includes 2 billion g/d of groundwater, 24.4 billion g/d of surface water flowing into the state in the Tennessee River, and 8.2 billion g/d of surface water flowing into the Tennessee River in Alabama from tributaries, most of which originate in the state. Total water availability for the Tennessee River watershed in Alabama is 34.6 billion g/d.

SUMMARY OF FINDINGS

The Tennessee River watershed includes all or part of 15 counties in north Alabama and is contained in the Cumberland Plateau, Highland Rim, and East Gulf Coastal Plain physiographic sections. The area is underlain by clastic and calcareous geologic units ranging in age from Cambrian to Cretaceous. Topographic, hydrologic, and soil characteristics of the area are controlled, in large part, by the local and regional geologic structure and stratigraphy.

The Tennessee River watershed was divided into six geologic areas based on common stratigraphy, geologic structure, and hydrogeology. Groundwater recharge in much of the Tennessee River watershed is local. Numerous methods have been used for estimating recharge, including development of water budgets, measurement of seasonal changes in groundwater levels and flow velocities. However, equating average annual baseflow of streams to groundwater recharge is the most widely accepted method.

Separating runoff and baseflow from total stream discharge can be accomplished by several methods including (1) recession analysis (2) graphical hydrograph separation and (3) partitioning of stream flow using daily rainfall and stream discharge. More recently, a number of computer models have automated hydrograph separation techniques. Discharge data for 20 streams in the Tennessee River watershed with current or discontinued USGS discharge measurement stations were used in the recharge evaluation. Discharge data for each stream were analyzed using computer hydrograph separation programs and the Meyboom manual recession analysis method. Based on the general agreement between the Meyboom method and the WHAT program, values of baseflow estimated by the WHAT program were used to estimate volumes of groundwater recharge.

Results obtained during this study from the Meyboom recession analysis method and the WHAT program indicated estimated annual recharge to be 5.3 and 6.1 inches for geologic area 1, 2.3 and 3.4 inches for geologic area 2, 7.5 and 7.8 inches for geologic area 3, 4.6 and 6.7 inches for geologic area 4, and 4.8 and 6.4 inches for geologic area 6. Due to the relatively small size of area 5, discharge data were unavailable. However, all Paleozoic units in the other 5 geologic areas outcrop in geologic area 5. Therefore, the average of recharge values for the other five areas was assigned to area 5 (4.9 and 6.1 inches).

Groundwater availability in the Tennessee River watershed is generally defined as the total amount of groundwater of adequate quality stored in the subsurface. Total available groundwater in the Tennessee River watershed is more than 718 billion gallons per year or about 2 billion g/d.

Although the available groundwater volume estimated for the Tennessee River watershed is more than 718 billion gallons, prediction of the location of this water in the subsurface with available hydrogeologic data and exploration techniques is difficult. Analysis of specific capacity data from numerous wells in the area indicated several northeast and southeast trends in Limestone, Madison, and Morgan Counties with maximum specific capacities of more than 1,000 g/min/ft of drawdown. These trends exhibit a positive correlation with joint and fracture trends identified by previous investigations in north Alabama.

Calculations of recurrence intervals are used to evaluate the frequency of occurrence of many different events including flood, drought, and in this evaluation, volumes of baseflow. The average baseflow with a 2 percent chance of occurrence is 64 million g/d/mi^2, and the average baseflow with a 50 percent chance of occurrence is 162 million g/d/mi^2.

Surface water is composed of precipitation that falls and moves along the land surface as overland runoff, enters water bodies directly as direct flow, or infiltrates into the subsurface and returns to the surface as baseflow. The sum of all stream discharge in a specified area represents the total volume of available surface water (impounded waters were not considered in this assessment of surface-water availability). The method chosen for this assessment was the determination a unit discharge (cfs/s/mi^2) for gauged streams that was applied to ungauged streams in similar geographic and hydrogeologic areas. Unit discharges were determined for the same streams used for the estimation of recharge rates and available groundwater.

Unit discharge averages in each geologic area were used to calculate total surface-water availability. Total surface-water availability for the Tennessee River watershed is the sum of volumes of the 6 geologic areas plus Tennessee River discharge entering Alabama at the Tennessee state line. Total surface-water availability for the Tennessee River watershed based on geologic areas was determined to be 4.4 billion ft^3/d (32.6 billion g/d).

Total average available water in the Tennessee River watershed in Alabama is composed of 2 billion g/d of groundwater, 24.4 billion g/d of surface water flowing into the state in the Tennessee River, and 8.2 billion g/d of surface water flowing into the Tennessee River in Alabama from tributaries, most of which originates in the state. Total water availability for the Tennessee River watershed in Alabama is 34.6 billion gallons per day.

REFERENCES CITED

Baker, R. M., 2002, Dye trace investigations in the vicinity of Chapman Mountain, city of Huntsville, Alabama: Alabama Geological Survey open file report, 35 p.

Baker, R. M., Cook, M. R., Moss, N. E., Henderson, W. P., 2005, Discharge and water withdrawal assessment, Mountain Fork watershed, Madison County, Alabama: Geological Survey of Alabama Open-File Report 0527, 27 p.

Bossong, C. R., 1988, Geohydrology and susceptibility of major aquifers to surface contamination in Alabama: Area 2: U.S. Geological Survey Water Investigations Report 88-4177, 16 p.

Bossong, C. R., and Harris, W. F., 1987, Geohydrology and susceptibility of major aquifers to surface contamination in Alabama; Area 1: U.S. Geological Survey Water Investigations Report 87-4068, 23 p.

Chandler, R. V., and Moore, J. D., 1991, Fluorescent dye trace tests for storm water drainage wells in the Muscle Shoals area, Alabama, Final report: Alabama Geological Survey open file report, 305 p.

Cook, M. R., 1997, Origin and evolution of anomalous hydrogeochemical character of the Tuscaloosa aquifer system of west-central Alabama: University of Alabama unpublished Masters Thesis, 94 p.

Cook, M. R., 2004, Alternative water source assessment: An investigation of deep Cretaceous aquifers in southeast and south-central Alabama: Geological Survey of Alabama open file report, 43 p.

Copeland, C. W., Bolin, D. E., Doyle, F. L., Holler, D. P., Kidd, J. T., and Moser, P. H., 1975, Geology, in Geological Survey of Alabama, Environmental geology and hydrology, Huntsville and Madison County: Alabama, Alabama Geological Survey Atlas Series 8, 118 p.

Ebersole, S. M., 2008, Hydrologic Cycle in Alabama, Geological Survey of Alabama unpublished graphic.

Freeze, R. A., and Cherry, J. A., 1979, Groundwater: Englewood Cliffs, N. J., Prentiss-Hall, Inc., 604 p.

Fetter, C. W., 1994, Applied hydrogeology, Third Edition, New York, New York, Macmillan, Inc., 691 p.

Geological Survey of Alabama, 2006, Geologic map of Alabama, digital version 1.0: Alabama Geological Survey Special Map 220A [Adapted from Szabo, M. W., Osborne, W. E., Copeland, C. W., Jr., and Neathery, T. L., 1988, Geologic map of Alabama (1:250,000): Alabama Geological Survey Special Map 220].

Holler, D. P., 1975, Recognition and projection of the contact between the Mississippian Fort Payne Chert and Tuscumbia Limestone in Madison County, Alabama: University of Alabama, M.S. thesis, 76 p.

Jennings, S.P., and Cook, M. R., 2008, Summary results of test well drilling in the North-Central and New Market areas by the Madison County Water Department, Madison County, Alabama: Geological Survey of Alabama Open-File Report 0806, 23 p.

Johnston, D. D., 2008, Results of recession analysis using the PART model: Data from the Alabama Department of Economic Development Office of Water Resources.

Kidd, R. E., and Bossong, C. R., 1987, Application of the precipitation-runoff model in the Warrior coal field, Alabama: U.S. Geological Survey Water-Supply Paper 2306, 42 p.

Lim, J. K., Engle, B. A., Tang, Z., Choi, J., Kim, K., Muthucrishnan, S., and Tripathy, D., 2005, Automated web GIS based hydrograph analysis tool, WHAT: Journal of the American Water Resources Association, December edition, p. 1407-1416.

Malmberg, G. T., and Downing, H. T., 1957, Geology and ground-water resources of Madison County, Alabama: Alabama Geological Survey County Report 3, 225 p.

Mann, S. D., Raymond, D. E., and Baker, R. M., 1996, Documentation for a wellhead protection program; Madison County Water Department, Madison County, Alabama: Geological Survey of Alabama Open-File Report, 56 p.

Meyboom, P., 1961, Estimating groundwater recharge from stream hydrographs: Journal of Geophysical Research, v. 66, no. 4, p. 1203-1214.

McGregor, S. W., O’Neil, P. E., Rheams, K. F., Moser, P. H., and Blackwood, R., 1997, Biological, geological, and hydrological investigations in Bobcat, Matthews, and

Shelta Caves and other selected caves in north Alabama: Geological Survey of Alabama Bulletin 166, 198 p.

Nathan, R. J., and McMahan, T. A., 1990, Evaluation of automated techniques for baseflow and recession analysis: Water Resources Research, v. 26, no. 7, p. 1465-1473.

Osborne, W. E., Szabo, M. W., Copeland, C. W., Jr., and Neathery, T. L., 1989, Geologic map of Alabama, (1:500,000): Alabama Geological Survey Special Map 221.

Osborne, W. E., and Raymond, D. E., 1992, The Knox Group in the Appalachian fold-thrust belt and Black Warrior basin of Alabama: Stratigraphy and petroleum exploration: Geological Survey of Alabama Circular 162, 34 p.

Purdue University, 2004, WHAT-web-based hydrograph analysis tool, URL http://cobweb.ecn.purdue.edu/~what/ accessed numerous times in 2008 and 2009.

Raymond, D. E., Osborne, W. E., Copeland, C. W., and Neathery, T. L., 1988, Alabama stratigraphy: Geological Survey of Alabama Circular 140, 97 p.

Risser, D. W., Gburek, W. J., and Folmar, G. J., 2005, Comparison of methods for estimating ground-water recharge and baseflow at a small watershed underlain by fractured bedrock in the eastern United States: U.S. Geological Survey Water Scientific Investigations Report 2005-5038, 31 p.

Rutledge, A. T., 1998, Computer programs for describing the recession of ground-water discharge and for estimating mean ground-water recharge and discharge from streamflow records--Update: USGS Water Investigations Report 98-4148, 51 p.

Sapp, C. D., and Emplaincourt, Jacques, 1975, Physiographic regions of Alabama: Alabama Geological Survey Special Map 168.

Sellinger, C. E., 1996, Computer program for performing hydrograph separation using the rating curve method: National Oceanic and Atmospheric Administration Technical Memorandum ERL GLERL-100, 11 p.

Shirmohammadi, A., Knisel, W. G., and Sheridan, J. W., 1984, An approximate method for partitioning daily streamflow data: Journal of Hydrology, p. 335-354.

Southeast Regional Climate Center, 2009, Historical Climate Summaries for Alabama, URL http://www.sercc.net/climateinfo/historical/historical_al.html, accessed February 11, 2009.

Szabo, M. W., Osborne, W. E., Neathery, T. L., and Copeland, C. W., Jr., 1988, Geologic map of Alabama, (1:250,000): Alabama Geological Survey Special Map 220.

Thomas, W. A., 1972, Mississippian stratigraphy of Alabama: Geological Survey of Alabama Monograph 12, 121 p.

USGS, 2008, 2009, Real time water data for the nation, Alabama and Tennessee stream discharge data, URL http://waterdata.usgs.gov/usa/nwis/rt accessed numerous times during 2008 and 2009.

Zurawski, A., 1978, Summary appraisals of the nation's ground-water resources-Tennessee region: USGS Professional Paper 813-L, 35 p.

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