

Arkansas Water Plan 2014 Update

Appendix I Statewide Physical Environment Report



water resources / environmental consultants



ARKANSAS WATER PLAN UPDATE TASK 3: PHYSICAL DESCRIPTION OF THE STATE OF ARKANSAS

AUGUST 7, 2014

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1.0 INTRODUCTION

The Arkansas Natural Resources Commission (ANRC) is required by state law to prepare and update a statewide water resources planning document. The previous update of the Arkansas Water Plan (AWP) was completed in 1990. In 2012, ANRC initiated an update of the 1990 AWP, which will be completed in 2014. This document was prepared as part of the 2014 update of the AWP (Project Task 3).

This document provides a physical description of the State of Arkansas, and introduces the Water Resources Planning Regions that will be used in the 2014 AWP update. This overview of the state's physical environment will serve as background for updated discussion and analysis of state water supplies, water use and demand, and alternatives for managing water resources in Arkansas. It includes general descriptions of surface and groundwater resources and the associated physiology, geography, geology, ecoregions, climate, and land uses found within the state.

2.0 WATER RESOURCES PLANNING REGIONS

Large amounts of water are contained in both the surface water and aquifer systems in Arkansas. Both are renewable resources in that they are sustained by the abundant precipitation that falls on the surface of the state. Aquifer systems are areas of permeable rock underground that contain groundwater. Surface waters flow through rivers and streams and are contained in the lakes and reservoirs of the state. A watershed is an area of land where all of the surface water that runs over it drains to the same point. Watersheds can range in size to cross national, state, or county boundaries. For purposes of this AWP update, the state has been divided into five Water Resources Planning Regions (Planning Regions) based largely on watershed boundaries within the state.

The Planning Regions used for this AWP update (Figure 2.1) are similar to the ones used in the 1990 AWP. In large part, each of these regions shares environmental, economic, and social characteristics that differ from those of the other Planning Regions. The boundaries of the Planning Regions are primarily defined by the drainage basins of the principal rivers flowing through the state, as well as other physical features. In the majority of cases, the Planning Region boundaries were created by modifying basin boundaries to follow county boundaries, to facilitate the use of data (e.g., economic, census, and water use data) aggregated at the county level.

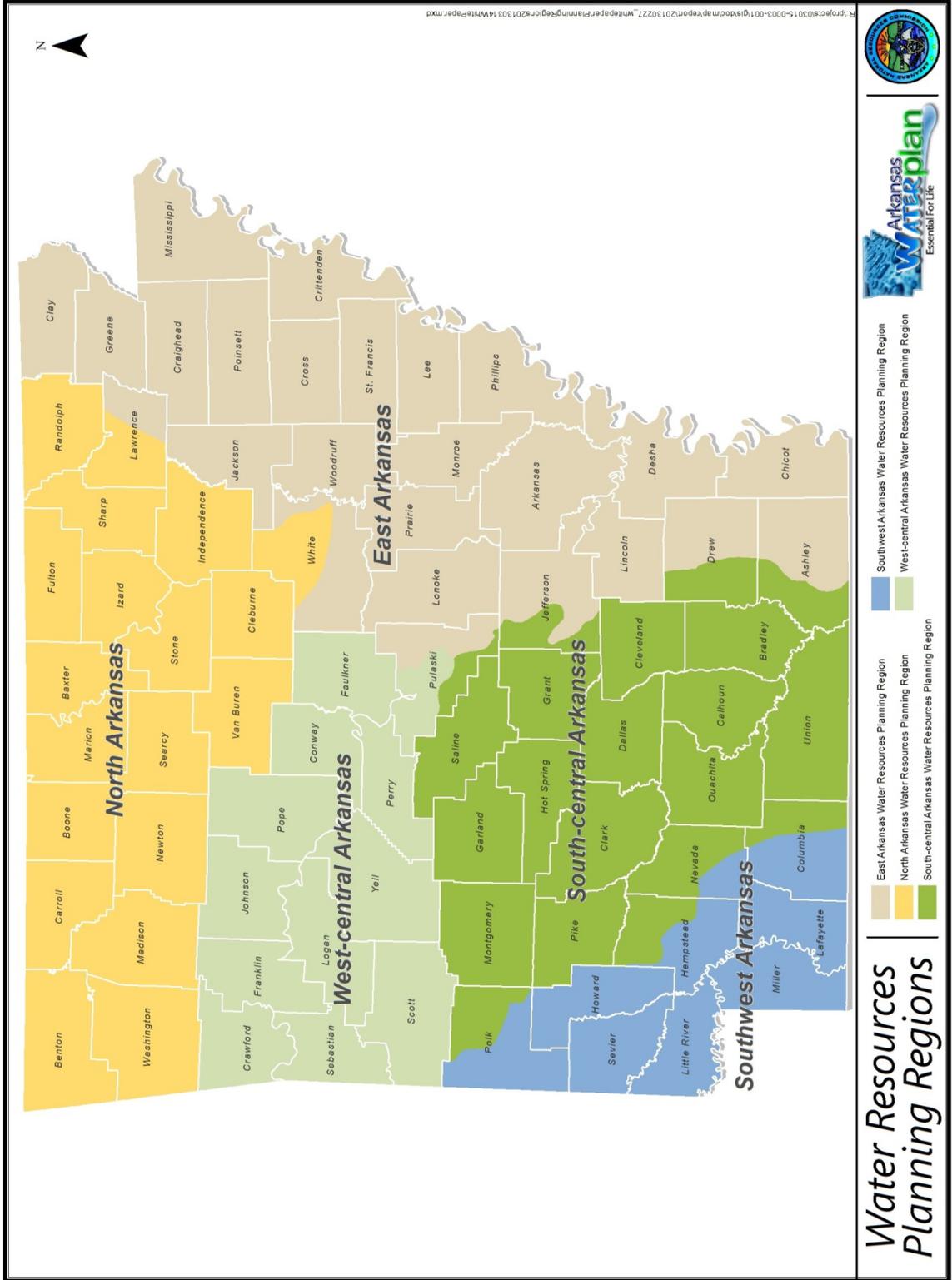


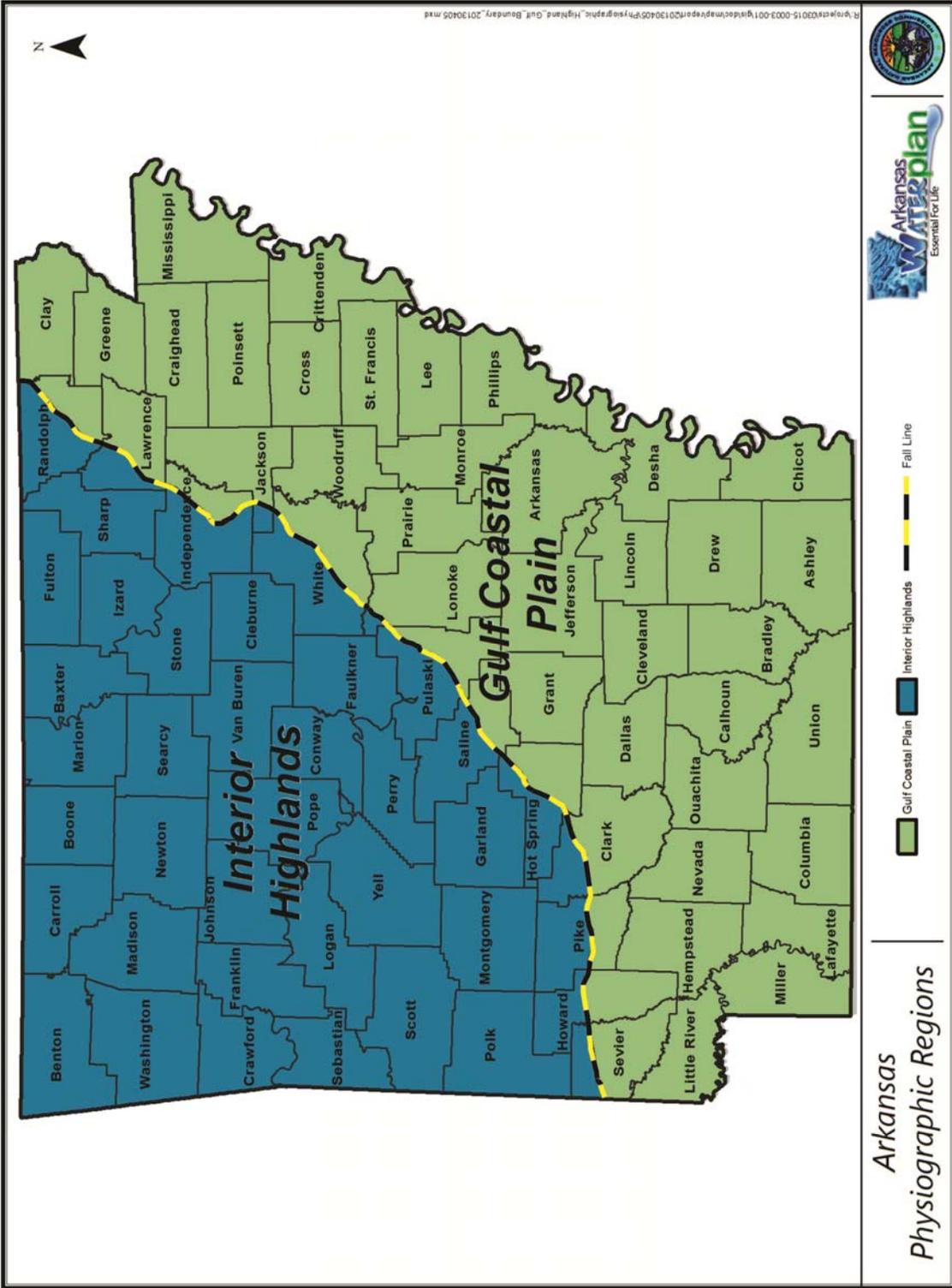
Figure 2.1. Arkansas Water Resources Planning Regions.

3.0 LANDFORMS AND GEOLOGY

Arkansas is divided into two major geophysical regions. These regions are the Interior Highlands of northern Arkansas, which generally consist of consolidated Paleozoic Era formations (ranging in age from Cambrian through Pennsylvanian), and the largely unconsolidated Mesozoic Era (Cretaceous age) and Cenozoic Era (Tertiary and Quaternary age) formations of the Coastal Plain of the southern and eastern regions (Figure 3.1). These two major geophysical regions are separated by the “fall line” which generally is defined in geologic terms as the contact of the consolidated Paleozoic formations with the unconsolidated formations of the Cretaceous, Tertiary, and Quaternary systems. These major subdivisions are further divided into smaller geophysical units based on geologic and topographic characteristics, as shown in Table 3.1.

Table 3.1 Geophysical regions of Arkansas.

Major Division	Province	Section
Interior Highlands	Ozark Plateaus	Salem Plateau
		Springfield Plateau
		Boston Mountains
	Ouachita Mountains	Arkansas Valley
		Fourche Mountains
		Central Ouachita Mountains
		Athens Plateau
Coastal Plain	Gulf Coastal Plain	Mississippi River Alluvial Plain
		West Gulf Coastal Plain



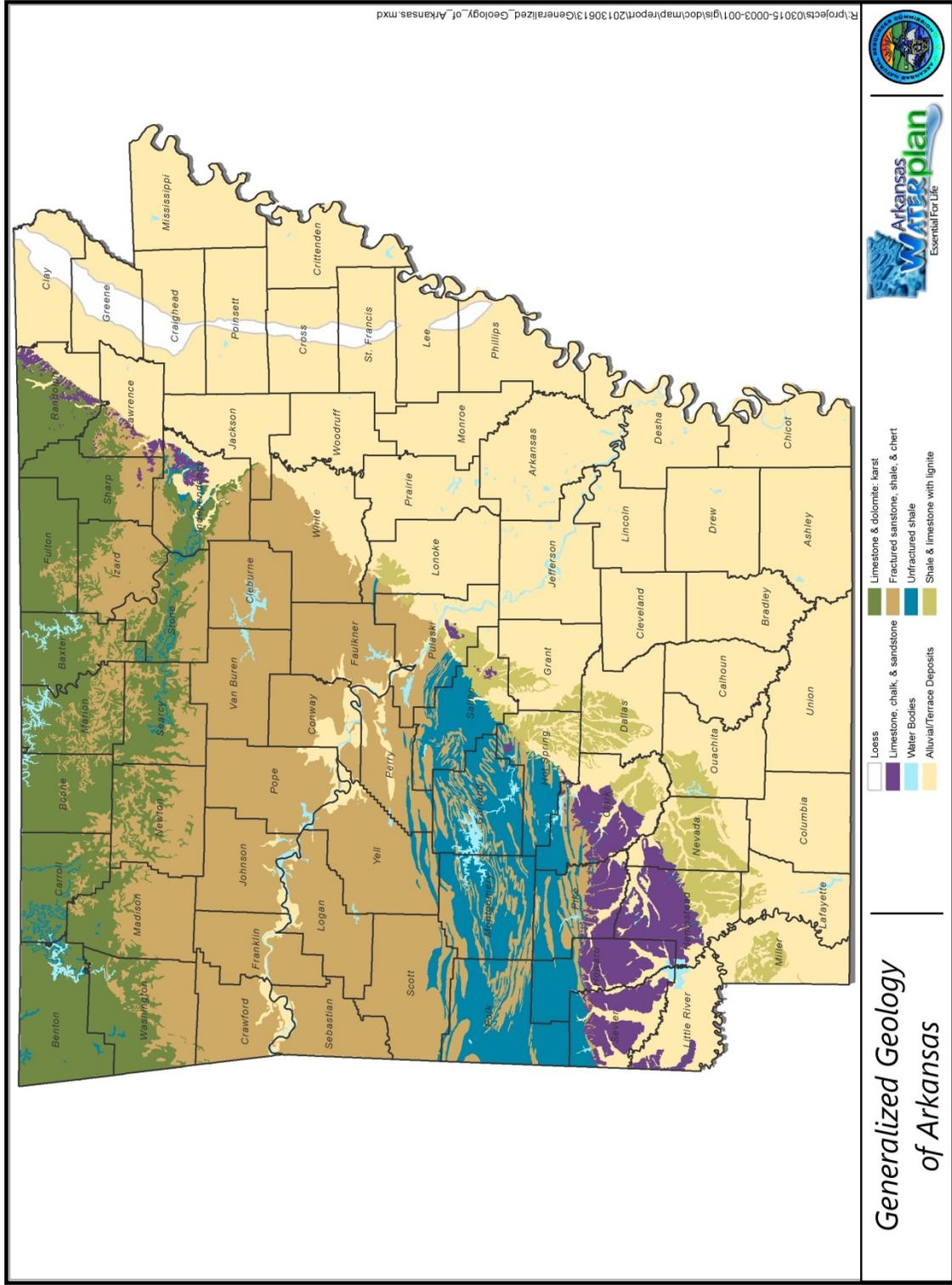
DRAFT Figure 3.1. Major physiographic regions (Foti 2008).

3.1 Interior Highlands

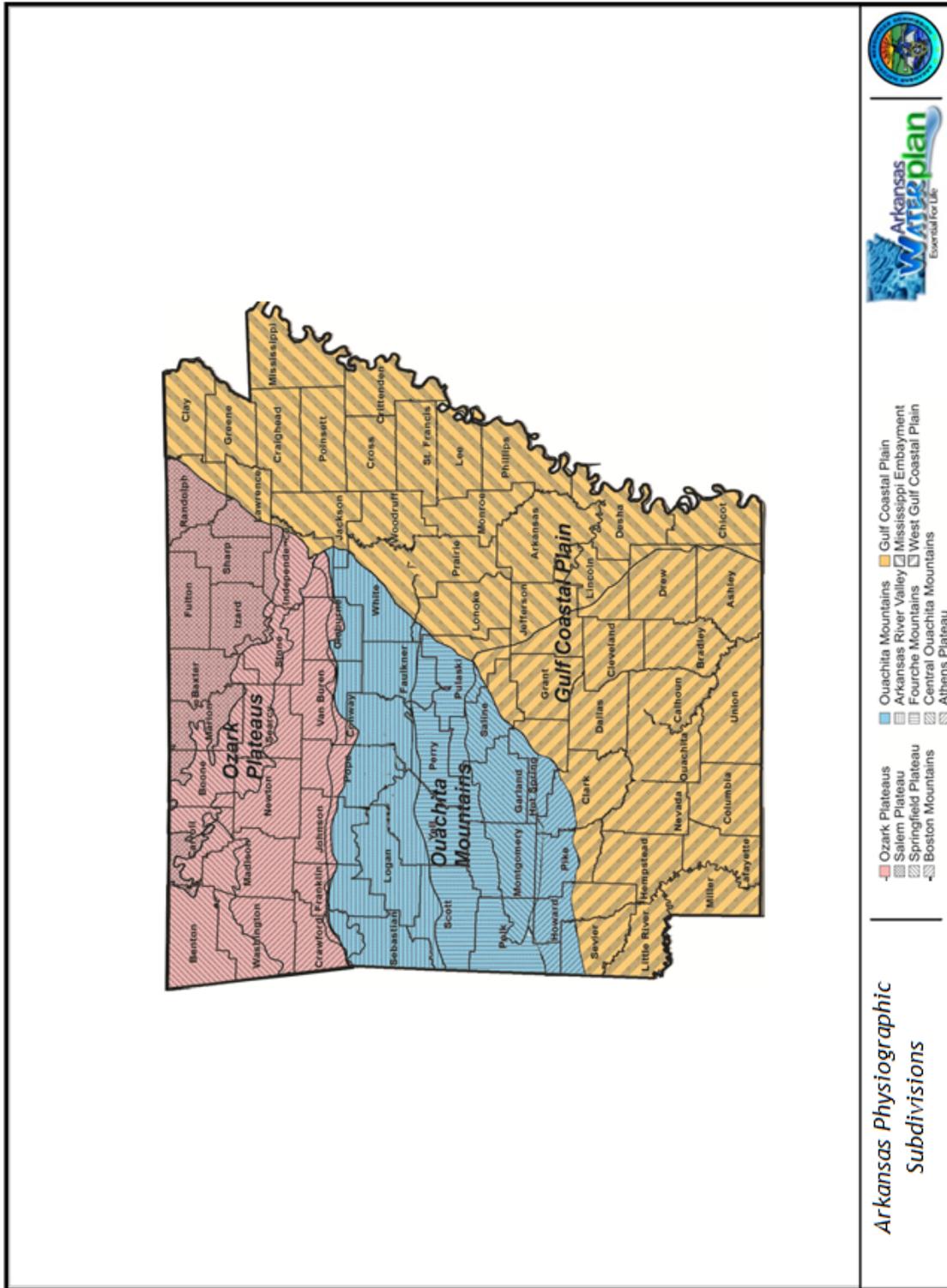
The Interior Highlands are underlain by thick sequences of consolidated Paleozoic age rocks (Figure 3.2) consisting of sandstone, shale, chert, novaculite, limestone, and dolostone. A thin drape of younger unconsolidated clays, sands, and gravel (i.e. alluvium) is often found in valley floors and associated with the streams and rivers. The Interior highlands are characterized by hilly to mountainous terrain (Foti 2008), where elevations range from 250 to 2,753 feet above sea level. Rivers and streams in this physiographic region tend to be relatively fast-moving, with steep slopes. Water from rainfall runs off quickly, which can result in flash flooding that usually lasts less than one day. The hilly terrain is suitable for construction of large reservoirs.

The Interior Highlands is further divided into two areas of nearly equal size. To the north are the Ozark plateaus, and to the south is the Ouachita province (Figure 3.3). Between them flows the Arkansas River, through a wide valley included in the Ouachita subdivision. In this Arkansas River Valley stand the highest and most impressive peaks of the state—Nebo, Petit Jean and Magazine.

Generally, the hydrogeology of the Interior Highlands can be described as an area of consolidated formations which yield relatively low volumes of water to wells. However, with respect to surface water supplies, the topography of the area is especially conducive to the development of lakes. In general, if a quantity of water over 35 gallons per minute is needed, the potential user should develop surface water supplies.



DRAFT Figure 3.2. General Arkansas geology (ANRC 2013).



Draft Figure 3.3. Arkansas physiographic subdivisions.

3.1.1 Ozark Plateaus Province

The Ozark Plateaus province (Figure 3.3) (also known as the Ozark Mountains) is a thoroughly dissected area with steep valley walls and narrow floors, although some plains occur. The geology of the Ozark Plateau province is characterized by consolidated sedimentary rock deposited mostly by shallow marine seas from the Ordovician through the Pennsylvanian period. This rock has undergone massive uplift but remains relatively horizontal with only minor deformations. The Ozark Plateaus cover northern Arkansas and extend into eastern Oklahoma and to the Missouri River to the north. This region is divided into three broad plateau surfaces based on elevation and age of surface rocks – the Salem and Springfield plateaus and the Boston Mountains.

3.1.1.1 Salem Plateau

The Salem Plateau is located mainly north and east of the White River in Arkansas. This is the lowest plateau surface in the Ozark Plateaus; elevations are generally 500 to 1,000 feet above sea level. Streams are gradually dissecting the broad uplands and the area is undulating to hilly, relief seldom exceeding 200 feet.

The Salem Plateau contains the oldest rock at the surface – Ordovician dolostone, sandstone and limestone –younger ones having been removed by erosion. The surface rocks are predominantly dolomite and limestone with some sandstone and shale. The Cotter dolomite of Lower Ordovician age, a massive formation 500 feet thick, covers most of the eastern and northern portions of this region. The Everton Limestone is the prominent formation in the western and southern areas. The Calico Rock Sandstone, a white colored sand, is at the base of the Everton.

Dolomite and silica-rich sand are quarried in this area. The former zinc-producing area of Arkansas was centered in the Ordovician rocks of Marion County, but zinc was mined in numerous other areas, where the same strata were exposed by stream cutting. Some lead is associated with the zinc deposits.

3.1.1.2 Springfield Plateau

The Springfield Plateau is found in northwestern Arkansas and in a narrow belt eastward. Elevations generally are from 1,000 to 1,500 feet above sea level. Extensive relatively level areas exist in Washington and Benton counties but relief of 200 to 300 feet occurs along major streams. Outliers of the Boston Mountains appear as isolated low mountains on the Plateau, the most notable being the Boat Mountain group near Harrison.

The Springfield Plateau is underlain by mostly Mississippian age limestone and chert from the Boone Formation. The limestone has undergone weathering, leaving large pieces of chert, which are especially prominent on hillsides where finer material have eroded away. The limestone is quarried in many locations. The St. Joe limestone member is at the base of the Boone Formation and is locally quarried for commercial purposes. The St. Joe Member is also the source rock for the majority of springs flowing in the Springfield Plateau.

Outliers of the Boston Mountains are especially common in the western part of the region. They consist largely of sandstone and shale found in the Boston Mountains but lack the Atoka formation which caps the Boston Mountains.

3.1.1.3 Boston Mountains

The Boston Mountains are the higher southern edge of the Ozarks. The mountains are primarily flat-topped summit ridges, representing the original erosion surface of the plateaus. Great stream dissection has occurred, creating steep sided mountains and deep narrow valleys. Elevations generally range between 1,500 and 2,200 feet above sea level but exceed 2,500 feet above sea level. Relief is mainly within the 500 to 1,000 feet range but exceeds 1,600 feet. The northern boundary is well marked by a retreating escarpment in most areas, being especially prominent in its central extent from Jasper to Mountain View. On the south, the mountains descend rather sharply to the Arkansas Valley.

The Boston Mountains lie adjacent to and south of the Springfield Plateau and contain the youngest rock at the surface – early Pennsylvanian sandstones and shale with minor limestone. They are capped by Pennsylvanian sandstone, which has been removed from the areas to the

north. The massive Atoka Formation, over 1,500 feet thick, is the most prominent geologic formation. The Atoka sandstone forms the bluffs at the top of the Boston Mountains.

3.1.2 Ouachita Mountain Province

The Ouachita Mountain province includes the Arkansas River Valley, and the Fourche Mountains, Central Ouachita Mountains, and Athens Plateau. The Arkansas River Valley is a low-lying region surrounding the valley of the Arkansas River and its major tributaries. The mountain ridges are separated by broad valleys. Once flat-lying, Pennsylvanian age sedimentary rocks (sandstone and shale) have been compressed into well developed east-west trending open folds (anticlines and synclines) and faults, which gradually diminish northward into the Ozark Plateaus. Erosional processes left the synclines as mountains and the anticlines as valleys.

The Fourche Mountains, Central Ouachita Mountains, and Athens Plateau are made of sedimentary rock folded to create generally parallel ridges and valleys which have an east-west orientation. Most of the mountain ridges are narrow, with steep slopes; crests tend to be sharp; valleys are generally rather broad. The Fourche Mountains, Central Ouachita Mountains, and Athens Plateau are distinguished largely by the spacing of the folds.

3.1.2.1 Arkansas River Valley

The Arkansas River Valley is from thirty to forty miles wide and the Arkansas River traverses it from northwest to southeast. The ridges are widely spaced, with valleys dominating. Elevations of valleys generally are 500 feet above sea level, declining eastward. Mt. Magazine, elevation 2,823 feet above sea level, and the highest point in the state, is in the Arkansas River Valley, as are Mount Nebo and Petit Jean Mountain. These prominent “mountains” are known by geologists as monadnocks, isolated, prominent hills, often formed by fluvial erosion, and generally found in a flat plain.

The western part of the Arkansas River Valley is composed of the Savanna Sandstone, Paris Shale, Spadra Shale, and Harthshorne Sandstone is all significant. Coal is important in the Paris and Spadra Shale. There are numerous natural gas fields in this region, producing a dry gas. The central and eastern portions of the valley are dominated by the alternating sandstone

and shale of the Hartshorne and Atoka Formation. The Arkansas River Valley is blanketed with alluvium consisting of clay, sand and gravel ranging in thickness from 60 feet in the western portion of the State, to slightly over 100 feet where the valley opens into the Mississippi Embayment near Little Rock. The Arkansas River Valley is bordered on the north and south by consolidated formations of the Ouachita Mountains.

3.1.2.2 Fourche Mountains

Fourche Mountains contain several major ridges and is a dominant geophysical feature in western Arkansas. The crest of Rich Mountain is 2,500 feet above sea level, while Fourche and Poteau mountains are a little lower. The folding is closer than in the Arkansas River Valley, but valley floors are broad and often of considerable elevation, around Mena reaching 1,100 feet above sea level at the center. The Jackfork Sandstone forms the major mountain ridges. The Stanley Shale is the most widespread formation.

3.1.2.3 Central Ouachita Mountains

The Central Ouachitas are very closely folded ridges and valleys. Some principal mountains are the Caddo, Cossatot, Trap, Crystal, and Zigzag. Elevations of 2,000 feet above sea level are common toward the center and the west, and local relief is between 300 and 900 feet. The Central Ouachitas consist of Ordovician and Silurian sandstone and shale. Two prominent formations are the Crystal Mountain sandstone which is overlain by the Mazarn shale. Arkansas novaculite is exposed along the outer edge of the Central Ouachitas, sometimes referred to as the Novaculite Uplift. The novaculite is Devonian in age and is situated below the Hot Springs sandstone. It is a very hard, fine-grained silica-rich rock, which has been broken by the folding of the Ouachita Mountains.

3.1.2.4 Athens Plateau

The Athens Plateau is a dominant range geophysical feature of western Arkansas. It is a very narrow belt extending along the southern edge of the Ouachita Mountains. The Athens Plateau Elevation is little above 500 feet above sea level and it has an undulating

appearance. Occasional hills are remnants of an older surface. The Jackfork Sandstone is particularly important in the major mountain ridges. The Stanley Shale is the most widespread formation.

3.2 Gulf Coastal Plain

The Gulf Coastal Plain of eastern and southern Arkansas generally consists of unconsolidated sands, clays, marls, and gravels. Lignite is also located within the strata of these regions. Geologic formations comprising the Gulf Coastal Plain in Arkansas are contained within the Mississippi Embayment which is a low lying basin that is filled with Cretaceous age to recent sediments. These formations consists mainly of a thick sequence of sand, silt, and clay, with local occurrences of limestone, chalk, and lignite, that are exposed at the surface in bands of varying width that roughly parallel the fall line before dipping gently beneath the surface to the south and southeast. The bands are several thousand feet thick at the Arkansas-Louisiana state line. Alluvial deposits blanket much of eastern Arkansas, the Red River Valley, and the Ouachita River Valley. The alluvium can be 250 feet thick and is composed of coarse sand and gravel at the base grading upward to silt and clay at the surface. Fresh groundwater in the Mississippi embayment can be found in alternating formations of sand, silt and clay and in alluvial deposits, which provide significant sources of water supply.

The hydrogeology of the Gulf Coastal Plain can be described as layers of unconsolidated silt, sand, and gravel which function as aquifers, yielding large quantities of water to wells. These aquifers are separated by clays which store greater volumes of water but have relatively low hydraulic conductivity, and therefore do not yield adequate volumes of water to wells.

The Gulf Coastal Plain is most commonly divided into the Western Gulf Coastal Plain and the Mississippi River Alluvial Plain of eastern and southern Arkansas. (Figure 3.3). The western portion of the Gulf Coastal Plain—the West Gulf Coastal Plain—extends across southern Arkansas. The eastern boundary of the West Gulf Coastal Plain is approximately the Arkansas River as it extends from Little Rock (Pulaski County) to Pine Bluff (Jefferson County), and then Bayou Bartholomew from Pine Bluff to the Louisiana border. These two waterways

separate the West Gulf Coastal Plain from the relatively recent stream deposits of the Mississippi River Alluvial Plain.

3.2.1 West Gulf Coastal Plain

The West Gulf Coastal Plain stands between 100 and 500 feet above sea level. It has a gently rolling surface, only moderately dissected by streams. Much of the surface material is unconsolidated sands deposited in the sea which once covered the area. Some areas in the West Gulf Coastal Plain are interrupted by the more recent alluvial deposits of the major rivers such as the Saline, Ouachita, and Red.

Generally, the surface materials are unconsolidated to semi-consolidated sand and clay. Scattered deposits of lignite are found also, especially in the Wilcox Group. The Midway Group contains some semi-consolidated white limestone. The bauxite deposits of Pulaski and Saline counties occur in this surface area while the oil and gas deposits of South Arkansas are in older and much deeper formations below the Coastal Plain.

Scattered Cretaceous formations occupy the inner edge of the West Gulf Coastal Plain from the Oklahoma line to Clark County. Most of the beds are coarse sand, clay, or gravel. The lowermost formation is the Trinity Group which also contains gypsum. The Tokio and Ozan Formations represent the middle Cretaceous and contain some lignite; and the upper Cretaceous is represented by the Brownstown marl which is fossiliferous, calcareous clay, and the Nacatoch Sand.

3.2.2 Mississippi River Alluvial Plain

The Mississippi River Alluvial Plain in eastern Arkansas is generally flat, with local relief of less than 100 feet. Elevations range from 500 to 100 feet above sea level, decreasing southward. Recent alluvium and terrace deposits cover much of the lowlands in the southeastern half of the state. The recent alluvium has been deposited by flood waters of the streams and consists of a variety of water-washed material, especially clay, silt, sand, and gravel. The terrace deposits are frequently older, often Pleistocene, representing former levels of bottomland below which streams have now cut.

Crowley's Ridge is a striking irregularity in the alluvial plain. It is 3 to 12 miles wide, rising 200 feet above the plain in the north and 100 feet in the south. It has a deep cover of loess, fine wind-deposited material, and is dissected into a rolling hill region. The outcropping edge of Crowley's Ridge is surfaced with the outcropping formations of the Claiborne and Wilcox Groups. Loess caps the higher portions of Crowley's Ridge. Loess is a fine, wind-blown silt derived from the alluvial deposits to the west of the ridge.

The Tertiary formations of Crowley's Ridge basically act as a barrier to flow in the alluvial aquifer from the east side of the ridge to the west side. The exception to this constraint is found in certain areas such as Poinsett County where the Memphis Sand sub crops beneath the silt and loess deposits of the ridge. Here the Memphis aquifer may act as a conduit through the ridge allowing for some induced flow from the east side where the aquifer transmissivity is higher, and recharge from the Mississippi River is available. However, the amount of clay in the Memphis Sand in this area is uncertain and the flow through the ridge is not easily quantified.

4.0 ECOREGIONS

An ecoregion is an area containing generally similar ecosystems, as well as type, quality, and quantity of environmental resources (EPA 2013). The US Environmental Protection Agency (EPA) has defined seven ecoregions within Arkansas (Figure 4.1). Characteristics of each ecoregion are summarized in Table 4.1. There are four ecoregions within the Interior Highlands: the Ozark Highlands, Boston Mountains, Arkansas Valley, and Ouachita Mountains. There are three ecoregions within the Gulf Coastal Plain: the South-Central Plains, the Mississippi Alluvial Plain, and the Mississippi Valley Loess Plains. These ecoregions represent a diverse range of habitats, from alpine meadows and mountain streams to bottomland hardwood swamps. Within these ecoregions, the Arkansas Game and Fish Commission has further classified 47 different land habitats within Arkansas (Anderson 2006). These habitats support a large number of plant and animal species, such that in 2002, Arkansas was ranked as the 19th most biodiverse state in the United States (Stein 2002).

Table 4.1. Characteristics of Arkansas ecoregions (Woods, et al. 2004, Fulmer and Harp 1977, Foti 2008, Stroud 2011, Stroud 2012, Anderson 2006).

Ecoregion	Biodiversity	Native Vegetation	Fisheries	Other	Planning Regions
Ozark Highlands	High	Forest dominated by oak and hickory, and savannas and tallgrass prairies.	Streams are often spring-fed, have moderate to steep gradients with gravelly substrates; fish communities have large numbers of sensitive species and diverse minnow populations.	Karst geologic features	North
Boston Mountains	High	Oak-hickory forest, oak-pine woodland, oak-hickory-pine forest, and savanna.	Streams have moderate gradients with substrates of gravel, rubble, boulders, or bedrock; fish communities are primarily sensitive species, including darters, minnows, and sunfishes.		North, West-central
Arkansas Valley	High	Mix of woodland, forest, savanna, and prairie in the uplands, bottomland hardwoods in the bottomlands. Oak-hickory forest and oak-hickory-pine forest are the most common forest communities.	Large numbers of sensitive species, such as sunfish, minnows, darters, catfishes (madtoms) common.	Floodplains, terraces, hills, plains, and scattered mountains	North, West-central, East
Ouachita Mountains	High	Overall, oak-hickory-pine forest is the dominant natural vegetation; magnolia and sugar maple occur on north slopes and short-leaf pine on south slopes.	Streams have steep gradients, and substrates are made up of gravel, cobbles, boulders, or bedrock; fish communities are dominated by sensitive species.	Steep east to west trending ridges, result in primarily north and south-facing slopes	West-central, Southwest, South-central
South-Central Plains	Moderate	Oak-hickory-pine forest on drier uplands, bottomland hardwood in floodplains, pine flatwoods on river terraces, blackland prairie.	Streams have low gradients; fish communities often have sensitive species present, but not to a large degree.		Southwest, South-central, East
Mississippi Alluvial Plain	Low	Bottomland hardwood, prairie.	Streams have very low gradients and fine-grained substrates; fish communities have few or no sensitive species.	Important for support of migrating birds	North, West-central, East
Mississippi Valley Loess Plains	Moderate	Oak-hickory forest mixed with areas of beech-maple forest similar to those present in the Appalachian Mountains, including tulip poplar.	Headwater streams are shallow with steep gradients and fine substrates; fish communities are dominated by headwater species.		East

5.0 AQUATIC BIODIVERSITY

Arkansas ranks in the nation's top tier in natural aquatic biodiversity. Arkansas is in the top ten states with greatest biodiversity of freshwater fish (NatureServe 2002). Almost 200 native fish species occur in Arkansas, 74 native species of mussel, and nearly 60 native crayfish (Robison and Buchanan 1988, Jones-Shulz 2009, Wagner 2011). There are a number of aquatic and semi-aquatic species that occur only in Arkansas, i.e., endemic species. Endemic species that have been identified include 3 mussels, 15 crayfish, 2 mayflies, 5 caddisflies, 8 stoneflies, and 5 fishes (Robison and Allen 1995). These species are sensitive to changes in water levels, flow regime, and water quality.

Arkansas lakes, rivers, and wetlands also support a large number of nesting and migrating birds. Nesting birds that utilize Arkansas waterbodies include common species such as egrets, herons, kingfishers, and wood duck, and rarer species such as Bald Eagle, Osprey, and King Rail. The very rare Ivory-billed Woodpecker is believed by many to live in wetlands in east Arkansas. Arkansas is located in the Mississippi Flyway. Large numbers of migratory waterfowl and shorebirds move through Arkansas in the spring and fall, and significant numbers make Arkansas their winter home. Bird species that migrate through the state include plovers, sandpipers, gulls, terns, pelicans, and cormorants. Eastern Arkansas hosts one of the world's largest wintering populations of mallard ducks every year, and is considered the most important wintering area for these birds in North America. Over a dozen duck species winter in Arkansas, as well as geese, loon, cormorant, and gull species (White 2010, 2011).

6.0 CLIMATE

Strongly influenced by the Gulf of Mexico, the climate of Arkansas is humid sub-tropical and is characterized by long summers, relatively short winters, and wide range in temperatures. Temperature, precipitation, and evaporation data for the state were obtained from the National Weather Service, Oceanic and Atmospheric Administration National Climatic Data Center (NOAA NCDC) and the Prism Climate Group and reviewed. Summaries of these data are presented below, along with discussions of factors that influence Arkansas' climate and long-term climate trends in the state.

6.1 Temperature

Average annual temperatures vary little over the state. The greatest regional temperature differences are seen in the winter, when the northwest is typically cooler than the southeast (NOAA NCDC 2013b). Normal monthly high and low temperatures for the state are shown on Figure 6.1. Extremes in temperature can vary from winter lows around zero degrees Fahrenheit (°F) to summer highs above 100 °F. Summers can exhibit extended periods of very warm to hot temperatures. The average growing season ranges from 180 days in the northwest to more than 230 days in the southeast (NOAA NCDC 2013b).

6.2 Precipitation

Average precipitation in the state ranges from 43 to 69 inches per year (Figure 6.2). The highest annual rainfalls occur in the Ouachita Mountains. The driest area of the state is the north, in the Ozark Highlands (Buckner 2011). Late spring (May) and late fall (November) are typically the wettest months, while August is typically the driest month (Figure 6.3). Although the state receives precipitation throughout the year, droughts of short duration are frequent and are accentuated by high evaporation rates during the growing season (Figure 6.3).

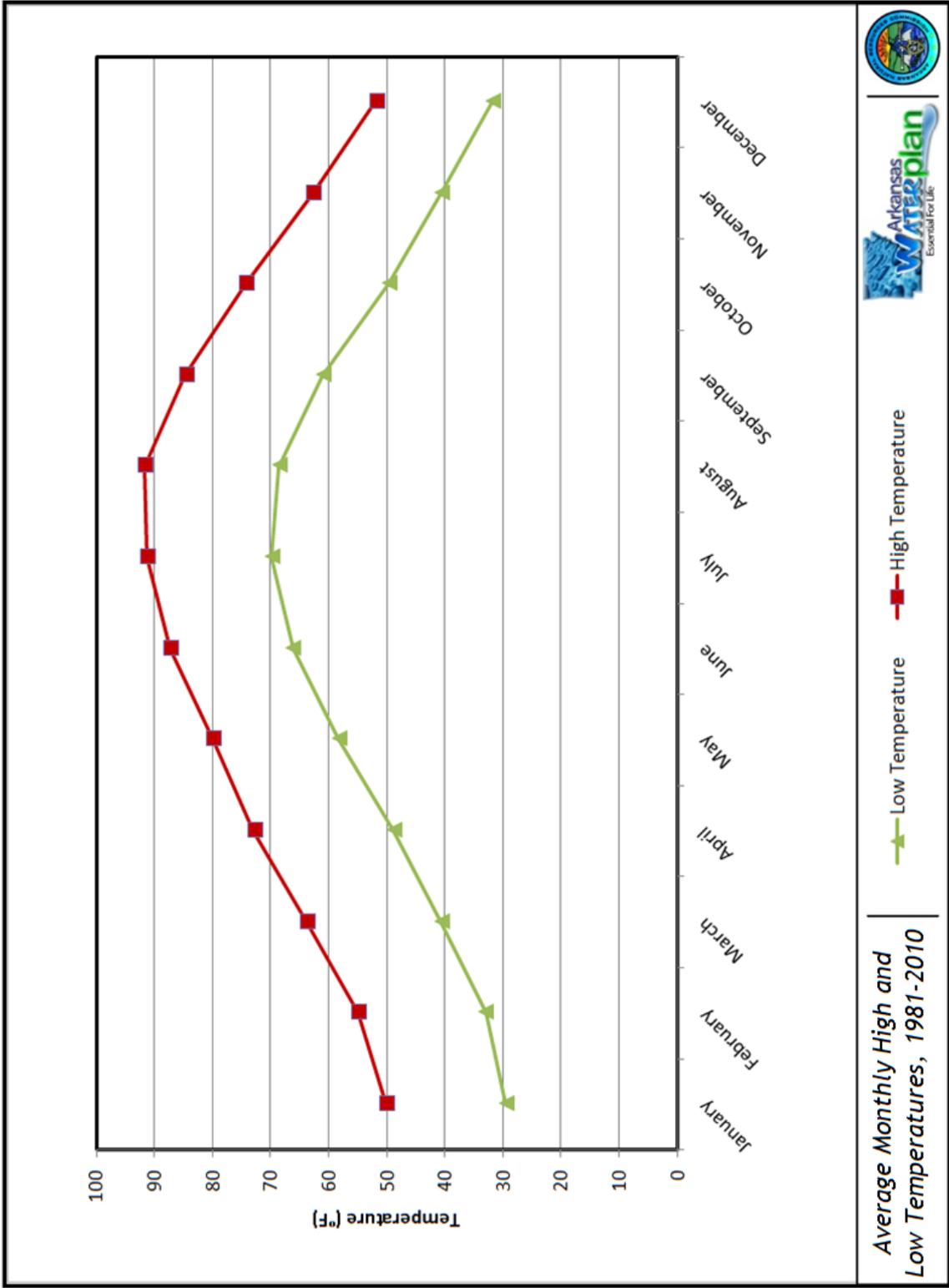


Figure 6.1. Average monthly high and low temperatures, 1981 through 2010 (PRISM Climate Group 2012a).

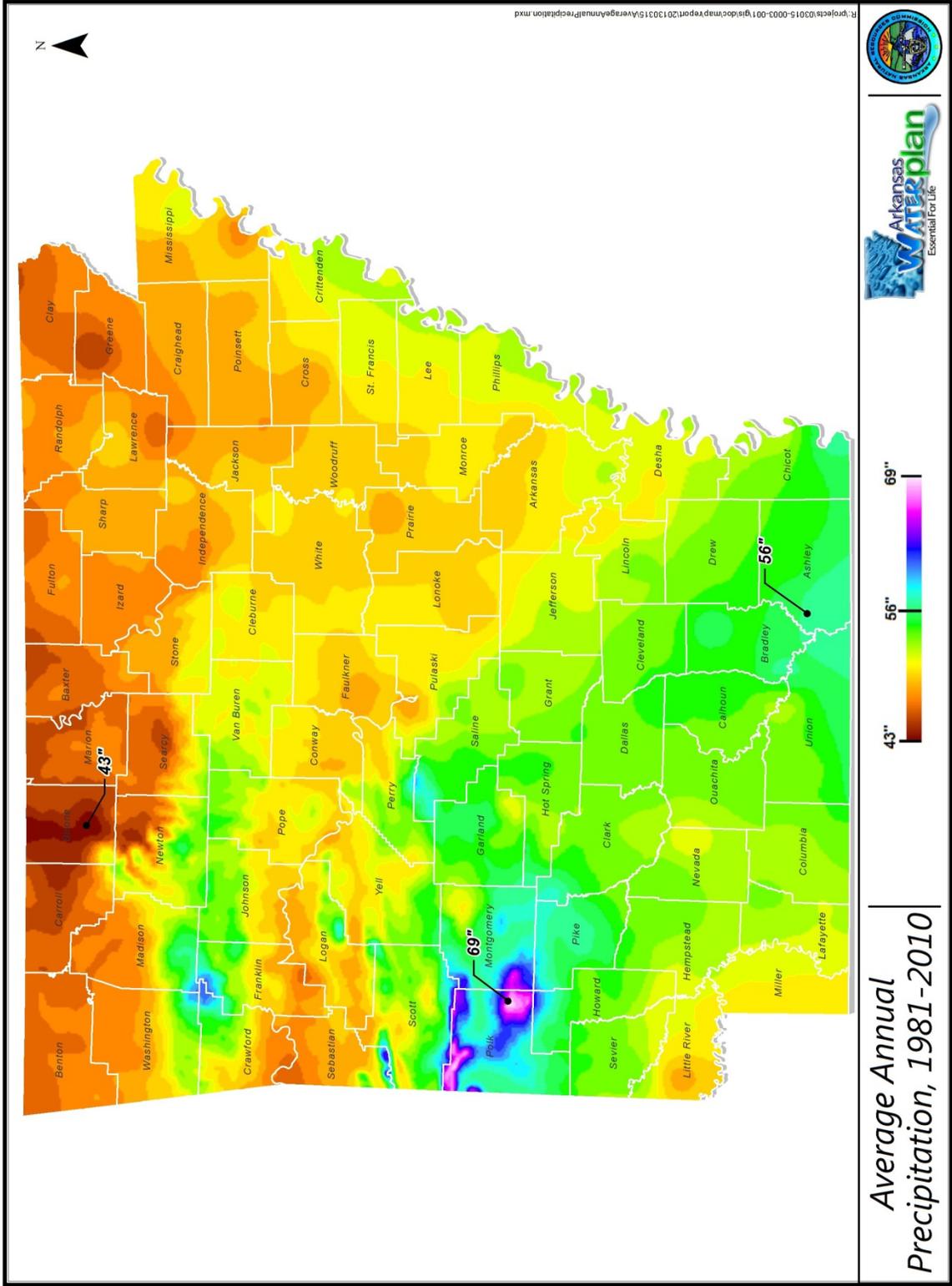


Figure 6.2. Annual average precipitation, 1981 through 2010 (PRISM Climate Group 2012b).

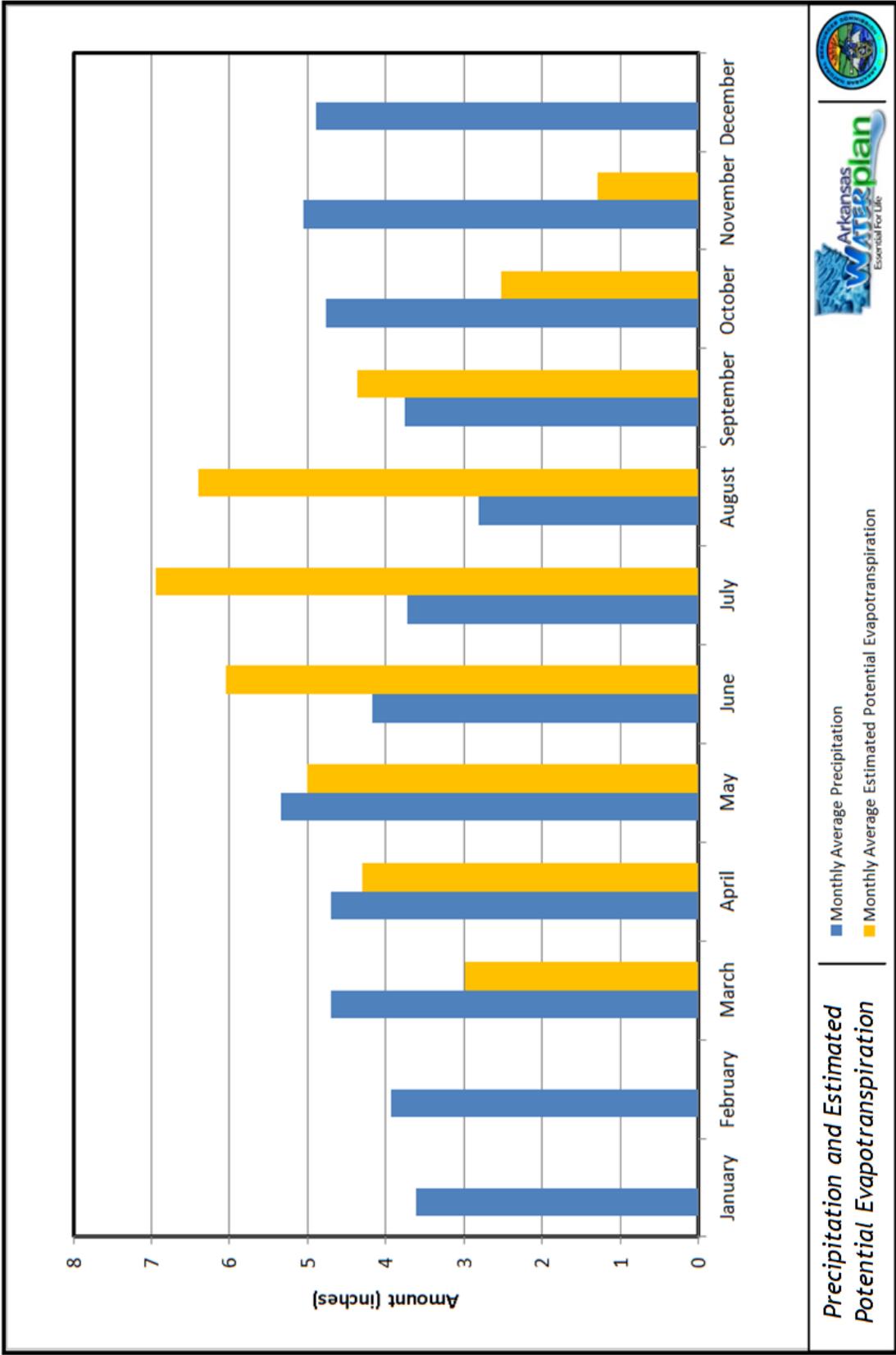


Figure 6.3. Monthly average precipitation and monthly average of estimated potential evapotranspiration, 1981 through 2010 (NOAA NCDC 2013a, PRISM Climate Group 2012b).

Summer precipitation primarily occurs during rainstorms, where locally high rainfall amounts can occur over a short period of time. During the fall, winter, and early spring, precipitation events are usually less intense and of longer duration. Precipitation falls in the state an average of 100 days out of the year. Most of the precipitation in the state falls as rain; however, snow does occur, most frequently at the higher elevations in the northwest area of the state (NOAA NCDC 2013b).

6.3 Evaporation

Evaporation is the process by which water changes from liquid to gaseous water vapor. When the conversion from liquid to water vapor occurs on leaves, the process is called transpiration. Evapotranspiration is the combination of these processes. The amount of evapotranspiration is controlled primarily by sunlight, but is also influenced by humidity and wind (Scott, et al. 1998).

Potential evapotranspiration is the maximum rate at which water in soil and on plants can change to water vapor, assuming there is no shortage of water to be changed. Actual evapotranspiration is usually less than the potential evapotranspiration. Potential evapotranspiration is difficult to measure, but can be estimated from pan evaporation, a meteorological measurement. Pan evaporation is the rate of evaporation of water from a specific style of open pan at a weather station. In humid climates, like in Arkansas, potential evapotranspiration is similar to pan evaporation. In this region, the ratio of potential evapotranspiration to pan evaporation is assumed to be 0.85. Evaporation exhibits less variation from year to year and place to place than precipitation (Scott, et al. 1998).

There are four weather stations in Arkansas where pan evaporation has been measured consistently since 2000: Blakely Mountain Dam, Blue Mountain Dam, Keiser, and Stuttgart. Figure 6.4 shows the locations of these weather stations. Figure 6.3 shows monthly average potential evapotranspiration estimated from available pan evaporation measurements at these four stations for the period of 1981 through 2010.

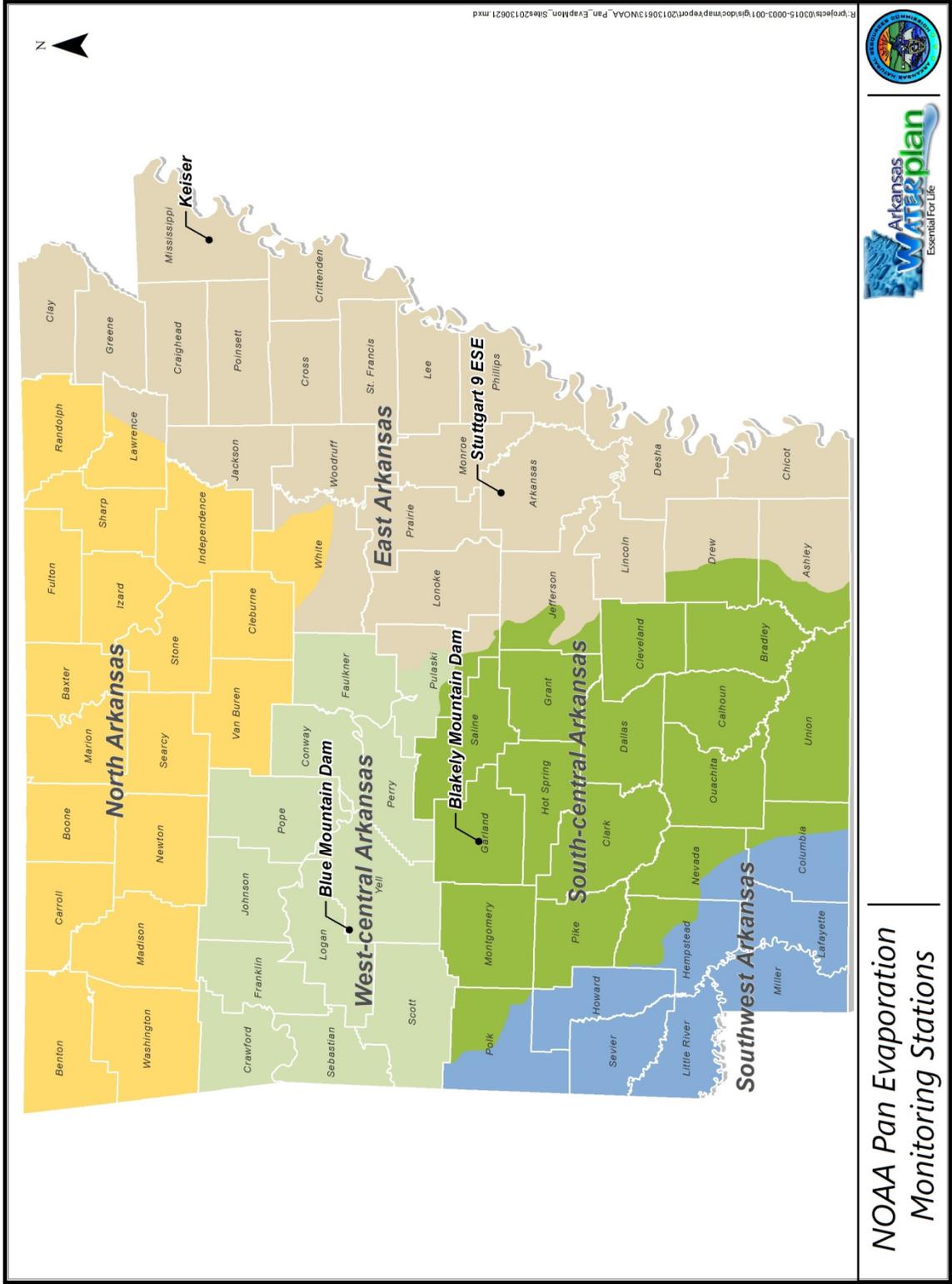


Figure 6.4. Pan evaporation monitoring stations in Arkansas.

The estimated potential evapotranspiration is highest in July, and exceeds the normal precipitation 6 months out of the year (April through September). Potential evapotranspiration rates are lowest during the winter months, when sunlight and plant growth are at a minimum.

Arkansas is a precipitation-dominated state, with less evaporation than rain and/or snowfall (Figure 6.3), and overall has a natural water surplus.

6.4 Drought

As discussed above, drought does occur in Arkansas, usually over short periods of time. Drought severity can be characterized using the Palmer Drought Severity Index. The Palmer Drought Severity Index was developed by Wayne Palmer (Palmer 1965). The index has four levels of drought severity: mild (-1), moderate (-2), severe (-3), and extreme (-4). The calculations used to develop the index are complex, but are generally based on the duration of the dry period and the magnitude of the “abnormal moisture deficiency,” which is a weighted measure of the difference between the normal precipitation of the area and the amount of precipitation the area has actually received (Palmer 1965). Figure 6.5 shows the Palmer Drought Severity Index values for Arkansas from 1895 through 2012; values less than zero indicate drought and follow the classification system discussed above. Periods of multiple consecutive years of drought have occurred in Arkansas, including in 1930 to 1935, 1953 to 1957, and 1963 to 1967 (Figure 6.5). During these periods, large areas of the state experienced conditions that were classified in the Palmer Drought Severity Index as severe or extreme drought for a number of consecutive months (National Weather Service 2013, NOAA NCDC 2013a). The state is currently experiencing a period of mild to moderate drought that began in 2011 (Figure 6.5).

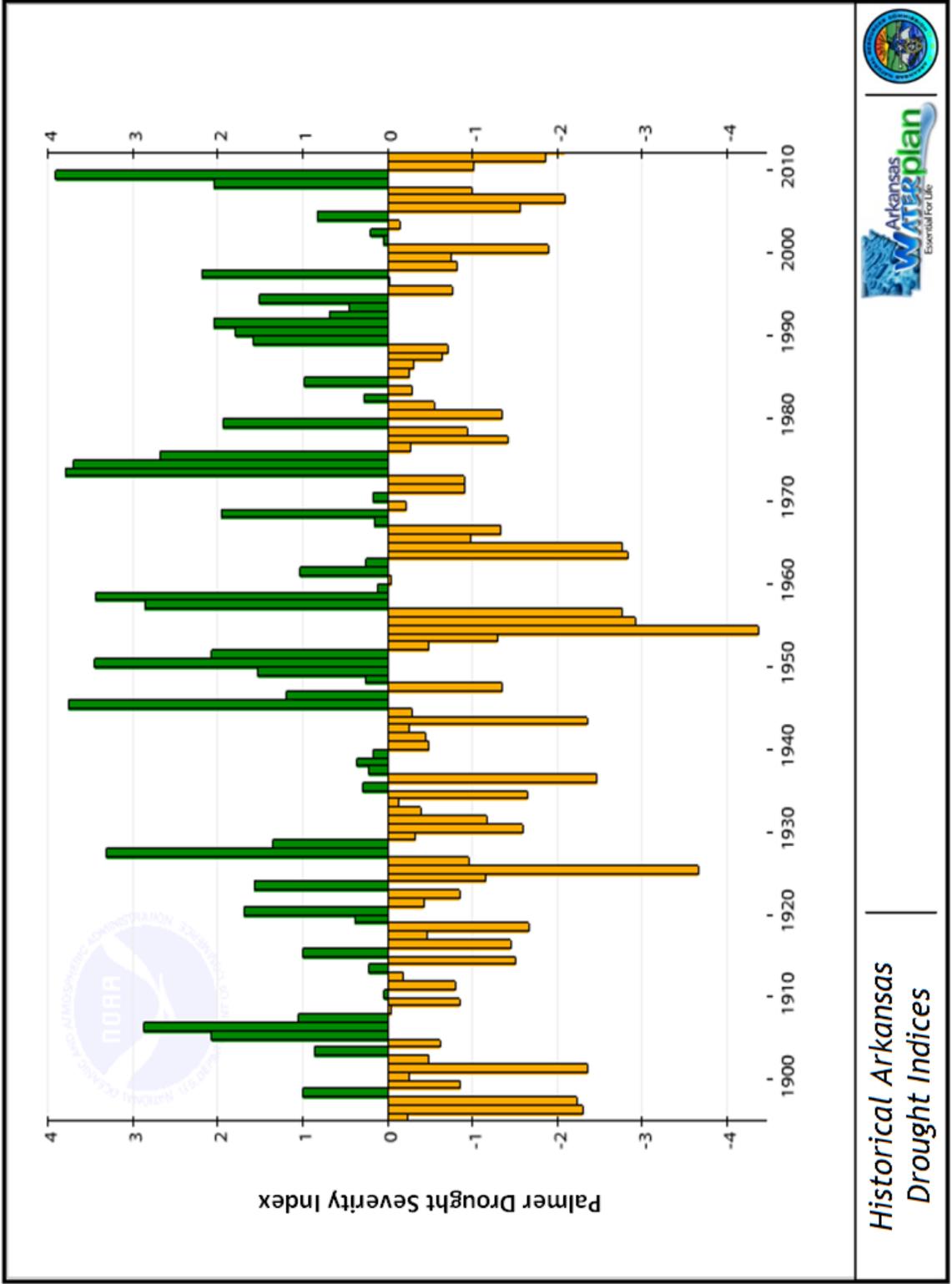


Figure 6.5. Historical Palmer Drought Severity Index values (NOAA NCDC 2013a).

6.5 Climate Influences

Weather in the state is strongly influenced by the Gulf of Mexico, particularly the interaction of warm, moist air from the Gulf of Mexico to the south with dry, cool air from the Rocky Mountains to the west (Buckner 2011). Because it is closer to the Gulf of Mexico, the southern portion of the state receives, on average, 5 to 6 more inches of rain per year (NOAA NCDC 2013b).

These large-scale patterns can be influenced by the cyclical fluctuation of ocean surface temperature and air pressure in the tropical Pacific Ocean, known as the El Niño Southern Oscillation. During both the El Niño and La Niña phases of the oscillation, Arkansas tends to experience wetter winters and drier springs, with little difference from normal conditions during the rest of the year (Climate Prediction Center 1997).

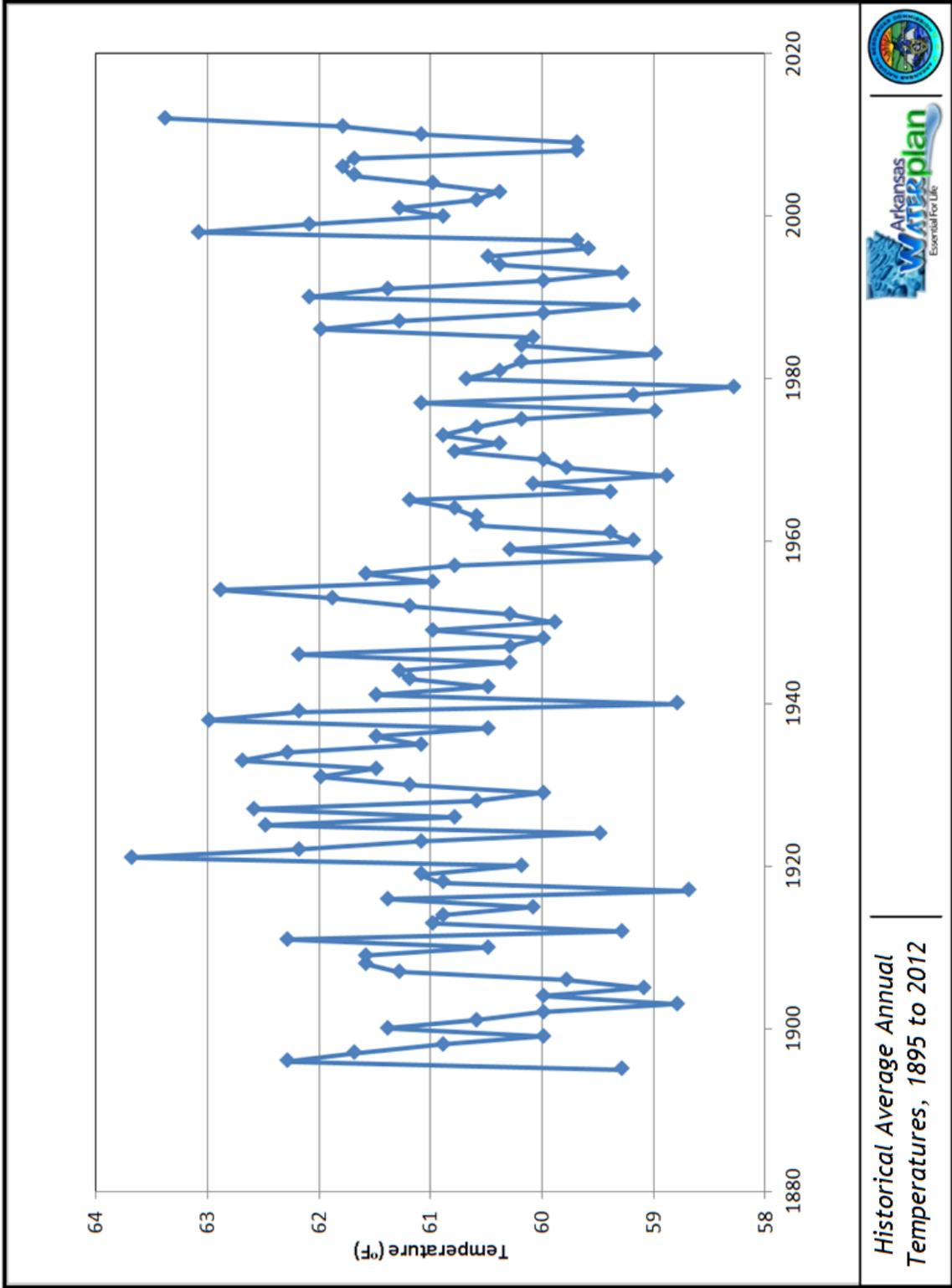
Weather patterns in the state are also influenced by the Ozark Mountains and the Ouachita Mountains (NOAA NCDC 2013b). These mountains, located in the western part of the state, can cause moist air from the Gulf of Mexico to rise, producing rainstorms. The flat terrain of the eastern part of the state offers little friction to slow down these storms, allowing them to become stronger as they move east across the state (Buckner 2011).

6.6 Climate Variability

In 2007, the Arkansas Governor's Commission on Global Warming (Commission) was established to, among other tasks, evaluate the potential impacts of global warming on the state citizens, natural resources, and economy. The Commission's literature review identified the following climate change effects anticipated for the state:

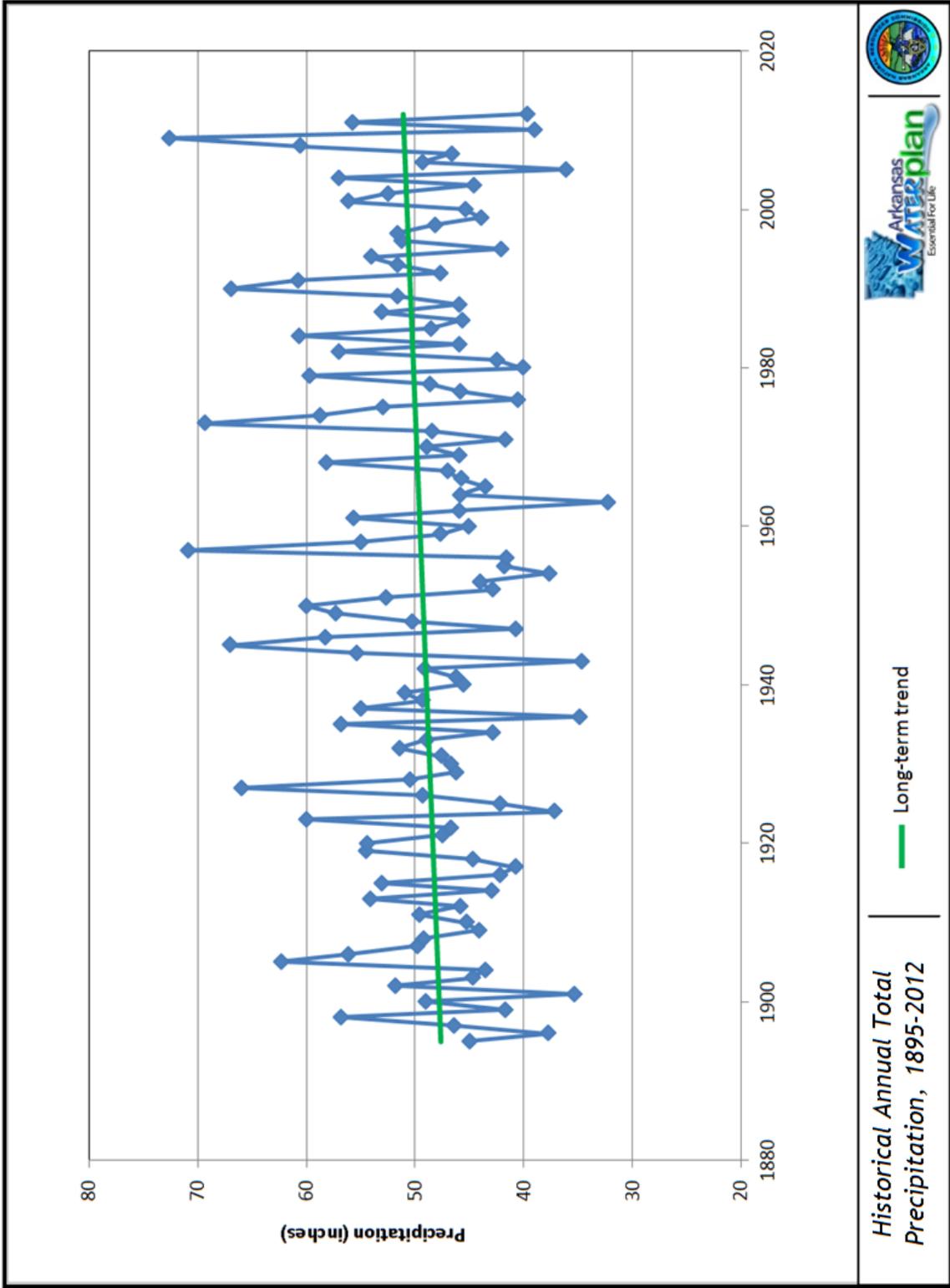
- Increased incidence of severe weather events;
- Increased incidence of flooding;
- Increased incidence of drought;
- Possible saltwater intrusion into aquifers, resulting from sea level rise; and
- Changes in climatic zones (Arkansas Governor's Commission on Global Warming 2008).

Plots of statewide annual average temperature and total annual precipitation from 1895 to 2012 are shown on Figures 6.6 and 6.7, respectively. The temperature data appear to exhibit a cycle of change, where temperatures in the first half of the 20th century were warmer than the temperatures in the second half, but appear to be warming again in the early 21st century (Figure 6.6). The US Department of Agriculture (USDA) develops a plant hardiness zone map that shows annual average minimum winter temperature. The 2012 update of the USDA map shows warmer minimum temperatures in the state as compared to the zone map from 1990, which follows the cycle shown on Figure 6.6 (Clark and Karklis 2012). Total precipitation appears to exhibit a slight long-term increasing trend (Figure 6.7). An updated analysis of long-term precipitation trends across the state is being prepared as part of the 2014 AWP update.



*Historical Average Annual
Temperatures, 1895 to 2012*

Figure 6.6. Historical average annual temperatures, 1895 to 2012 (NOAA NCDC 2013a).



*Historical Annual Total
Precipitation, 1895-2012*

— Long-term trend

Figure 6.7. Historical annual total precipitation, 1895 to 2012 (NOAA NCDC 2013a).

7.0 LAND USE

Topography and soil type are the principal factors governing the use of land. Steep slopes and thin soils, which frequently occur in the Interior Highlands, preclude the development of cropland and favor the growth of forests, grassland, and pasture. Conversely, the flat terrain and deep soils in eastern Arkansas are conducive to agricultural uses. Land use data retrieved from the National Land Cover Database (MRLC 2006) reflect these patterns across the state. Figure 7.1 shows the transition from the forest- and grassland-dominated land in the western two-thirds of the state to the heavily cultivated cropland in the east. Figure 7.2 illustrates the percentage of state area that is classified into each land use category (MRLC 2006).

The majority of the state is covered by forest, with approximately 16% of the forest used as commercial timberland and 19% in national forest. Table 7.1 shows the acreages of the different forest land uses in Arkansas. Well-managed forest protects water quality (Arkansas Forestry Commission 2010a, Arkansas Forestry Commission 2010b).

Table 7.1. Forest land use in Arkansas (Arkansas Department of Parks and Tourism 2013, US Fish and Wildlife Service Southeast Region 2012).

Land Use	Area (acres)
Forest industry	2.5 million
National forest	2.9 million
National wildlife refuges	0.38 million
Wildlife management areas	0.43 million

Approximately one-third of the state land area is used for agricultural purposes, such as pasture or cropland. The majority of the water used in Arkansas is used for crop irrigation (Funkhouser, Eng and Moix 2008). The 2007 Census of Agriculture reported that 7,367,068 acres of cropland were harvested in the state, and 4,460,682 acres (60%) of this cropland was irrigated (USDA National Agricultural Statistics Service 2007). Figure 7.3 shows the distribution of irrigated cropland in the state in 2007.

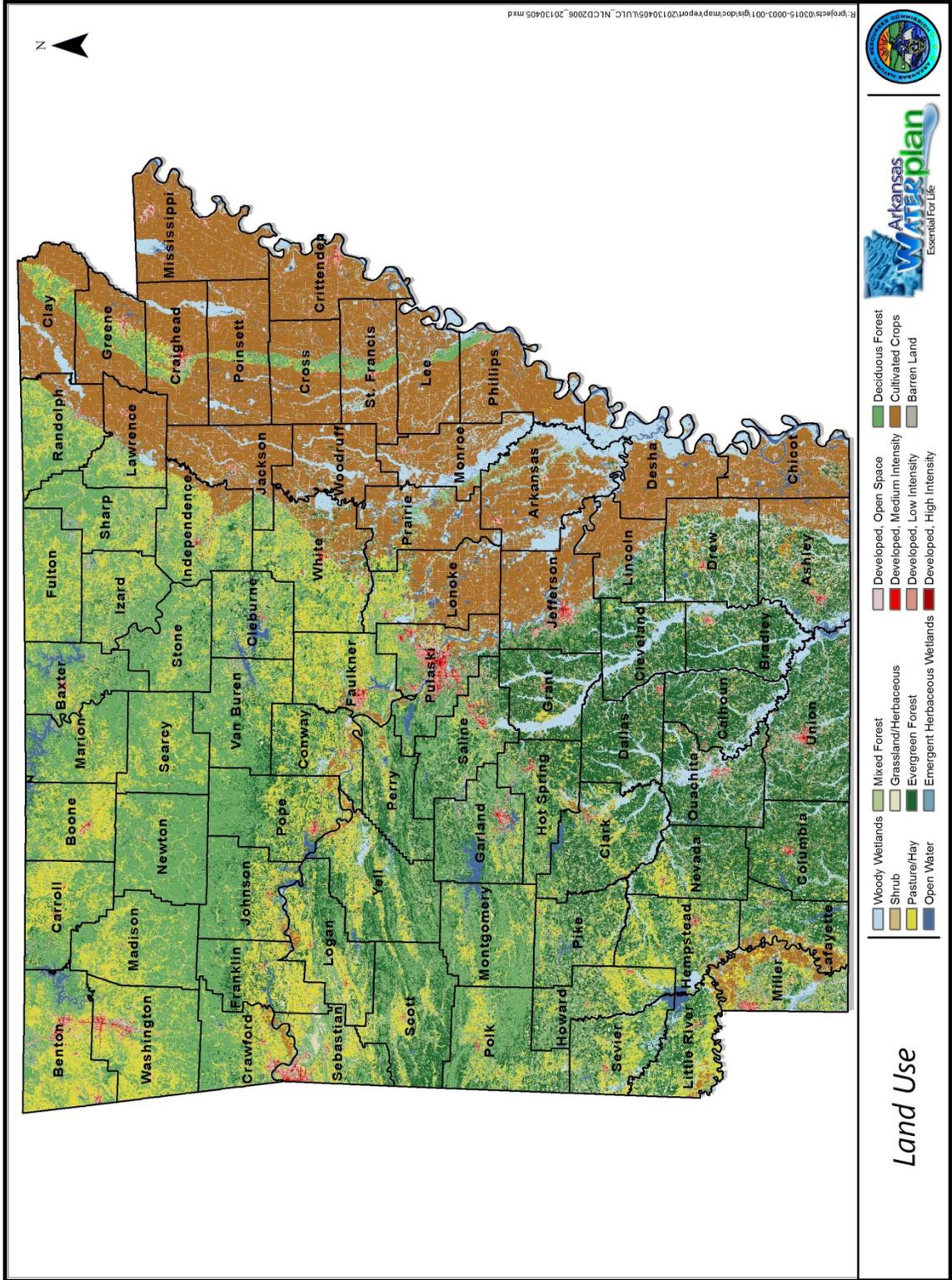


Figure 7.1. Arkansas land use (MRLC 2006).

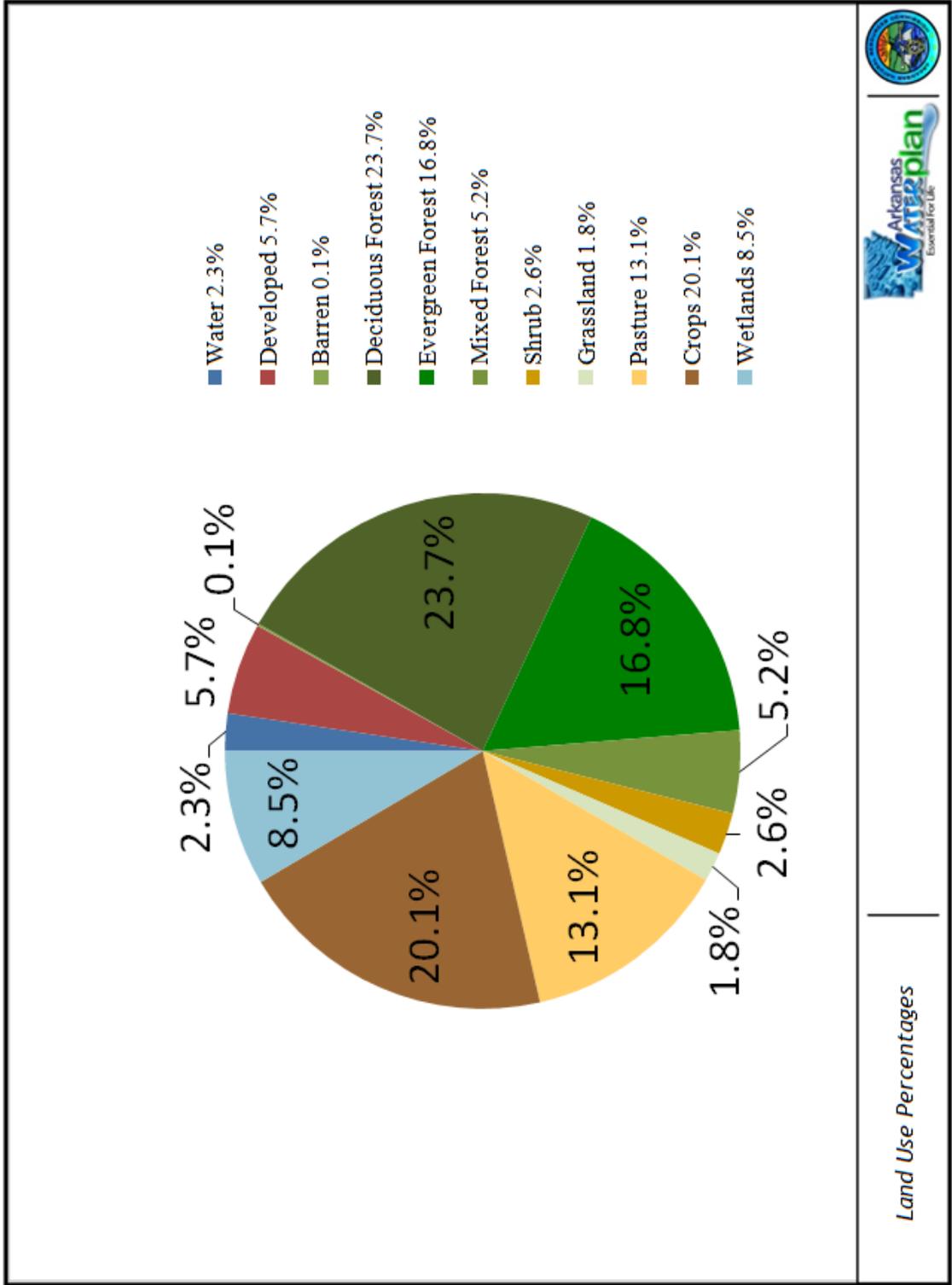


Figure 7.2. Land use percentages (MRLC 2006).

In 2007, there were 3.1 million acres of federal land in Arkansas, including national forests, national parks, and military installations (USDA NRCS and Iowa State University, Center for Survey Statistics and Methodology 2009).

Land use data from the Natural Resources Inventory from the years 1987 (which were reported in the 1990 AWP) and 2007 are compared in Table 7.2. Agricultural land uses (cropland and pasture) are the only land uses that decreased over this time period. Developed land saw the largest increase.

Table 7.2. Comparison of Arkansas land use data (1987 versus 2007) (USDA NRCS and Iowa State University, Center for Survey Statistics and Methodology 2009).

Land Use	1987 Area (10³ acres)	2007 Area (10³ acres)	Percent Change
Developed	1,272	1,809	42%
Water	852	902	6%
Federal	3,049	3,104	2%
Cropland	7,969	7,379	-7%
Pastureland	5,569	5,167	-7%
Forest land	14,851	15,095	2%
Other rural	471	578	14%
TOTAL	34,036	34,036	---

8.0 SURFACE WATER

There are over 87,000 miles of rivers and streams in Arkansas and over 515,000 acres of lakes, reservoirs, and ponds (Figure 8.1) (Dewald and Olsen 1994). The Arkansas Department of Environmental Quality (ADEQ) has further classified these surface waterbodies by water resource type (Table 8.1) (ADEQ 2009). Major rivers in the state include the Arkansas River, Mississippi River, Ouachita River, Red River, St. Francis River, and White River. Surface water availability issues, both water quantity and water quality, are discussed in detail in the Water Resources Issues section of the Task 5 report.

Table 8.1. Surface water resources in Arkansas (ADEQ 2009).

Water Resource Type	Quantity
Total streams	87,617 miles
Perennial streams	28,408 miles
Intermittent streams	53,465 miles
Ditches and canals	5,250 miles
Border streams	493 miles
Lakes, reservoirs, and ponds	515,635 acres

8.1 Streamflow

Approximately 30 billion gallons of water enters Arkansas daily from other states through the Arkansas River, White River, and St. Francis River and their tributaries. An average of 210 billion gallons per day flows along the state border through the Mississippi River (Arkansas Geological Survey 2013, Howard, Colton and Prior 1997). Streamflow originating in the state averages around 40 billion gallons per day. The majority of this flow comes from precipitation runoff. Historical average annual surface runoff, in inches, is shown on Figure 8.2.

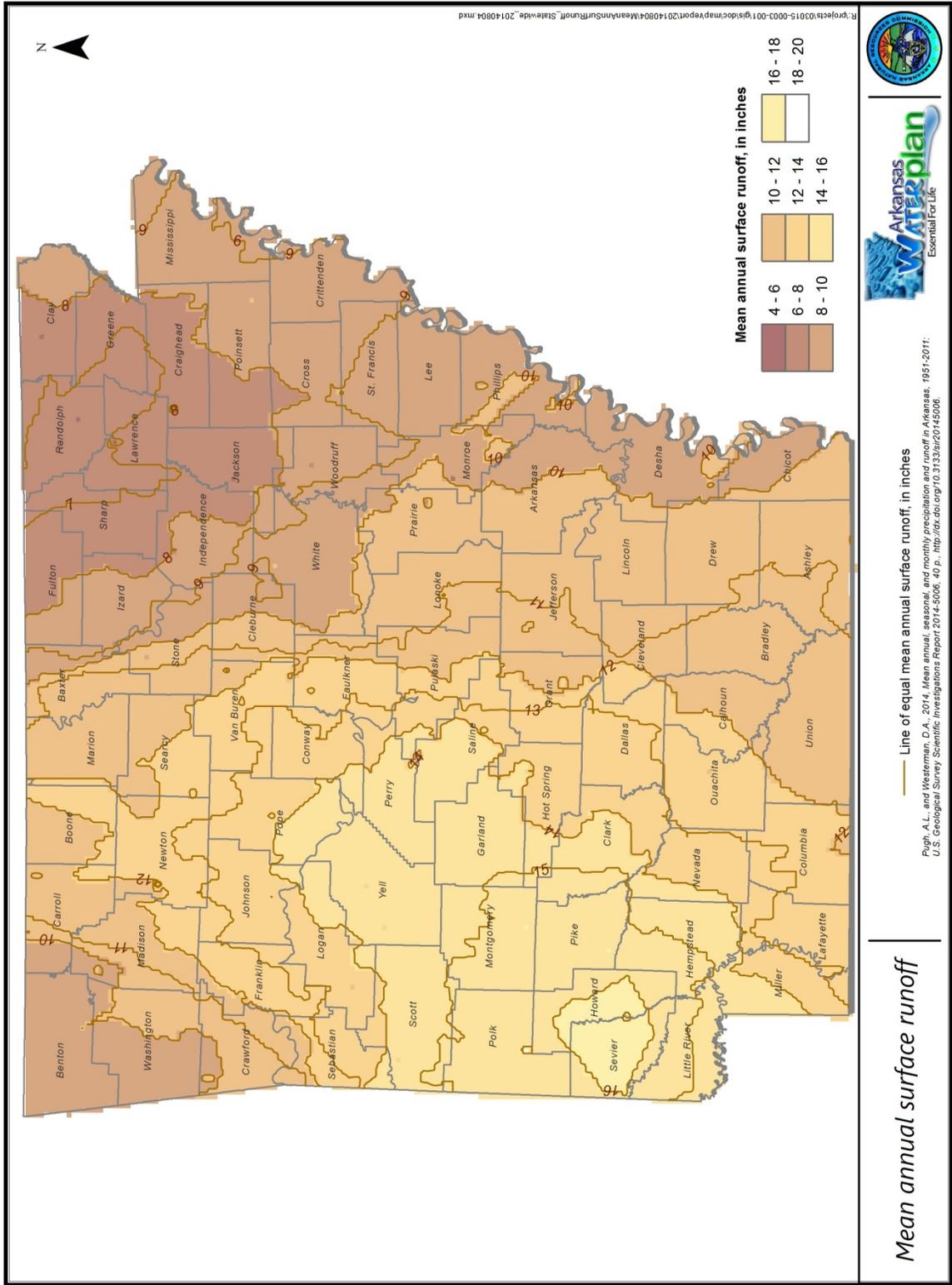


Figure 8.2. Average annual surface runoff in Arkansas, 1951 to 2011 (Pugh and Westerman 2014).

Few streams in the state are unaffected by regulation or diversion (Ludwig 1992). Four of the five major rivers in the state have their flow regulated (Figure 8.1). Flow in the Arkansas River in the state is regulated by the dams that make up the McClellan-Kerr Arkansas River Navigation System, as well as reservoirs on tributaries in Oklahoma and Arkansas. Flow in the White River is regulated by four mainstem reservoirs and two tributary reservoirs in Arkansas and Missouri. Flow in the Ouachita River is regulated by reservoirs on the mainstem and tributaries, as well as dams associated with the Ouachita-Black River Navigation System. Flow in the Red River in Arkansas is regulated by reservoirs on the mainstem and tributaries in Oklahoma, Texas, and Arkansas.

Streamflow is generally lowest in Arkansas streams during June through October, the period of highest water demand and lowest precipitation. Streamflow is generally highest during the winter and late spring months, the period of lowest water demand and higher precipitation. Generally, tributary streams in the Ozark Mountains and the Ouachita Mountains have higher base flow due to the influence of springs (see Section 9.0), while those in the Arkansas River Valley and southern Arkansas periodically dry up following extended periods of low precipitation (Funkhouser, Eng and Moix 2008).

Long-term flow records in the state have been analyzed for trends. Several flow gage stations on streams in eastern Arkansas, in the Gulf Coastal Plain, exhibit declining trends (see Figure 8.3) (Ludwig 1992, Czarnecki, Hays and McKee 2002). Long-term flow records in streams in the remainder of the state generally do not exhibit trends (Figures 8.4 through 8.6). Figure 8.7 shows the locations of the flow gauges for Bayou Bartholomew, Arkansas River, White River, and Ouachita River. An updated analysis of long-term trends in flow records is being completed for the 2014 AWP.

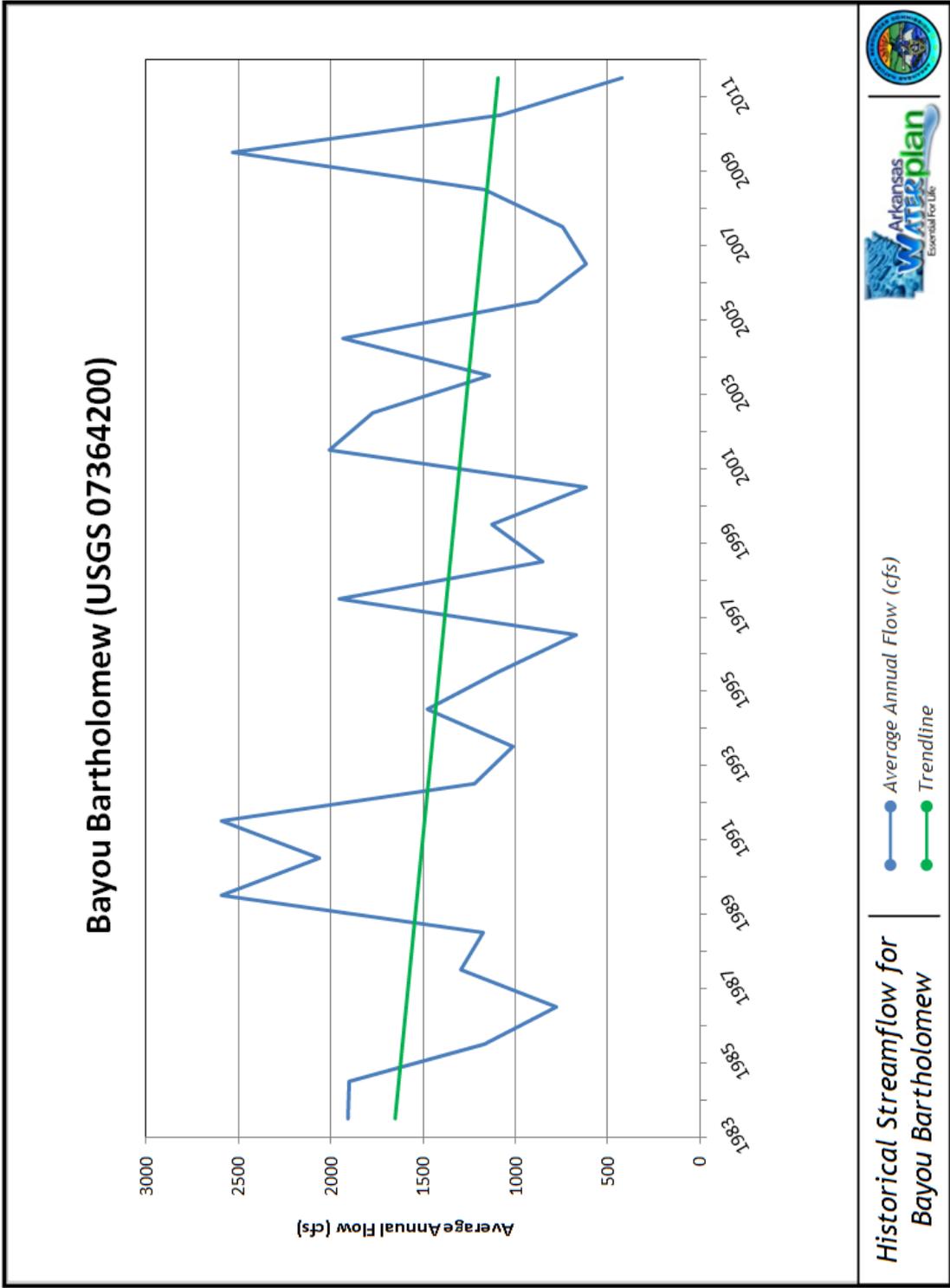


Figure 8.3. Historical streamflow at Bayou Bartholomew, which exhibits a declining trend (USGS 2013).

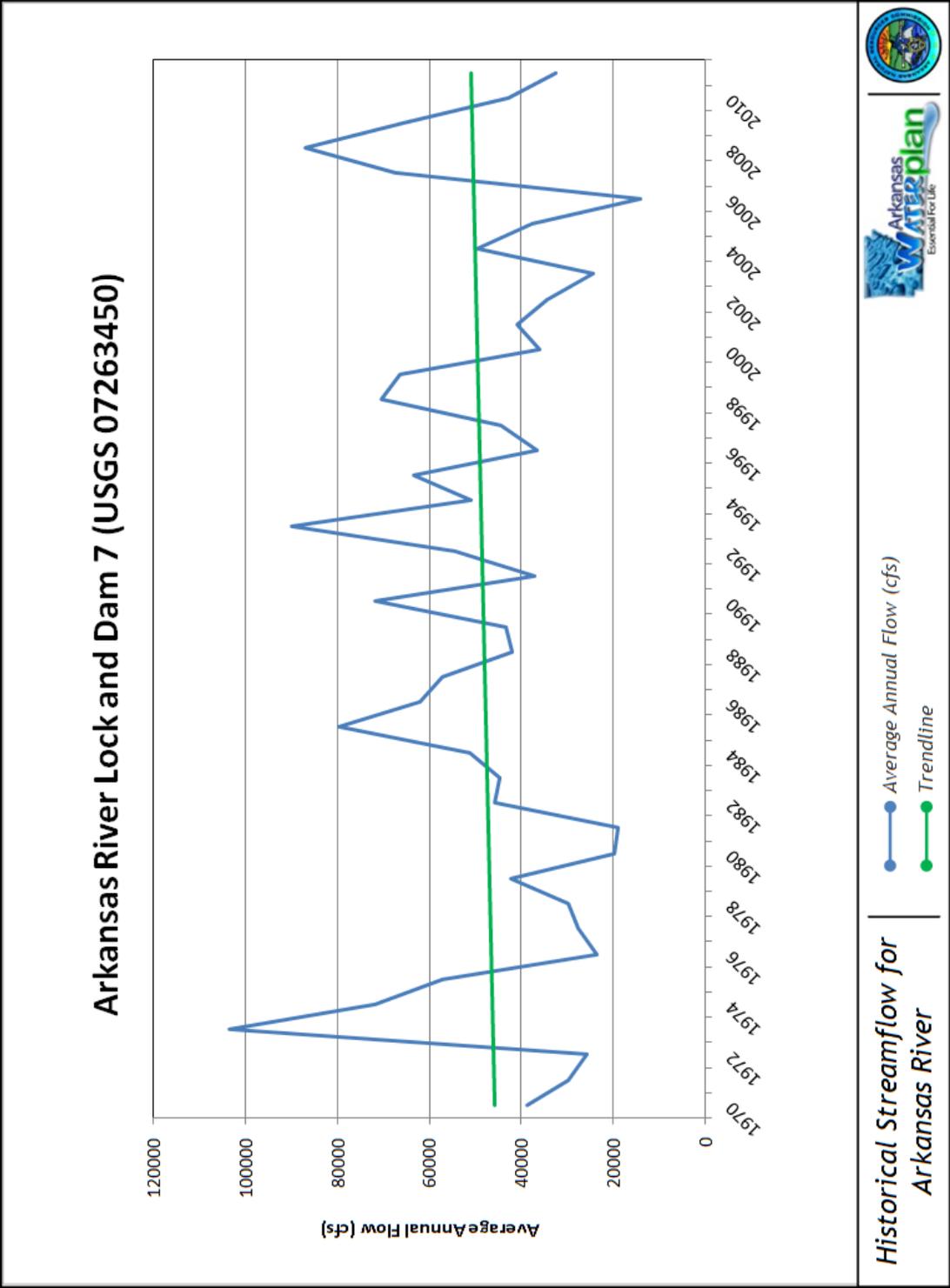


Figure 8.4. Historical streamflow for Arkansas River (USGS 2013). The historical record does not exhibit an increasing or decreasing trend.

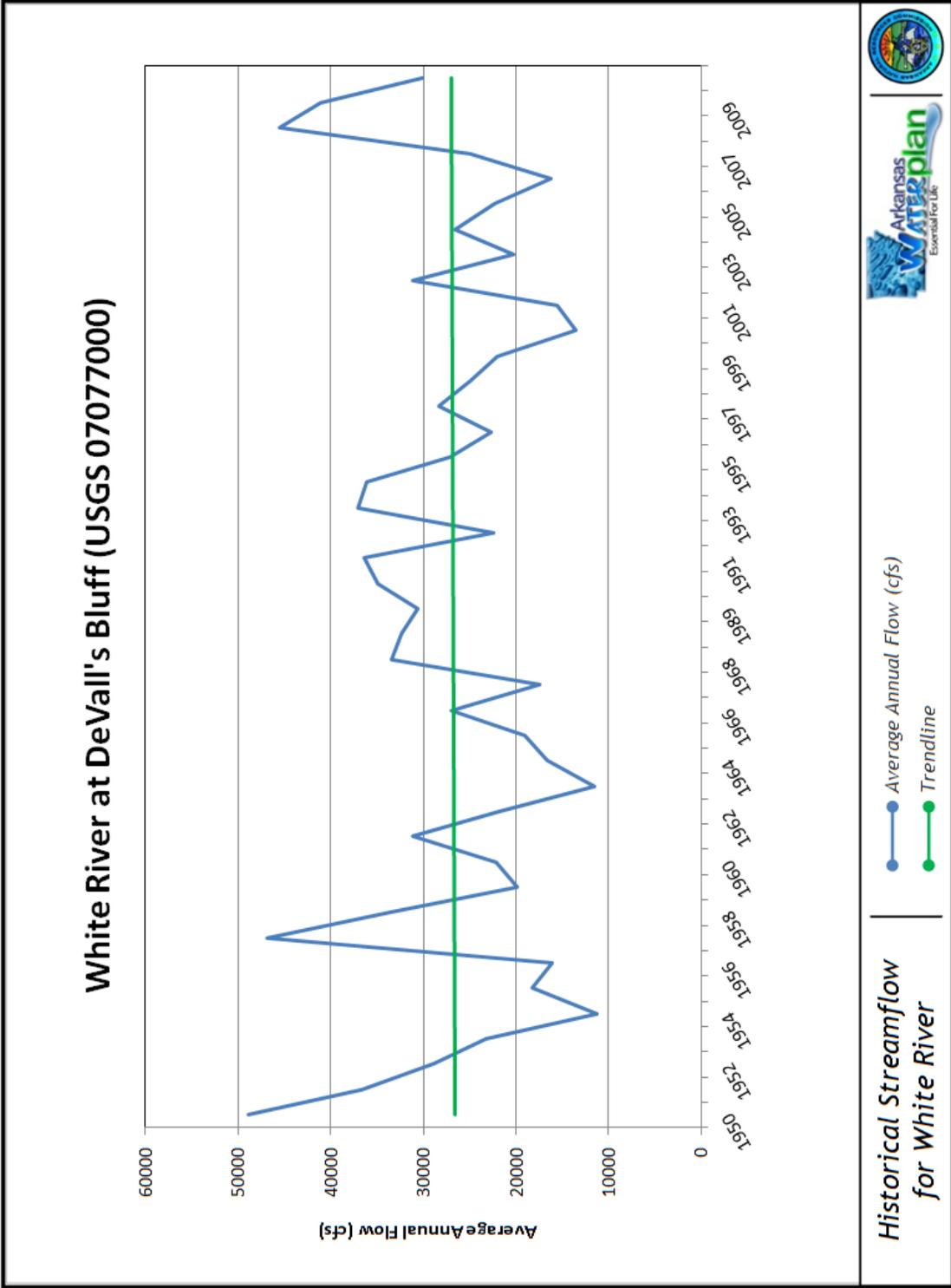


Figure 8.5. Historical streamflow for the White River (USGS 2013). The historical record does not exhibit an increasing or decreasing trend.

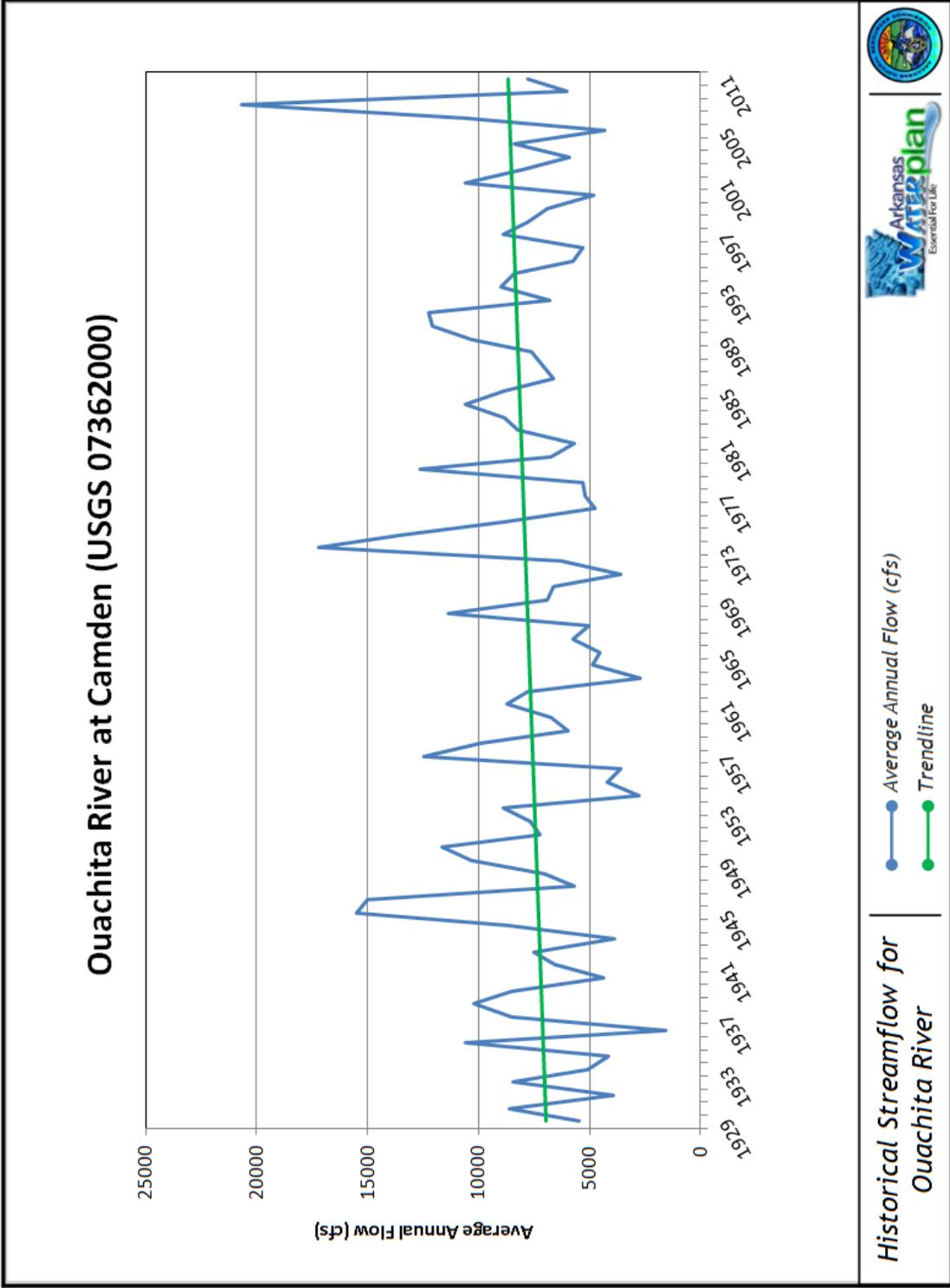


Figure 8.6. Historical streamflow for the Ouachita River (USGS 2013). The historical record exhibits a change resulting from construction of an impoundments.

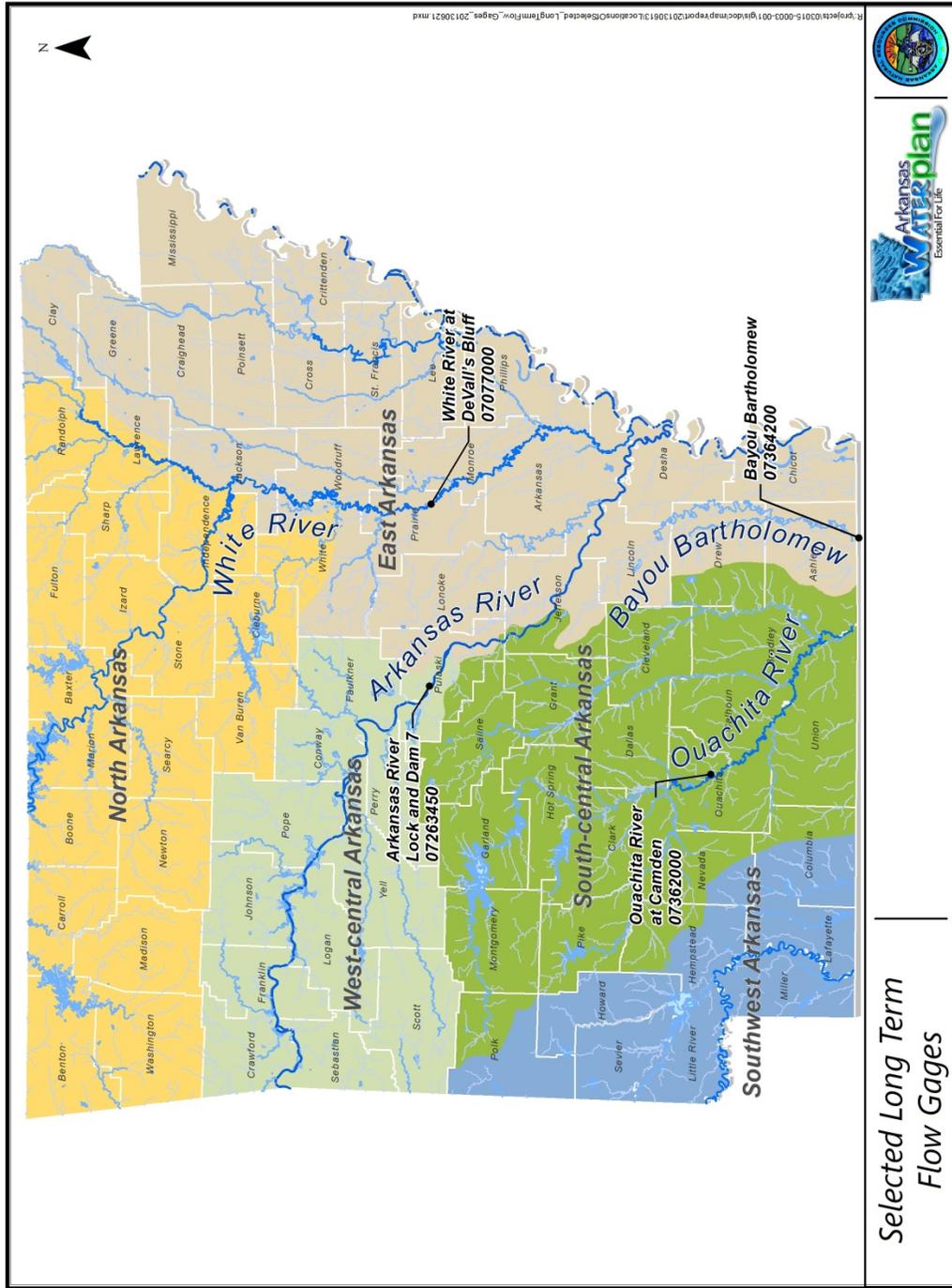


Figure 8.7. Locations of selected long-term flow gages (USGS 2013).

8.2 Impoundments

There are approximately 110,500 impoundments in Arkansas with a combined surface area of over 515,000 acres and storage of over 15 million acre-feet. These include 25 Arkansas Game and Fish Commission impoundments and 10 US Forest Service (USFS) impoundments (Arkansas Game and Fish Commission 2010, Arkansas Soil and Water Conservation Commission 1981). There are 25 US Army Corps of Engineers (USACE) impoundments in the state, 11 of which make up the McClellan Kerr Arkansas River Navigation System. Three of the USACE non-navigation impoundments cross the Arkansas-Missouri state line. The majority of remaining impoundments in the state are small farm ponds (Arkansas Soil and Water Conservation Commission 1981). Table 8.2 lists the largest reservoirs in Arkansas, along with the planning basin in which each one is located and the surface area and storage area of each one. An update to the impoundment inventory is being conducted as part of the 2014 AWP update.

Table 8.2. Largest reservoirs in Arkansas.

Reservoir Name	Surface Area (acres)	Volume (10⁶ acre-feet)	Owner	Planning Region
Bull Shoals Lake	45,440	3.04	USACE	North
Lake Ouachita	40,100	2.76	USACE	South-central
Greers Ferry Lake	31,500	1.91	USACE	North
Beaver Lake	28,220	1.65	USACE	North
Norfork Lake	22,000	1.25	USACE	North

8.3 Water Quality

Based on the results of the 2008 state-wide water quality assessment, surface water quality in Arkansas is generally good (ADEQ 2009). In the mountainous areas of the Interior Highlands, surface water quality tends to be the least impacted, with high dissolved oxygen levels and low biochemical oxygen demand and low concentrations of nutrients. Geology in these mountainous areas tends to influence surface water alkalinity, hardness, and total dissolved solids concentrations (Woods, et al. 2004).

Surface water quality in the Gulf Coastal Plain, and the Arkansas River Valley in the Interior Highlands, tends to be more influenced by land use. In particular, surface waters in these

areas generally have higher levels of turbidity and total suspended solids. In addition, dissolved oxygen levels are relatively lower, and biochemical oxygen demand is relatively higher (Woods, et al. 2004).

Surface water quality issues will be discussed in detail in the Task 5 report.

9.0 GROUNDWATER

Groundwater is an important water resource for the State and constitutes greater than 70 percent of the total water use in Arkansas (Kresse and others 2013). The groundwater report, *Aquifers of Arkansas – Protection, Management, and Hydrologic and Water-Quality Characteristics of Arkansas’ Groundwater Resources* (Kresse and others 2013), divides aquifers into the two major physiographic regions of the state — Interior Highlands and Coastal Plain — and their respective subdivisions. Besides the obvious differences in the mountainous upland regions as compared to extensive flat-lying, lowland and valley areas, these two regions have differences in underlying rock type, geologic structure, and depositional history, which have produced aquifers having very different capabilities for storing and transporting underground water. These capabilities combined with various land uses associated with both regions have resulted in aquifers having differing well yields and uses, water-quality conditions, and vulnerability to various land-use activities. This section provides an overview of the major geologic formations that serve as valuable sources of water supply across the State. These formations are described in more detail in subsequent sections for the planning regions. Table 9.1 lists the formations or groups of formations that are aquifers, their locations, and use for the aquifers of Arkansas.

Table 9.1. Location, formations, and use for the aquifers of Arkansas.

Formation or Group of Formations	Geologic Age	Hydrogeologic Unit Name ¹	Aquifer Code	Major Physiographic Division	Physiographic Province	Physiographic Section	Aquifer Use ²	Water-Quality Sites
Coastal Plain Alluvium	Quaternary	Mississippi River Valley, Ouachita-Saline, and Red River alluvial aquifers	110ALVM, 112ALVM, 112VLTR, 112TRRC	Gulf Coastal Plain	Mississippi Alluvial Plain and West Gulf Coastal Plain	Mississippi Alluvial Plain and West Gulf Coastal Plain	IR, ps, in	4,061
		Vicksburg-Jackson confining unit	124JCKS				D	
		Upper Claiborne aquifer	124CCKF				IN, IR, ps	
		Middle Claiborne aquifer	12405MP, 124SPRT, 124MMPS				IR, PS, IN	
Jackson Group	Tertiary	Vicksburg-Jackson confining unit	124JCKS				PS, d	45
Cockfield Formation	Tertiary	Upper Claiborne aquifer	124CCKF				D	12
Sparta Formation	Tertiary	Middle Claiborne aquifer	12405MP, 124SPRT, 124MMPS				PS, ir, in	170
Cane River Formation	Tertiary	Lower Claiborne confining unit	124CRVR, 124CANR				PS	143
Carrizo Sand	Tertiary	Lower Claiborne aquifer	124CRRZ				D	12
Wilcox Formation	Tertiary	Middle Wilcox aquifer	124WLCX, 124WLCXG				PS, ir, in	170
Nacatoch Sand	Cretaceous	Nacatoch aquifer*	211NCTC				PS	143
Ozan Formation	Cretaceous	Ozan aquifer*	212OZAN				D	14
Tokio Formation	Cretaceous	Tokio aquifer*	212TOKO				PS, in	165
Trinity Group	Cretaceous	Trinity aquifer*	218TRNT				PS, in	38

Table 9.1. Location, formations, and use for the aquifers of Arkansas (continued).

Formation or Group of Formations	Geologic Age	Hydrogeologic Unit Name ¹	Aquifer Code	Major Physiographic Division	Physiographic Province	Physiographic Section	Aquifer Use ²	Water-Quality Sites
Moorefield Formation through McAlester Formation	Mississippian and Pennsylvanian	Western Interior Plains Confining System	325HRSR,	Interior Highlands	Ozark Plateaus	Boston Mountains	D	287
			325MICAL					
			326ATOK					
Boone Formation	Mississippian	Springfield Plateau aquifer	328BLYD,	Interior Highlands	Ozark Plateaus	Springfield-Salem Plateaus	D, ps	95
			328CNHL					
			328JKFK,					
Potosi Dolomite through Clifty Limestone	Ordovician through Devonian	Ozark aquifer	3331BSVL	Interior Highlands	Ozark Plateaus	Springfield-Salem Plateaus	PS, d	131
			331MFLD,					
			331PTKN					
Collier Shale through Boggy Formation	Cambrian through Pennsylvanian	Ouachita Mountain shallow aquifer system*	330BOON	Interior Highlands	Ouachita Province	Ouachita Mountains	D	162
			361FRVL,					
			364EVRN,					
Arkansas River Valley Alluvium	Quaternary	Arkansas River Valley alluvial aquifer*	364JCHM,	Interior Highlands	Ouachita Province	Arkansas Valley	PS, IR, d	680
			364STPR					
			367CTJF,					
			367CTTR					
			368WLL,					
			371POTS					
			325HRSR,					
			325MICAL					
			326ATOK,					
			328JKFK					
			330ARKS,					
			330HSPG					
			330STNL,					
			350MSRM					
			361PKCK,					
			364BGFK					
			110ALVM,					
			110TRRC					
			112TRRC					

¹Marked with a stenisk where termed an aquifer for this report only; all other units are regionally designated hydrogeologic units.

²IR= irrigation, PS = public supply, IN = industrial, D = domestic. Listed in order of highest use by volume. Primary use in capital letters; secondary use in small caps.

9.1 Aquifers

There are significant differences in the availability of groundwater across the State. Aquifers of the interior highlands are represented by a thick sequence of highly fractured, well lithified formations dominated by carbonates (limestone and dolostone) in the Ozark Plateaus, and shale and sandstone lithologies in the Boston Mountains and Ouachita Mountains. Ozark Plateau aquifers are recognized as major aquifers, where the shallow aquifer system represented by rocks of the Boston Mountains and Ouachitas are viewed as minor aquifers and less important on a regional scale. The most productive aquifers are found in the Coastal Plain where there are thick sequences of unconsolidated sand, clay, and gravel.

9.1.1 Interior Highland Aquifers

Generally, the hydrogeology of the Interior Highlands can be described as an area of consolidated formations which yield relatively low volumes of water to wells. The low specific capacity in these wells is a direct result of the lithological nature of the strata itself. The consolidated formations typically are confined with most of the water yielded to wells coming through secondary porosity found in fractures and bedding planes. Typically, the most noted aquifers within the Interior Highlands are the deep Ozark aquifer, and the Bigfork Chert and Arkansas Novaculite aquifers in the central Ouachita Mountains. The Atoka Formation is significant as a source of shallow domestic wells in the Ouachita Mountains and Arkansas River Valley, but yields are typically small and therefore, limited for other purposes.

Ouachita Province aquifers consist mostly of shale, sandstone, and chert beds of Cambrian to Pennsylvanian age (Collier Shale through Boggy Formation) and Quaternary alluvium. Groundwater occurs in high permeability fracture and fault zones. The most important water-yielding strata in the Ouachita Province are the Big Fork Chert, Arkansas Novaculite, and Atoka Formation. Only limited quantities of water are available for domestic and non-irrigation farm use; however, the Arkansas River Valley alluvium aquifer can yield relatively large volumes of water, but this formation is not widespread (T. Fugitt, ANRC, personal communication, April 9, 2013).

Formations comprising the Ozark Plateaus extend across most of northern Arkansas and consist of a thick sequence of lithified, flat-lying to southward-dipping limestone and dolomite that contains some beds of sandstone, shale, and chert. Rocks that comprise the system range in age from Ordovician to Pennsylvanian (Potosi Dolomite through Clifty Limestone). Dissolution of limestone and dolomite rocks of the Ozark Plateaus has resulted in the development of solution features (conduits, sinkholes, and caves) typical of karst terrain, where springs are common. Solution features are hydrologically important because they serve as the principal conduits for concentrated groundwater flow and, thus, account for practically all the permeability within the aquifers of the Ozark Plateaus.

The Ozark aquifer and the Springfield Plateau aquifer underlie the Springfield-Salem Plateaus. The thick, extensive, and productive Ozark aquifer (Figure 9.1) is the principal source of groundwater in northern Arkansas and is considered to be a major aquifer. This aquifer consists of numerous geologic formations, but most of the water withdrawn from the aquifer is obtained from only a few water-yielding strata, such as the Roubidoux Formation and the Gunter Sandstone. The Springfield Plateau aquifer consists of interbedded Mississippian limestone and chert (Boone Formation) that generally yield only small volumes of water to wells. Because the aquifer is thin, relative to the great thickness of the Ozark aquifer, and has been highly dissected by erosion, it is used primarily as a source of water for domestic supply.

The Ozark Plateaus aquifers are confined on its southern margin by the Western Interior Plains confining system which is a thick sequence of poorly permeable Pennsylvanian and Mississippian rocks that underlie the Boston Mountains. Groundwater occurs and moves in fractures and along bedding planes of sandstones and shale. Although this region is designated as a confining system (low permeability formations that impede the vertical movement of groundwater), this region is important as a local source of water supply to households, farms, stores, parks, and small community water supplies (Kresse and others 2013) and is considered to be a minor aquifer (Renken 1998).

9.1.2 Coastal Plain Aquifers

The hydrogeology of the Gulf Coastal Plain can be described as layers of unconsolidated silt, sand, and gravel which function as aquifers, yielding large quantities of water to wells. These aquifers are separated by clays which store greater volumes of water but have relatively low hydraulic conductivity, and therefore do not yield adequate volumes of water to wells. The aquifers of the Gulf Coastal Plain consist of strata with high volumes of sand which has a high hydraulic conductivity and; therefore, a high specific yield of water to wells. Major aquifers in the Gulf Coastal Plain include the Nacatoch, Wilcox, Sparta/Memphis, Cockfield, and Mississippi River Valley alluvial aquifers.

These large aquifers provide water to wells used for agriculture, public supply, and industry. However, clay and marl formations of the Gulf Coastal Plain also serve as water supply sources for rural domestic wells, especially where only a small amount of water is needed.

The largest and most productive of the State's major aquifers are in the Gulf Coastal Plain (Figure 9.1). This region is underlain by poorly consolidated formations that are blanketed with alluvium in the east along the Mississippi River and along the Red and Ouachita Rivers. From youngest to oldest, the following formations serve as aquifers in the Coastal Plain: alluvium, which includes the Ouachita and Red River alluvial aquifers and the Mississippi River Valley alluvial aquifer (the most important aquifer in Arkansas in terms of sheer volume of use and economic benefits), the Jackson Group, the Cockfield Formation, the Sparta Formation, the Cane River Formation, the Carrizo Sand, the Wilcox Formation, the Nacatoch Sand, the Ozan Formation, the Tokio Formation, and the Trinity Group. All but the Jackson Group are considered to be major aquifers and are used as a significant source of water supply in the region.

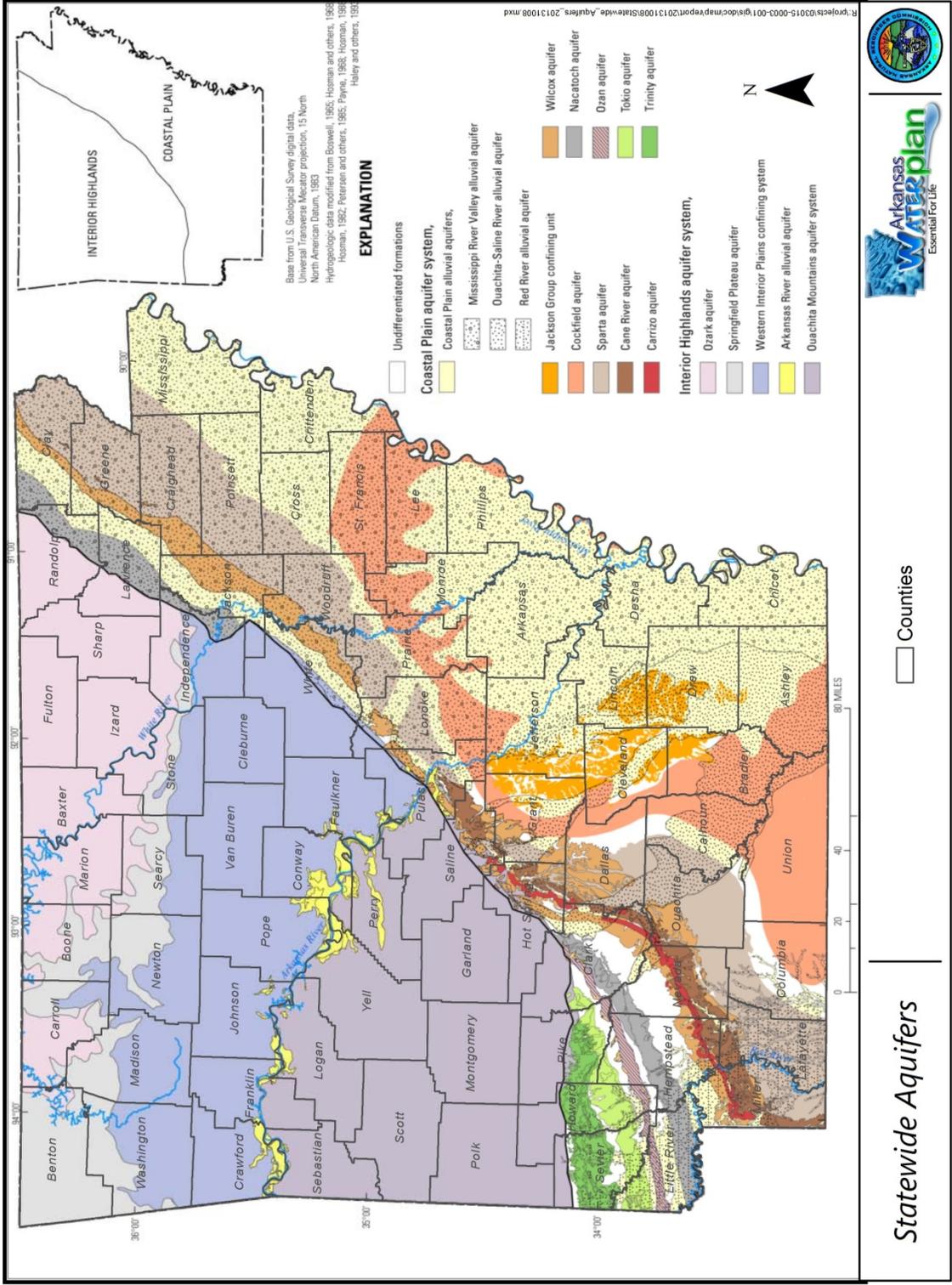


Figure 9.1. Major aquifers in Arkansas.

The Jackson Group is a regional confining unit that historically served as an important source of domestic supply (Kresse and others 2013).

The unconsolidated sand and gravel that comprise the Quaternary alluvial aquifers have intergranular porosity, and all contain water primarily under unconfined or water-table conditions. The hydraulic conductivity of the aquifers is variable, depending on the sorting of aquifer materials and the amount of silt and clay present, but generally it is high. The alluvial aquifers are susceptible to contamination because of their generally high hydraulic conductivity. Groundwater in the Red River and Ouachita alluvial aquifers flows along relatively short flow paths from recharge to discharge areas typical of local flow systems; however, the Mississippi River Valley alluvial aquifer has a regional flow system.

The remaining aquifers consist of semi-consolidated and unconsolidated sand interbedded with silt, clay, and minor carbonate (limestone) rocks. Porosity is intergranular, and the hydraulic conductivity of the aquifers is moderate to high. The aquifers underlie the alluvium in the Coastal Plain are of fluvial, deltaic, and shallow marine origin. The aquifers are in a thick wedge of sediments that dips and thickens toward the Arkansas-Louisiana border. The varied depositional environments of these sediments have caused complex interbedding of fine- and coarse-grained materials. Water in topographically high recharge areas is unconfined, but, it becomes confined as it moves southward. Discharge may occur by upward leakage to shallower aquifers. These aquifers typically have lengthy regional flow paths, and because flow is sluggish near the ends of regional flow paths, the aquifers commonly contain unflushed saline water in their deeply buried, down dip parts. Where shallower aquifers have been heavily pumped, saltwater intrusion has locally contaminated groundwater.

9.2 Groundwater Quality

ADEQ classifies groundwater quality in Arkansas aquifers as good to very good (ADEQ 2009). The chemistry of groundwater in Arkansas ranges from calcium bicarbonate to sodium bicarbonate water types. Groundwater in the Mississippi River Valley alluvial aquifer tends to have high iron concentrations (up to 70 mg/L) as well as high manganese concentrations. Elevated chloride concentrations (100 to 300 mg/L) occur in many individual aquifers in the

Coastal Plain associated with poor flushing of residual salinity in clayey parts of the aquifer, upwelling of high-salinity water from underlying formations, and evapotranspiration in poorly drained backswamp areas (Kresse and others 2013) High levels of radon occur in some areas of the Ozark Aquifer (ADEQ 2009, Todd, et al. 2009). Issues related to groundwater quantity and quality are discussed in detail in the report for Task 5.

9.3 Groundwater-Surface Water Connections

Groundwater recharge throughout Arkansas generally comes from precipitation which percolates into the groundwater system, especially where major aquifers are exposed at land surface. Statewide groundwater recharge has been estimated at about 2 inches per year, and as low as 0.4 inches per year (Broom and Lyford 1981). Another estimate ranges from 3 to 8 inches depending on the permeability of the surface material (Bedinger and Jeffery 1964). Other sources of groundwater recharge include rivers that are hydraulically connected to aquifers and lateral and vertical flow from adjacent and underlying water-bearing strata.

In large areas of the state, water moves readily between surface water and groundwater systems. The fractures present in the geology of the Ozark and Ouachita Mountains provide an easy path for surface water to move underground. Most often, this water moves relatively quickly through the network of fractures and/or solution channels, to emerge elsewhere as a spring that flows into a stream or reservoir. In the Karst geology of the Ozark Mountains, streams can disappear underground, returning to the surface farther downstream.

In the Gulf Coastal Plain, and along major Arkansas rivers, surface water can readily percolate down through the unconsolidated geology of alluvial aquifers. In alluvial aquifers along large rivers, such as the Arkansas River, Red River, and Ouachita River, water readily moves into the aquifer when river levels are high and from the aquifer to the river when river levels are low. This also happens in the Mississippi River Valley alluvial aquifer where it is close to the Mississippi River.

Aquifer recharge from streams during high-flow is a natural process. However, when the groundwater gradient is altered by pumping from wells, additional aquifer recharge is induced. Recharge is induced when water is withdrawn from an aquifer adjacent to a stream or other

surface water source, to which it is hydrologically connected. This process is also commonly referred to as “stream capture”. This scenario was identified by the US Geological Survey in Arkansas as early as the 1960’s.

The role of wetlands as a source of groundwater recharge is minor compared to other factors in the overall water budget. In one wetland study in the Cache River Basin, groundwater flow was a minor component of the water budget, accounting for less than one percent of both inflow and outflow (Gonthier and Kleiss 1996).

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