Water Availability Report

FINAL

Arkansas Natural Resources Commission

Arkansas State Water Plan Update

January 2014

CDM Smith

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Acronyms

µg/L	micrograms per liter
ADEQ	Arkansas Department of Environmental Quality
ADH	Arkansas Department of Health
AFY	acre-feet per year
AGFC	Arkansas Game and Fish Commission
ANRC	Arkansas Natural Resources Commission
APCEC	Arkansas Pollution Control and Ecology Commission
ARV	Arkansas River Valley
ASA	Assistant Secretary of the Army
AWP	Arkansas Water Plan
AWRPR	Arkansas Water Resources Planning Regions
BMPs	best management practices
CECs	contaminants of emerging concern
cfs	cubic feet per second
CW	Civil Works
CWA	Clean Water Act
DO	dissolved oxygen
EA	environmental assessment
E-coli	Escherichia coli
ELOHA	Ecological Limits of Hydrologic Alternation
EPA	U.S. Environmental Protection Agency
F	Fahrenheit
FC	Flood Control
FONSI	Finding of No Significant Impact
ft/d	feet per day
ft^2/d	square feet per day
FW	Fish and Wildlife Enhancement
GCRASA	Gulf Coast Regional Aquifer System Analysis
gpm	gallons per minute
gpm/ft	gpm per foot
in/yr	inches per year
IWR	Institute of Water Resources
LRD	Little Rock District
LT2 Rule	Long-Term 2 Enhanced Surface Water Treatment Rule
M&I	municipal and industrial
MAWA	Mid-Arkansas Water Alliance
MCLs	maximum contaminant levels
MERAS	Mississippi Embayment Regional Aquifer Study
mg/L	milligrams per liter
mgd	million gallons per day

mi^2	square miles
MNW	Multi-Node Well
MRV	Mississippi River Valley
N	Navigation
NEPA	National Environmental Policy Act
NOAA	National Oceanographic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRWU	Nonriparian Water Use
NWIS	National Water Information Service
NWQA	National Water Quality Assessment
O&M	operation and maintenance
P	Power
PCB	polychlorinated byphenyls
R	Recreation
RMSEs	root mean square errors
RRPPWS	Rules and Regulations Pertaining to Public Water Systems
SDWA	Safe Drinking Water Act
SFR	Streamflow Routing
TDS	total dissolved solids
TKN	total Kjeldahl nitrogen
TMDL	total maximum daily load
TNC	The Nature Conservancy
TOC	total organic carbon
TSS	total suspended solids
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WIP	Western Interior Plains
WQ	Water Quality
WS	Water Supply

Section 1

Introduction

Under Arkansas state law, the Arkansas Natural Resources Commission (ANRC) is responsible for preparing and periodically updating 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 to be completed in 2014. As part of this update, this report describes the water availability.

The update to the AWP involves several major steps including the quantification of current and future water availability. These estimates of future water availability are intended for statewide and regional planning purposes, and are not intended to replace local water resource planning efforts.

This report describes the methods and data used to quantify current and future water availability. Surface water and groundwater availability forecasts are developed to the year 2050. The information presented in this report is used to establish a complete statewide, county, and regional quantification of current and future water availability by source of supply (groundwater and surface water).

Surface water availability is provided by calculating the water that is excess to the current and future demands. Excess water calculations were completed for 9 major river basins and 23 smaller river basins within the larger basins (**Figure 1-1**). The surface water calculations are made with data from 51 gaging stations and the results of the calculations are described in Section 3. Data from most of these gaging stations were used to evaluate current surface water quality in Section 4.

One of the current and future demands that are included in the excess water calculations is how much water should be left in the stream to support fish and wildlife flows. Fish and wildlife flows were included in excess water calculations in the 1990 AWP using the Arkansas Method, a seasonal proportion of stream flow developed by the Arkansas Game and Fish Commission (AGFC) in 1987. The Arkansas Method is used to determine surface water availability in the 2014 AWP, but the ANRC recognizes that there should be a process to use alternative approaches to determining fish and wildlife flows. A discussion of a process to propose an alternative approach and how that approach would be evaluated for approval by the ANRC is provided in Section 7 of this report.

Groundwater availability is assessed using a hydrologic model of the Mississippi embayment developed by the U.S. Geological Survey (USGS). This model was run for base conditions (2010) and for future conditions (2050) based on the groundwater demands that are described in the AWP Water Demand Forecast Report (CDM Smith 2013). The modeled effect of groundwater withdrawal is described in Section 5. Groundwater quality throughout the state is described in Section 6 to identify areas where groundwater may have to be treated before use.

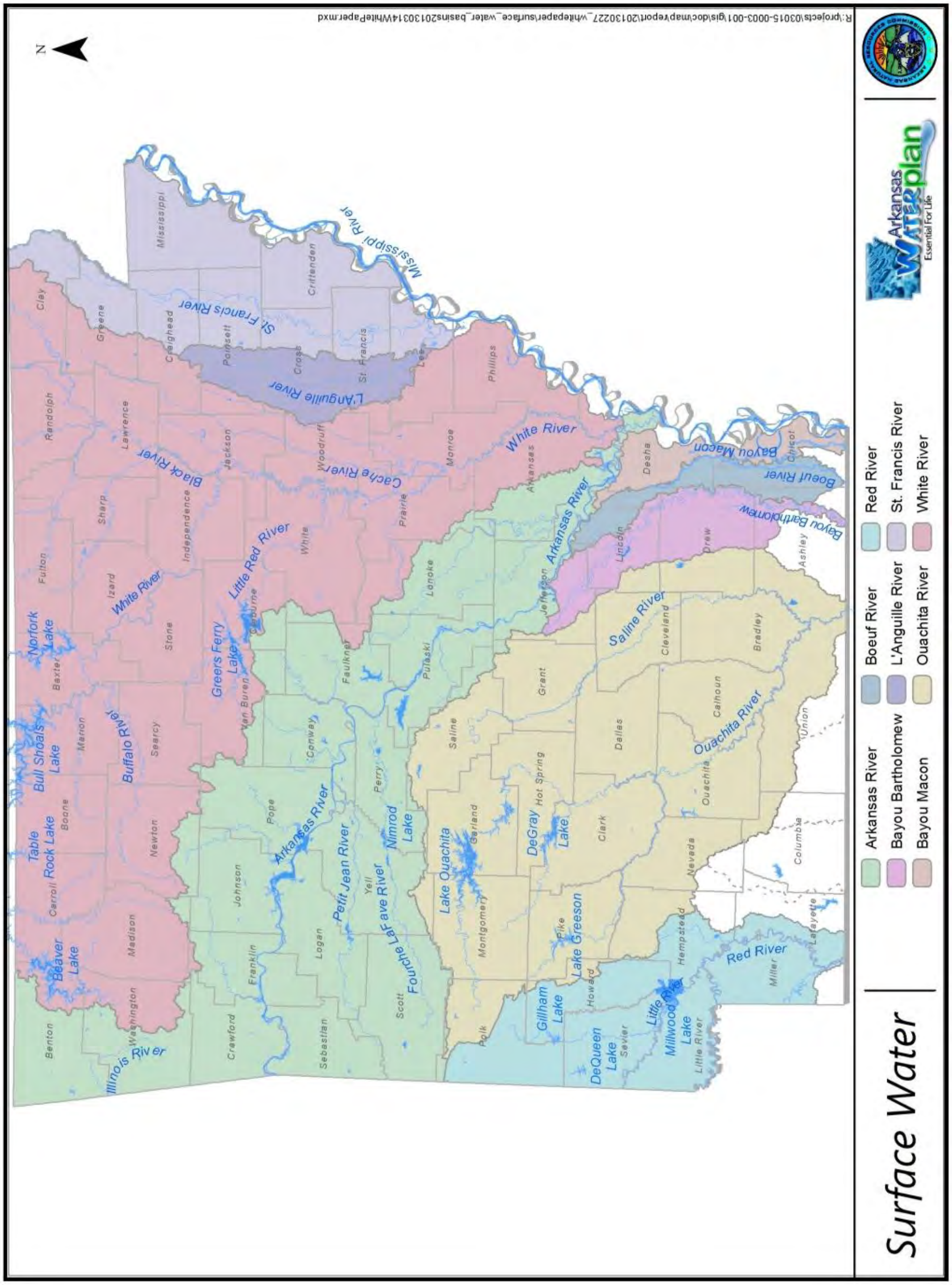

Figure 1-1. Arkansas Major River Basins

The primary data used to develop the groundwater model and groundwater quality assessments are derived from the Water Use Registration Data Base and include withdrawal point information (i.e., Measurement Point Identification with associated latitude and longitude coordinates) and water sources (i.e., aquifer codes or surface water Hydrologic Unit Code 8 codes). Thus, water use of each county are quantified at the individual withdrawal point level with a specific coordinate and source.

The report is an assessment of the availability of surface water and groundwater, within the physical (e.g., seasons, water quality) and legal (e.g., compacts, navigation) constraints of its use. The information in this report combined with its companion, the *Water Demand Forecast Report*, are the fundamental building blocks of the AWP. They provide the best planning level estimates to answer the questions: *How much water do we have?* and *How much water do we need?*. These reports are not intended to answer the next critical question for water planning, which is *What is the difference between what we have and what we need (the gap)?* The final critical question will be addressed by the AWP gap analysis, which is expected to be complete at the end of January 2014.

Five water resource planning regions have been identified as a framework to quantify and compare available water supply with demands. The overall purpose of the Planning Regions is to group areas of the state with shared resources and similar economic, social, and institutional characteristics in order to facilitate the water resource planning process and to devise basin- and resource-focused planning needs, goals, and management practices/solutions to address local and regional needs.

The Water Resource Planning Regions used for this AWP update are shown in **Figure 1-2**. They are: East, North, West-central, South-central, and Southwest. These Water Resource Planning Regions 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 follow county boundaries to facilitate the use of data (e.g., economic, census, and water use data) aggregated at the county level.

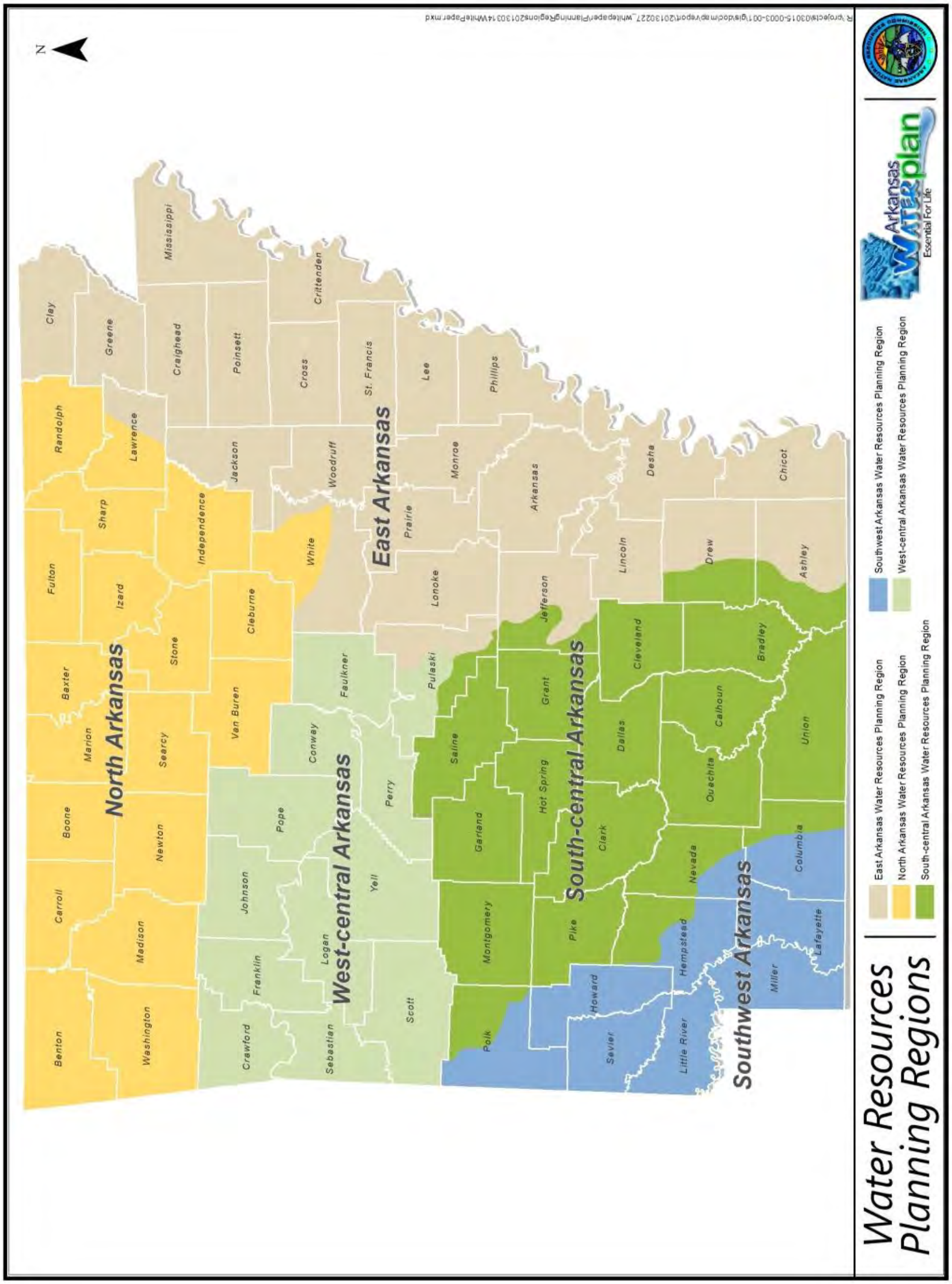

Figure 1-2. State Water Resource Planning Regions

Section 2

Summary

This report has planning level estimates of current and future surface water and groundwater availability in Arkansas. The future projections of water availability are to the year 2050. It is important to note that these estimates of future water availability are intended for statewide and regional planning purposes and are not intended for use outside of the context of the AWP or to replace local water resource planning efforts.

2.1 Surface Water Availability

To estimate the amount of surface water that may be available for use, the AWP Water Supply Availability Technical Work Group concurred that data stemming from the "Excess Surface Water calculations would be used for determining surface water availability in the AWP update. Excess surface water is determined via a calculation of how much surface water there is in a stream less the amount of that water that is excess to the demands and can be considered for nonriparian use or interbasin transfer on an average annual basis. The excess surface water analysis was completed for nine major stream basins as well as select sub-basins that are of special interest within the nine major basins. Excess surface water available in smaller watersheds located at the periphery of the state that flow outward from the state boundary was also analyzed. **Figure 2-1** presents the nine major basins as well as the interior and periphery subbasins for which excess surface water was calculated.

The calculation of excess surface water has two parts: 1) the flow in the river basins, and 2) the amount of water necessary to meet demands. Flow in the rivers was determined as an annual average based on the period of record at 51 gaging stations around the state. Average monthly streamflows were based on either available USGS published values or calculated from the available data and then aggregated to determine average annual flow.

Excess surface water was defined in 1985 by the General Assembly as 25 percent of that amount of water available on an average annual basis above the amount required to satisfy existing and projected needs. Those needs are:

1. Existing riparian rights as of June 28, 1985;
2. The water needs of federal water projects existing on June 28, 1985;
3. The firm yield of all reservoirs in existence on June 28, 1985;
4. Maintenance of instream flows for fish and wildlife, water quality, aquifer recharge requirements, and navigation; and
5. Future water needs of the basin of origin as projected in the state water plan.

The first three of these legislatively determined surface water needs (or demands) are straight-forward and are assumed to be accounted for directly in the streamflow data. The last two require further calculations, assumptions, and projections.

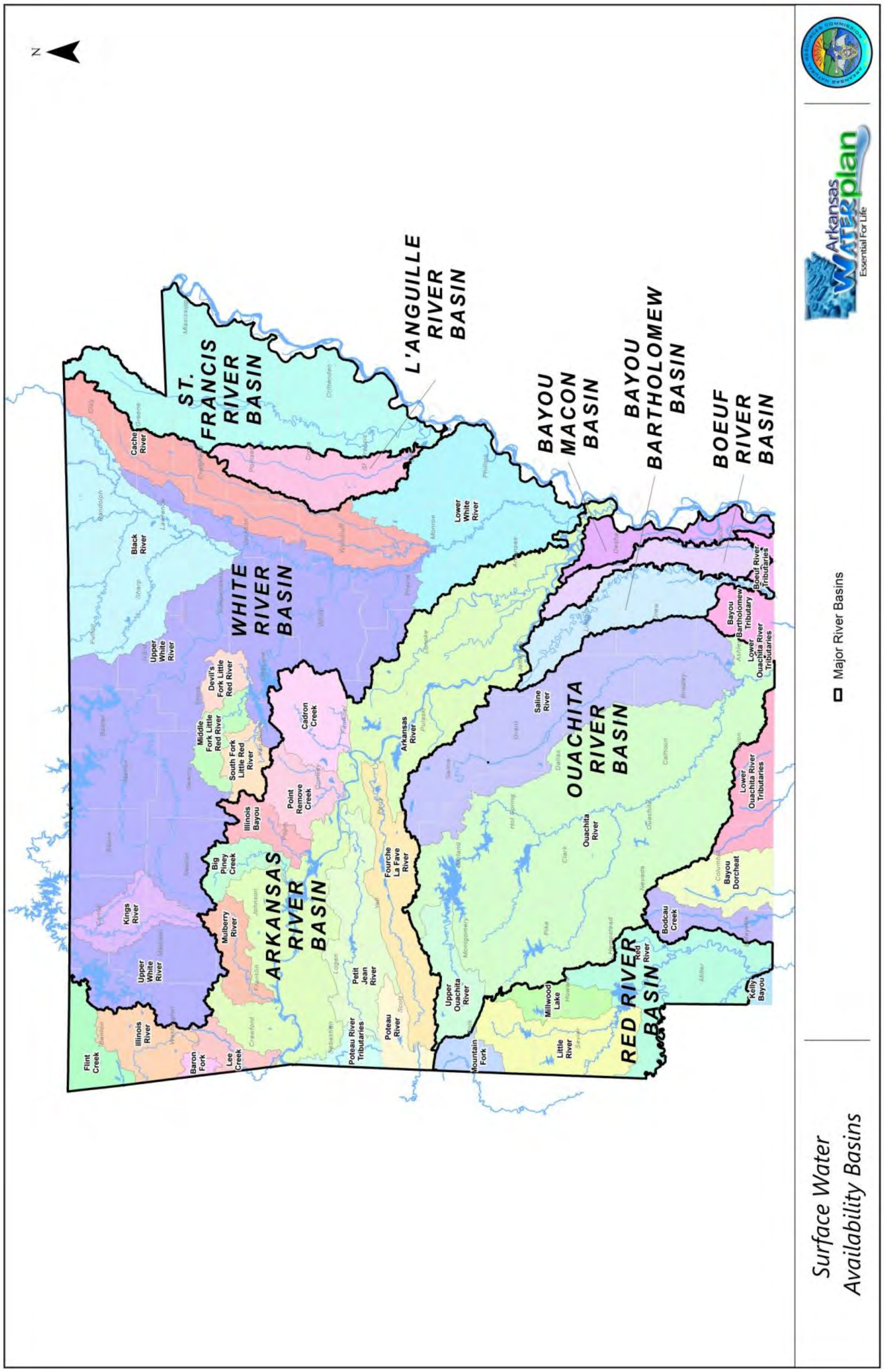

Figure 2-1. Surface Water Availability Basins

The required instream flows are estimated by:

- *Fish and Wildlife Flows* – A specific percentage of stream flow using the Arkansas Method.
- *Water Quality* –Maintaining enough flow in the stream to allow for proper dilution of permitted pollutant discharges to the stream.
- *Aquifer Recharge* –Assumed to be reflected in the streamflow data.
- *Navigation* – Specific navigation flow requirements currently apply only to the Arkansas and White Rivers.

The future water needs of the basin of origin are quantified in the *Water Demand Forecast Report* (CDM Smith 2013) and were applied in the excess water calculations. The excess water available in the 32 river basins is shown in **Table 2-1.** In the table, the nine major river basins are shown in bold text, with their sub-basins listed underneath. As discussed above, excess surface water is determined based on average annual streamflow. However, the calculations incorporate monthly average flow data. For purposes of nonriparian water use and permitting in the White River Basin, the transfer amount shall not exceed on a monthly basis an amount which is 50 percent of the monthly average (for each individual month) of excess surface water as calculated for Table 2-1.

Table 2-1. Calculated Excess Surface Water

Stream/Watershed	Excess Surface Water (AFY)
St. Francis River	670,000
L'Anguille River	90,800
White River	2,141,000
Upper White River	1,742,000
Cache River	161,000
Kings River	42,300
Black River	695,000
South Fork of Little Red River	37,000
Middle Fork of Little Red River	36,300
Devil's Fork of Little Red River	24,600
Arkansas River	3,310,000
Spavinaw Creek (and tribs)	21,200
Flint Creek	3,600
Illinois River	45,000
Baron Fork	6,300
Lee Creek	24,000
Poteau River	29,700
Poteau River Tributaries	15,700
Mulberry River	42,600
Big Piney Creek	3,700
Illinois Bayou	41,700
Point Remove Creek	41,900
Cadron Creek	47,700
Petit Jean River	81,800
Fourche La Fave River	66,000

Table 2-1. Calculated Excess Surface Water

Stream/Watershed	Excess Surface Water (AFY)
Red River	1,140,000
Little River	379,000
Saline River	38,700
Kelly Bayou	4,700
Bodcau Creek	34,600
Bayou Dorcheat	42,600
Mountain Fork	30,500
Ouachita River	979,000
Upper Ouachita River	61,900
Saline River	272,000
Ouachita River Tribs-East	2,900
Ouachita River Tribs-West	46,200
Bayou Bartholomew	89,100
Bayou Bartholomew Tributaries	25,500
Boeuf River	42,300
Boeuf River Tributaries	9,500
Bayou Macon	27,100

It is important to note that, although there is an abundance of surface water available on an average annual basis, the demands for that surface water do not necessarily correlate to the times of year when that water is available in a stream. The supporting monthly or seasonal flow data and, if necessary, additional streamflow characterizations (e.g., low flow characteristics, etc.) will be used in the gap analyses, which will be performed to identify areas of water surplus and deficit and to develop strategies to take advantage of that surplus or to overcome deficits.

One of the current and future needs that are included in the excess water calculations is how much water should be left in the stream to support fish and wildlife flows. As noted above, excess water calculations apply the Arkansas Method to quantify fish and wildlife flows. There is recognition that there should be a process to use alternative approaches to determining fish and wildlife flows. A process for proposing an alternative approach and how that approach would be evaluated for approval by the ANRC is provided in Section 7 of this report.

2.2 Groundwater Availability

Currently, about 71 percent of the water supply in the state is provided from groundwater sources. Groundwater availability and use are very different in different parts of the state, controlled primarily by geology. Arkansas is typically divided into two major geologic subdivisions—the Interior Highlands of northern Arkansas, which generally consist of consolidated Paleozoic formations, and the largely unconsolidated formations of the Gulf Coastal Plain of the southern and eastern regions of the state. Most of Arkansas' groundwater production is from sand and gravel aquifers in the Mississippi River Embayment of the Gulf Coastal Plain. Because of the high water demand in the southern and eastern portion of the state (East Water Resource Planning Region), the focus of quantitative water availability estimates for this area. The water availability in the other planning regions is based on existing research and is qualitative in nature.

In simple terms, the availability of groundwater in the aquifers in the East Water Resources Planning Region can be estimated based on the thickness of groundwater in the aquifers and the ability of the aquifers to transmit (yield) water. The concept is simple, but the calculations are complex and require the assistance of computer-based modeling to complete. The USGS has developed a computer model of this area and that model was used to estimate the water availability out to the year 2050 for the 2014 AWP. The groundwater availability estimate for this area was developed by running the USGS model with the future groundwater demands from the *Water Demand Forecast Report* (CDM Smith 2013) to calculate the effect on the aquifers. The effect of groundwater use is generally demonstrated by declines in water level in the aquifer. The decline in water level impacts the ability to pump water from the aquifer. The modeling effort was used to calculate the difference between the amount of water needed and the amount of water that can be pumped from the aquifer under different pumping scenarios. The pumping scenarios included unconstrained pumping which allows mining (depleting) the aquifer and constrained pumping which maintains specified levels of water in the aquifer.

As illustrated in **Table 2-2**, the East Water Resource Planning Area is forecasted to have a groundwater supply gap in 2050 of between 5,600 and 7,200 million gallons per day [mgd] (about 6,200,000 and 8,000,000 acre-feet per year [AFY]). The resulting water level declines from the projected pumping are shown on a county-by-county basis on the figures in Section 5.

Table 2-2. Summary of Model Results for Sustainable and Mining Scenarios for the Alluvial, Sparta, and Wilcox Aquifers

Scenario	Pumping Level Limitation	Climate Assumption	Groundwater Demand 2050	Available Groundwater Capacity	Groundwater Supply Gap 2050
1	None	Dry		3,070 mgd	5,890 mgd
2		Wet		3,320 mgd	5,640 mgd
3	Water level declines limited to original water in the original thickness of the aquifer	Dry	8,960 mgd	1,770 mgd	7,190 mgd
4		Wet		2,030 mgd	6,930 mgd

In the western and northern portions of Arkansas (North, West-central, South-central, and Southwest) the hydrogeologic conditions are such that groundwater supply is generally limited. However, current demands for groundwater are being met and the projected demands for groundwater are not anticipated to increase significantly. Overall, no groundwater supply gap is projected for the Water Resource Planning Regions, other than the East Water Resource Planning Regions. This is an overall assessment that may not be applicable to specific areas. The gap analysis will be used to identify areas where a gap between groundwater demand and supply may occur in the future.

2.3 Water Quality

The availability of water for use is tempered by the quality of the water. If the water quality is unsuitable for the intended use, then one or a combination of actions are necessary to mitigate water quality: improve the water quality by controlling the contribution of pollutants, find an alternate source of water, or treat the water so that it meets the quality requirements for use.

2.3.1 Surface Water Quality

Surface water quality is judged by comparing measurements of chemical constituents in water to water quality criteria that have been established for different water uses. Surface water quality that does not meet water quality criteria is considered "impaired." Impairments are determined for segments of streams and for lakes separately. **Table 2-3** shows the statewide assessment of water uses that cannot be met by the measured surface water quality as reported in 2008. (Note that more recent statewide water quality assessments have been completed. The assessment from 2008 is used here because it is the most recent assessment that has been approved by the US Environmental Protection Agency [EPA].) Surface water quality affected the use of water for recreation (fishing and primary contact) and water supply (domestic, agricultural, and industrial) in 2008. The only water use that was not impacted by water quality was secondary recreational contact.

Table 2-3. Water Uses not Supported by the Measured Surface Water Quality as Reported in 2008

Water Use	% of Assessed Stream Miles Considered Impaired	% of Assessed Lake Acres Considered Impaired
Consumption of Fish by Humans	4%	7%
Aquatic Life	25%	3%
Primary Contact(e.g., full immersion)	6%	0%
Secondary Contact (e.g., incidental immersion)	0%	0%
Domestic Water Supply (no water treatment before consumption)	5%	27%
Agricultural and Industrial Water Supply	10%	0%

2.3.2 Groundwater Quality

While surface water quality is measured and reported in surface water features (lakes and streams), groundwater quality is measured and reported in aquifers. As noted in Section 2.2, the aquifers of Arkansas are geographically and geologically distinct: the Coastal Plain of eastern Arkansas and the Interior Highlands of western Arkansas.

The information on groundwater quality comes entirely from the draft "Aquifers of Arkansas: Protection, Management, and Hydrologic and Geochemical Characteristics of Arkansas' Groundwater Resources" (Kresse et al. in review). Groundwater quality information was compiled from more than 500 historical and recent publications and from greater than 8,000 sites with groundwater quality data. The water quality data measurements were obtained from the USGS National Water Information System (NWIS) database and the Arkansas Department of Environmental Quality (ADEQ) and entered into a spatial database to investigate distribution and trends in groundwater quality constituents for each of the aquifers.

Aquifers in the Coastal Plain Province consist of various geologic units with generally good water quality, except for elevated iron concentrations and localized areas of high salinity. In the Coastal Plain, the prevalence of long regional flow paths resulted in regionally predictable and mappable geochemical changes along these flow paths. Trends for individual water quality constituents were generally elevated iron and nitrate concentrations with lower pH values and dissolved solids in the outcrop areas, transitioning to lower iron and nitrate and higher pH and dissolved solids downgradient in the formations. In general, groundwater quality is not currently impacting the use of groundwater in this area. However, as the groundwater gap begins to impact groundwater availability, actions to improve the groundwater quality in downgradient areas may have to be considered.

The aquifers in the Interior Highlands region of western Arkansas generally occur in shallow, fractured, well-indurated, structurally-modified bedrock of this mountainous region of the state. In the Interior Highlands, short, topographically controlled flow paths (from hilltops to valleys) within small watersheds represent the predominant groundwater flow system. Changes in groundwater quality are dominantly noted to be related to rock type and residence time along individual flow paths. In general, the groundwater quality is adequate for the existing uses, although in the Ozark and Springfield Plateau aquifers, rapid influx of surface- derived contaminants, especially nitrogen, threaten the groundwater quality in these areas.

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Section 3

Surface Water Availability

3.1 Introduction

This section describes the process for estimating surface water availability. This analysis of available surface water is completed for the nine major river basins as well as select sub-basins within the nine major basins that are of special interest. Surface water available in smaller watersheds located at the periphery of the state that flow outward from the state boundary was also analyzed.

3.2 Background

Arkansas is a riparian reasonable use state with some legislation to deal with emerging issues. Riparian use of water is a property right. Riparian land touches a lake, stream, river, or other watercourse. Riparian landowners may use water on the property, but can be limited if their use unreasonably harms another riparian's use. No permission or permit is required from the government before a riparian owner uses water. However, in Arkansas all surface water withdrawals are required to be registered with the ANRC. The ANRC Rules for the Utilization of Surface Water provide a mechanism for nonriparian owners to divert excess surface water for nonriparian use upon approval of the ANRC, if the water will be applied to reasonable and beneficial use and the diversion will cause no significant adverse environmental impact.

If a person does not already possess a riparian right to use a stream, they can apply for a Nonriparian Water Use (NRWU) Permit. This permit allows an entity to use water that is not adjacent to their land. However, before approving a NRWU Permit application, the ANRC must first determine that excess surface water exists. In 1985, the General Assembly defined "excess surface water" to be 25 percent of that amount of water available on an average annual basis above the amount required to satisfy existing and projected needs. Those needs included:[1]

1. Existing riparian rights as of June 28, 1985;
2. The water needs of federal water projects existing on June 28, 1985;
3. The firm yield of all reservoirs in existence on June 28, 1985;
4. Maintenance of instream flows for fish and wildlife, water quality, aquifer recharge requirements, and navigation; and
5. Future water needs of the basin of origin as projected in the state water plan.

Excess surface water estimates were previously established in the 1990 Water Plan. These estimates have been updated based on data collected since the last AWP update.

[1] A.C.A. § 15-22-304 and A.C.A. § 15-22-202.

3.3 Excess Surface Water

The basis of the excess surface water availability analysis was existing streamflow data. Streamflow data are collected by the U.S. Geological Survey (USGS) and the U.S. Army Corps of Engineers (USACE). Streamflow data collection sites within each river basin were selected based on the availability of adequate data and relevance to the required calculations. Additional consideration was given to those stations used in the 1990 AWP. Additional sources of data were identified (e.g., operational data for the Huxtable Pumping Station on the St. Francis River), and if appropriate relevant data were incorporated into the analysis.

3.3.1 Streamflow Data

Fifty-one USGS gage stations were used to calculate excess surface water availability for the 2014 AWP update. **Table 3-1** presents a list of the gages used to determine excess surface water in both the 1990 and 2014 AWP updates. Gages used in this analysis that were also used in the USGS streamflow trend analysis study (to be published in late 2013) are indicated. The stream gages used for this analysis were selected based on:

- Gaging stations used for the 1990 AWP
- Location with respect to specific watersheds
- Period of record and quality of the data

Excess surface water is estimated on an annual average basis. Average monthly streamflows were based on either available USGS published values or calculated from the available data and then aggregated to determine average annual flow. Entire periods of record were not used in cases where significant changes to the flow regime in a basin have occurred (e.g., impoundment and stream regulation such as in the Upper White River Basin). When appropriate, consistent periods of record were generally used to calculate average annual flows for sub-basins within a major river watershed (e.g., the Saline River within the Ouachita River Basin). However, it was recognized that there were several cases when the available periods of record were not consistent and the actual periods of record used for analyses were selected on a case-by-case basis.

For basins or sub-basins where significant data gaps exist in the gage records, numerical techniques were applied to estimate streamflows to the extent necessary. The primary technique that was used was the drainage area ratio method. This method applies drainage area ratios to surrogate gage records to estimate flows for the study basin. **Appendix A** to this report includes a summary of the calculation method and relevant assumptions for each basin for which excess surface water was calculated. **Appendix B** presents the calculation spreadsheets used for each basin along with maps of each basin and sub-basin analyzed. The maps also show each gage used in the analyses.

Table 3-1. Summary of USGS Gage Stations used to Calculate Excess Surface Water

River Basin	USGS Station Number	Station Name	Gage Status	Used for 1990 AWP Update	Used for 2014 AWP Update	Used for USGS Trend Analysis
St. Francis	7047800	St. Francis River at Parkin, AR	Active	•	•	•
	7047900	St. Francis Bay at Riverfront, AR	Active	•	•	
L'Anguille	7047950	L'Anguille River at Palestine, AR	Active		•	

Table 3-1. Summary of USGS Gage Stations used to Calculate Excess Surface Water

River Basin	USGS Station Number	Station Name	Gage Status	Used for 1990 AWP Update	Used for 2014 AWP Update	Used for USGS Trend Analysis
White	7050500	Kings River near Berryville, AR	Active		•	
	7072500	Black River at Black Rock, AR	Active		•	•
	7074000	Strawberry River near Poughkeepsie, AR	Active		•	
	7074420	Black River at Elgin Ferry, AR	Active		•	
	7074500	White River at Newport, AR	Active	•		•
	7075000	Middle Fork of Little Red River at Shirley, AR	Active		•	
	7075300	South Fork of Little Red River near Clinton, AR	Active		•	
	7075500	South Fork of Little Red River near Clinton, AR	Inactive		•	
	7077000	White River at DeValls Bluff, AR	Active	•	•	
	7077555	Cache River near Cotton Plant, AR	Active		•	
	7077800	White River at Clarendon, AR	Inactive	•		
Arkansas	7195430	Illinois River south of Siloam Springs, AR	Active		•	
	7195855	Flint Creek near West Siloam Springs, AR	Active		•	
	7196900	Baron Fork at Dutch Mills, AR	Active		•	•
	7191220	Spavinaw Creek near Sycamore, OK	Active		•	
	7249985	Lee Creek near Short, OK	Active		•	•
	7247000	Poteau River at Cauthron, AR	Active		•	•
	7247250	Black Fork below Big Creek near Page, OK	Active		•	
	7249400	James Fork near Hackett, AR	Active		•	•
	7249447	Mill Creek at Fort Smith, AR	Inactive		•	
	7252000	Mulberry River near Mulberry, AR	Active		•	•
	7257006	Big Piney Creek at Hwy 164 near Dover, AR	Active		•	•
	7257500	Illinois Bayou near Scottsville, AR	Active		•	
	7260500	Petit Jean River at Danville, AR	Active		•	•
	7260673	West Fork Point Remove Creek near Hattieville, AR	Active		•	
	7261000	Cadron Creek near Guy, AR	Active		•	•
	7261500	Fourche La Fave River near Gravelly, AR	Active		•	•
	7263450	Arkansas River near Murray Dam near Little Rock, AR	Active	•	•	
Red	7338750	Mountain Fork at Smithville, OK	Active		•	
	7340000	Little River near Horatio, AR	Active		•	•
	7340500	Cossatot River near DeQueen, AR	Inactive		•	
	7341200	Saline River near Locksburg, AR	Active		•	
	7341500	Red River at Fulton, AR	Inactive	•		
	7344370	Red River at Spring Bank, AR	Active		•	
	7344400	Red River near Hosston, LA	Inactive	•	•	
	7347000	Kelly Bayou near Hosston, LA	Inactive		•	
	7348700	Bayou Dorcheat near Springhill, LA	Active		•	•
	7349500	Bodcau Bayou near Sarepta, LA	Active		•	

Table 3-1. Summary of USGS Gage Stations used to Calculate Excess Surface Water

River Basin	USGS Station Number	Station Name	Gage Status	Used for 1990 AWP Update	Used for 2014 AWP Update	Used for USGS Trend Analysis
Ouachita	7356000	Ouachita River near Mt Ida, AR	Active		•	•
	7362000	Ouachita River at Camden, AR	Active	•	•	•
	7362100	Smackover Creek near Smackover, AR	Active		•	
	7362500	Moro Creek near Fordyce, AR	Active		•	
	7363500	Saline River near Rye, AR	Active		•	•
	7364100	Ouachita River near AR/LA State Line	Inactive	•		
	7364300	Chemin-A-Haut Bayou near Beekman, LA	Inactive	•	•	
	7364700	Bayou De Loutre near Laran, LA	Inactive	•	•	
	7365800	Cornie Bayou near Three Creeks, AR	Inactive	•	•	
	7365900	Three Creeks near Three Creeks, AR	Inactive	•	•	
	7366200	Little Cornie Bayou near Lillie, LA	Active	•	•	•
Bayou Bartholomew	7364200	Bayou Bartholomew near Jones, LA	Active	•	•	•
Boeuf River	7367700	Boeuf River near AR/LA State Line	Inactive	•	•	
Bayou Macon	7369700	Bayou Macon near Kilbourne, LA	Active	•	•	

NOTE: Gage operational status as of September 30, 2012

3.3.2 Flow Adjustments

To determine the excess surface water in a given basin, the average annual yield was adjusted to account for the following:

- Existing uses
- Instream Flow Requirements
  - Fish and wildlife flows
  - Water quality
  - Aquifer recharge requirements
  - Navigation
- Future demands as determined through demand forecasts developed for the current AWP update

After accounting for the above, the remaining average annual volume is multiplied by 25 percent to estimate total excess surface water in the basin.

Additional rules apply with regard to nonriparian withdrawals from the mainstem of the White River. For the White River Basin, A.C.A. § 15-22-304 (e) states: the transfer amount shall not exceed, on a monthly basis, an amount which is 50 percent of the monthly average of each individual month of excess surface water. This limits any individual nonriparian user to 50 percent of the total calculated excess surface water in the mainstem of the White River.

3.3.2.1 Existing Uses

Existing surface water uses were generally taken as being accounted for directly in the streamflow data. That is, current surface water withdrawals are generally reflected in the streamflow data itself when that data is relatively current. In specific cases where continuous streamflow data is not current (e.g., the Boeuf River), the difference between the demands estimated for the base year in the current AWP update and the surface water demands estimated in the 1990 plan were deducted.

3.3.2.2 Instream Flow Requirements

Instream flow requirements were determined and incorporated into the calculations as appropriate. Instream flow requirements for the different categories are not additive. The highest instream need represents the amount of water required to satisfy all the existing instream needs at the selected location.

Fish and Wildlife Flows

For the current AWP update, the Arkansas Method was used to determine fish and wildlife flow requirements for each stream analyzed. This is the same method used for the 1990 AWP update. The Arkansas Method divides the water year into three seasons and a specified percentage of the mean monthly flow is calculated as the instream requirement for fish and wildlife. The seasons and the percentage of flow required for each season are as follows:

- November through March – 60 percent
- April through June – 70 percent
- July through October – 50 percent

Water Quality

The 7Q10 low-flow characteristic is commonly used in establishing effluent discharge limits for National Pollutant Discharge Elimination System (NPDES) permits. The 7Q10 is the lowest 7-day average flow that occurs on average once every 10 years. This characteristic was used as the instream flow requirement for water quality. To the extent practicable, published values were used in the calculations. The individual basin calculation spreadsheets document the source of 7Q10 values used and how, if any, adjustment was made in the calculations.

Aquifer Recharge

Requirements for aquifer recharge were not calculated for direct use in this analysis. It is generally recognized that the net effect of aquifer recharge that may be occurring for a given stream is reflected in the streamflow data, particularly on a mean monthly and mean annual basis. Basin instream flow requirements necessary to recharge aquifer depletions were not investigated in this report. Also, because fish and wildlife flow requirements are generally the controlling values in the calculations and represent such a significant fraction of the average annual flow, no additional detailed analysis was deemed warranted.

Specific navigation flow requirements currently apply only to the Arkansas and White Rivers in Arkansas. The target minimum flow necessary for commercial navigation for the Arkansas River is 3,500 cubic feet per second (cfs) at Van Buren and 3,000 cfs at Little Rock. The target flow for navigation used for the excess surface water calculation on the White River is 9,650 cfs. This flow is based on USACE's authorization for maintenance of a navigation channel for 8-foot draft barges from the lower end of the river up to Augusta and for 4.5-foot draft barges from Augusta to Newport. It is the same flow rate used for the 1990 update of the AWP. It is recognized that without maintenance (i.e., channel in a more natural state), higher flows may be necessary to satisfy real time navigation requirements. Maintenance is dependent upon USACE receiving funding authorization from Congress, and although that funding is not necessarily provided each year it is appropriate to use the flows associated with the authorized navigation purposes for excess surface water calculation.

3.3.2.3 Projected Demands

Projected surface water demands for each basin and sub-basin analyzed were provided by the Water Demand Working Group. Projected surface water demands were subtracted from the calculated available annual flow after adjustment for instream flow needs.

3.3.3 Excess Surface Water Available

Table 3-2 presents a summary of the excess surface water available for interbasin transfer or use by nonriparians on an average annual basis. The calculation spreadsheets in Appendix B include the mean monthly streamflow along with the total average annual flow that is available for each watershed analyzed. It is important to note that, although there is an abundance of water available on an average annual basis, the demands for that water do not necessarily correlate to the times of year when that water is available in a stream. The supporting monthly or seasonal flow data and, if necessary, additional streamflow characterizations (e.g., low flow characteristics, etc.) will be used in the gap analyses, which will be performed to identify areas of water surplus and deficit and to develop strategies to take advantage of that surplus or to overcome deficits.

Table 3-2. Calculated Excess Surface Water Available for Interbasin Transfer or Nonriparian Use

Stream/Watershed	Calculation Point	Excess Surface Water (AFY)
St. Francis River	Mouth	670,000
L'Anguille River	Mouth	90,800
White River	Mouth	2,141,000
Upper White River	Confluence with Cache River	1,742,000
Cache River	Mouth	161,000
Kings River	State Line	42,300
Black River	Mouth	695,000
South Fork of Little Red River	U/S of Greers Ferry Lake	37,000
Middle Fork of Little Red River	U/S of Greers Ferry Lake	36,300
Devil's Fork of Little Red River	U/S of Greers Ferry Lake	24,600
Arkansas River	Mouth at MS River	3,310,000
Spavinaw Creek (and tribs)	AR/OK & AR/MO State Line	21,200
Flint Creek	AR/OK State Line	3,600
Illinois River	AR/OK State Line	45,000
Baron Fork	AR/OK State Line	6,300
Lee Creek	Mouth	24,000
Poteau River	AR/OK State Line	29,700
Poteau River Tributaries	AR/OK State Line	15,700
Mulberry River	Mouth	42,600
Big Piney Creek	Mouth	3,700
Illinois Bayou	Mouth	41,700
Point Remove Creek	Mouth	41,900
Cadron Creek	Mouth	47,700
Petit Jean River	Mouth	81,800
Fourche La Fave River	Mouth	66,000
Red River	AR/LA State Line	1,140,000
Little River	U/S of Millwood Lake	379,000
Saline River	U/S of Millwood Lake	38,700
Kelly Bayou	AR/LA State Line	4,700

Table 3-2. Calculated Excess Surface Water Available for Interbasin Transfer or Nonriparian Use

Stream/Watershed	Calculation Point	Excess Surface Water (AFY)
Bodcau Creek	AR/LA State Line	34,600
Bayou Dorcheat	AR/LA State Line	42,600
Mountain Fork	AR/OK State Line	30,500
Ouachita River	AR/LA State Line	979,000
Upper Ouachita River	U/S of Lake Ouachita	61,900
Saline River	Mouth	272,000
Ouachita River Tribs-East	AR/LA State Line	2,900
Ouachita River Tribs-West	AR/LA State Line	46,200
Bayou Bartholomew	AR/LA State Line	89,100
Bayou Bartholomew Tributaries	AR/LA State Line	25,500
Boeuf River	AR/LA State Line	42,300
Boeuf River Tributaries	AR/LA State Line	9,500
Bayou Macon	AR/LA State Line	27,100

3.4 U.S. Army Corps of Engineers Projects

An updated summary of USACE reservoir projects used for water supply has been prepared by the USACE and is documented in the Institute for Water Resources (IWR) Publication 2012-R-02, 2011 Municipal and Industrial (M&I) Water Supply Database, dated April 2012. This report provides data on projects operated and maintained by the USACE that contain storage space for M&I water supply, including those projects located in Arkansas. Data in the reports are limited to those projects where storage has been authorized and/or is under a repayment through either a storage or surplus water agreement. The data are current as of December 31, 2011, and updates the 2010 data contained in IWR Report 2011-R-06 dated June 2011. The document provides detailed breakdowns of the current storage allocations for USACE projects. It is the intent of USACE to issue this report on an annual basis. As an example of a reservoir allocation, **Table 3-3** presents the water supply allocation for Greers Ferry Lake as of February 2012 based on information provided directly by the Little Rock District of the USACE.

Table 3-3. Water Supply Allocation for Greers Ferry Lake

USER	STORAGE ALLOCATION (Contract Amount) (acre-feet)	YIELD (mgd)
City of Heber Springs	1,032.953	0.835
City of Heber Springs (pending)	3,554.102	2.873
Community Water System	228.858	0.185
Community Water System Phase 1	3,818.835	3.087
Community Water System Phase 2	4,329.745	3.500
Red Apple Inn CC	65.565	0.053
Thunderbird CC	55.668	0.045
Tannenbaum Golf Course	90.306	0.073
City of Clinton	912.958	0.738
City of Clinton	2,179.717	1.762
Mid-Arkansas Water Alliance	18,556.050	15.000
Unallocated	15,175.243	??

The narrative below describes the general process required for contracting with the USACE for withdrawals from USACE projects and for reallocation of storage.

3.4.1 Contracting with USACE for Reservoir Storage

Based on discussions with Little Rock District (LRD) Corps of Engineers personnel and their responses to requests for data and information, the following information is the general understanding with respect to contracting directly with the USACE for storage in a USACE reservoir. Two scenarios are addressed herein. The first is for a "Surplus Water Supply Contract" for the withdrawal of water only when a lake is above normal (conservation) pool (Section 4.4.1). The second is for a "Conventional Water Supply Contract (Section 4.1.2)." It is important to note that although these contract vehicles are referred to as "water supply contracts," the USACE does not have jurisdiction over the water but rather is contracting for storage volume in the reservoirs. Surface water withdrawals from the USACE projects are subject to registration and/or permitting, as applicable.

3.4.1.1 Surplus Water Supply Contracts

1. Withdrawals from a USACE lake, when the lake level is above the top of conservation pool could conceivably be made under a "Surplus Water Supply Contract" between an entity and the USACE. The process would be initiated by a written request from the contracting entity to the USACE District describing the reason for the withdrawal, etc., including potential quantity of withdrawal. The decision as to whether or not the contracting process would proceed would be made by either the Chief of Operations or by the District Engineer. Very early in the process, a meeting should be scheduled so that everyone understands the request and the process. There would be a significant number of contract stipulations with respect to this type of contract in order to preclude misuse. Approximate minimum time for completing the contracting process would likely be on the order of 6 months. If it were determined that there were no significant concerns, the process may move along more quickly.

2. Because this contract would be a federal action, an environmental assessment (EA) pursuant to the National Environmental Policy Act (NEPA) would likely be required. Assuming a "Finding of No Significant Impact" (FONSI), the technical component of this process would likely take a minimum of 6 months to complete (potentially 6 to 12 months). Historically, when a request was made for the withdrawal, and it was determined that an EA would be required, the Corps would have to request funding for the study, which would be performed by the Corps when funding became available. As of 2012, revised federal legislation provides a mechanism whereby an entity requesting a withdrawal can provide the funding to perform the required studies.

3. Permanent intake structures would probably be required, with withdrawal sites specifically identified and included in the contract.

4. The intake elevation would have to be above the top of the conservation pool. An example is that the lowest withdrawal point might be 8 inches above the top of the conservation pool. It is understood that if a user under this type of contract were ever found to be in breach of the contract stipulations, particularly constraints on the withdrawal (e.g., none in the conservation pool), they would lose the right to utilize the water.

5. An easement would also be required for installations and pipelines located within the boundary of the USACE "white line," which is a horizontal boundary defined at a specified measurement vertically above the top of the flood pool. The USACE typically owns or has flowage easement up to specified elevations around a project lake. However, up tributaries, flowage easements can go up to different elevations. Consent to easement will be necessary for any intake pipe or structure on USACE flowage easements.

3.4.1.2 Conventional Water Supply Contracts

1. When there is a portion of the USACE discretionary authorization in the conservation pool of a reservoir that is unallocated, there is the potential for entering into a "Water Supply Contract" for withdrawals from the conservation pool. This would be the type of contract typically utilized. Assuming these reallocation requests proceed, each reservoir has a known volume of storage that could potentially be reallocated.

2. The process for entering into a Water Supply Contract would also be initiated by a written request to the USACE. A reallocation study and an EA would be required. These studies are performed by the USACE (or by one of its contractors). Studies have typically been either 100 percent government funded or 50 percent cost share. At present, there is a mechanism by which the requesting party can fully fund the studies in order that they may proceed. The technical aspects of this process could potentially be completed in about one year (assuming a FONSI). However, historically the process has taken a minimum of 3 years, and can take as long as 7 years. The process time line is dependent on complexity and effects to existing project purposes. As an example, the Mid-Arkansas Water Alliance (MAWA) contract (for Greers Ferry Lake) wasn't signed until May 2010, even though the EA for the MAWA contract was finalized in 2007. Under this type of contract, the user pays for the capital cost of the storage allocated to the user. The USACE uses an extensive process to determine the current basis for this cost, amortized over a maximum of 30 years.

3. To complete the process, a Water Reallocation Study must be conducted and the resulting report completed and approved by the Assistant Secretary of the Army (ASA) for Civil Works (CW). A reallocation report is separate from a reallocation action. A reallocation report can include future needs, but a reallocation action can only be in the context of satisfying immediate needs. A reallocation action is not complete until a water supply agreement for those immediate needs is approved. The agreement can be approved at the District level up to the level of the ASA (CW) depending on the quantity of storage being reallocated. Congressional approval is necessary when the determination that reallocation would seriously affect the purposes that were authorized, surveyed, planned, constructed, or which would involve major structural/operational changes. Any new reallocation agreement must provide the states or other entities with financial incentives not available elsewhere and the use of existing storage in USACE facilities must be cheaper for the potential user than the construction of new or additional facilities. Reallocation to water supply can include the permanent transfer of storage from authorized uses such as flood control, hydropower, other conservation, or sediment pools.

   The Water Reallocation Study will include the following:

   A. Identity and quantity of the new use of the storage and name of the user;

   B. Evaluation of impacts to other project purposes and users;

   C. Determination of environmental effects;

      a. National Environmental Policy Act Documentation (i.e., Environmental Assessment with FONSI or Environmental Impact Statement);

   D. Determination of price to be charged to the new user; and

   E. Determination of appropriate compensation, if any to existing users/beneficiaries.

4. The user also pays an annual operation and maintenance (O&M) cost associated with this allocation in perpetuity. Sponsors (contracted entities) are responsible for their pro-rata share of additional costs required to operate and maintain the project. These costs consist of annual O&M expense; repair, replacement, rehabilitation, and reconstruction costs; and dam safety assurance costs.

5. Once contracted, an ongoing accounting of inflows, outflows, losses, and user withdrawals is made. An entity retains 100 percent of its allocation as long as the water surface is above the top of the conservation pool. When the water surface of the lake drops below the top of the conservation pool, the contracted storage remaining for a given entity is computed based upon the previously mentioned parameters on a monthly basis. An entity's contracted storage remaining is debited each month based upon its water usage and its prorated share of lake losses. Additionally, an entity's contracted storage remaining is credited each month based upon its prorated share of lake inflows. An entity's contracted storage remaining will decrease when the sum of its water usage withdrawals and its prorated share of lake losses exceed its prorated share of lake inflows; its contracted storage remaining will increase when its prorated share of lake inflows exceed the sum of its water usage withdrawals and its prorated share of lake losses. Whenever the lake level rises to or above the conservation pool, an entity's contracted storage remaining is reset to 100 percent of its allocation because the conservation pool has been regained.

The simplest and fastest way for an entity to obtain water from a USACE project would be to enter into an agreement with one of the entities that already has a storage allocation and Water Supply Contract in place. This could either be through an entity that already has a withdrawal point (e.g., City of Heber Springs, Community Water System, etc. on Greers Ferry Lake) or through the addition of a new withdrawal point (which may require an EA) for an existing entity.

3.4.2 USACE Reservoirs in Arkansas

Table 3-4 provides a current summary of USACE reservoir projects in the state including authorized purposes and their current use as a water supply source. Where water supply is not indicated as an authorized purpose of the reservoir but water supply use is shown, such use has generally been created through reallocations of storage from the authorized purposes.

Table 3-4. USACE Reservoirs in Arkansas

Lake/Dam	USACE District	River	Authorized Purposes*	Current Water Supply Use?
Beaver	Little Rock	White River	FC, P, WS, R	Yes
Table Rock	Little Rock	White River	FC, P	Yes
Bull Shoals	Little Rock	White River	FC, P	Yes
Norfork	Little Rock	North Fork River	FC, P	Yes
Greers Ferry	Little Rock	Little Red River	FC, P	Yes
Blue Mountain	Little Rock	Petit Jean River	FC	Yes
Nimrod	Little Rock	Fourche La Fave River	FC	Yes
DeQueen	Little Rock	Rolling Fork River	FC, WS, WQ, R, FW	Yes
Gillham	Little Rock	Cossatot River	FC, WS, WQ, R, FW	Yes
Dierks	Little Rock	Saline River	FC, WS, R, FW	Yes
Millwood	Little Rock	Little River	FC, WS, R, FW	Yes
Ouachita/BlakelyMountain	Vicksburg	Ouachita River	FC, N, R, P	Yes
Greeson/Narrows	Vicksburg	Little Missouri River	FC, P, R	No
DeGray	Vicksburg	Caddo River	FC, WS, R, P	Yes

*FC = Flood Control; P = Power; WS = Water Supply; R = Recreation; WQ = Water Quality; FW = Fish and Wildlife Enhancement; N = Navigation

3.5 Interstate Compacts

3.5.1 Arkansas River Compact

The Arkansas River Compact is an interstate compact negotiated and signed by the states of Arkansas and Oklahoma. The area involved is "the Arkansas River Basin immediately below the confluence of the Grand-Neosho River with the Arkansas River near Muskogee, Oklahoma, to a point immediately below the confluence of Lee Creek with the Arkansas River near Van Buren, Arkansas, together with the drainage basin of Spavinaw Creek in Arkansas, but excluding that portion of the drainage basin of the Canadian River above Eufaula Dam"(**Figure 3-1**) The compact has multiple purposes including to provide for an equitable apportionment of the waters of the Arkansas River between the states of Arkansas and Oklahoma and to promote their orderly development.

The apportionment of the waters of the Arkansas River Basin is defined in Article IV of the compact. This article provides for each state's rights to develop and use the waters of particular sub-basins, with limitations that the annual yield (as defined in the compact) shall not be depleted beyond specific percentages.

The annual yield of the interstate compact areas is to be determined by December 31 of each year. The flows are calculated on an annual basis and included in the Arkansas Compact Commission report. If depletion of the flows is greater than that specified in the compact, steps are to be taken to assure that 60 percent of the current runoff be delivered to the downstream state.

3.5.2 Red River Compact

Arkansas is part of the Red River Compact that is an interstate compact agreement among the states of Arkansas, Oklahoma, Texas, and Louisiana. One purpose of the compact is to promote comity among these participating states by cooperating in the equitable apportionment and development of the water in the river basin as provided by the agreement. There are five defined reaches in the Red River Basin. The Red River basin in Arkansas is included in Reach II (**Figure 3-2**). The Ouachita River, Bayou Bartholomew, Bayou Macon, and Boeuf River basins are included in Reach IV. The area covered by the compact includes essentially all watersheds in Arkansas located south of the Arkansas River watershed boundary.

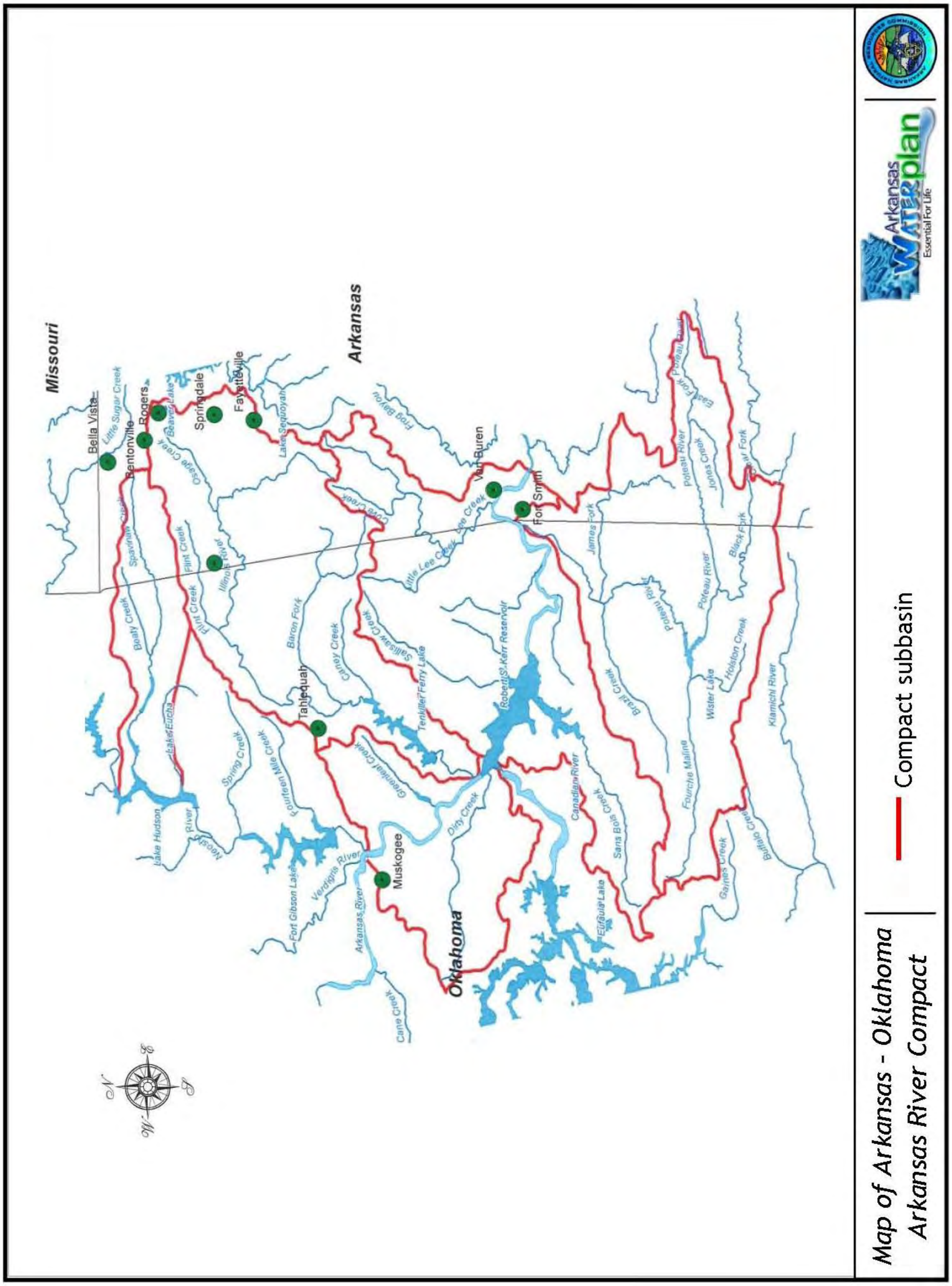


Figure 3-1. Map of Compact Areas and Basins

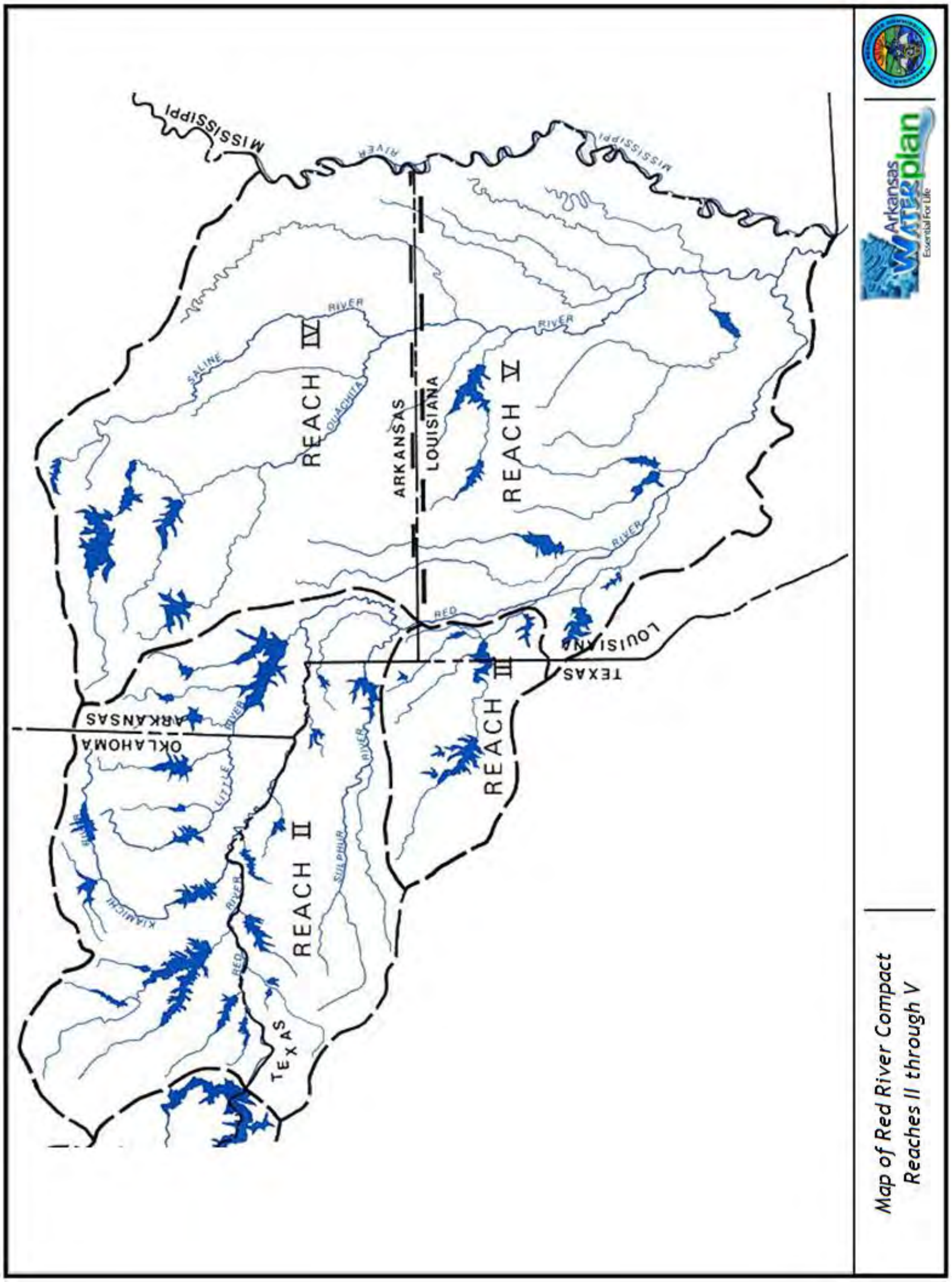


Figure 3-2. Map of Compact Areas and Reaches

The compact provides specific criteria for the apportionment of water in each reach to the various states. According to Article II, Section 2.01 of the compact, each affected state may use the water allocated to it by the compact in any manner deemed beneficial by that state. Each state may freely administer water rights and uses in accordance with the laws of that state, but such uses shall be subject to availability of water in accordance with the apportionments made by the compact.

In the previous update of the AWP, it was recognized that the amount of water required to satisfy compact requirements could not be quantified for multiple reasons. The first reason is that for certain reaches compact compliance is based on a percentage of total runoff in a basin. Runoff, as defined in the compact, includes flow in the streams and water that has been diverted from the streams for other uses. The amount of water that is diverted from streams is not accurately quantified (on a real-time basis); therefore, the amount of runoff in the basins is unknown. Another reason the compact requirements cannot be quantified is because the requirements are based on the previous week's runoff and diversions. Therefore, the compact requirements change from week to week, depending on the runoff available in a basin the previous week. Using average weekly discharge for the period of record would give an idea of the weekly discharges that could be expected at a specific location (where such data is available). However, the compact requirements cannot be determined using these data since the requirements are based on a percentage of the actual weekly runoff for a basin.

Section 4

Surface Water Quality

4.1 Introduction

This section characterizes surface water quality for the State of Arkansas. Water quality is characterized in terms of its suitability for the various use sectors for which water demand is being updated (the water demand update is addressed in a separate report). For the purposes of the water supply update, water quality is addressed primarily at the locations where surface water availability is being updated (Section 3).

Both current surface water quality and changes in surface water quality over time, particularly since the 1990 AWP, are addressed in this section. Current surface water quality is characterized through discussion of the state list of impaired waters that is prepared by the ADEQ in fulfillment of the requirements of Section 303(d) of the Clean Water Act (CWA). Changes in water quality since the 1990 AWP are identified through discussion of historical biennial water quality assessments conducted by ADEQ (as required by Section 305(b) of the CWA) and analysis of water quality data. In addition, long-term changes in water quality are assessed at those sites of interest where the data record spans at least 30 years.

4.2 Background

Water demand forecasting for the AWP update has been estimated for nine water use sectors (**Table 4-1**). Each of these water use sectors has requirements with regard to both the volume and quality of water needed, summarized in Table 4-1.

Table 4-1. Summary of Water Use Sector Water Supply Needs

Water Use Sector	Surface Water Volume Needs	Surface Water Quality Considerations
Thermoelectric energy	Thermoelectric power generation facilities (e.g., gas and coal-fired power plants) require water for cooling.	Chemicals in water can affect cooling systems through corrosion, clogging, or encouraging growth of biologicals such as algae or zebra mussels that clog the system.
Navigation	In rivers where commercial goods are transported by barge, there is a minimum water depth that must be maintained for barges to be able to travel.	Sediment in rivers and streams can fill in navigation channels. The more sediment in a river, the quicker the navigation channel will fill, and the more frequently dredging will be required.
Industrial	Water is used in a variety of industrial processes, in mining and natural gas extraction, and for cooling at some industrial facilities.	Chemicals in water can affect industrial processes, machinery, and cooling systems.
Agricultural	Crops and livestock require adequate water to survive and thrive. In eastern Arkansas, many farmers flood their fields after crops are harvested in fall and winter to provide habitat for migrating ducks and other waterfowl.	High levels of some metals or chloride (salt) in water can harm crop plants. Chemicals and pathogens in water can cause illness in livestock and waterfowl. Chemicals and pathogens in water can also cause illness in aquaculture fish directly or indirectly by causing changes in water chemistry, such as pH or dissolved oxygen (DO) levels.

Table 4-1. Summary of Water Use Sector Water Supply Needs

Water Use Sector	Surface Water Volume Needs	Surface Water Quality Considerations
Drinking water	Adequate water for drinking is essential for human health.	Chemicals and pathogens in water can cause illness in humans. Nutrients in drinking water reservoirs can cause blooms of algae that lead to problems with water filtration, taste and odor, and toxins; and increase disinfection byproduct precursors.
Interstate water compacts	Arkansas is a member of Red River Compact that was negotiated to ensure equitable apportionment and development of the interstate waters of the Red River and its tributaries. This compact requires that specific volumes be allowed to flow from Arkansas to the downstream state of Louisiana.	Article XI of the Red River Compact states that each state involved in the compact has the duty and responsibility to "prevent, regulate, and diminish" pollution of the Red River and its tributaries that cross state lines, in order to prevent adverse effects on downstream states.[1]
Fish and wildlife support	All wildlife requires water, and those creatures that live in water, such as fish and shellfish, require specific minimum water levels and flow rates to be healthy and successfully reproduce.	Pathogens, nutrients, and other chemicals in water can cause illness in aquatic organisms directly or indirectly by causing changes in water chemistry, such as pH or DO levels.
Recreation	There are minimum water depth requirements for use of recreational boats.	Pathogens and chemicals in water can make swimmers ill. At high enough levels, these same pathogens and chemicals may harm boaters and fishermen. Pollution in water and/or sediments can be transferred to fish in high enough levels that eating the fish is harmful to human health. In addition, water quality can affect the aesthetics of waterbodies and their desirability for recreation (e.g., brown water, presence of scum, or algae mats).
Minimum flows for water quality	In Arkansas, the minimum flow that must be maintained in state rivers and streams for dilution of wastewater discharges is usually the 7Q10 flow. The 7Q10 flow is determined for each stream based on historical flow records, and is the minimum 7-day average flow that occurs, on average, every 10 years.	Dischargers must consider flow and quality of receiving waters so that effluent concentrations do not contribute to exceedences of water quality standards.

[1] http://www.oscn.net/applications/oscn/deliverdocument.asp?id=97778&hits=

The CWA requires states to establish water quality standards for all surface waters within their boundaries with the goal of protecting beneficial uses of waterbodies and protecting public health and welfare. Water quality standards for waterbodies in Arkansas are set forth in Arkansas Pollution Control and Ecology Commission (APCEC) Regulation No. 2, *Regulation Establishing Water Quality Standards for Surface Waters of the State of Arkansas.*

Water quality standards consist of four basic elements: (1) designated uses of the waterbodies, (2) numeric or narrative water quality criteria, (3) an anti-degradation policy to maintain and protect existing uses and high-quality waterbodies, and (4) general policies to address implementation of the water quality standards (EPA 2012b). Each surface waterbody in Arkansas has been assigned one or more "designated uses" in APCEC Regulation No. 2. Examples of designated uses include aquatic life, primary contact recreation, secondary contact recreation, domestic water supply, agricultural water supply, and industrial water supply. Numeric and/or narrative criteria for pollutants are also listed in Regulation No. 2 for the purpose of supporting the designated uses in each waterbody.

Table 4-2 lists the water use sectors with the relevant regulatory designated uses. Note that there are no specific designated uses that protect the interstate compact, critical low flow (7Q10), or navigation water use sectors. However, waterbodies where these water use sectors apply have designated uses and protection of these designated uses protects these water use sectors.

Table 4-2. Comparison of Water Use Sectors Addressed in Water Supply Availability Evaluation and Designated Uses Specified in APCED Regulation No. 2

Water Use Sectors	Designated Uses from APCEC Regulation 2
Interstate compacts	▪ All
Minimum flows	▪ All
Fish and wildlife	▪ Ecologically sensitive waterbody ▪ Aquatic life
Navigation	▪ All
Recreation	▪ Primary contact recreation ▪ Secondary contact recreation ▪ Natural and scenic waterway ▪ Extraordinary resource waters
Drinking water	▪ Domestic water supply
Industrial	▪ Industrial water supply
Agriculture	▪ Agricultural water supply

Section 305(b) of the CWA requires states to assess the water quality of the waters of the state (both surface water and groundwater) and prepare a comprehensive report documenting the water quality, which is to be submitted to the U.S. Environmental Protection Agency (EPA) every 2 years. ADEQ is the agency in Arkansas responsible for enforcing the water quality standards and preparing the comprehensive report for submittal to EPA. ADEQ relies on chemical data from its ambient water quality monitoring network to assess whether surface waterbodies are meeting their designated uses, although biological surveys are also conducted on a site-specific basis to further document whether an aquatic life use is being attained. Section 303(d) of the CWA requires states to report waterbodies that are not meeting applicable water quality standards (which may include nonattainment of a designated use) and prioritize those listed waterbodies based on the need for corrective action and the severity of the pollution (if applicable). Waterbodies can also be included on the list of impaired waterbodies if they are subject to fish consumption advisories, (i.e., eating fish could cause health problems in people), though fish consumption is not a designated use included in APCEC Regulation No. 2

4.3 Current Water Quality

In accordance with the CWA and EPA mandate, ADEQ is required to compile a biennial water quality inventory report that assesses the ability of the state's waterbodies to support their designated uses. In the same manner, ADEQ is also required to compile a biennial list of impaired waterbodies containing those waterbodies that fail to support their designated use(s), the pollutant(s) causing the impairment(s), and the suspected source(s) of those pollutants. The water quality inventory report is commonly referred to as the "305(b) report" and the impaired waterbodies list is referred to as the "303(d) list" in reference to the sections of the CWA that require their development. In 2004, ADEQ began combining these two documents into a single "Integrated Water Quality Monitoring and Assessment Report" according to EPA guidance.

Each 305(b) report summarizes water quality data collected during the respective monitoring period and assesses this data with respect to numeric, statistical, and/or narrative criteria necessary to support designated uses. Waterbodies are assessed for support of the aquatic life, primary contact recreation, secondary contact recreation, domestic water supply, industrial water supply, and agricultural water supply designated uses, as well as the fish consumption use. If observed data do not meet criteria for support of a designated use, then the waterbody is considered impaired and the waterbody is included on the 303(d) list. The 303(d) list is then used to identify waterbodies where a total maximum daily load (TMDL) or other corrective actions may be necessary to restore the waterbody to fully support its designated uses.

Although water quality assessments were submitted to EPA in 2010 and 2012, the 2008 assessment is the most recent state water quality assessment that has been approved by EPA, which oversees the assessment program. Therefore, the 2008 water quality assessment and list of impaired waterbodies are used to describe current surface water quality in Arkansas.

4.4 Statewide Summary

In 2008, almost 10,000 miles of streams and over 350,000 acres of lakes in Arkansas were assessed for water quality by ADEQ (**Table 4-3**). Sixty-three percent of the assessed stream miles and 64 percent of the assessed lake acreage were determined to be meeting numeric water quality criteria and supporting all of their designated uses. **Table 4-4** summarizes the impaired waters in Arkansas by their impaired uses. Note that in the 305(b) report and the 303(d) list, the agricultural water supply and industrial water supply designated uses are combined, and support of these designated uses is not assessed separately. The locations of these impaired waters are shown on **Figures 4-1 through 4-6**.

Table 4-3. Miles of Streams and Acres of Lakes in Arkansas Assessed for Water Quality in 2008 (ADEQ 2009)

Waterbody Type	Total in Arkansas	Assessed in 2008	Percent Assessed
Rivers and streams	87,617.4 miles	9,849.7 miles	11.2%
Lakes	515,635 acres	357,896 acres	69.4%

Table 4-4. Summary of 2008 Impaired Waters in Arkansas (ADEQ 2008)

Designated Use Not Supported	Water Use Sector Impacted	Miles of Assessed Streams	Acres of Assessed Lakes
Aquatic life	Fish and Wildlife	2,439.9	11,248
Agriculture and industrial water supply	Agriculture, Industrial	967.7	0
Domestic water supply	Drinking Water	448.3	97,105
Fish consumption[1]	Recreation	363.3	23,637+
Primary contact recreation	Recreation	564.8	0
Secondary contact recreation	Recreation	7.0	0
Total		**4,086.5**	**127,520**

[1] As noted previously, fish consumption is not a designated use included in APCEC Regulation No. 2, but waterbodies can be designated as impaired if sportfish in a waterbody are not safe for human consumption.

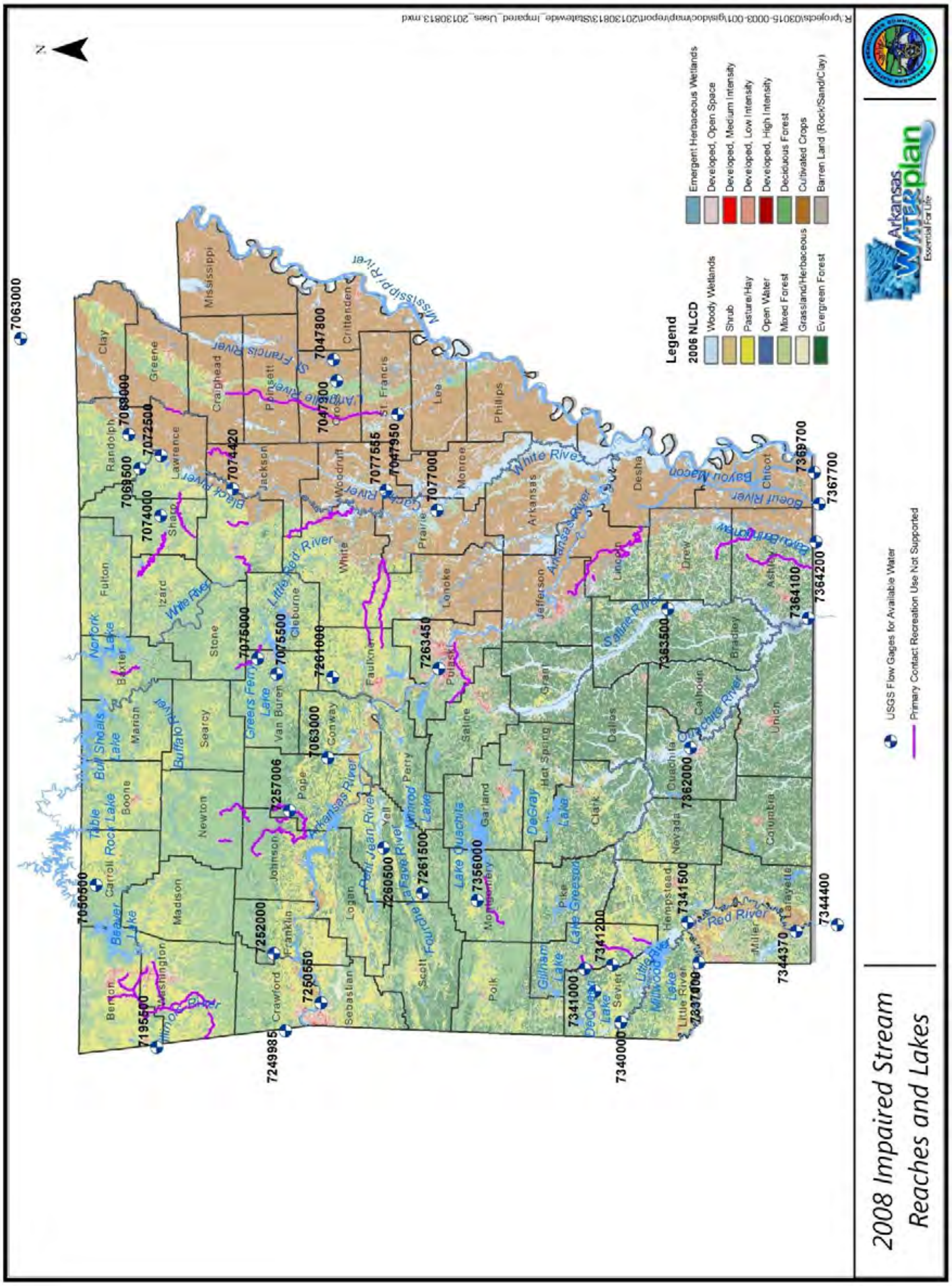


Figure 4-1. Impaired Stream Reaches and Lakes Not Supporting the Primary Contact Recreation Designated Use

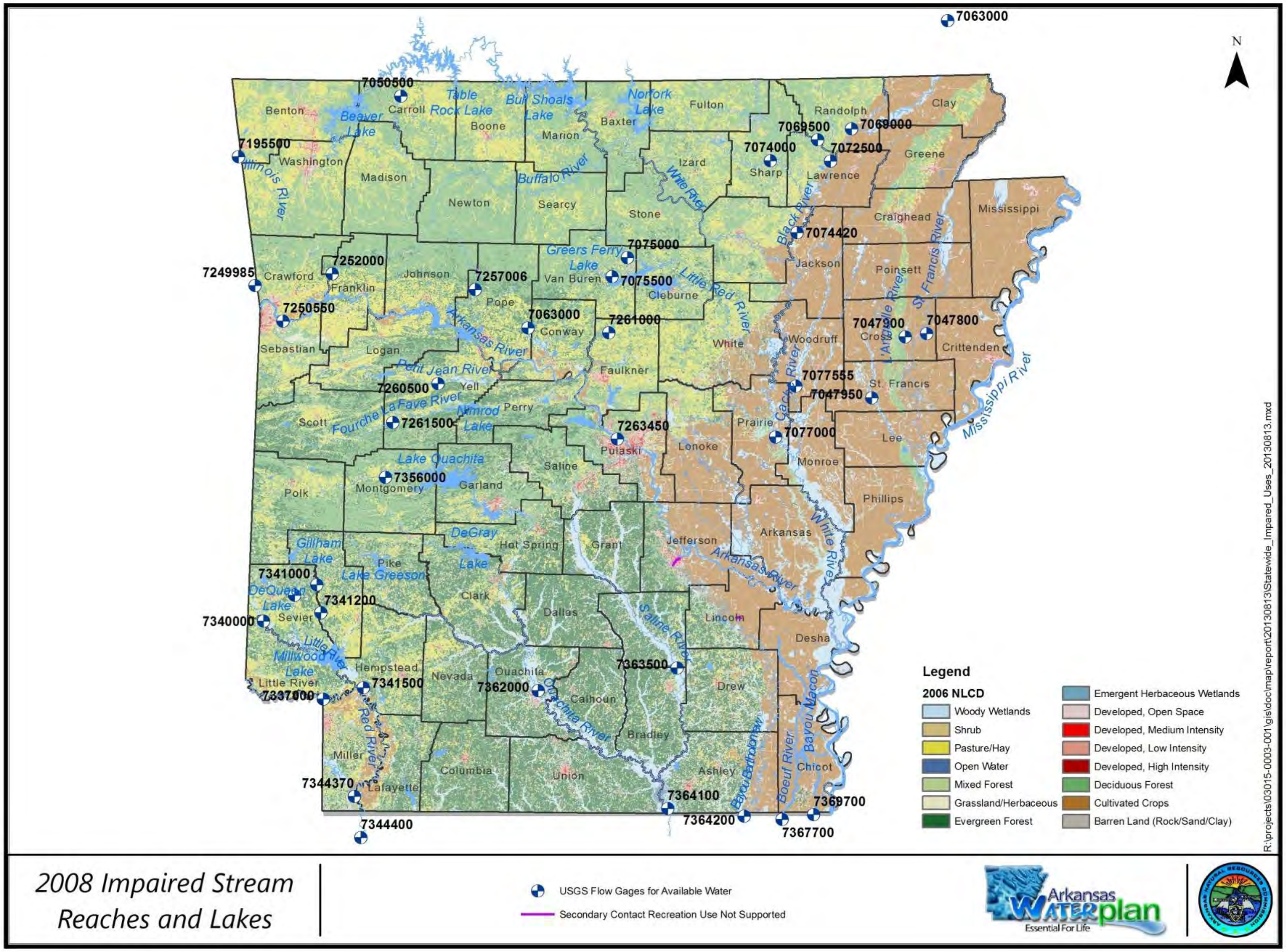


Figure 4-2. Impaired Stream Reaches and Lakes Not Supporting the Secondary Contact Recreation Designated Use

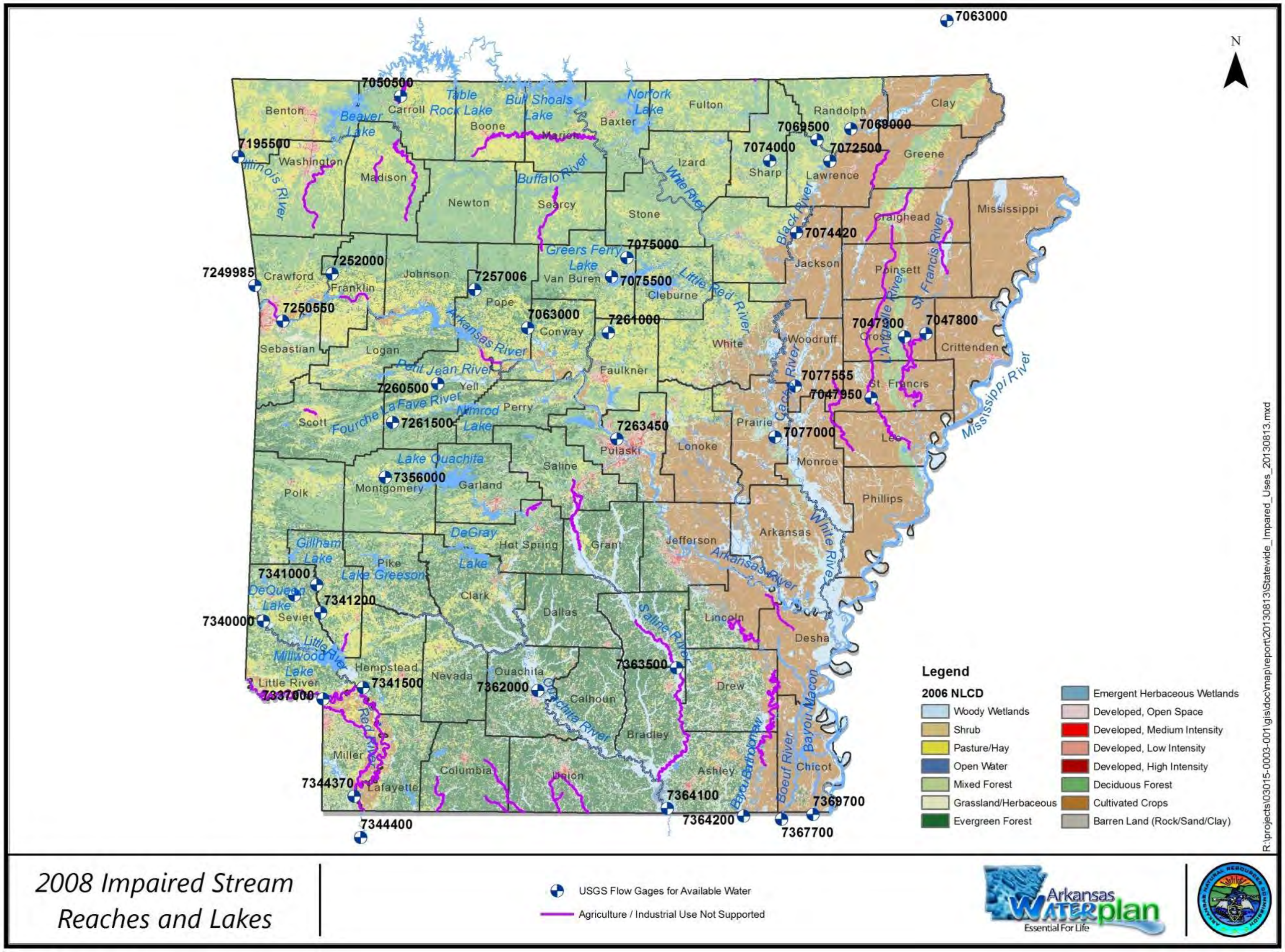


Figure 4-3. Impaired Stream Reaches and Lakes Not Supporting the Agricultural/Industrial Water Supply Designated Use

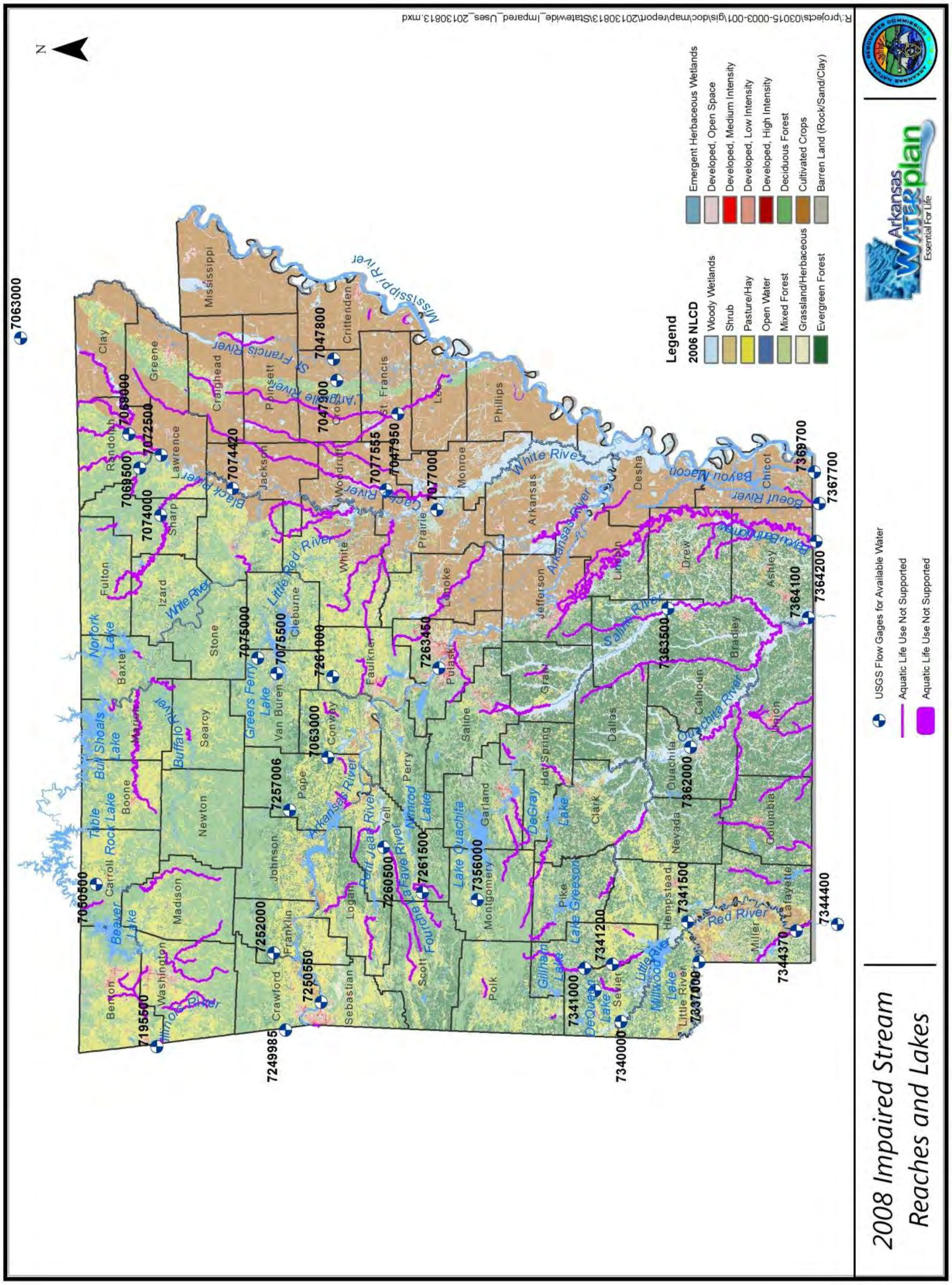


Figure 4-4. Impaired Stream Reaches and Lakes Not Supporting the Aquatic Life Designated Use

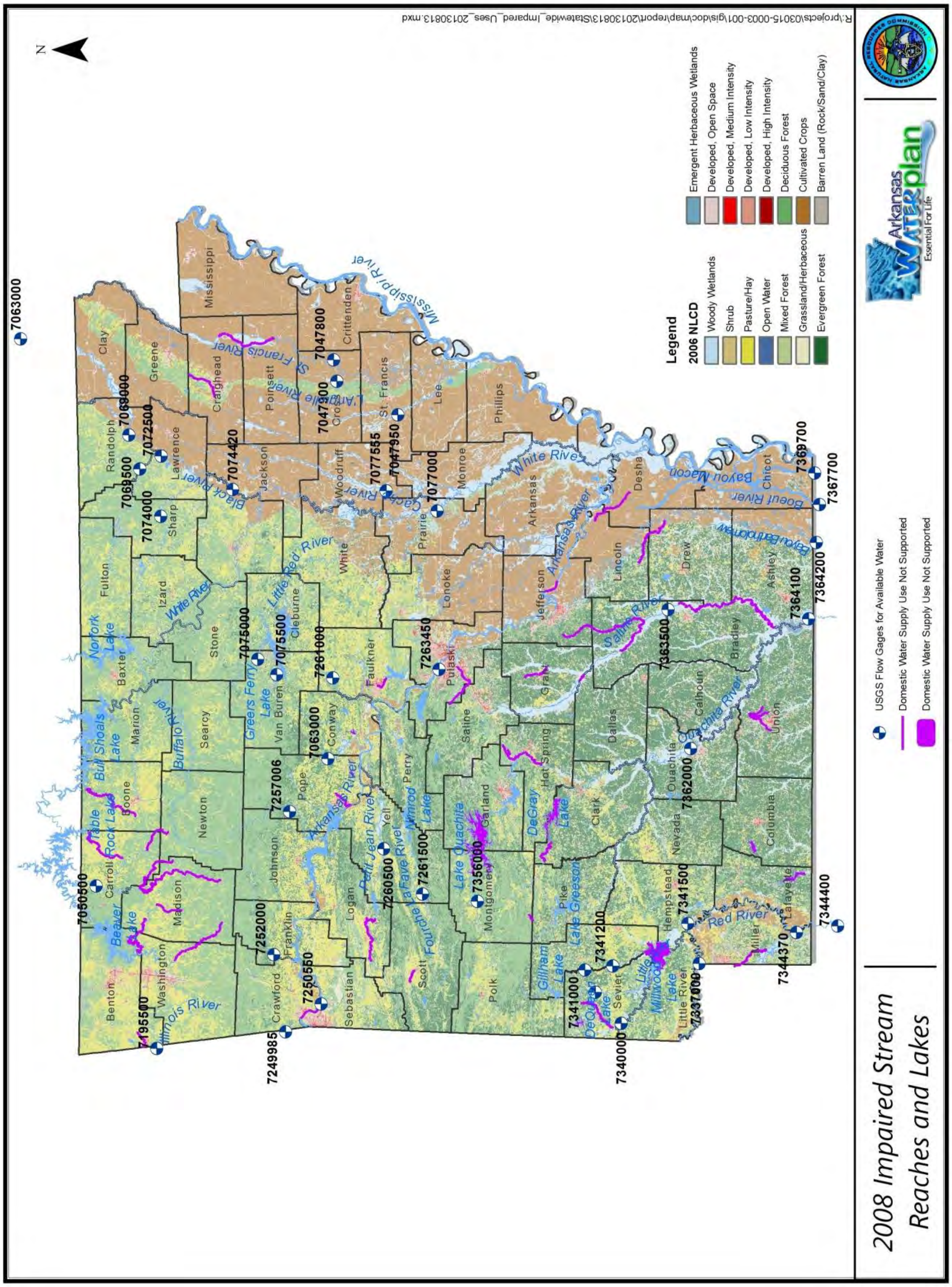


Figure 4-5. Impaired Stream Reaches and Lakes Not Supporting the Domestic Water Supply Designated Use

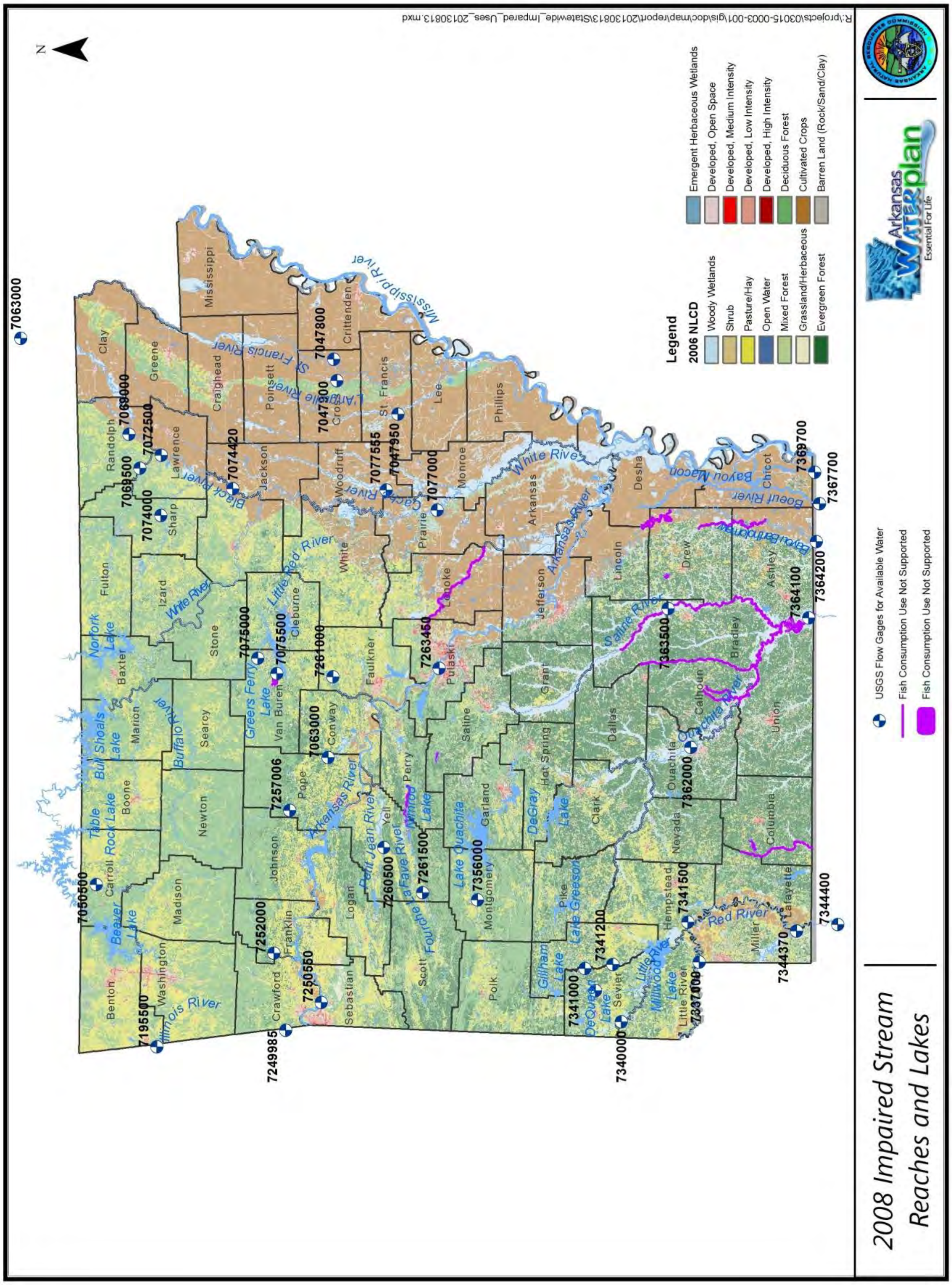


Figure 4-6. Impaired Stream Reaches and Lakes Not Supporting the Fish Consumption Designated Use

4.5 Water Quality at Surface Water Availability Update Sites

Forty USGS gage stations are being used to estimate available surface water flow and volume for the 2014 AWP update. Half of these stations are located on stream reaches included on the 2008 impaired waters list. **Table 4-5** indicates which of the gage stations are located on impaired stream reaches, along with the designated uses not supported, and the water use sectors that are impacted.

Table 4-5. Summary of Current Water Quality at USGS Gage Stations used to Determine Available Surface Water (ADEQ 2008)

USGS Station Number	Station Name	Stream Segment	Designated Uses Not Supported	Water Use Sectors Impacted
7047800	St. Francis River at Parkin, AR	8020203-009	Agriculture and industry	Agriculture and/or industrial[1]
7047900	St. Francis Bay at Riverfront, AR	8020203-008	Agriculture and industry	Agriculture and/or industrial
7047950	L'Anguille River at Palestine, AR	8020205-002	Agriculture and industry, aquatic life	Agriculture and/or industrial, fish and wildlife
7050500	Kings River near Berryville, AR	11010001-037	Agriculture and industry	Agriculture and/or industrial
7069000	Black River at Pocahontas, AR	11010009-005	Aquatic life	Fish and wildlife
7075000	Middle Fork of Little Red River at Shirley, AR	11010014-027	Primary contact recreation	Recreation
7075500	South Fork Little Red River near Clinton, AR	11010014-036	Fish consumption	Recreation
7077555	Cache River near Cotton Plant, AR	8020302-017	Aquatic life	Fish and wildlife
7195500	Illinois River near Watts, OK	*Not evaluated, outside of state*		
7250550	AR River at James W Trimble L&D near Van Buren, AR	11110104-001	Domestic water supply, Agriculture and industry	Drinking Water, agriculture and/or industrial
7261500	Fourche La Fave River near Gravelly, AR	11110206-007	Aquatic life	Fish and wildlife
7337000	Red River at Index, AR (potential)	11140106-001	Agriculture and industry	Agriculture and/or industrial
7341000	Saline River near Dierks, AR	11140109-014	Aquatic life	Fish and wildlife
7341200	Saline River near Locksburg, AR	11140109-010	Aquatic life	Fish and wildlife
7341500	Red River at Fulton, AR	11140106-001	Agriculture and industry	Agriculture and/or industrial
7344370	Red River at Spring Bank, AR	11140201-003	Agriculture and industry, aquatic life	Agriculture and/or industrial, fish and wildlife
7344400	Red River near Hosston, LA	*Not evaluated, outside of state*		
7362000	Ouachita River at Camden	8040201-005	Aquatic life	Fish and wildlife
7363500	Saline River near Rye	8040204-003	Agriculture and industry, aquatic life, fish consumption	Agriculture and/or industrial, fish and wildlife, recreation
7364100	Ouachita River near AR/LA State Line	8040202-002	Aquatic life, fish consumption	Fish and wildlife, recreation
7364200	Bayou Bartholomew near Jones, LA	8040205-001	Aquatic life	Fish and wildlife

[1] Support of these uses is not assessed separately

4.6 Water Quality in Arkansas Water Resources Planning Regions

Water quality impairments from 2008 for each of the five Arkansas Water Resources Planning Regions (AWRPR) are discussed below.

4.6.1 North Arkansas Water Resources Planning Region

In 2008, 2,324 miles of streams and 129,691 acres of lakes were assessed for water quality by ADEQ in the North AWRPR. **Table 4-6** summarizes the extent of waterbodies in the North AWRPR that do not support designated uses and water use sectors impacted. Table C.1 in **Appendix C** summarizes the waterbodies in this AWRPR that were assessed for the 2008 biennial assessment, those that were not attaining their designated uses, and the use sectors that were impacted. Table C.1 also summarizes the pollutants and sources causing the impairments identified in the assessment.

Table 4-6. Impaired Waters in the North AWRPR in 2008 (ADEQ 2008)

Designated Use Not Supported	Water Use Sector Impacted	Miles of Assessed Streams	Acres of Assessed Lakes
Aquatic life	Fish and wildlife	561	2,031
Fish consumption	Recreation	2	50
Primary contact recreation	Recreation	195	0
Secondary contact recreation	Recreation	0	0
Domestic water supply	Drinking water	168	0
Agricultural and industrial water supply	Agricultural and/or industrial	196	0
Total impaired		**816**	**2,081**

In this region, the aquatic life designated use (i.e., fish and wildlife water use sector) is most often impaired in both streams and lakes. Low DO is the most common cause of aquatic life impairment in streams (245.3 miles). Sediment/siltation is the cause of the aquatic life designated use impairment for the greatest lake area; 1,500 acres.

4.6.2 West-Central Arkansas Water Resources Planning Region

In the West-Central AWRPR, ADEQ assessed water quality in 1,378.7 miles of streams and 76,237 acres of lakes for the 2008 305(b) report. **Table 4-7** summarizes the extent of waterbodies in the West-Central AWRPR that do not support designated uses and use sectors. Table C.2 in Appendix C summarizes the waterbodies in this AWRPR that were assessed for the 2008 biennial assessment, those that were not attaining their designated uses, and the use sectors that were not supported. Table C.2 also summarizes the pollutants and sources causing the impairments identified in the assessment. The majority of impaired stream miles in this region do not support the aquatic life designated use (fish and wildlife water use sector). Low DO is the most frequently identified cause of aquatic life use impairment. Fairly equal proportions of the impaired lake acreage in this region do not support the aquatic life, fish consumption, and domestic water supply designated uses (fish and wildlife, recreation, and drinking water use sectors). In lakes, sediments/siltation is the cause of aquatic life impairment, mercury is the cause of fish consumption impairment, and beryllium is the cause for domestic water supply impairment. Note that changes to the state beryllium criterion are expected to result in reclassification of many waterbodies impaired due to beryllium levels to supporting the domestic water supply designated use.

Table 4-7. Impaired Waters in the West-Central AWRPR in 2008 (ADEQ 2008)

Designated Use Not Supported	Water Use Sector Impacted	Miles of Assessed Streams	Acres of Assessed Lakes
Aquatic life	Fish and wildlife	296.5	2,900
Fish consumption	Recreation	8.7	3,946
Primary contact recreation	Recreation	68.2	0
Secondary contact recreation	Recreation	0.0	0
Domestic water supply	Drinking water	39.4	2,675
Agricultural and industrial water supply	Agricultural and/or industrial	28.4	0
Total		**362.1**	**9,521**

4.6.3 Southwest Arkansas Water Resources Planning Region

In the Southwest AWRPR, 961.5 miles of streams and 44,020 acres of lakes were assessed for water quality by ADEQ in 2008. **Table 4-8** summarizes the extent of waterbodies in the Southwest AWRPR that do not support designated uses and use sectors. Table A.3 in Appendix C summarizes the waterbodies in this AWRPR that were assessed for the 2008 biennial assessment, those that were not attaining their designated uses, and the use sectors that were not supported. Table C.3 also summarizes the pollutants and sources causing the impairments identified in the assessment. The majority of the impaired streams in this planning region do not support the agricultural and industrial water supply designated use due to levels of total dissolved solids (TDS) and sulfate. The majority of the impaired lake acreage in this region does not support the domestic water supply designated use (drinking water use sector) due to beryllium levels. Note that changes to the state beryllium criterion are expected to result in reclassification of many waterbodies impaired due to beryllium levels to supporting the domestic water supply designated use.

Table 4-8. Impaired Waters in the Southwest AWRPR in 2008 (ADEQ 2008)

Designated Use Not Supported	Water Use Sector Impacted	Miles of Assessed Streams	Acres of Assessed Lakes
Aquatic life	Fish and wildlife	191.8	0
Fish consumption	Recreation	32.0	3,150
Primary contact recreation	Recreation	36.4	0
Secondary contact recreation	Recreation	0.0	0
Domestic water supply	Drinking water	28.7	41,130
Agricultural and industrial water supply	Agricultural and/or industrial	241.1	0
Total		**465.9**	**43,130**

4.6.4 South-Central Arkansas Water Resources Planning Region

ADEQ assessed the water quality of 1,820 miles of streams and 90,071 acres of lakes in the South-Central AWRPR for the 2008 biennial assessment. **Table 4-9** summarizes the extent of waterbodies in the South-Central AWRPR that do not support designated uses and use sectors. Table C.4 in Appendix C summarizes the waterbodies in this AWRPR that were assessed for the 2008 biennial assessment, those that were not attaining their designated uses, and the use sectors that were not supported. Table C.4 summarizes the pollutants and sources causing the impairments identified in the assessment. In this region, aquatic life (fish and wildlife water use sector) is the designated use not supported in the majority of the impaired stream miles. Zinc levels are the most frequent cause of impairment of the aquatic life designated use in streams. The domestic water supply designated use (drinking water use sector) is not supported for the majority of the impaired lake acreage in the planning region due to levels of beryllium. Note that changes to the state beryllium criterion are expected to result in reclassification of many water bodies impaired due to beryllium levels to supporting the domestic water supply designated use.

Table 4-9. Impaired Waters in the South-Central AWRPR in 2008 (ADEQ 2008)

Designated Use Not Supported	Water Use Sector Impacted	Miles of Assessed Streams	Acres of Assessed Lakes
Aquatic life	Fish and wildlife	652.8	300
Fish consumption	Recreation	209.1	3,946
Primary contact recreation	Recreation	22.0	0
Secondary contact recreation	Recreation	0.0	0
Domestic water supply	Drinking water	193.0	53,300
Agricultural and industrial water supply	Agricultural and/or industrial	225.9	0
Total		**775.1**	**59,081**

4.6.5 East Arkansas Water Resources Planning Region

In the East AWRPR, water quality of 3,075 miles of streams and 15,578 acres of lakes were evaluated for the 2008 biennial assessment. **Table 4-10** summarizes the extent of waterbodies in the East AWRPR that do not support designated uses and use sectors. Table C.5 in Appendix C summarizes the waterbodies in this AWRPR that were assessed for the 2008 biennial assessment, those that were not attaining their designated uses, and the use sectors that were not supported, as well as the pollutants and sources causing the impairments identified in the assessment. The aquatic life designated use (fish and wildlife water use sector) was not supported in the majority of impaired stream miles and all of the impaired lake acreage. For streams, low DO is the most frequent cause of this impairment. The majority of the lake acreage is impaired due to nutrient levels.

Table 4-10. Impaired Waters in the East AWRPR in 2008 (ADEQ 2008)

Designated Use Not Supported	Water Use Sector Impacted	Miles of Assessed Streams	Acres of Assessed Lakes
Aquatic life	Fish and wildlife	1,420.5	5,817
Fish consumption	Recreation	104.5	0
Primary contact recreation	Recreation	263.4	0
Secondary contact recreation	Recreation	7	0
Domestic water supply	Drinking water	65.4	0
Agricultural and industrial water supply	Agricultural and/or industrial	420.1	0
Total		**1,758.6**	**5,817**

4.7 Water Quality Changes

4.7.1 Changes Since the 1990 AWP Update

This section evaluates how water quality at available water supply sites has changed since the 1990 AWP. In the following sections, long-term water quality trends at selected locations and historical listings of impaired water bodies are discussed. Information is also presented from water quality studies and monitoring programs identified by members of the Water Quality subgroup.

4.7.1.1 Analysis of Long-Term Water Quality Records at Water Supply Sites

The target period of record for analysis of long-term water quality trends was established at 30 years. To identify water quality monitoring stations with a period of record 30 years or longer, data from ADEQ water quality monitoring stations was retrieved from both the ADEQ website and the EPA STORET database, and data from USGS water quality monitoring stations was retrieved from the USGS National Water Information Service (NWIS) website database. The surface water quality database on the ADEQ website includes data back to only 1990. Water quality data collected by ADEQ prior to 1990 was retrieved from the EPA STORET database (legacy version). The period of record for the ADEQ and USGS water quality monitoring stations was determined based on the earliest and latest dates associated with the water quality data stored in these databases. In general, active stream water quality monitoring stations established prior to 1984 have a 30-year period of record. In the 1990 AWP, water quality discussions were based on data from 1970 through 1986.

Of the 40 USGS gaging stations used to estimate available surface water, 23 had associated water quality stations with a 30-year or longer data record (**Figure 4-7**). The data from each of these water quality stations were downloaded into Excel and graphs of the available DO, inorganic nitrogen (nitrate + nitrite nitrogen), total Kjeldahl nitrogen (TKN), total phosphorus, pathogens, total suspended solids (TSS), and turbidity were prepared. These graphs were reviewed to identify suitable long-term water quality datasets for analysis. There were few sites with 30 years of comparable pathogen results because ADEQ changed from analyzing for fecal coliforms to analyzing for *Escherichia coli* (*E. coli*), to assess for pathogen impairment in 1999. There were also a number of sites where the data record for TKN was less than 30 years.

The seasonal Kendall test was selected to analyze for trends in the long-term data record. This is a nonparametric statistical test that detects monotonic as well as linear trends. In this analysis, the data from each season is analyzed for trends, and the results from these analyses are combined for the overall test result.[2] For the trend analysis, untransformed concentrations were evaluated across years, by month. Harned et al. (2009) determined that analysis of untransformed water quality concentrations using the seasonal Kendall test gave the same result as analysis of log-transformed water quality concentrations.

[2] http://acwi.gov/monitoring/conference/2006/2006_conference_materials_notes/Concurrent_SessionG/G5Trends/G5_Helsel.pdf

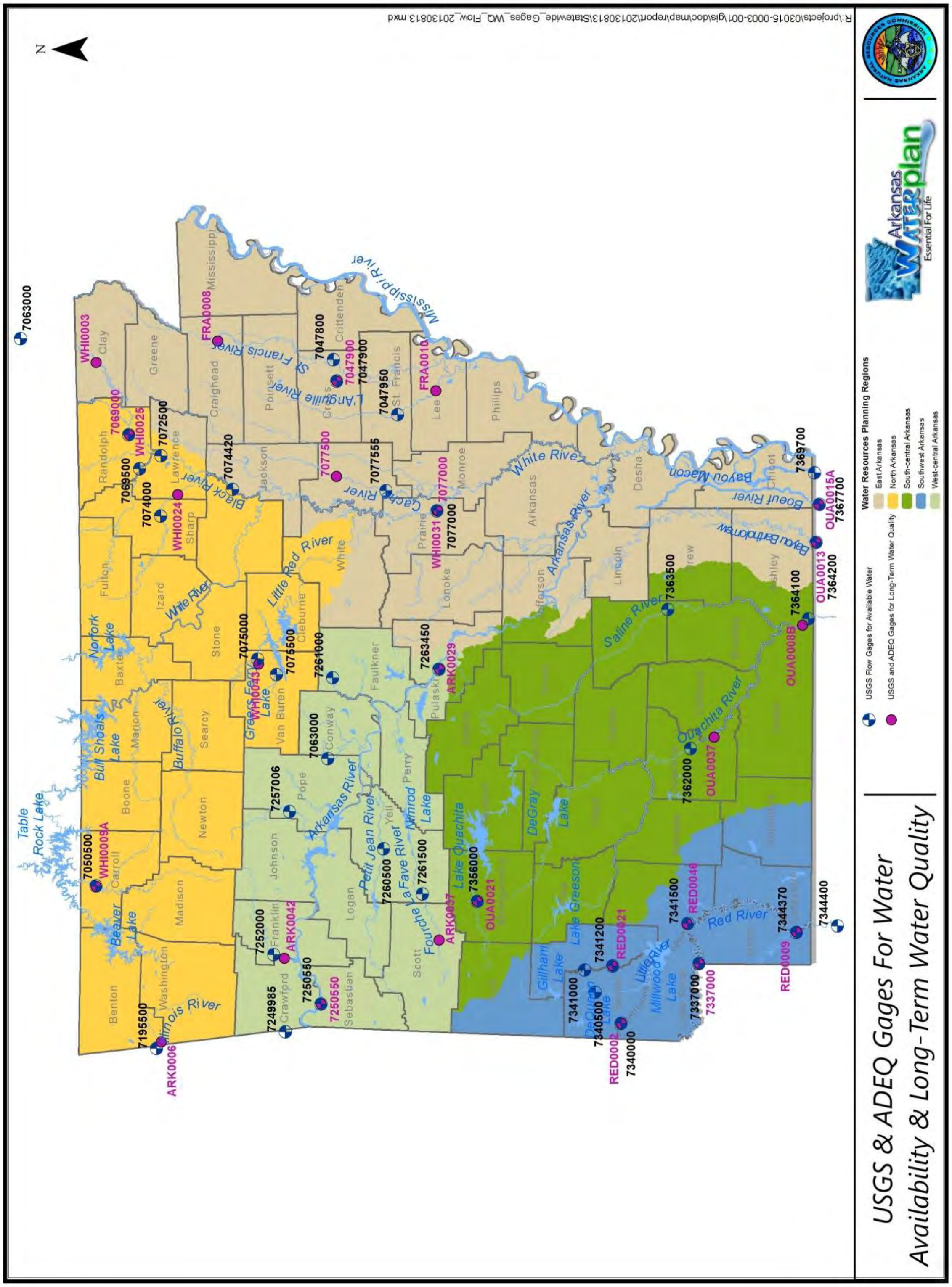


Figure 4-7. Locations of Water Quality Stations and Water Availability Gages

The influence of censored data, i.e., concentrations reported as less than detection, was considered in the trend analysis. Data from most of the water quality sites included censored results, particularly for nutrient measurements. At several sites, over 10 percent of the measurements for at least one parameter were censored. In general, the seasonal Kendall test provides useful results when applied to data sets with censored data, as long as the same detection limit is used over the entire period being analyzed (Harned et al. 2009). However, detection limits for total phosphorus, inorganic nitrogen, and TKN changed at least twice over the period used for the trend analysis. In those instances when more than 5 percent of the data for one of these parameters was censored, and more than one detection limit was reported in the data, all censored data were set to the value of the lowest detection limit prior to performing the seasonal Kendall test. In addition, all reported values less than the highest detection limit were also set to the detection value prior to performing the seasonal Kendall test.

The water quality data analyzed were also adjusted to remove the influence of changes in flow characteristics on concentrations. Linear regression analysis was used to determine which parameters are influenced by flow at each water quality station. Flow records from the USGS gages being used to determine water availability were used in the analyses. The linear regression analyses were performed using log transformed flow and water quality data. Analyses with p values less than 0.05 (i.e., 95 percent confidence) were assumed to indicate that flow influences concentrations of the water quality parameter. The regression analysis was not performed for several of the sites because the flow record covered less than two-thirds of the water quality record.

Concentrations of flow-influenced parameters were adjusted prior to application of the seasonal Kendall test. First, concentrations were estimated from flow using equations based on the regressions. In some instances, a nonlinear quadratic regression resulted in a better fit (based on the R2 value). A table of the equations used to estimate the flow-based concentrations is included as **Appendix D.** The flow-influenced parameters were adjusted by subtracting the flow based concentrations. The seasonal Kendall test was then run on these adjusted values.

The results of the seasonal Kendall test can be suspect when there are long gaps in the data record. The datasets with gaps of around 10 years in the data record were excluded from the analysis. The results of the seasonal Kendall test for water quality trends at sites where water supply availability is being evaluated are summarized in **Table 4-11**. The arrows show the direction of statistically significant trends indicated by the analysis results (i.e., type I error=5 percent with 95 percent confidence).

At almost all of the sites analyzed, TSS exhibited a declining trend. The results for the other water quality parameters were more variable, with either no trend or both increasing and decreasing trends, over time.

Table 4-11. Summary of Results of Seasonal Kendall Test for Trend

AWRPR	USGS Station	Stream Name	Water Quality Station(s)	Period of Record	Water Quality Trends: Dissolved Oxygen	Inorganic Nitrogen	TKN	Total Phosphorus	Turbidity	TSS+	Fecal Coliforms
East	07047800	St. Francis River	FRA0008	1974 – 2013	None	None*	⇩	None*	None*	⇩*	< 30 yrs
East	07047900	St. Francis Bay	07047900	1973 – 2009	⇩*	< 30 yrs	< 30 yrs	< 30 yrs	< 30 yrs	None*	< 30 yrs
East	07047950	L'Anguille River	FRA0010	1974 - 2013	⇩	None	< 30 yrs	None	⇧	⇩	< 30 yrs
East	07063000	Black River	07064000, WHI0003	1972 – 2013	⇩	⇩*	< 30 yrs	None	None*	⇩*	< 30 yrs
East	07077000	White River	07077000, WHI0031	1967 – 2013	None	⇩*	< 30 yrs	None*	⇩*	None	None
East	07077555	Cache River	07077500	1973 – 2013	⇧*	< 30 yrs	None*	None*	< 30 yrs	< 30 yrs	None
East	07364200	Bayou Bartholomew	OUA0013	1968 – 2013	None*	⇧*	None	⇧*	NR[1]	⇩*	None
East	07367700	Boeuf River	OUA0015A	1971 – 2013	None	⇧*	⇩	None*	NR[1]	⇩*	< 30 yrs
North	07050500	Kings River	07050500, WHI0009A	1974 – 2013	⇧	None	None	None	None	⇩	⇧
North	07069000	Black River	WHI0025	1977 – 2013	⇩	⇩	< 30 yrs	None	None	⇩	< 30 yrs
North	07074000	Strawberry River	WHI0024	1974 – 2013	None	None	< 30 yrs	⇧	⇧	None	<30 yrs
North	07075000	Middle Fork Little Red River	WHI0043	1974 – 2013	⇩	⇩	< 30 yrs	⇩	None	⇩	< 30 yrs
North	07195500	Illinois River	ARK0006	1968 – 2013	NR[1]	NR[1]	< 30 yrs	⇩	⇩*	⇩*	None*,[2]

[1] Analysis results not reported due to long gap in data record
*Flow adjusted data used in analysis
[2] Data ends 1999

Table 4-11. Summary of Results of Seasonal Kendall Test for Trend (continued)

AWRPR	USGS Station	Stream Name	Water Quality Station(s)	Period of Record	Water Quality Trends						
					Dissolved Oxygen	Inorganic Nitrogen	TKN	Total Phosphorus	Turbidity	TSS+	Fecal Coliforms
South-central	07356000	Ouachita River	OUA0021	1976 – 2013	⇩*	None*	None	None*	⇧*	⇩*	< 30 yrs
South-central	07362000	Ouachita River	OUA0037	1970 – 2013	None*	⇩	⇩*	⇩*	None*	⇩*	None*
Southwest	07337000	Red River	07337000	1968 – 2013	⇩	< 30 yrs	⇧*	⇧*	< 30 yrs	None*	None*
Southwest	07340000	Little River	07341001 RED0002	1972 – 2013	⇩*	None*	NR[1]	None*	None*	⇩*	< 30 yrs
Southwest	07341200	Saline River	07341200, RED0021	1974 – 2013	⇧*	⇧*	< 30 yrs	⇧*	⇩	⇩*	< 30 yrs
Southwest	07344370, 07344400	Red River	RED0009	1968 – 2013	None	None	None	⇩	⇩	⇩	UP[3]
West-central	07250550	Arkansas River	07250550	1975 – 2013	None	< 30 yrs	⇩	None*	< 30 yrs	⇧*	⇩*
West-central	07252000	Mulberry River	ARK0042	1983 – 2013	⇧	None	< 30 yrs	⇩	⇩	⇩	< 30 yrs
West-central	07261500	Fourche La Fave River	ARK0037	1974 – 2013	⇩*	None*	< 30 yrs	⇩*	NR[1]	⇩*	< 30 yrs
West-central	07263450	Arkansas River	ARK0029	1974 – 2013	None	⇩*	⇩	⇧*	None*	⇩*	< 30 yrs

+Highlighted cells indicate results for total suspended sediment rather than total suspended solids.
*Flow adjusted data used in analysis

[1] Analysis results not reported due to long gap in data record
[3] Data ends 1997

4.7.1.2 Historical Water Quality Assessments

The results of the trend analyses are discussed below by planning region.

West-Central Arkansas Water Resources Planning Region

Four of the sites where water quality trends were evaluated are located in the West-central AWRPR. Water quality trends exhibited by the sites evaluated in the West-central AWRPR are consistent for TKN (declining) and TSS (declining). DO and total phosphorus exhibited an increasing trend at one site, and a declining trend at another. One of the sites had a 30-year record for fecal coliforms, which exhibited a declining trend.

Water quality trends at the two Arkansas River sites were similar. At both sites, no trend was apparent in DO and declining trends were identified in TKN. At the upstream site (07250550), no trend was apparent for total phosphorus, while an increasing trend was identified at the downstream site. TSS exhibited a declining trend at the downstream site, while suspended sediment (a different parameter than TSS) at the upstream site exhibited an increasing trend. The upstream site is located on a stream segment classified as not supporting domestic water supply and agricultural and industrial water supply designated uses due to high levels of chloride and TDS (ADEQ 2008).

The Fourche la Fave River near Harvey, Arkansas is included on the 2008 303(d) list for not supporting the aquatic life designated use due to low DO and sediment and/or siltation (ADEQ 2008). The trend analysis shows that DO levels at this site have declined over time. Concentrations of TSS, a surrogate used to evaluate sediment/siltation impairment, have also declined over time.

An increasing trend in DO, over time, and declining trends in total phosphorus, turbidity, and TSS were exhibited at the evaluation site on the Mulberry River (at I-40). This stream segment is classified as attaining all designated uses (ADEQ 2008).

North Arkansas Water Resources Planning Region

Five of the sites evaluated for water quality trends are located in the North AWRPR. A variety of water quality trends are exhibited at these sites. Some of the sites in this region exhibit trends in DO concentration, both increasing and declining. Both increasing and declining trends are also seen in historical levels of inorganic nitrogen, total phosphorus, turbidity, and fecal coliforms.

The Kings River near Berryville, Arkansas (WHI0009A) is on the 2008 303(d) list for not supporting the agricultural and industrial water supply designated use due to TDS levels (ADEQ 2008). Nutrients and turbidity have remained relatively stable over time, while DO and TSS levels improved. These parameters can impact the fish and wildlife water use sector. Fecal coliform levels increased over time. Fecal coliforms can impact the recreational water use sector.

The Black River near Pocahontas (WHI0025) is included on the 2008 303(d) list for not supporting the aquatic life designated use due to low DO (ADEQ 2008). The trend analysis shows that DO levels have been declining over time at this location. Concentrations of inorganic nitrogen and TSS have improved (declined) over time.

The Strawberry River near Smithville (WHI0024) is classified as supporting all designated uses. Concentrations of DO, inorganic nitrogen, and TSS have been relatively stable over the long term at this site. Total phosphorus and turbidity levels, however, have increased. These parameters can impact the fish and wildlife water use sector.

The Middle Fork of the Little Red River near Shirley (WHI0043) is included on the 2008 303(d) list for not supporting the primary contact recreational designated use due to high pathogen levels (ADEQ 2008). The data record for fecal coliforms and *E. coli* at this site was shorter than the target for long-term trend analysis in this evaluation; therefore, there is no information from this analysis related to the water quality impairment. Nutrient and TSS levels have improved (declined) over time; however, DO levels have declined. All of the parameters exhibiting trends can impact the fish and wildlife water use sector.

Arkansas does not evaluate designated use support of the Illinois River at the location in Oklahoma where water supply availability is being evaluated. However, the site in Arkansas where water quality trends were evaluated (near Siloam Springs, Arkansas) is located on a stream segment classified as not supporting the aquatic life designated use due to sediment and/or siltation (ADEQ 2008). Levels of TSS and turbidity, surrogate parameters for sediments/siltation, have declined over time, as have total phosphorus concentrations. All of these parameters affect the fish and wildlife water use sector.

Southwest Arkansas Water Resources Planning Region

Four sites in the Southwest AWRPR were evaluated for water quality trends. Trends in turbidity and TSS at these sites were consistent (all declining). However, trends for the remaining water quality parameters evaluated varied among the sites.

The water quality trends exhibited at the two sites on the Red River were different for all of the water quality parameters. Both of these sites are located on stream segments classified as not supporting the agricultural and industrial water supply designated use due to high minerals concentrations. The downstream site (07344370) is located on a stream segment classified as also not supporting the aquatic life designated use due to sediment and/or siltation (ADEQ 2008). Turbidity and TSS concentrations have declined over time at this location. If this trend continues, it is possible that the impact of sediment/siltation on the fish and wildlife water use sector at this location may be reduced in the future.

All stream segments of the Little River are classified as supporting all designated uses (ADEQ 2008). No trends were identified in nutrient levels. Declining trends were exhibited by DO, turbidity, and TSS.

The Saline River near Lockesburg is included on the 2008 303(d) list for not supporting the aquatic life designated use due to lead concentrations (ADEQ 2008). At this location, levels of DO, turbidity, and TSS have improved over time, while concentrations of inorganic nitrogen and total phosphorus have increased. These parameters can impact the fish and wildlife water use sector.

South-Central Arkansas Water Resources Planning Region

Two of the sites evaluated for water quality trends were located in the South-central AWRPR, both on the Ouachita River. The upstream site (07356000), located upstream of the reservoirs, is classified as supporting all designated uses (ADEQ 2008). DO and TSS concentrations have declined at this site over time while turbidity has increased. No trends in nutrient levels were identified.

The Ouachita River at the downstream site is included on the 2008 303(d) list for not supporting the aquatic life designated use due to metals concentrations (ADEQ 2008). Nutrient and TSS concentrations have declined over time at this site suggesting that these parameters are not likely to impact the fish and wildlife water use sector here.

East Arkansas Water Resources Planning Region

Water quality trends were evaluated at eight sites in the East AWRPR. Trends identified for all of the parameters evaluated at these sites were fairly consistent. No trend was identified for DO at five of the sites, but declining trends for DO were identified at the other three sites. Where sufficient data records were available to assess trends, TKN concentrations tended to exhibit a declining trend. At most of the sites total phosphorus did not exhibit a trend. A couple sites showed increasing trends for turbidity; however, the majority of sites did not exhibit a strong trend in turbidity levels. TSS exhibited a declining trend at the majority of the sites. No trend was apparent in fecal coliform levels at those sites with sufficient data records.

Five of the water quality sites are located on stream reaches classified as not supporting one or more designated uses. The sites on the St. Francis River, St. Francis Bay, and L'Anguille River are included on the 2008 303(d) listing for not supporting the agricultural and industrial water supply designated use due to minerals concentrations. The sites on Bayou Bartholomew and the Cache River are included on the 2008 303(d) list for not supporting the aquatic life designated use due to metals concentrations. The L'Anguille River near Marianna, Arkansas is included on the 2008 303(d) list for not supporting the aquatic life designated use due to low DO levels (ADEQ 2008). The results of the trend analysis indicate that DO concentrations have declined over time at this location.

4.7.2 Historical Water Quality Assessments

Use attainment statistics as reported in 305(b) reports from 1990 to 2008 are compiled in **Tables 4-12 through 4-15**. (Although ADEQ submitted draft 305(b) reports in 2010 and 2012, these reports have not yet been approved by EPA.) Table 4-12 shows the total number of stream miles assessed for each report as well as how many of the assessed stream miles were found to be not supporting their designated uses. Table 4-13 shows the number of stream miles impaired by each pollutant or pollutant category.

Table 4-12. Miles of Impaired Streams from Biennial Assessments 1990 through 2008

Designated Use	Water Use Sector	1990[a]	1992	1994	1996	1998	2000[b]	2002	2004	2006[b]	2008
Fish consumption	Recreation	NR	185.8	65.7	374.9	732.8	372.9	372.9	294.7	466.4	363.3
Aquatic life	Fish and Wildlife	349	2882.9	849.8	3284.9	2607.2	802.4	898.8	1130.7	2707.8	2439.9
Primary contact	Recreation	2074.5	783.4	1156.9	1507.7	502	33.1	33.1	121.5	114.2	564.8
Secondary contact	Recreation	NR	0	0	21.5	0	0	0	0	4.6	7
Domestic water supply	Drinking Water	NR	864.8	862.2	849.9	115.8	77.7	77.7	280.7	446.5	448.3
Agricultural and industrial water supply	Agriculture, Industrial	NR	160.1	168.1	0	0	0	0	218.9	605.6	967.7
Total miles impaired		3077.1	3265.2	2032.3	1911.8	1147.3	1177.3	1292.7	1632	3434.9	4086.5
Percent miles impaired		65.30%	47.30%	28.10%	22.10%	13.50%	14.50%	15.00%	17.50%	34.80%	41.50%
Total miles assessed		4712.6	6902.2	7233.6	8667.7	8513.4	8112	8606	9305.7	9857.1	9849.7

Notes: NR=not reported

(a) Reported as not meeting fishable and swimmable goals.

(b) Approved 303(d) list not available.

Table 4-13. Impaired Stream Miles for Specific Pollutants and Pollutant Categories

Causes	1990	1992	1994	1996	1998	2000	2002	2004	2006	2008
Priority Organics	45.7	151	69.7	69.7	65.7	65.7	65.7	65.7	57.1	44.8
Metals	0	0	NR	28.4	36.5	6.6	6.6	NR	NR	NR
Aluminum	NR	NR	NR	NR	NR	NR	NR	20.3	11.7	20.3
Beryllium	NR	NR	NR	NR	NR	NR	NR	NR	444.1	454
Cadmium	NR	NR	NR	NR	NR	NR	NR	NR	NR	2.5
Copper	NR	NR	NR	NR	NR	NR	NR	123.9	2.5	417.7
Lead	NR	NR	NR	NR	NR	NR	NR	20.3	738.3	618.1
Zinc	NR	NR	NR	NR	NR	NR	NR	68.3	758.9	744.9
Ammonia	26	29.4	20.3	3	11.5	11.5	11.5	11.5	11.5	12
Minerals	32.4	367.8	334.8	382.2	54.1	24	24	NR	NR	NR
Chloride	NR	NR	NR	NR	NR	NR	NR	215.5	561.9	691.7
Sulfate	NR	NR	NR	NR	NR	NR	NR	24.5	379.8	511
Total Dissolved Solids	NR	NR	NR	NR	NR	NR	NR	245.2	769.3	1021.7
Nutrients	32	141.3	182.5	122.7	279.9	42.2	55	NR	NR	NR
Nitrogen	NR	NR	NR	NR	NR	NR	NR	87.4	70.6	624.8
Phosphorus	NR	NR	NR	NR	NR	NR	NR	12.8	29.4	59.8
Siltation/Turbidity	618.9	2,276.7	2,464.9	2,864	2,109.7	662.6	798	944.2	1,022.5	1,156.3
Organic Enrichment/Low DO	39	46	10	18	10	10	10	19.2	1,252.8	1,308
Fecal Coliforms	1,963.1	174.6	652.7	598.1	210.3	12.7	12.7	121.5	NR	NR
E. coli	NR	NR	NR	NR	NR	NR	NR	NR	182.8	638.8
Unknown Toxicity	9	NR	NR	NR	NR	NR	NR	NR	NR	NR
Other Inorganics	315.8	NR	NR	NR	NR	NR	NR	NR	NR	NR
pH	33.5	NR	NR	NR	NR	NR	NR	NR	119.7	NR
Mercury	NR	NR	227.9	239.8	367.1	307.2	307.2	417.7	409.3	319
Dissolved Oxygen	NR	NR	NR	NR	NR	34.8	2	NR	NR	NR
Temperature	NR	NR	NR	NR	NR	NR	NR	31.7	119.5	86.1

Note: NR = not reported

Table 4-14. Lake Acres Impaired for Specific Designated Uses

Designated Use	Use Sector(s)	1990[a]	1992	1994	1996	1998	2000[b]	2002	2004	2006[b]	2008
Fish consumption	Recreation	NR	10	>20,702	27,342	17,100	16,950	16,950	16,950	>23,637	>23,637
Aquatic life	Fish and Wildlife	0	0	0	0	0	0	4,960	8,480	11,583	11,583
Primary contact	Recreation	0	0	0	0	0	0	200	200	0	0
Secondary contact	Recreation	NR	0	0	0	0	0	200	200	0	0
Domestic water supply	Drinking Water	NR	0	0	0	0	0	0	0	97,105	97,105
Agriculture & industrial water supply	Agriculture, Industrial	NR	0	0	0	0	0	0	0	0	0
Total acres impaired		0	<10	>20,702	27,342	17,100	16,950	16,950	16,950	108,353	127,520
Total acres assessed		355,063	355,063	356,254	356,254	356,254	355,954	355,954	356,254	356,506	357,896

Notes: NR=not reported
(a) Reported as not meeting fishable and swimmable goals.
(b) Approved 303(d) list not available.

Table 4-15. Impaired Lake Acres for Specific Pollutants and Pollutant Categories

Causes	1990	1992	1994	1996	1998	2000	2002	2004	2006	2008
Priority Organics		<10	<10	<10	<10	<10	<10	<10	<10	<10
Beryllium	NR	NR	0	0	0	0	0	0	9 lakes	97,105
Copper			0	0	0	0	0	0	0	335
Mercury			20,692	27,332	17,902	16,950	16,950	16,950	16,950	>18,677
Nutrients									4,625	4,625
Siltation/Turbidity									8 lakes	3,235
Unknown										30,485

Based on Table 4-12, there appears to be a significant improvement in designated use support in streams between 1990 and 1998 followed by a gradual decline through 2004, and then a very significant decrease in 2006 and 2008. However, it is difficult to draw conclusions about trends in the overall quality of the state's rivers and streams from these data, for several reasons. First, if any of the designated uses of a waterbody are not supported, then the waterbody is listed as "not meeting uses" even though all of its other designated uses are supported. Second, a large number of the water quality monitoring stations are purposely located in areas known to have, or suspected of having, water quality contamination resulting in a higher percentage of problem areas being monitored and skewing the results toward the impaired category. Third, new, and/or modified water quality standards can result in a number of waterbodies being added to the 303(d) list even though there may have been no change in the quality of water in the waterbodies. For example, more stringent standards for some metals were established in 2004, leading to new impairment listings for many streams without a corresponding change in water quality. As shown in Table 4-13, there was a significant increase in the number of waterbodies impaired for beryllium, lead, and zinc as reported in the 2006 305(b) report. Finally, changes in assessment criteria have also influenced the number of streams impaired for a particular parameter. Prior to 2006, ADEQ considered a waterbody to be supportive of a designated use if less than 25 percent of observed data exceeded the numeric water quality standards for minerals. In 2006, the assessment criteria was lowered to 10 percent of observed data exceeding minerals standards, resulting in a significant increase in the number of streams listed as impaired for minerals. Other factors, such as newly assessed streams and changes in EPA guidance, may also result in changes in the amount of waterbodies on the 303(d) list that do not reflect changes in overall water quality.

Table 4-14 shows the total acreage of lakes assessed for each report as well as how supportive they were of their designated uses. Prior to 1998, no impairments were reported in the assessed lakes. In 1998, 17,100 acres of lake were considered impaired because fish consumption was not supported due to mercury concentrations that exceeded the Food and Drug Administration's action levels (Tables 4-14 and 4-15). In 2006, changes in beryllium criteria implemented in 2004 resulted in a significant increase in impaired lakes. The beryllium criteria have since been increased significantly and it is likely that most of those lakes listed as impaired for beryllium will be removed in the next EPA-approved list.

4.8 Surface Water Quality Monitoring

To determine whether available water is of suitable quality for designated uses (and meet the needs of water use sectors), water supplies must be analyzed to determine the levels of chemicals and microorganisms present in the water. Several federal and state agencies and organizations are involved in monitoring water quality in Arkansas, including ADEQ, ANRC, the Arkansas Department of Health (ADH), and the USGS.

ADEQ monitors water quality of surface waters through several programs. The ambient water quality monitoring network includes 150 sites on rivers, streams, and impoundments that are sampled monthly for chemical analysis. The roving water quality monitoring network includes 200 sites. These sites are divided into four regional groups. Each group of sites is sampled for chemical and bacterial analysis on a rotating basis, bimonthly over a 2-year period, every 6 years. Bacterial analysis is also performed on samples from the ambient water quality monitoring network within the active region of the roving water quality monitoring network. In addition, ADEQ conducts water quality monitoring during "intensive surveys." These surveys can involve water sampling for chemical and bacterial analysis, as well as biological sampling to evaluate water quality. Intensive surveys are conducted for a variety of purposes, including determination of TMDLs, and to augment water quality information from the routine water quality monitoring networks for more accurate assessment of designated use support (ADEQ 2009, ADEQ 2012, ADEQ 2013).

Through its nonpoint source management program, ANRC oversees water quality monitoring programs in 10 nonpoint source priority watersheds (**Table 4-16**). Parameters monitored by these programs typically include nutrients and sediment, turbidity, and/or TSS.

Table 4-16. ANRC Nonpoint Source Priority Watersheds

Priority Watershed	Associated AWRPR(s)
Beaver Reservoir	North
Poteau River	West-central
Bayou Bartholomew	East
Illinois River	North
Lake Conway Point Remove	West-central
Lower Ouachita Smackover	South-central
Strawberry River	North
Upper Saline River	South-central
L'Anguille River	East
Cache River	East

The monitoring and reporting requirements for surface water used for human consumption are authorized by both the federal Safe Drinking Water Act (SDWA) and ADH's Rules and Regulations Pertaining to Public Water Systems (RRPPWS) (Arkansas State Board of Health 2012). A summary of these requirements can be found in Chapter 5 of Arkansas Public Water System Compliance Summary, "Microbial Disinfection By-Products Rules" (ADH 2012). There are currently 88 public water supply systems in Arkansas that use surface water (ADH n.d.). Depending on the treatment methods used and the number of customers served by the public water supply utilizing surface water, the monitoring requirements for the raw surface water, or source water, will vary. Turbidity, E. coli, and cryptosporidium data are required by EPA's Long-Term 2 Enhanced Surface Water Treatment Rule (LT2 Rule). Total organic carbon (TOC) data are required by ADH's "Microbial Disinfection By-Products Rules." Monitoring for TOC and alkalinity is specifically identified in ADH's RRPPWS as being required for raw surface water; these parameters must be sampled once per month unless monitoring frequency is reduced based on treated water TOC results. Surface public water supply systems are required to submit the monthly reports to ADH (Arkansas State Board of Health 2012). Currently the monthly reports are scanned and available electronically, which has been an ongoing practice since early 2001. Monthly reports from the early 1920s to 2000 are housed at ADH, but the availability of these reports and other supporting documentation from this time period is not readily known (personal communication, Lyle Godfrey, ADH, July 17, 2013).

There are 78 active stream water quality sampling sites maintained by the USGS in Arkansas. In addition, USGS has active water quality sampling programs at 27 sites in nine Arkansas lakes (USGS 2013). Water quality parameters monitored at these sites usually include parameters for which numeric ambient water quality criteria have been set.

4.9 Existing Local Studies

There have been a few recent studies of water quality trends in selected areas of the state. These are summarized below by AWRPR. Note that no existing studies of water quality trends were identified from the Southwest AWRPR.

4.9.1 West-Central Arkansas Water Resources Planning Region

The Fort Smith water utility has active water quality monitoring programs in the Lee Creek and Frog Bayou watersheds. The Lee Creek monitoring program includes 10 sites that have been sampled for water quality analysis and biological integrity over periods ranging from 9 to 21 years (**Table 4-17**). All of these sites exhibit increasing trends in nutrient loading. Biological integrity at five of the sites is starting to decline, while at two of the sites, Buckhorn and Upper Lee Creek, biological integrity is improving (personal communication, L. McAvoy, Fort Smith Utility, July 2, 2013).

Table 4-17. Summary of Lee Creek Monitoring Program

Station/Stream	Monitoring Start Year	Water Quality	Biological
Blackburn Cr	2000	X	
Buckhorn	2002	X	X
Cove Cr	1998	X	X
Fall Cr	1998		X
Jenkins Cr	1996	X	X
Little Lee Cr	2004	X	
Mountain Fork	1998	X	X
Upper Lee Cr	2003	X	X
Weber Creek	2004	X	
Lee Creek Reservoir	1992	X	X

The Frog Bayou monitoring program includes four sites where water quality and biological sampling have occurred for between 23 and 15 years (**Table 4-18**). Analysis of water quality indicates that nutrient loads to the watershed are increasing. Biological integrity at most of the sites is beginning to decline; however, biological integrity in Lake Fort Smith is stable or increasing (personal communication, L. McAvoy, Fort Smith Utility, July 2, 2013).

Table 4-18. Summary of Frog Bayou Monitoring Program

Station/Stream	Monitoring Start Year	Water Quality	Biological Integrity
Frog Bayou	1991	X	X
Jack Creek	1998	X	X
Jones Fork Creek	1993	X	X
Lake Fort Smith	1991	X	X

The Lake Conway-Point Remove watershed is an ANRC nonpoint source priority watershed. Two 1-year water quality monitoring Section 319 projects have been completed on Galla Creek in this watershed. In these projects, chemical water quality data were collected at two sites over a 2-year period from July 2008 through July 2010. The reports on these projects state that concentrations of nutrients and TSS and turbidity measurements increased from the upstream to the downstream station. In addition, total phosphorus and ammonia concentrations and turbidity measurements increased from one project year to the next, while TSS concentrations declined slightly and TKN did not change (personal communication, R. Alberson, ANRC, July 3, 2013).

4.9.2 North Arkansas Water Resources Planning Region

Analysis of trends in nutrient and suspended sediment concentrations at selected surface water quality stations in the USGS Ozark Plateaus National Water Quality Assessment (NWQA) study unit for the period from 1970 to 1992 did not identify any significant changes in water quality over time (Davis et al. 1996). Several of the sites analyzed in the NWQA study were also used to evaluate water supply availability for the 2014 AWP. The Strawberry River, Illinois River, and Beaver Lake watersheds are ANRC priority nonpoint source watersheds. Recently, a Section 319 water quality monitoring study was completed in the Strawberry River watershed to document the impact of best management practices (BMPs). In this study, water quality and biological sampling was conducted at a site upstream of the BMP location and a site downstream, in three subwatersheds, a total of six sites. Samples were collected from these sites during 2008 through 2011. Comparisons of orthophosphate, nitrate, and TSS concentrations from prior to and after implementation of the BMPs showed increases at most of the sampling sites, both upstream and downstream of the BMP locations (personal communication, R. Alberson, ANRC, July 3, 2013).

A recent study by the Arkansas Water Resources Center evaluated water quality trends at six sites in the Illinois River and Beaver Lake watersheds using data collected through Section 319 projects over the period from 1997 through 2010. In this study, flow-adjusted concentrations were analyzed using parametric and nonparametric statistical approaches. The study identified declining trends in concentrations of phosphorus and sediment (Bailey, Haggard, and Massey 2011).

4.9.3 South-Central Arkansas Water Recourses Planning Region

The Saline River watershed is an ANRC priority nonpoint source watershed. A Section 319 water quality study was conducted in this watershed from 2006 through 2008. During this study, nutrient and TSS measurements were collected at a site on the Middle Fork of the Saline River, and a site on the South Fork of the Saline River. During the period of the study, concentrations of total phosphorus, TKN, and TSS declined at the Middle Fork sampling site. At the South Fork sampling site, concentrations of total phosphorus and TKN declined, while TSS increased. There were only slight changes in ammonia concentrations at both sites (personal communication, R. Alberson, ANRC, July 3, 2013).

4.9.4 East Arkansas Water Resources Planning Region

The Bayou Bartholomew and L'Anguille River watersheds are ANRC priority nonpoint source watersheds. A Section 319 water quality study of Bayou Bartholomew was conducted during the period from 2005 through 2010. In this study, water quality samples were collected at two sites on Bayou Bartholomew and analyzed for nutrients and TSS. Over the period of the study, the water quality at the upstream site exhibited declines in ammonia, TSS, and turbidity. Concentrations of total phosphorus and total nitrogen did not exhibit a trend. At the downstream site, nutrient and turbidity concentrations did not exhibit a trend, while TSS increased (personal communication, R. Alberson, ANRC, July 3, 2013).

A Section 319 water quality study of the L'Anguille River was conducted from 2004 through 2011. In this study, water quality samples were collected at five sites on the L'Anguille River every month. This study concluded that nutrient and mineral concentrations increased slightly over the period of the study, while turbidity and TSS declined (personal communication, R. Alberson, ANRC, July 3, 2013).

4.10 Existing Issues

In the 2008 305(b) report, the majority of stream miles were impaired due to low DO (1,308 miles), siltation/turbidity (1,156 miles), and TDS (1,022 miles). The most frequently identified sources of pollutants causing stream impairments were agriculture and erosion (ADEQ 2009).

There are fish consumption advisories due to mercury for 343 miles of streams and 11 lakes in the state. In addition, there are 48 miles of stream and one lake subject to fish consumption advisories due to dioxin, and 2 miles of stream closed to fishing due to polychlorinated biphenyl (PCB) contamination (ADEQ 2009).

4.11 Changes Since the 1990 AWP Update

The only surface water quality issue identified in the 1990 AWP was nonpoint source pollution (Arkansas Soil and Water Conservation Commission 1990). Nonpoint source pollution is still the primary cause of water quality impairment in the state (ADEQ 2009).

In 1990, there were only three active fish consumption advisories, one due to dioxin and the others due to PCBs (ADPCE 1990). Between 1990 and 1992, one PCB fish consumption advisory was ended and three dioxin fish consumption advisories were added (ADPCE 1992). Between 1992 and 1994, two dioxin fish consumption advisories were removed and one was added, and 17 mercury fish consumption advisories were added. One mercury fish consumption advisory was removed in 2011, but mercury remains an issue in several Arkansas streams and lakes (ADH, AGFC, ADEQ 2011).

There are 15 superfund sites in Arkansas. These are sites abandoned by their owners where hazardous wastes are present, that are part of the EPA Superfund Program for cleanup of abandoned hazardous waste sites. Surface water contamination has been an issue at six of these sites. Half of these sites were active at the time of the 1990 AWP. The Cedar Chemical Co. site came under the Superfund program in 2002, Mountain Pine Pressure Treatment in 1999, and Ouachita-Nevada Wood Treaters in 2000. Remediation activities to protect surface water quality have been completed at most of the sites (**Table 4-19**). At several of the sites, these activities have been completed since the 1990 AWP. Two of these sites have been removed from the National Priorities List and are no longer Superfund sites (EPA 2013). As result of these activities, surface water quality issues associated with Superfund sites have decreased since the 1990 AWP.

Table 4-19. Superfund Sites with Surface Water Quality Issues[1] (EPA 2013)

Site Name	EPA ID	Site Location (County)	Contaminated Water Resources	Remediation Complete	Removed from NPL
Cedar Chemical Co.	ARD990660649	Phillips	Surface water	Ongoing	NA
Frit Industries	0600106	Lawrence	Coon Creek	Surface water collection and treatment system completed in 1985	1997
Gurley Pit	ARD035662469	Crittenden	Fifteen Mile Bayou	Runoff management system completed in 1994	2003
Mid-South Wood Products	ARD092916188	Polk	Prairie Creek, East Fork Moon Creek	Contaminated soils removed	NA
Mountain Pine Pressure Treatment	ARD049658628	Yell	Surface water	Sludge removal in 1988, contaminated soil stabilized in 2005	NA
Ouachita-Nevada Wood Treaters	ARD042755231	Ouachita	Caney Creek, wetlands	Contaminated soil and water removed in 2000	NA
Vertac	ARD000023440	Pulaski	Rocky Branch Creek	Removal of contaminated soil and hazardous materials in 1997	NA

[1] Highlighted sites were added to the National Priorities List after 1990

4.12 Emerging Issues

There is growing interest in the occurrence of a group of chemicals called contaminants of emerging concern (CECs), which include pharmaceuticals, personal care products (e.g., soap and shampoo), natural and synthetic hormones, surfactants, pesticides, fire retardants, and plasticizers primarily in surface waters, but also starting to be measured in groundwater across the nation. The risks to human health and the environment from the majority of these chemicals are unknown, which is why they are referred to as "contaminants of emerging concern." In 2004, USGS, with several partners, collected water samples from 17 sites upstream and downstream of wastewater treatment plants on seven streams in northwest Arkansas, and one site on North Sylamore Creek, and analyzed them for selected antibiotics and disinfectants, fire retardants, plasticizers, insect repellents, fragrances, detergents, flavorings, fuels, solvents, polycyclic aromatic hydrocarbons, and over-the-counter medications; a total of 108 chemicals. Forty-two of the 108 chemicals were detected in the water samples. Caffeine was one of the most frequently detected chemicals. There was only one "background" site where none of these chemicals were detected. At all of the rest of the sites, at least one of these chemicals was present (Galloway, et al. 2005). Detection, however, does not indicate there is an effect.

Numeric nutrient criteria are being developed for Arkansas lakes and streams. There were increasing trends in inorganic nitrogen at several sites across the state. Nutrient impairment might become an issue once numeric nutrient criteria are promulgated.

Section 5

Groundwater Availability

5.1 Introduction

Arkansas has a long history of proactive assessment of their water resources, including groundwater. Currently, about 71 percent of the water supply in the state is provided from groundwater sources. Arkansas' development of groundwater is surpassed by only four other states in the U.S. The AWP was last updated in 1990 and included a recommendation that critical groundwater areas be identified. This recommendation was implemented pursuant to Act 154 of 1991, which directed the ANRC to identify these critical groundwater areas based on significant groundwater level declines or water quality degradation. These evaluations are supported by monitoring data and scientific review.

The state cooperated in a large-scale groundwater evaluation and modeling project conducted by the USGS covering the aquifers of the Mississippi embayment, which includes the eastern portion of the state, where the most significant groundwater development occurs. This area includes the alluvial deposits associated with the Mississippi River and major tributaries, where the greatest groundwater development occurs. Groundwater withdrawals from the alluvial aquifer have the potential to change historical groundwater/surface water interaction. Groundwater withdrawals may capture return flows that would have historically returned to the stream as baseflow and even drawdown the water table below the top of the stream elevation inducing flow from the stream to the alluvial aquifer. This study also assessed deeper aquifers that are also widely used, including the Sparta and Wilcox sands. A series of reports (USGS 2009; USGS 2011; and USGS 2013) were produced that included development of a numerical groundwater model of the Mississippi embayment aquifers that is intended for use as a planning tool. These reports concluded that the current level of groundwater use in Arkansas is not sustainable.

The purpose of this section is to summarize information on the availability of groundwater and to use the existing model to assess the potential for future groundwater production. The latest version of the USGS Mississippi Embayment Regional Aquifer Study (MERAS) groundwater model is used to assess the availability of groundwater, to assess the impact of continuing to attempt to meet current and future demands from groundwater, and to estimate long-term sustainable groundwater production.

This section focuses quantitative evaluations on the eastern portion of the state, where a model is available and the greatest quantity of groundwater is currently used. The western portion of the state is addressed on a more qualitative basis. Section 5.2 summarizes the hydrogeologic framework and describes the aquifers that are used for groundwater production. Section 5.3 summarizes the development and calibration of the MERAS groundwater model. Section 5.4 documents adaptation of the MERAS model to assessment of future groundwater demand. Results of the groundwater evaluation are presented in Section 5.5. A qualitative assessment of groundwater availability in the western portion of the state is presented in Section 5.6. Existing groundwater quality is presented in Section 6.

5.2 Hydrogeologic Setting

The groundwater systems in Arkansas have been extensively investigated and monitored by both state and federal agencies due to the economic importance of this resource. A brief summary of this regional understanding of the groundwater systems is presented in this section to provide background for the model that is described in a subsequent section.

5.2.1 Regional Groundwater Investigations

The basis for understanding of aquifer systems in Arkansas is the extensive and long-term monitoring that has been conducted in the state. The USGS began working closely with the Arkansas Geological Commission and the University of Arkansas, Agricultural Experiment Station to collect water-level measurements from a network of existing water wells in the alluvial and Sparta aquifers of eastern and southern Arkansas. This monitoring network included 208 wells in the alluvial aquifer, and 75 wells in the Sparta aquifer. This monitoring network has been expanded over time and now includes 28 real-time wells and over 1,500 wells and springs that are monitoring annually. These wells are distributed across the state and include all of the significant aquifers. These data are analyzed and reported in the annual *Ground-Water Protection and Management Report*; a report generated as part of the AWP activities since the early 1990s.

Early records show significant groundwater withdrawals beginning around 1910, and drawdowns in the water levels occurred in response, especially in areas of high groundwater use in the Grand Prairie area. As early as 1929, water-level declines were attributed to irrigation water use by the USGS.

To better understand the use and long-term viability of the alluvial and Sparta Sand aquifers, a number of groundwater models were developed to simulate aquifer dynamics and to allow examination of future conditions under current and future management concepts. The Arkansas Water Science Center of the USGS has a long history of numerical modeling in the area of the Mississippi embayment, with analog models construction as far back as the 1970s, and more recently using numerical simulation models. In the 1980s, the USGS began the Gulf Coast Regional Aquifer System Analysis (GCRASA) study to compile data and simulated groundwater flow in three main parts—the Mississippi River Valley alluvial aquifer, the Mississippi embayment aquifer system, and the Gulf Coastal lowland aquifer system. Three-dimensional, numerical groundwater simulation models were developed in the mid-1980s by the USGS (Mahon and Ludwig 1990) in cooperation with USACE to simulate the impact of future increases in pumping on the alluvial aquifer. This steady-state model covered the northeast portion of Arkansas and was used to assess the saturated thickness of the alluvial aquifer under increased demands out to 2050. A model focused on the Sparta aquifer in southeast Arkansas and northeast Louisiana was developed for a similar purpose in parallel by the USGS in cooperation with the Arkansas Soil and Water Conservation Commission (now ANRC) (Fitzpatrick, Kilpatrick, and McWreath 1988). Over the years, these models were expanded and refined through subsequent studies by the USGS in collaboration with ANRC. These models supported a better understanding of the long-term health of the alluvial and Sparta Sand aquifers and formed the basis for the current models that include the entire eastern Arkansas aquifer system. It is this knowledge and information gained from these past modeling studies, as well as decades of groundwater, water quality, and streamflow data gathering, that allow for the most holistic regional model of the Mississippi embayment developed to date.

The MERAS model was developed in 2006 for use as a tool to evaluate groundwater availability within the Mississippi embayment as part of the USGS Groundwater Resources Program. This model is described in Section 5.3.

5.2.2 Climate

Climate within Arkansas ranges from humid, temperate in the northern part of the state to humid, subtropical in the southern part of the state. Precipitation is usually greater in the southern part of the state (approximately 56 inches per year [in/yr] in the southern Mississippi embayment) than in the northern part (approximately 48 in/yr). Precipitation is distributed fairly evenly throughout the year with the greatest amounts generally occurring in April and the least in October (Kleiss et al. 2000). The average temperature ranges from 58 degrees Fahrenheit (F) in the north to 66 degrees F in the south (Cushing et al. 1970). Much of the precipitation is consumed by evapotranspiration. Another large part runs off to the many streams in the state. Snowfall in the capital of Little Rock averages 5.2 in/yr.

A USGS report recently reviewed precipitation variability within the MERAS model area and showed that climate varies significantly; both temporally and spatially. There were five distinct historical wet periods and six distinct dry periods that occurred from 1895 to 2008. There was an overall drying trend starting at 1895 and continuing through 1943 with a slight 5-year wet period from 1918 to 1923. Between 1923 and 1970, the climate fluctuated slightly with periods of both wet and dry; however, after 1970 there is an overall 30-year wet period until 2004 where the climate seems to be shifting into a drier period. Spatially, there were differences between the north and south, as well as, the east and west. A dry period existed between 1961 and 1970 for the northeastern site (Memphis, Tennessee) and the western site (El Dorado, Arkansas) and a wet and dry period for the southeastern site (Jackson, Mississippi) for the same time period. A wet period existed from 1983 to 1987 for the southeastern site (Jackson, Mississippi) and the northeastern site (Memphis, Tennessee), while the southwestern (El Dorado, Arkansas) site fluctuates with periods of both wet and dry (Clark et al. 2011).

5.2.3 Aquifers of Arkansas

Arkansas is typically divided into two major geologic subdivisions—the Interior Highlands of northern Arkansas, which generally consist of consolidated Paleozoic formations, and the largely unconsolidated formations of the Gulf Coastal Plain of the southern and eastern regions of the state. Much of Arkansas' groundwater production is sourced from Quaternary deposits of sand and gravel in the Mississippi River Embayment of the Gulf Coastal Plain, which is the focus of this groundwater availability analysis. A portion of the geologic information in this section is derived from the draft "Aquifers of Arkansas: Protection, Management, and Hydrologic and Geochemical Characteristics of Arkansas' Groundwater Resources" (Kresse, et al., in review) which provides more detail on the hydrogeology of groundwater aquifers across the state.

Interior Highlands – Ozark Plateau Province, Arkansas River Valley, and Ouachita Mountains

The Interior Highlands are most commonly divided into the Springfield Plateaus, Salem Plateaus, and the Boston Mountains, while further south the Ouachita Mountain Province including the Arkansas River Valley is found. These regions consist of consolidated formations of primarily limestone, sandstone, shale, and some shallow alluvial deposits along the Arkansas River and other streams.

The Springfield Plateau aquifer (approximately 30 gpm individual well yield), including the Boone Formation, is a reliable, though vulnerable, supply of groundwater for shallow domestic water use in northern and north-central Arkansas. The karst terrain associated with the limestone formations of this plateau make this aquifer extremely vulnerable to surface contamination.

The Arkansas River Valley is traversed by the Arkansas River from the northwest to the southeast. The Arkansas River Valley alluvial plain is a distinct hydrogeological area. The western part of the Arkansas River Valley is composed of the Savanna Sandstone, Paris Shale, Spadra Shale, and Hartshorne Sandstone. Coal is an important industry in the Paris and Spadra Shale. There are numerous natural gas fields in this region, as well. 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 alluvial aquifer (300 – 700 gpm) of western Arkansas is a reliable source of available groundwater in western Arkansas. Yields from the aquifer are appropriate for small to medium size public supply water use needs, as well as moderately sized irrigation wells. The Arkansas River, and is an excellent source of recharge to nearby wells developed in the coarse-grained alluvial stratum. The maintained pools of the river, along with adjacent coarse-grained sediments, bank storage, and other floodplain deposit features hydraulically connected to the alluvial material, provides this constant source of recharge.

Sedimentary rock comprises the Ouachita Mountains. Most of the mountain ridges are narrow, with steep slopes and sharp crests. Generally, the hydrogeology of the Interior Highlands can be described as an area of consolidated formations that yield relatively low volumes of water to wells. The consolidated formations typically are confined with most of the water yielded to wells coming through secondary porosity found in fractures and bedding plains. Typically, the most noted aquifers within the Interior Highlands are the deep Ozark aquifer, and the Big Fork 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.

The Ouachita Mountains aquifer (5 – 15 gpm), consisting primarily of consolidated formations of sandstone, shale, and chert strata, is a reliable, though vulnerable, supply of groundwater for shallow domestic water use throughout the Ouachita Mountains of western Arkansas. Well yields typically are 5 to 15 gpm, from formations such as the Atoka and Big Fork Chert; therefore, the aquifer is considered to be reliable only for domestic wells, and other small-yield wells.

Ozark aquifer - The Ozark aquifer (100 – 300 gpm), consisting primarily of deep Ordovician limestone and dolomite strata such as the Roubidoux Formation and the Gunter Member of the Gasconade Dolomite, is a reliable source of groundwater. Groundwater level trends indicate a relatively stable surface in much of northern Arkansas indicating that current and future water use needs can be supplied from the aquifer. Groundwater yields are adequate to supply water for small to moderate size public supply wells, livestock, poultry, and other uses.

Gulf Coastal Plain – West Gulf Coastal Plain and Mississippi Embayment

The Mississippi Embayment of eastern Arkansas is a trough filled by fluvial (stream) sediments of great depth. Elevations range from 500 to 100 feet, decreasing southward. Recent alluvium and terrace deposits cover much of the lowlands in the southeastern half of the state. Particularly, they provide the surface materials in the Mississippi Embayment and along the rivers of the West Gulf Coastal Plain. Major aquifers in the Gulf Coastal Plain include the Nacatoch, Wilcox, Sparta/Memphis, Cockfield, and Mississippi River Valley alluvial aquifers. **Figure 5-1** illustrates the layered structure of the aquifer system.

The Nacatoch aquifer (150 - 300 gpm) is a reliable source of municipal, industrial, and other uses in and near its outcrop area in southwestern and northeastern Arkansas. Groundwater quality is a concern down gradient due to high salinity.

The Mississippi River valley alluvial aquifer (1,000 – 3,000 gpm) is composed of unconsolidated materials ranging from clay and silt in upper part and grading downward to coarse sand and gravel at the base (Hosman and Weiss 1991). Most of the groundwater pumping, approximately 95 percent, in the Mississippi Embayment occurs in the alluvial aquifer.

The Cockfield Formation of Eocene age crops out in south-central Arkansas. Southeast from its outcrop belt in Chicot and Desha Counties, the Cockfield (100 – 350 gpm) is the only source of serviceable groundwater for communities in this part of the state.

Below the Cockfield are the very extensive sands of the Sparta/Memphis aquifer (500 – 1500 gpm) in the middle part of the Claiborne Group (also Eocene in age). The Sparta aquifer is used in southern Arkansas and Memphis aquifer in the northeastern Arkansas. The top of this major aquifer typically occurs at depths of 200 to 600 feet, and in some areas as deep as 1,000 feet.

Below the Sparta sand aquifer lies the Wilcox aquifer (100 – 500 gpm), which is the principal source of residential drinking water for community public water systems and is composed of fine to medium sand, silt, clay, and lignite. In eastern and northeastern Arkansas, it is referred to as the "1,400-foot sand." The water produced from this aquifer is a soft, sodium bicarbonate type but saline in downgradient areas. Withdrawals are primarily for public and industrial supplies.

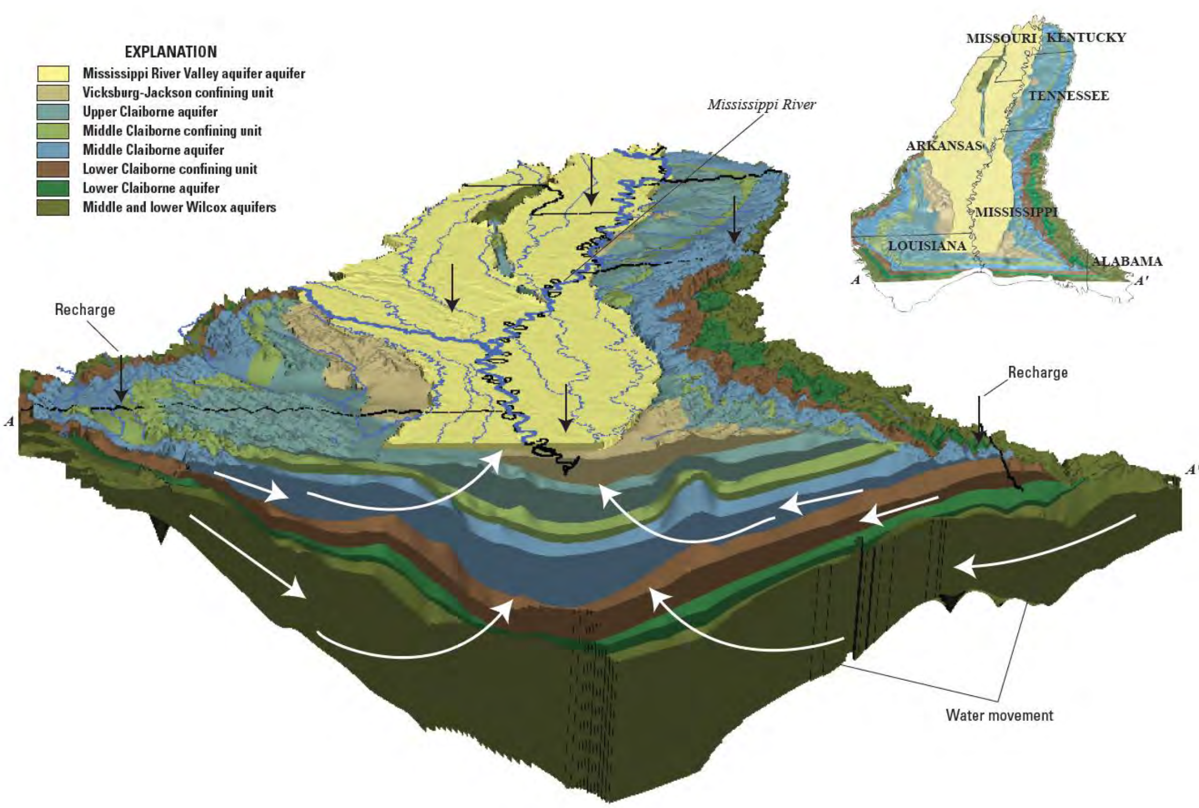


Figure 5-1. Cross-section of Mississippi Embayment Showing Principal Aquifers (Clark et al. 2011)

5.2.3.1 Mississippi Embayment Alluvial Aquifers

Areal Extent

The Mississippi embayment extends across parts of Alabama, Arkansas, Illinois, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee, covering an area of approximately 160,000 square miles (mi^2). The alluvial aquifer, shown in **Figure 5-2**, covers an area of approximately 32,000 mi^2 within the Mississippi Embayment, and approximately 54 percent of this aquifer is located in eastern Arkansas (Clark and Hart 2009).

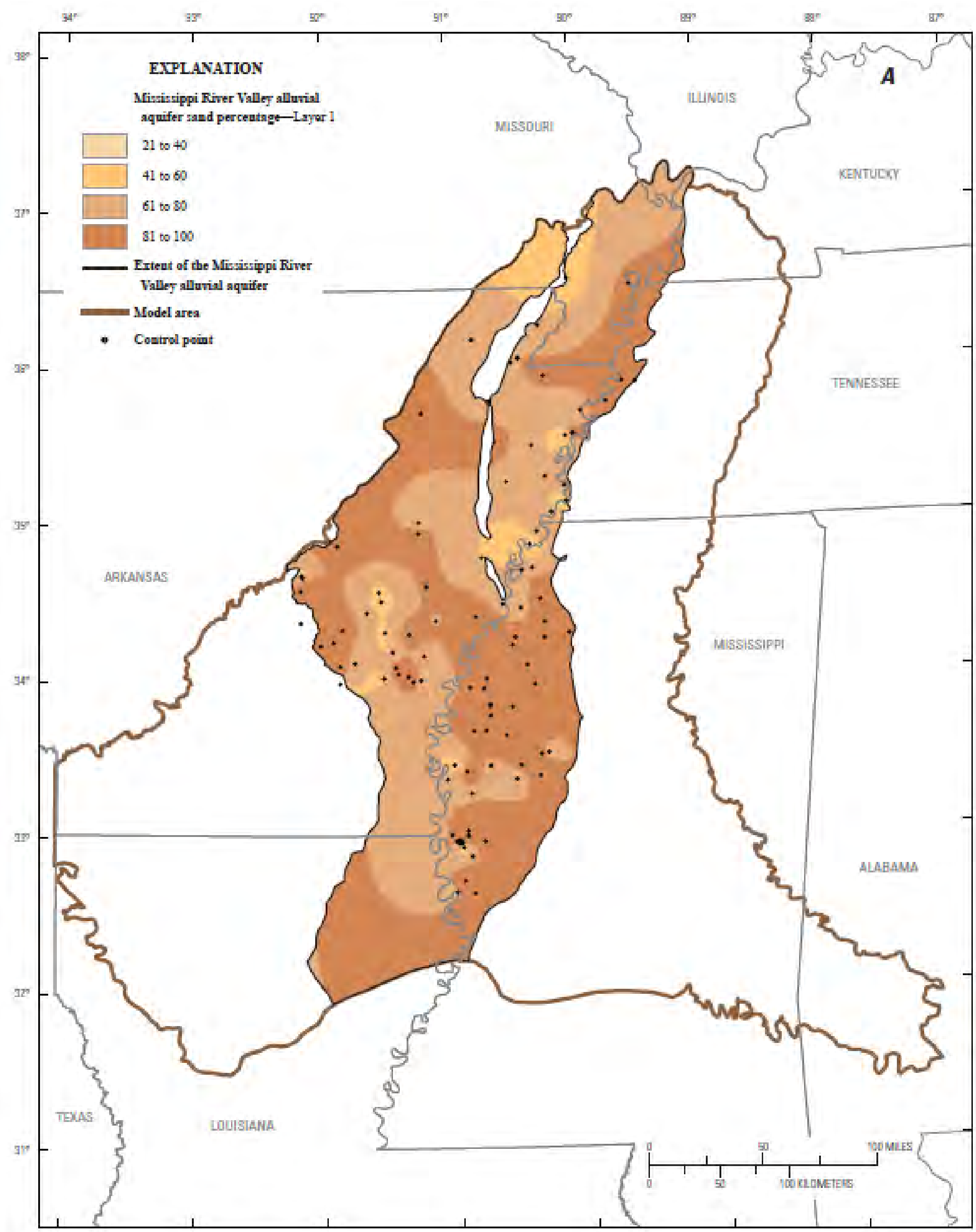


Figure 5-2. Extent of the Mississippi Alluvial Aquifer (Clark and Hart 2009)

Hydraulic Properties

The alluvial aquifer effectively can be divided into two distinct units based on lithology: a lower unit that contains the primary aquifer consisting of coarse sands and gravels derived from alluvial and terrace deposits that coarsen downward, and an upper unit that consists of fine sand, silt, and clay that serves as a confining unit of varying competency, which is of local importance as a lower-yield aquifer primarily for domestic use.

Sources of Recharge

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.

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 U.S. Geological Survey as early as the 1960's. Analysis of the potentiometric map for the fall of 1959 indicates that during this period water was moving from the Arkansas River into the alluvial aquifer in Lincoln and Arkansas counties at a rate of about 12 million gallons per day (mgd). The spring potentiometric surface indicated a flow from the river to the alluvial aquifer of about 9 mgd. "Withdrawals of water for rice irrigation…have resulted in a large cone of depression centered in Arkansas County, Arkansas. The cone of depression has now reached the White River, and movement of water from the stream into the river apparently has begun. These early observations of stream capture were realized before the construction of the lock and dam system on the Arkansas River (Bedinger and Jeffrey, 1964).

Historical Water Use

The alluvial aquifer is an extremely important aquifer in terms of total water use in Arkansas. Around 94 percent of all groundwater used in Arkansas is produced from the alluvial aquifer. Over 47,000 wells were reported with use in the alluvial aquifer as of 2010 (Kresse et al. in review). The economy of eastern Arkansas is heavily reliant on agriculture, and water from the alluvial aquifer drives agricultural production. Groundwater use rates have increased steadily from 1935 to 2010 based on the latest statewide assessment of groundwater use by the USGS. The majority of the increase is attributed to irrigation, which has increased consistently over time for all reported water-use data. In 1935, the average groundwater use was approximately 320 mgd; by 2010, groundwater use increased to approximately 7,800 mgd (see **Figure 5-3**).

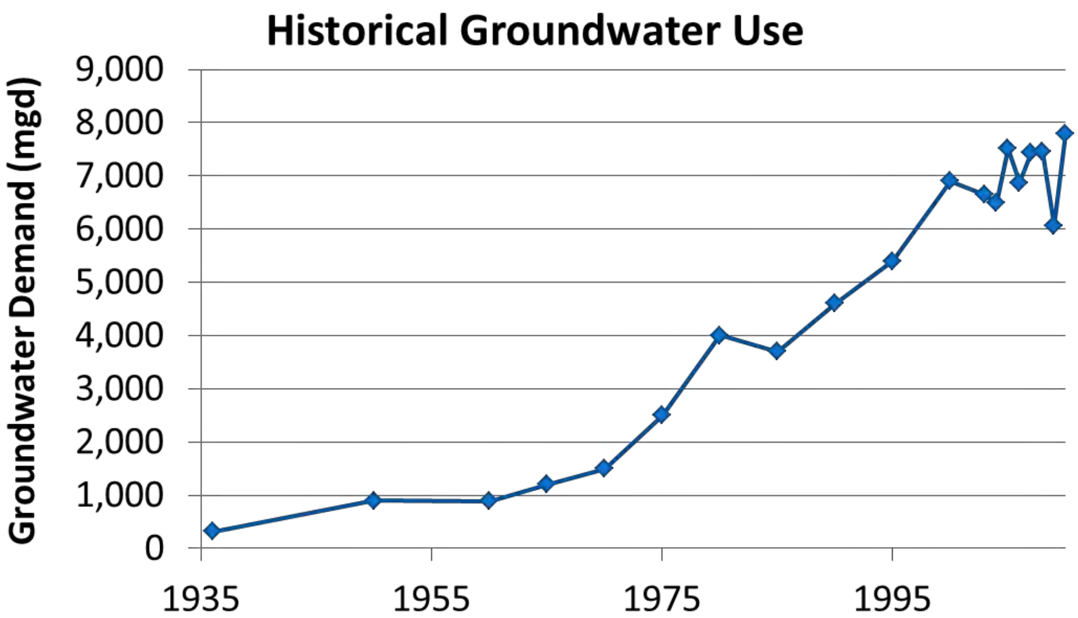


Figure 5-3. Historical Groundwater Use in Arkansas (USGS Data)

Water Level Trends

Due to the historical increase in pumping rates in the alluvial aquifer, the resulting water-budget imbalance resulted in regional water-level declines, formation of extensive cones of depression, reduction of the amount of water in storage, and decreases in well yields. In some areas, water levels have declined to the extent that water cannot be pumped at the rates needed to support demand, particularly for irrigation (Czarnecki and Schrader 2013a), and deeper wells into underlying formations had been required to reach water (Mahon and Poynter 1993).

Predevelopment water levels for the alluvial aquifer typically were reported as near ground surface (within 20 feet) and sloped gently from the northwest to southeast mirroring topography. As groundwater irrigation spread across eastern Arkansas, groundwater withdrawals exceeded recharge and water levels declined. Vast changes in water levels were seen as early as 1929, when one of the first water-level map of the area was created from water levels in wells measured in the Grand Prairie region. In 2010, long-term water-level changes were evaluated using hydrographs from 173 wells in the alluvial aquifer for a period from 1984 to 2008. The mean annual change in water level for the alluvial aquifer in eastern Arkansas was a decline of 0.38 feet per year. These water-level changes varied considerably across the study area, such as in Cross and Lonoke counties where declines averaged about 1.5 feet per year

Projected Groundwater Use

Based on projections of demand for groundwater in Arkansas, groundwater pumping is expected to increase to more than 9,000 mgd by 2050 (see **Figure 5-4**), with much of this increased production (approximately 97 percent) occurring in the alluvial aquifer. The sustainability of this continued increase in groundwater pumping will depend on the water levels, and associated groundwater storage in the alluvial aquifer. Groundwater modeling completed to assess projected impacts of pumping increases on water levels and groundwater storage is presented in Section 5.5.

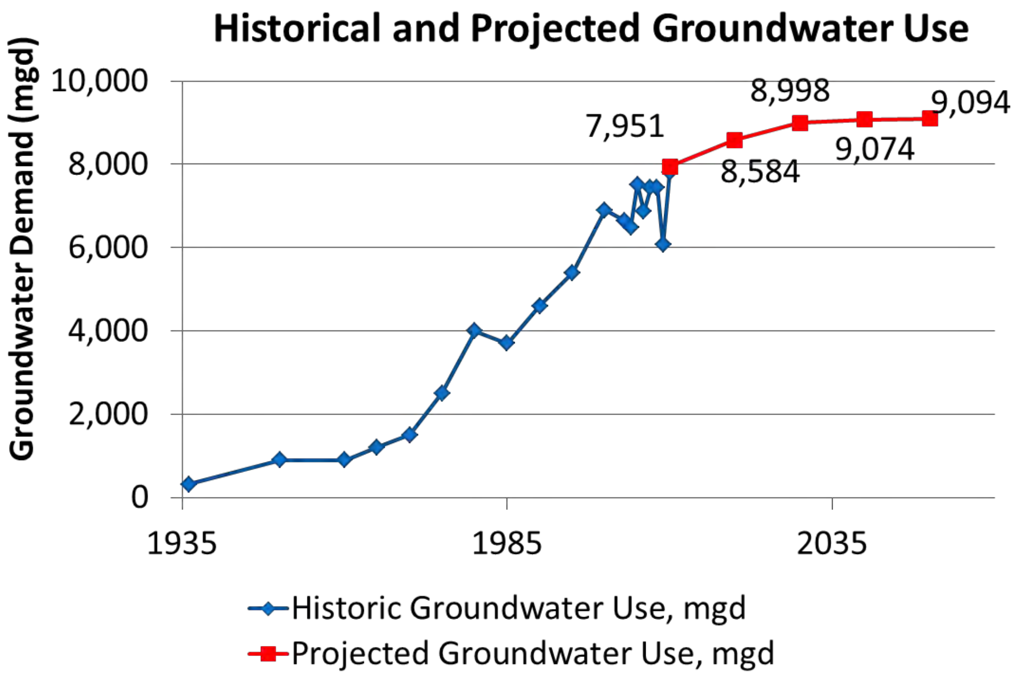


Figure 5-4. Historical and Projected Groundwater Use in Arkansas

5.2.3.2 Mississippi Embayment Tertiary Age Aquifer System

Areal Extent

The major confined sand aquifers of Tertiary age in the Gulf Coastal Plain include the Cockfield, Sparta/Memphis, and Wilcox aquifers.

The Cockfield Formation crops out extensively over south-central Arkansas. It is exposed over practically all of Union County and parts of Bradley, Cleveland, Dallas, Grant, and Saline Counties (Hosman et al. 1968; Hosman 1982; Petersen et al. 1985). The Cockfield Formation has not been observed in outcrop or identified in the subsurface north of 35 degrees north latitude (Hosman et al. 1968).

The Sparta sand covers much of eastern Arkansas. In northeastern Arkansas, the Sparta aquifer commonly is referred to as the Memphis aquifer. The terms "Greensand" and "El Dorado sand" are informal terms applied to the upper and lower major sand units within the Sparta aquifer in southern Arkansas.

The Wilcox Group of Eocene age extends throughout most of eastern and southern Arkansas. The upper unit of the Wilcox Group predominates in the southern part of Arkansas and consists of complexly interbedded layers of clay, sandy clay, thin and discontinuous sand, and lignite (Joseph 1998), and the thin sands of this unit serve as aquifers primarily in the southern extent of the Wilcox Group (Hosman et al. 1968). In southern Arkansas, the Wilcox Group overlies the Midway Group, crops out in a discontinuous band 1 to 3 miles wide (Joseph 1998), and commonly is overlain by terrace deposits and alluvium of Quaternary age.

Hydraulic Properties

The hydraulic properties of the Tertiary age aquifers in the Mississippi Embayment vary widely, with the highest transmissivity zones in the thickest sand intervals. The Sparta/Memphis Sand in northeastern Arkansas is mainly composed of thick bedded, very fine to gravely, well-sorted sand, but contains some argillaceous, micaceous, and lignitic materials. Hosman et al. (1968) reported transmissivity values for the Sparta aquifer from Arkansas ranging from about 1,800 to 17,400 square feet per day (ft^2/d), storage coefficients ranging from 0.0002 to 0.0024, hydraulic conductivity ranging from about 11 to 110 feet per day (ft/d), and specific capacities in wells ranging from 7 to 14 gpm per foot (gpm/ft). Plebuch and Hines (1969) reported well yields from the Sparta aquifer as high as 700 gpm and transmissivity ranging from 3,200 to 15,400 ft^2/d.

Sources of Recharge

Due to the presence of confining units separating the alluvial aquifer and the underlying consolidated formations of the Paleozoic Erathem, including sandstone, shale, and limestone strata, the primary source of recharge to the consolidated formations is direct infiltration of precipitation and leakage from surface water bodies in the outcrop areas. Limited leakage from overlying alluvium and other aquifers with higher hydraulic heads could occur based on localized competency of the confining members. Natural discharge occurs by leakage through the overlying and underlying confining units, leakage into adjacent units with lower hydraulic heads, and discharge to rivers within the outcrop area.

Historical Water Use

There is widespread use of the Cockfield aquifer across eastern Arkansas for domestic purposes, but aquifer yields are high enough in some areas to supply M&I systems as well (Petersen et al. 1985; Joseph 1998b; Yeatts 2004).

The Sparta aquifer is an extremely important aquifer in eastern Arkansas, generally providing water of excellent quality, with wells often yielding hundreds to thousands of gpm. The Sparta aquifer provided 196.64 mgd in 2010; 2.5 percent of all groundwater used in Arkansas (Holland 2013). Over 700 wells were reported with use in the Sparta aquifer as of 2010. Traditionally, the Sparta aquifer was used for public and industrial supply, but irrigation use, particularly in the Grand Prairie region, has increased as water levels in the alluvial aquifer decreased. As of 2010, more water is used from the Sparta aquifer for irrigation than for any other purpose.

The Wilcox aquifer yields water of generally excellent quality, and users often refer to the aquifer as having the best water quality in the state (Scott et al. 1998). Good water quality and yields have led to its use for domestic, industrial, and municipal supply.

Water Level Trends

Increases in groundwater pumping in the consolidated formations have impacted water levels, in some cases forming localized cones of depression around areas of heavy pumping. Water-level declines in the Sparta aquifer are a major concern for users in Arkansas and have been noted throughout the Sparta aquifer in Arkansas. Severe water-level declines were noted in southern and east-central Arkansas since development of the Sparta aquifer for primarily M&I uses in these areas. The mean water level elevation change in the Sparta Aquifer for the 1984 to 2008 period was a decline of up to 1.5 feet per year in Arkansas, Bradley, Cleveland, Jefferson, Poinsett, and Prairie counties. A cone of depression in the 1995 potentiometric surface of the Sparta aquifer was observed in western Poinsett and Cross counties, which were caused by withdrawals for irrigation.

Projected Groundwater Use

Groundwater pumping in the Mississippi Embayment Tertiary age aquifers is expected to decrease slightly in the future. Groundwater modeling completed to assess projected impacts of continued pumping is presented in Section 5.5.

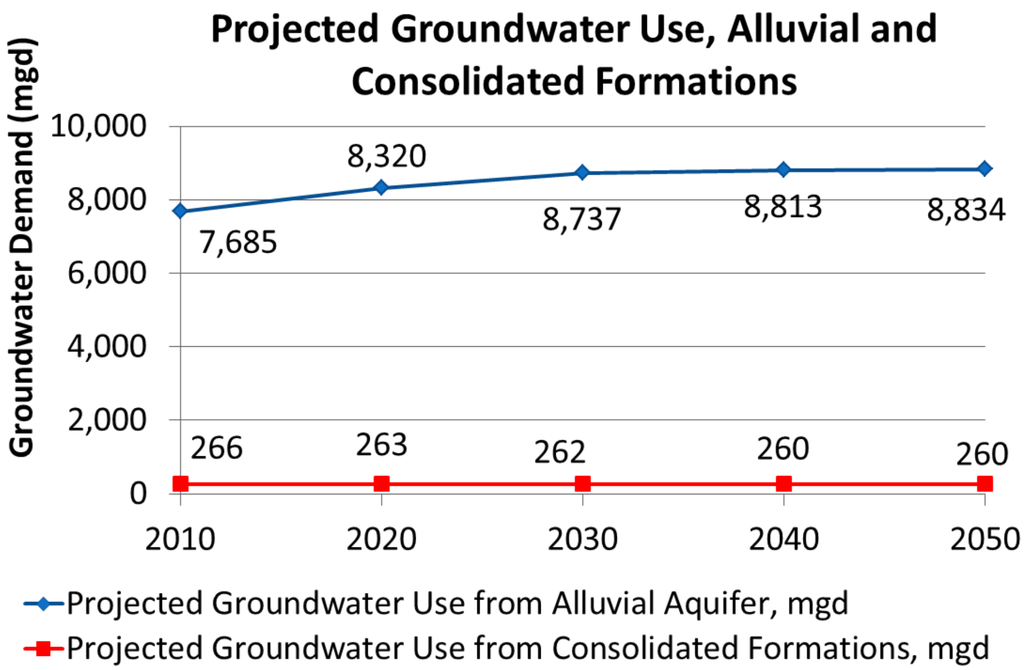


Figure 5-5. Projected Groundwater Use in Arkansas, Alluvial and Consolidated Formation

5.3 Mississippi Embayment Groundwater Model

The groundwater availability in eastern Arkansas was evaluated using a three-dimensional, finite difference groundwater flow model of the Mississippi Embayment. The MERAS was conducted by the USGS and prepared in cooperation with the ANRC. As part of this study a groundwater-flow model was developed to assess water availability in the Mississippi Embayment. This model is referred to as the MERAS model (MERAS 1.0), originally developed in 2006 and documented in the USGS Scientific Investigations Report 2009-5172 (Clark and Hart 2009). The MERAS model (MERAS 1.1) was then used to further examine changes in groundwater pumping, storage, water-level declines, and sources on spatial and temporal scales in the Groundwater Availability of the Mississippi Embayment Professional Paper 1785 (Clark et al. 2011). The MERAS model was also used to simulate two climate scenarios by extending the model simulation period 30 years from 2008 to 2038.

In 2013, the USGS in cooperation with the ANRC investigated several methods to improve the match between observed and simulated groundwater levels within the Mississippi River Valley alluvial and middle Claiborne (Sparta) aquifers in the MERAS Model (Clark et al. 2013). This resulted in a recalibration of the MERAS model referred to as MERAS 2.0.

5.3.1 Summary of USGS Modeling Reports

The MERAS model described above and used as the basis for this groundwater availability assessment for Arkansas has been thoroughly documented in previous USGS reports.

- The MERAS: Documentation of a Groundwater-Flow Model Constructed to Assess Water Availability in the Mississippi Embayment (Clark and Hart 2009)
- Groundwater Availability of the Mississippi Embayment (Clark et al. 2011)
- Enhancements to the MERAS: Groundwater-Flow Model and Simulations of Sustainable Water-Level Scenarios (Clark et al. 2013)

The following is a summary of the model area, hydrogeologic units, climate, and land use within the model area.

5.3.1.1 Area Description

The MERAS model includes approximately 78,000 mi^2 of an area referred to as the Mississippi Embayment (**Figure 5-6**). The model area encompasses eight states including the eastern portion of Arkansas. Within the model boundary there are approximately 6,900 miles of simulated streams, 70,000 wells, and 10 primary hydrogeologic units.

5.3.1.2 Hydrogeologic Units

The MERAS model includes 10 primary hydrogeologic units. These hydrogeologic units include two primary aquifers—the Mississippi River Valley alluvial aquifer and the middle Claiborne (Sparta) aquifer. The model area lies within parts of three physiographic sections—West Gulf Coastal Plain, East Gulf Coastal Plain, and the Mississippi Alluvial Plain sections of the Coastal Plain physiographic province (**Figure 5-6**).

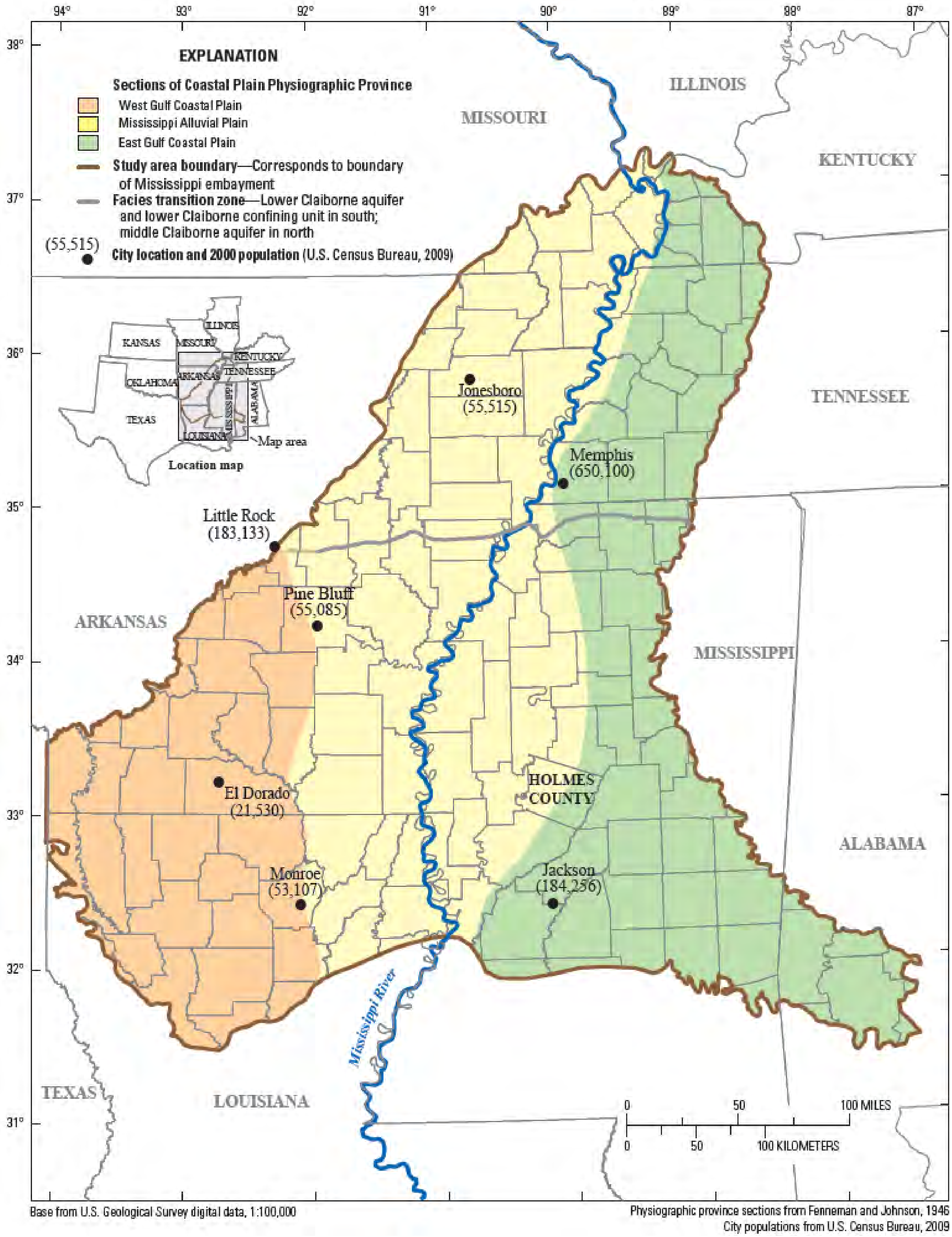


Figure 5-6. Coastal Plain Physiographic Province Sections in the Model Area (Clark et al. 2011)

5.3.1.3 Climate

The climate in the model area is moderate with a mean annual precipitation of 48 inches in the north to 56 inches in the south. Precipitation is distributed evenly throughout the year with the greatest amount accumulating in April and least in October. The average temperature ranges from 58 degrees F in the north to 66 degrees F in the south. Much of the annual precipitation is lost via evaporation and direct runoff to streams in the model area.

5.3.1.4 Land use

Land use in the Mississippi Embayment is primarily agricultural (**Figure 5-7**). Irrigated land accounts for approximately 45 percent of the model area, forested land is 38 percent, wetlands are 14 percent, and 3 percent is urban land (USGS 2008). For the purposes of the MERAS groundwater model, approximately 35 percent of the irrigated acreage is soybean, 22 percent cotton, 10 percent pasture, 7 percent rice production, 5 percent for corn and wheat, and 2 percent for other crops or nonagricultural land (Stuart et al. 1996).

In Arkansas, 94 percent of the groundwater withdrawals were for irrigation. This irrigation occurs predominantly in the eastern portion of the state and in the southwest corner along the Red River.

5.3.2 Groundwater Flow Model Development

The MERAS groundwater flow model was used as the basis for assessing the groundwater availability for the 2014 AWP Update. The MERAS model area encompasses the eastern portion of the state in which a majority of Arkansas groundwater withdrawals occur. The following sections describe the spatial and temporal discretization, hydraulic properties, and initial conditions of the groundwater flow model.

5.3.2.1 Model Framework

The groundwater flow model is a finite-difference model developed in MODFLOW-2005 (Harbaugh 2005) with a uniform grid oriented north-south consisting of 414 rows, 397 columns, and 13 layers. The rectangular grid contains over 160,000 cells, though many cells area inactive because they are located outside the active model area focusing on the Mississippi embayment. Cells are a uniform 1 mi^2 (1 mile by 1 mile) with varying vertical thickness by cell and by layer.

Each previous implementation of the MERAS model simulated a different time period depending on the objective of the study: calibrate the model to historic observations or simulate future conditions. The original MERAS model was developed to simulate 137 years (1870-2007) using 69 stress periods. The model used in this study is derived from a version of the MERAS model used to assess future pumping and climatic scenarios (Clark et al. 2011), with an additional extension of the simulation period to 2050.

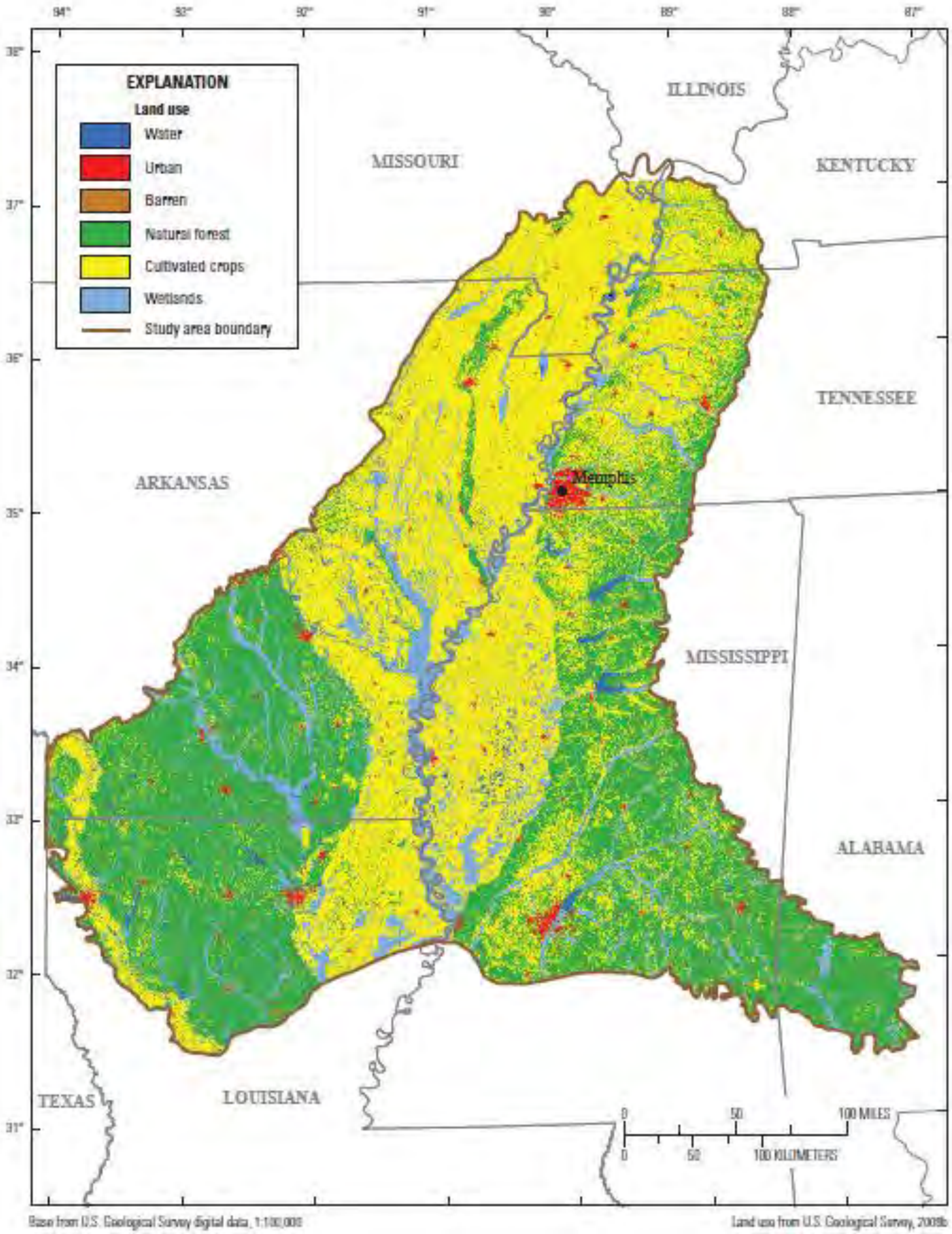


Figure 5-7. Typical Land-Use Types in the Mississippi Embayment Model Area (Clark et al. 2011)

5.3.2.2 Hydraulic Properties

The hydraulic properties in the MERAS model were determined by available aquifer test information, literature values for similar hydrogeologic units, and previous groundwater studies in the model area. The comparison between major aquifers described in Section 5.2 and the model layering is presented in **Table 5-1**.

Initial estimates of vertical anisotropy, specific yield, and specific storage were based upon literature values (Fetter 1994; Freeze and Cherry 1979) and were adjusted during model calibration.

The hydraulic properties were further refined during model calibration in the 2013 Enhanced MERAS (MERAS 2.0) groundwater flow model. The hydraulic properties in this enhanced version of the MERAS model reflect the latest understanding of hydraulic properties in the Mississippi embayment. To achieve additional refinement and obtain a better match of observed and simulated water levels, pilot points were employed to refine storage and hydraulic conductivity values. Pilot points are used to allow greater flexibility in the spatial assignment of aquifer properties. Pilot points allow the hydraulic properties to be assigned to a specific location and change the value throughout the calibration process. The hydraulic properties for each model cell is interpolated based upon the values of surrounding pilot points. Pilot points were distributed uniformly across the alluvial and Sparta aquifers at approximately 5 mile spacing, resulting in a total of 2,056 pilot points for the alluvial aquifer and 2,271 pilot points for the Sparta aquifer.

Detailed documentation of the development of these hydraulic properties is described in the USGS Scientific Investigations Report 2013-5161 (Clark et al. 2013).

5.3.2.3 Recharge

Recharge zones and rates were developed during the calibration of the USGS MERAS model. **Figure 5-8** shows the 19 recharge zones developed based on soil type, geomorphology, or surficial geology. Zone numbers 101 to 108 represent recharge to the alluvial aquifer. Recharge zone numbers of other units are generally sequential from youngest to oldest. Exceptions are zone number 61 for the eastern outcrop of the middle Claiborne (Sparta) aquifer and zone number 10 representing the surficial deposits other than the loess is Tennessee and Mississippi.

Recharge was incorporated into the model using the MODFLOW-2005 Recharge (RCH) package (Harbaugh 2005).

Table 5-1. Correlation of Hydrogeologic Units Across States within the Mississippi Embayment Regional Aquifer Study (Clark et al. 2011)

ERATHEM	SYSTEM	EPOCH	GROUP	LOUISIANA	ARKANSAS Southern	ARKANSAS Northeastern	MISSOURI	KENTUCKY	TENNESSEE	MISSISSIPPI	ALABAMA	Hydrogeologic units	Model layer number
CENOZOIC	QUATERNARY	HOLOCENE / PLEISTOCENE		Alluvium and terrace deposits	Alluvium and terrace deposits	Alluvium and terrace deposits	Alluvium and terrace deposits	Alluvium and loess deposits	Alluvium and loess deposits	Alluvium, terrace, and loess deposits	Alluvium and terrace deposits	Mississippi River Valley alluvial aquifer	1
	TERTIARY	OLIGOCENE	Vicksburg	Vicksburg Formation	Not present in study area	Not present in study area	Not present in study area	Not present in study area	Not present in study area	Vicksburg Formation	Vicksburg Formation	Vicksburg-Jackson confining unit	2
		EOCENE	Jackson	Jackson Formation	Jackson Formation	Jackson Formation	Jackson Formation	Jackson Formation	Jackson Formation	Jackson Formation	Jackson Formation		
			Claiborne	Cockfield Formation	Cockfield Formation	Cockfield Formation	Cockfield Formation	Cockfield Formation	Cockfield Formation	Cockfield Formation	Gosport Sand	Upper Claiborne aquifer	3
				Cook Mountain Formation	Cook Mountain Formation	Cook Mountain Formation	Cook Mountain Formation	Cook Mountain Formation	Cook Mountain Formation	Cook Mountain Formation	Cook Mountain Formation	Middle Claiborne confining unit	4
				Sparta Sand	Sparta Sand	Memphis Sand	Memphis Sand	Sparta Sand	Memphis Sand	Sparta Sand	Lisbon Formation	Middle Claiborne aquifer[4]	5–7
				Cane River Formation	Cane River Formation			Tallahatta Formation		Zilpha Clay Winona Sand Tallahatta Formation	Tallahatta Formation	Lower Claiborne confining unit[2]	8–9
				Carrizo Sand	Carrizo Sand					Meridian Sand Member	Meridian Sand Member	Lower Claiborne aquifer[1]	10
		UPPER PALEOCENE	Wilcox	Dolet Hills Formation	Undifferentiated	Flour Island Formation	Flour Island Formation	Wilcox Formation	Flour Island Formation	Undifferentiated	Hatchetigbee Formation	Middle Wilcox aquifer	11
						Fort Pillow Sand	Fort Pillow Sand	No Wilcox deposits identified as being of Paleocene age	Fort Pillow Sand		Bashi Formation Tuscahoma Sand Nanafalia Formation	Lower Wilcox aquifer[3]	12–13
				Undifferentiated Naborton Formation		Old Breast-works Formation	Old Breast-works Formation		Old Breast-works Formation				
			Midway	Midway Group	Midway Group	Midway Group	Midway Group	Midway Group	Midway Group	Midway Group	Midway Group	Midway confining unit	Base of model

[1] Lower Claiborne aquifer includes the upper Wilcox aquifer in some parts of Mississippi.
[2] Winona and Tallahatta Formations are included with lower Claiborne confining unit in Hart and others (2008).
[3] Old Breastworks confining unit is included with middle Wilcox aquifer in Hart and others (2008).
[4] El Dorado confining unit and El Dorado Sand are included with middle Claiborne aquifer.

Modified from Hart and others, 2008

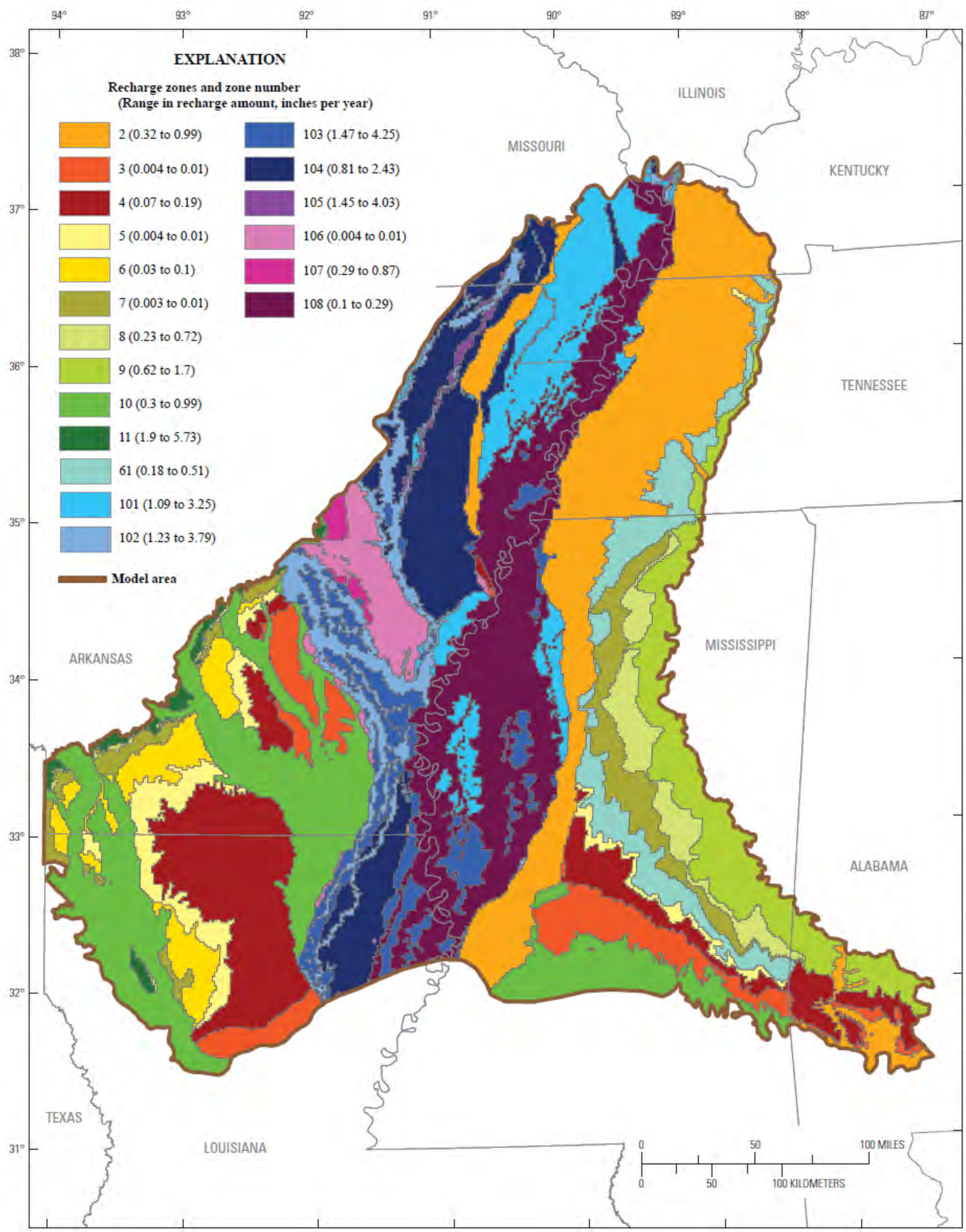


Figure 5-8. Zones Used for Recharge and Hydraulic Properties in the Model Area (Clark and Hart 2009)

5.3.2.4 Pumping

Pumping from irrigation, M&I and domestic wells are simulated using the Multi-Node Well (MNW) package (Halford and Hanson 2002). The USGS developed estimates of future groundwater demand through 2038 and these are documented in the USGS Scientific Investigations Report 2013-5161.

5.3.2.5 Streams

There are 43 streams included in the MERAS model (see **Figure 5-9**). Each stream is simulated using the Streamflow Routing (SFR) Package of MODFLOW (Prudic et al. 2004). The SFR package was used because it uses the continuity equation to route surface water flow through streams and rivers rather than using a specified head or river stage. The criteria for including a stream started with streams with a mean annual flow above 1,000 cfs. Other streams were added based upon the inclusion of previous groundwater models, which indicated surface water-groundwater interaction.

Of the 43 streams simulated, 20 streams were assigned zero inflow due to the fact that they started within the model area or near the model boundary; 12 streams with gages within 10 miles of the model boundary used the mean annual flow for the model inflow; and streams with gages that were further than 10 miles from the model boundary were corrected to account for the ungaged area.

5.3.3 Groundwater Model Calibration

The MERAS groundwater model has been developed, calibrated, and enhanced over the past 7 years. The first model was developed and calibrated beginning in 2006 (Clark and Hart 2009). The MERAS model was calibrated using comparisons of simulated and observed hydraulic heads, simulated and observed streamflows, and comparison of water budgets. The MERAS model was enhanced in 2013, which included the evaluation of methods to improve the MERAS model and resulting calibration.

The MERAS model was calibrated through a comparative analysis of the root mean square errors (RMSEs). The RMSEs for the MERAS model is computed using the simulated and observed hydraulic heads from 55,786 comparisons from 3,245 wells within the model area, **Figure 5-10**.

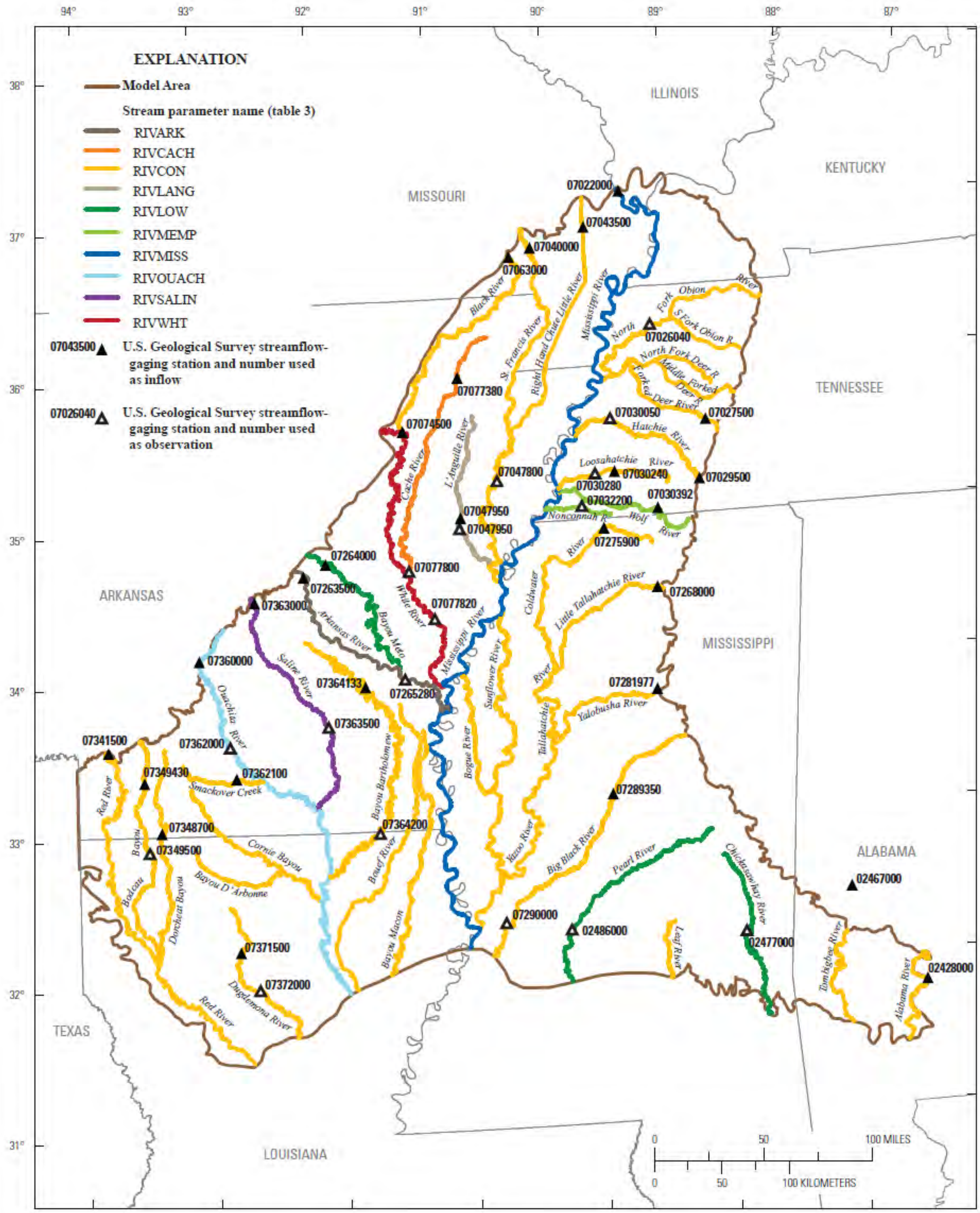


Figure 5-9. Streams Simulated in the Model Area (Clark and Hart 2009)

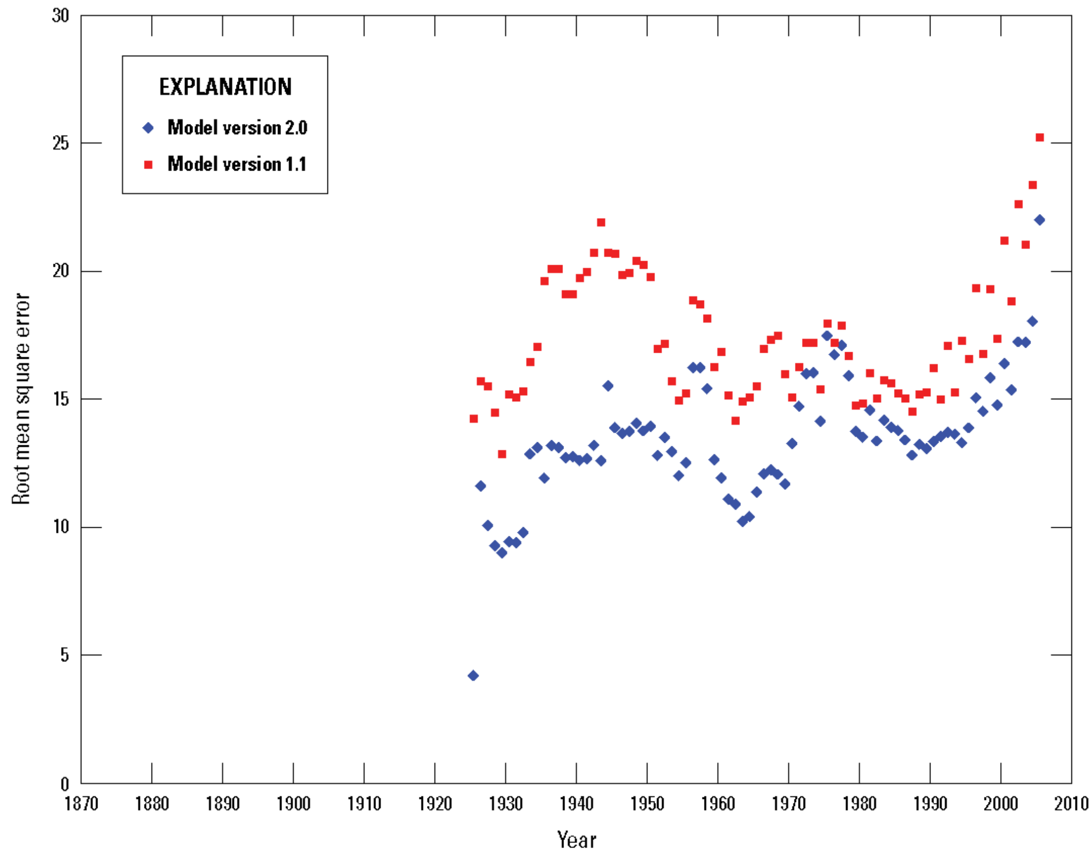


Figure 5-10. Comparison of Root Means Square Error of the Mississippi River Valley Alluvial Aquifer between the Mississippi Embayment Regional Aquifer Study (MERAS) Model Versions 1.1 and 2.0 (Clark et al. 2013)

Additional detail on the calibration process and evaluation of goodness of fit of the MERAS model can be found in the USGS documentation.

5.3.4 USGS Groundwater Availability Predictions

In the Mississippi embayment, groundwater pumping has produced water-level declines across large areas. This is a result of increased dependence on groundwater since the late 1970s, primarily pumping from the Mississippi River Valley alluvial aquifer. Historical water level observations in several locations have shown a decline in the hydraulic head.

In 2013, the MERAS model was used to simulate water levels associated the prolonged pumping to evaluate sustainability of the current and projected water use. To accomplish this, the USGS simulated several scenarios using a steady-state version of the MERAS model:

- Scenario 1 – Steady-state simulation of previous optimized pumping;
- Scenario 2 – Steady-state simulation of recent average pumping with reductions for surface-water diversions;

- Scenario 3A – Steady-state simulation of pumping constraints set at 50 percent of the alluvial aquifer predevelopment saturated thickness or 30 feet above the bottom of the alluvial aquifer, whichever was greater; and
- Scenario 3B – Steady-state simulation of pumping constraints used in scenario 3A, with constraints on Sparta aquifer wells in the Grand Prairie area set to reduce leakage from the overlying and hydraulically connected alluvial aquifer.

The results of these scenarios continued drawdown of the water levels in the principle groundwater supply aquifers (Mississippi River Valley alluvial aquifer and middle Claiborne (Sparta aquifer) under steady-state conditions. A reduction of pumping tends to dampen or flatten the decline of the hydraulic head in these aquifers.

The total amount of pumping from the alluvial and Sparta aquifers in the area of previously optimized pumping is greater than that of scenario 1 although it is still less than the demand (shown as the "desired rate" in **Figure 5-11**).

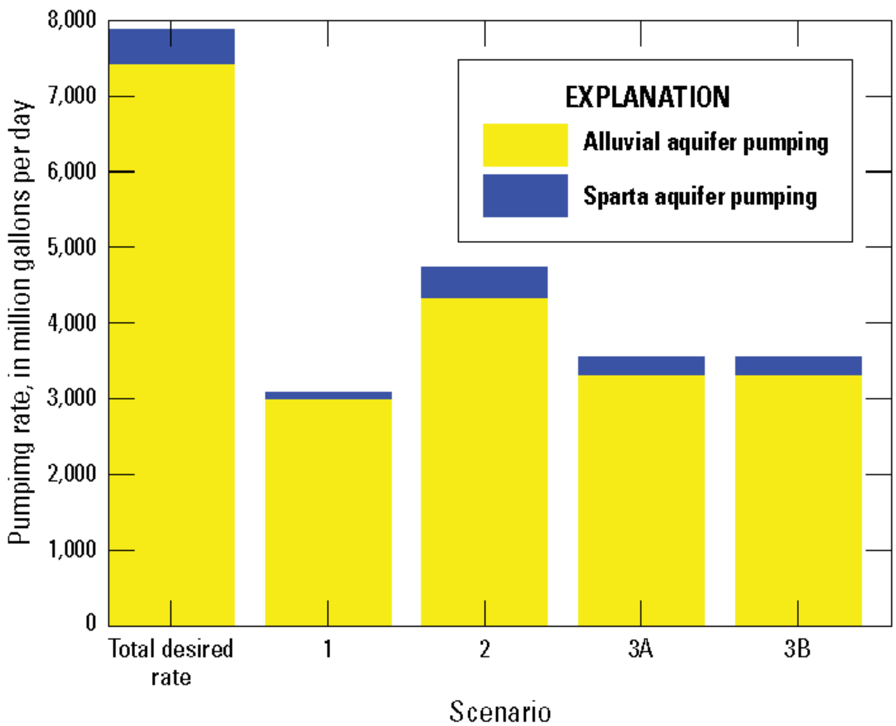


Figure 5-11. Comparison of Pumping Rates in the Alluvial and Sparta Aquifers by Scenario (Clark et al. 2013)

As indicated by Figure 5-11, each of the scenarios simulations resulted in achievable pumping rates considerably lower than the desired pumping (demand). In most scenarios pumping from the alluvial and Sparta aquifers are less than half of the desired pumping rates except for scenario 2. In scenario 2, recent pumping rates were simulated with reductions for surface water diversions associated with the Bayou Metro Project and Grand Prairie Area Demonstration Project. This shift of the dependence on groundwater supplies to surface water allows greater groundwater pumping from the aquifers compared to the other simulated scenarios.

5.3.5 Groundwater Model Sensitivities and Uncertainties

As stated in previous MERAS model reports (Clark and Hart 2009, Clark et al. 2011, Clark et al. 2013), an understanding of model limitations and uncertainties is essential to effectively using the simulation results. A detailed description of the limitations and uncertainties is provided in Kresse et al. (in review).

In this groundwater availability assessment, the MERAS model was used to simulate future groundwater pumping scenarios under dry and wet climates. Future water demands and climate are uncertain and should be used as guidance in making planning decisions if these scenarios would potentially occur in the future.

The goal of the MERAS model was to develop a model capable of reasonably predicting aquifer response in the Mississippi embayment at regional scales. The intent is not to reproduce individual local-scale observations. Although the MERAS model may not represent individual local-scale observations, it does provide a better understanding of the regional groundwater flow system in the Mississippi embayment.

5.4 Model Adaptation for use in Arkansas Water Plan

As described in the previous section, the USGS has developed and enhanced the MERAS model to provide a well-documented planning tool that is being used to support the AWP Update. The 2013 version of the USGS model was modified for this current assessment to allow transient evaluation of defined groundwater development scenarios. The 2013 version of the USGS model simulated steady state conditions, so storage parameters from the 2011 USGS model version were incorporated to allow transient evaluations. The model files from the enhanced 2013 version of the model were used for the evaluations presented in this report, with modifications to recharge, streamflow and well pumping data sets described in this section.

Datasets from the 2009 and 2011 versions of the model for stream flow and recharge were adapted for the extension of the modeling period to 2050 for the AWP Update Demand projections for groundwater in the MERAS area aquifers were incorporated from the recent evaluation (CDM Smith 2013) and merged with USGS projections for current production from surrounding states that are included in the model. Documentation of this adaptation is provided in the following sections. The last subsection addresses uncertainties and limitations of the modeling and projections completed for the AWP Update.

5.4.1 Extension of Climate Related Data Sets to 2050

Recharge to the groundwater system originates from surface processes, including deep percolation of precipitation, infiltration from streams, and deep percolation from irrigated lands. These are the only sources of water that are included in the MERAS model, other than streamflow entering the model domain. There is also some vertical movement of water between individual aquifers, dependent on relative head differences between the zones. The USGS model estimated the areal recharge component as a function of precipitation and considered soil types and land use in developing the recharge estimates during model calibration. These estimates were developed in the 2011 version of the model for a 30-year period, extending through 2037.

Two climate scenarios were developed by the USGS—a dry conditions scenario that was based on projection of recharge trends that included a relatively dry period, and a second climate scenario that utilized conditions similar to those observed in 1991 to represent wet climatic conditions. Streamflow was extended by the USGS using the relationships they developed during the calibration process between streamflow and precipitation. The exchange of water between the streams and groundwater is calculated in the model based on head differences between groundwater and stream stage. The data sets developed by the USGS used averages over a 2-year stress period for the simulations and included a slight upward trend in precipitation over the simulation period. This is a minimal limitation for the climate related factors, since the groundwater system buffers short-term changes and a longer term averaging approach is a reasonable representation of the recharge related components.

For the dry climatic condition, the USGS data sets were extended to the 2050 period by repeating the projected precipitation for the 2016 to 2037 period and assuming this remained the same for the remaining time until 2050. The streamflow data set was extended in the same manner, where the 2016 to 2037 data was assumed to be representative of conditions extending to 2050. For the wet climatic condition, the recharge value associated with the 1991 wet year was used for the entire simulation period. The stream conditions from 1991 were used for all periods in the wet climate simulation. The resulting average recharge from surface sources, other than calculated recharge from streams, was 2,440 mgd for the dry climate scenario and 3,350 mgd for the wet climate scenario.

5.4.2 Incorporation of Groundwater Demand Projections

Groundwater pumping demands were revised in the model to reflect updated water demand forecasts developed for the AWP only for the portion of the model area within Arkansas. Pumping in the model that occurs in the other seven states within the model boundary remained unchanged. The demand projections report (CDM Smith 2013) was used as the basis for defining groundwater demands by aquifer and location. The demand report used state records from the Water User Database, which contains information on well production rates and the aquifer from which the well produces. In cases where the aquifer was not indicated in the record, the production was assumed to be from the primary aquifer used in the county where the well was located. In the case of estimates of domestic well production, where no specific aquifer or location is available, the production was assigned to the dominant aquifer in the county and the location was assumed to be the geographic center of the county. A single well at this center location was used to represent the relatively small groundwater production by self-supplied domestic and livestock use.

Wells are used in the model to simulate groundwater development using the multi-node well package in MODFLOW. This approach to simulation of wells allows consideration of the difference between water levels that are simulated in the model for large cells (1-mile square) to a small diameter well (assumed to have a radius of 0.8 feet). Additional declines in water level within the well use an analytical approach to estimate the drawdown that would occur as water converges to the small diameter well in the center of the model cell. In addition, the calculations consider well efficiency, which represents additional losses associated with well construction. Both of these factors used to estimate the pumping water level in the well from the modeled water level in the large grid cell are related to the pumping rate simulated at the well. The loss factor had been previously estimated by the USGS during the calibration process as an average for all wells in the model. These USGS estimates were maintained for this modeling effort.

The multi-node well package is able to simulate conditions where the well is screened across more than one model layer. This is relevant to wells in the alluvial aquifer, which commonly are screened across the majority of the saturated interval of the alluvium. The alluvium is represented in the USGS model across a variable number of model layers, including all 13 layers in some areas of the model. The well simulation package allows representation of limitations on pumping at a well where dewatering occurs due to pumping. A limiting pumping water level may be specified for each well that is used to limit the pumping rate if excessive drawdown occurs. If the simulated pumping water level in the well, including consideration of the cell to well and well loss corrections, declines below the defined critical pumping level for the well, then the pumping rate is reduced by the package to maintain the water level no lower than the specified pumping level. This results in actual achieved pumping rates below those that are specified by model input files. The well configuration file does not restart a well that was disabled due to reaching the defined critical pumping level unless a rate of at least 20 of the specified rate can be obtained. This factor is the same as that specified by the USGS.

Preparation of the multi-node well package files required definition of the aquifer, the layer or layers corresponding to that aquifer, the average pumping rate over the 2-year simulation step, and the limiting pumping level elevation in the well. The demand projections (CDM Smith 2013) were prepared for the base period[3] representing current production rates, and for 10 year snapshots extending to 2050. These projections included the aquifer and demand on a location basis. Each well was processed to determine the model layers that corresponded to the aquifer associated with the well. For alluvial wells, the production was assigned layers extending from land surface to the deepest layer that represented alluvium in the model. For wells producing from the confined sands the production was assigned to a single layer representing the aquifer based on the aquifer code from the state database. The confined unit production was assigned to a single layer, as shown on **Table 5-2**.

Table 5-2. Correlation between Water User Database Aquifer Codes and MERAS Model Layers

Hydrogeologic Unit Name	Hydrogeologic Unit Short Name	Formation, Lithology or Aquifer Name	Aquifer Code	Model Layer
Mississippi River Valley alluvial aquifer	MRVA	Alluvium, Quaternary alluvium, Mississippi River Valley alluvial aquifers, Red River Valley alluvium	110ALVM	1
			112ALVM	1
			110QRNR	1
			112MRVA	1
			112RRVA	1
Mississippi River Valley alluvial aquifer		Pleistocene Series, Loess	112PLSC	1
			112LOSS	1
Mississippi River Valley alluvial aquifer		Terrace Deposits, Upland terrace deposits	112TRRC	1
			112UPTC	1
Vicksburg-Jackson confining unit	VKBG	Vicksburg-Jackson Group	123VKBG	2
			124JCKS	2
Upper Claiborne aquifer	UCAQ	Cockfield Formation of Claiborne Group	124CCKF	3
			124CLBR	3
Middle Claiborne confining unit	MCCU	Cook Mountain Formation of Claiborne Group	124CKMN	4
Middle Claiborne aquifer	MCAQ	Sparta Sand of Claiborne Group, Memphis aquifer (500-Foot Sand), Memphis Sand	124SPRT	5
			12405MP	6
			124MMPS	7
Lower Claiborne confining unit	LCCU	Cane River Formation of Claiborne Group, Zilpha Clay	124CRVR	8
			124ZLPH	9
*Lower Claiborne confining unit	WNTH	Winona-Tallahatta Formation	124TLLT	None
			124WNON	None

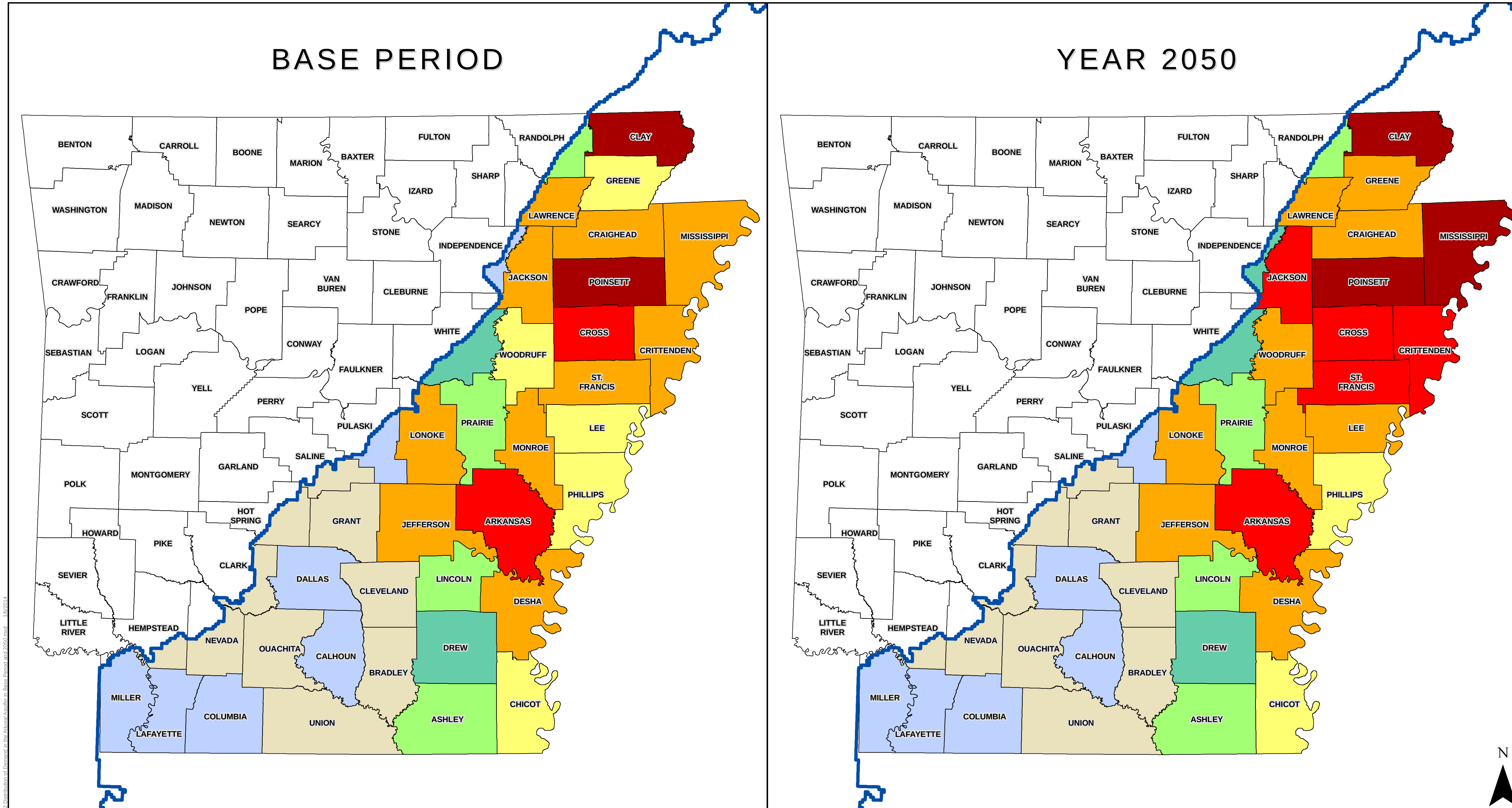
[3] In most demand sectors, the time period used for the "base period" is a 3 year average (2008-2010, or 2009-2011). When that information was not available, data for 2010 was used. For some sectors, it is based upon most recent data in an ANRC database that is on a 3 year update rotation (could be any year from 2009-2011).

Table 5-2. Correlation between Water User Database Aquifer Codes and MERAS Model Layers

Hydrogeologic Unit Name	Hydrogeologic Unit Short Name	Formation, Lithology or Aquifer Name	Aquifer Code	Model Layer
Lower Claiborne aquifer	LCAQ	Carrizo Sand of Claiborne Group, Meridian Sand of Tallahatta Formation, Meridian-Upper Wilcox aquifer	124CRRZ	10
			124MRDN	10
			124MUWX	10
Middle Wilcox aquifer	UWAQ	Wilcox Group, Flour Island Formation of Wilcox Group, Middle Wilcox aquifer	124WLCX	11
			124FLID	11
			124WLCXM	11
Lower Wilcox aquifer	LWAQ	Fort Pillow Sand (1400-Foot Sand) of Wilcox Group, Lower Wilcox aquifer	124FRPL	12
			124WLCXL	12
**Old Breastworks confining unit	ODBK	Old Breastworks Formation	124ODBK	13
Midway confining unit	MDWY	Midway Group, Porters Creek Clay	125MDWY	13
			125PRCK	13

The baseline simulation assumed that the well would produce up to the maximum rate specified in the demand projections, so the limiting elevation was set to the base of the deepest model layer specified for the well. This has the effect of allowing near complete dewatering of the aquifer near the well. A second well definition file was configured to represent a more sustainable condition, where the limiting elevation for the alluvial aquifer was set to the center of the aquifer, while for the confined sands; the limiting elevation was set to the top of the aquifer. This configuration maintains significant saturation in the alluvial aquifer and does not allow the confined sands to convert to unconfined conditions.

The well simulation files used the USGS pumping rates from the 2013 steady-state simulations assumptions for areas outside of Arkansas (average of 2000 to 2005 pumping rates), and were merged with the demand based wells within Arkansas. The individual 10-year demand projections were used for each of the respective periods. The pumping in Arkansas was represented with 51,351 individual well locations. In many cases, more than one well was located in a single model cell. The total groundwater demand across all aquifers ranges from 7,800 mgd in the base period, increasing to 8,900 mgd in 2050. Production from the alluvial aquifer comprises 97.5 percent of the total pumping, with about 2 percent from the Sparta and the remaining 0.5 percent from the Wilcox aquifer. **Figure 5-12** shows the distribution of groundwater demand by county for the alluvial aquifer for the base period and for 2050 for all water use sectors. For purposes of classification of the alluvium, loess in the southwestern portion of the MERAS model is also considered part of the alluvium. **Figure 5-13** presents the groundwater demand for the Sparta sands on the same basis.



Legend

- MERAS Outline
- County Boundary

Demand

- No significant demand
- < 50 MGD
- 50 - 100 MGD
- 100 - 200 MGD
- 200 - 300 MGD
- 300 - 400 MGD
- 400 - 500 MGD
- > 500 MGD

Figure 5-12
Distribution of Demand in the Alluvial Aquifer in Base Period and 2050

Arkansas State Water Plan Update
Groundwater Availability

Arkansas WATERplan
Essential For Life

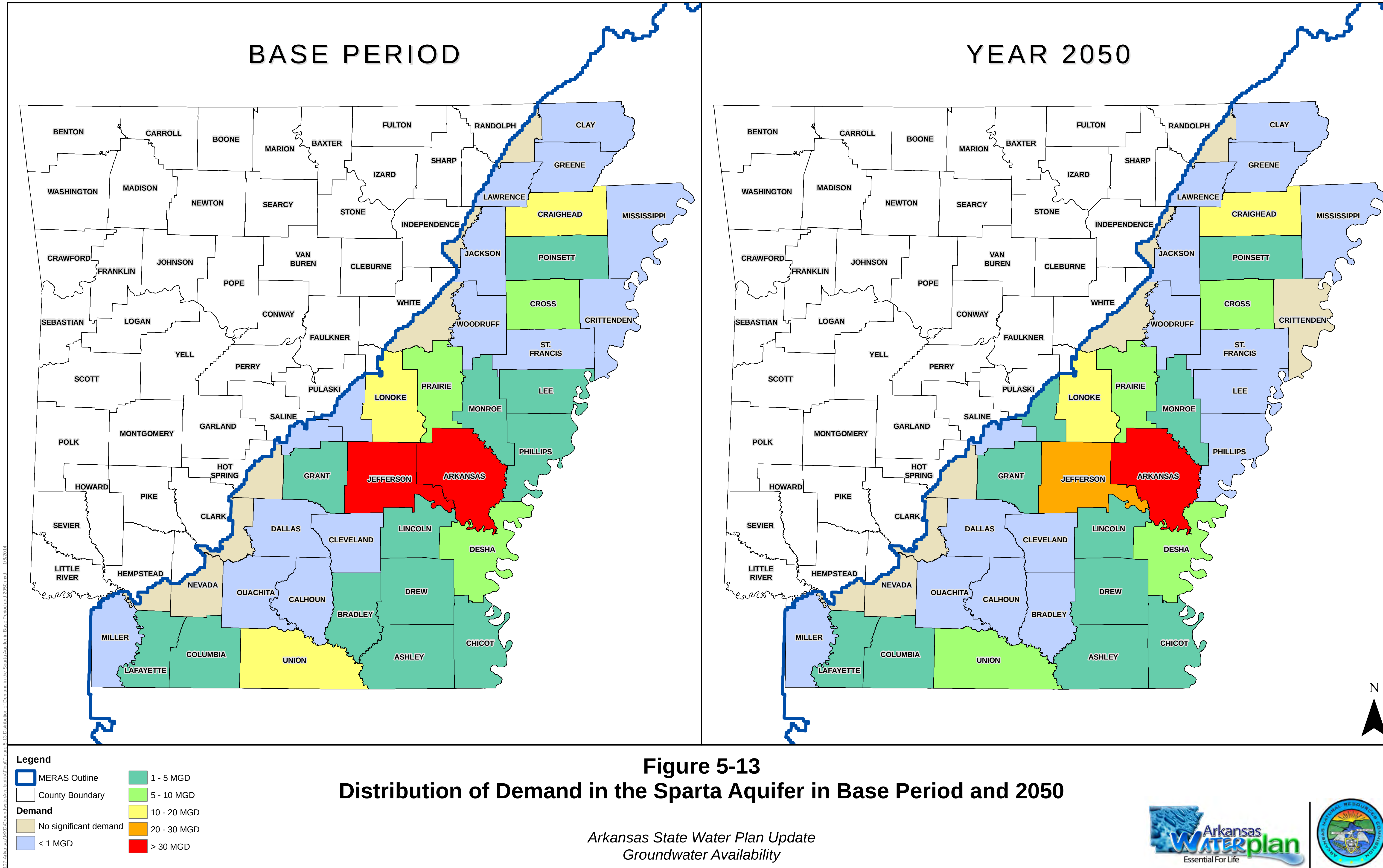


Figure 5-13
Distribution of Demand in the Sparta Aquifer in Base Period and 2050

Arkansas State Water Plan Update
Groundwater Availability

5.4.3 Development of Simulation Scenarios

The assessment of groundwater availability has been conducted by simulating four scenarios. All scenarios use the same estimates of demand for well production by aquifer. Two climatic conditions files were used to define the range of conditions for recharge. Scenarios 1 and 2 represent the maximum development of groundwater, where near complete aquifer depletion is allowed to meet the specified demand. These scenarios correspond to a condition where nonsustainable mining of groundwater will occur. Scenarios 3 and 4 represent a sustainable condition where aquifer drawdown is limited to the center of the alluvial aquifer and to the top of confined sands. The conditions of the simulation are summarized in **Table 5-3**.

Table 5-3. Summary of Simulation Scenarios

Scenario	Climate Assumption	Complete Dewatering Permitted
1	Dry	Yes
2	Wet	Yes
3	Dry	No
4	Wet	No

5.5 Modeling Results

The USGS MERAS groundwater model was run for each of the four scenarios to assess the availability of groundwater by aquifer and location. Internal accounting was implemented in the model to allow tracking of predicted production rates at individual wells and to allocate these rates to the water use sector. Analysis of the model results is presented in following sections.

5.5.1 Water Budget

The water budget describes the source and fate of groundwater in the simulations. The origin of all water in the model is either from deep percolation of precipitation or applied water, and infiltration of water from streams. An additional source of water is also present: removal of water from storage in porosity in the aquifer as it is dewatered. On a long-term basis, if groundwater production exceeds the various sources of recharge, the water in storage will make up the deficit by lowering of water levels. When the aquifer is significantly dewatered, the maximum production is limited by the recharge sources. Water will also be exchanged between the aquifers by leakage, which is limited by confining units. A balance is maintained by the groundwater system that is described by the following equation for the MERAS model:

$$\textit{Recharge} + \textit{Stream Seepage} + \textit{Storage change} = \textit{Stream Gains} + \textit{Well Production}$$

The demand pumping that was specified was unable to be maintained under any of the scenarios, since insufficient recharge is available to the aquifer. This is similar to the results found by the USGS in their modeling evaluations, where the estimates of groundwater pumping cannot be sustained by the aquifer system.

5.5.2 Simulations of Scenarios

The results of the simulations are presented for each of the four scenarios in following sections. Summary tables are presented in this section with detailed results by county and water use sector provided in **Appendix E**. **Table 5-4** summarizes the results from the modeling scenarios and the resulting available pumping and supply gap.

Table 5-4. Summary of Model Results for Sustainable and Mining Scenarios for the Alluvial, Sparta and Wilcox Aquifers

Scenario	Pumping Level Limitation	Climate Assumption	Groundwater Demand 2050	Available Groundwater Capacity	Groundwater Supply Gap 2050
1	Minimum water elevation equal to the bottom elevation of both unconfined and confined	Dry	8,960 mgd	3,070 mgd	5,890 mgd
2		Wet		3,320 mgd	5,640 mgd
3	Minimum water elevation equal to half the aquifer thickness in the alluvial aquifer and the top of formation in the confined aquifers	Dry		1,770 mgd	7,190 mgd
4		Wet		2,030 mgd	6,930 mgd

Figure 5-14 shows the modeled trend in well production in the alluvial aquifer over the five demand projection periods. Scenario 1 is able to provide a higher percentage of the groundwater demand, since the greater drawdown that is developed removes more water from storage. The achievable pumping rate converges toward equilibrium with recharge as the storage is depleted in the aquifer. Scenario 3 limits the drawdown and leaves a considerable volume of water in storage in the alluvial aquifer.

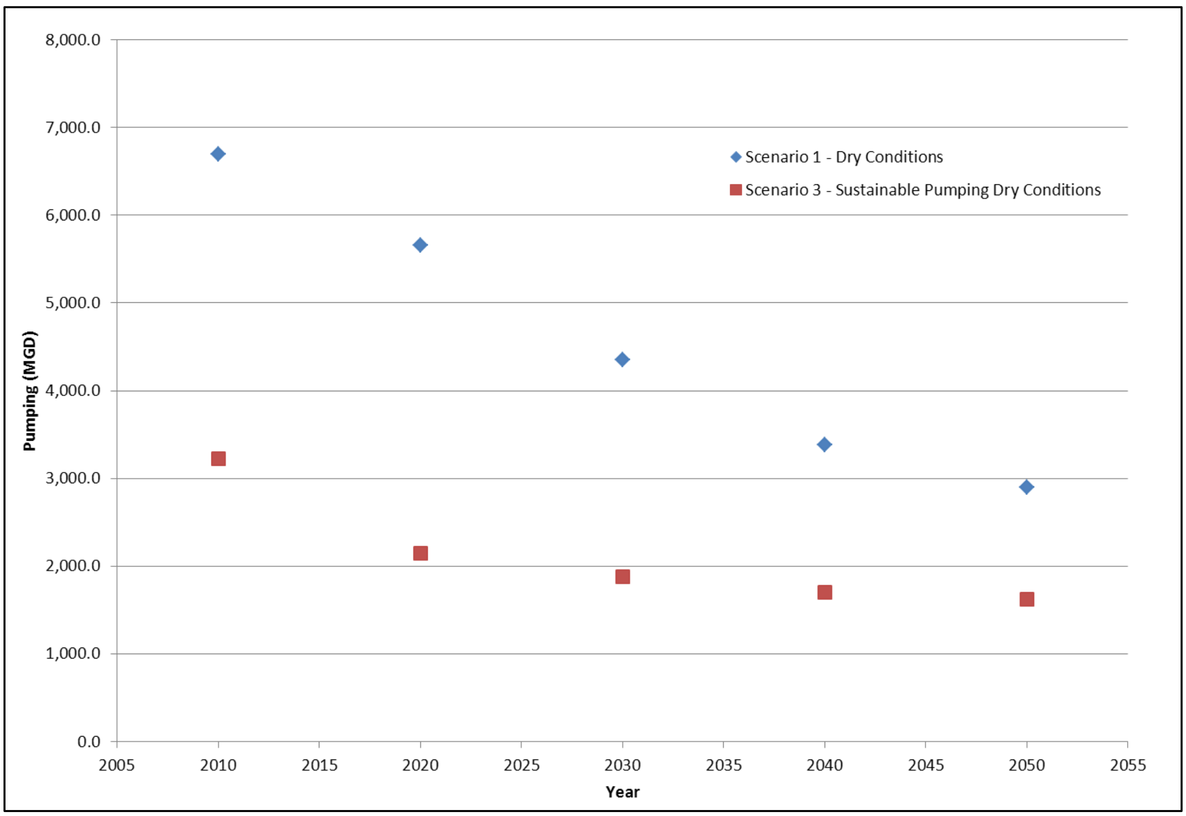


Figure 5-14. Modeled Alluvial Aquifer Well Production for Scenarios 1 and 3

The results of the individual simulations are provided below.

5.5.2.1 Scenario 1

This scenario represents continuation of groundwater pumping at greater than sustainable rates, with the well control file configured to allow near complete dewatering of the aquifer. The dry climatic conditions were used for both recharge and streamflow for this simulation. **Tables 5-5, 5-6, and 5-7** summarize the supply gap for the alluvial, Sparta, and Wilcox aquifers, respectively. The demand for all water use sectors increases from 7,600 mgd in the base period to 8,700 mgd for 2050 in the alluvial aquifer. The pumping results in dewatering of the aquifer, decreasing the ability of wells to obtain the specified demand. The resulting supply gaps are:

- Alluvial aquifer is 900 mgd during the base period, increasing to 5,900 mgd in 2050 (**Figure 5-15**).
- The Sparta aquifer is projected to have a decrease in demand over the simulation period, with 165 mgd for the base period, declining to 156 mgd in 2050. The supply gap for the Sparta is 10 mgd in the base period, increasing to 22 mgd in 2050 (**Figure 5-16**).
- The Wilcox aquifer demand is projected to remain stable at about 54 to 57 mgd, with a supply gap ranging from 16 to 20 mgd.

Figure 5-15 illustrates the projected supply gap by county for the alluvial aquifer, including the loess area in the southwestern portion of the model, in the base period and in 2050. The largest alluvial aquifer supply gaps are for the agricultural sector in Arkansas, Clay, Craighead, Cross, Lonoke, and Poinsett counties. **Figure 5-16** shows the supply gap for the Sparta Aquifer. The Sparta aquifer shows the greatest projected supply gap in Craighead County for the municipal sector. **Figures 5-17 and 5-18** show that the decline in modeled water levels between the base period and 2050 in the alluvial and Sparta aquifers, respectively. The levels are greatest in both the alluvial and Sparta aquifers in the northeastern portion of the state. An additional area of significant decline in water levels in the alluvial aquifer occurs in the southeastern portion of the state in Lincoln, Desha, and Chicot counties.

5.5.2.2 Scenario 2

Scenario 2 is the same as Scenario 1, except that wet climatic conditions are simulated using the high precipitation period from 1991 as the basis to describe an upper limit on the recharge quantity. The multi-node well package is configured to allow dewatering of the aquifers, with automatic reduction of pumping rates when water levels decline to the defined threshold level. **Tables 5-8, 5-9, and 5-10** summarize the supply gap for the alluvial, Sparta, and Wilcox aquifers. The increased water availability due to higher recharge rates results in a slightly lower supply gap for groundwater in the alluvial aquifer, and insignificant changes in the deeper confined aquifers. The supply gap in the alluvial aquifer ranges from 904 mgd for the base period, increasing to 5,590 mgd in 2050. The areas of shortage and changes in water levels do not change significantly from those in scenario 1.

Table 5-5 Summary of Groundwater Demands and Supply Gaps for the Alluvial Aquifer - Dry Scenario 1 Allowing Dewatering

	Base Period			2020			2030			2040			2050		
Water Use Sector	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**
Aquaculture	101.8	86.4	15.4	101.8	70.6	31.3	101.8	55.0	46.8	101.8	46.6	55.2	101.8	40.5	61.3
Self-Supplied Commercial	0.2	0.1		0.2	0.1	0.1	0.3	0.0	0.2	0.3	0.0	0.2	0.3	0.0	0.2
Self-Supplied Domestic	2.3	1.9	0.4	2.1	1.4	0.7	2.0	1.0	1.1	2.0	0.5	1.5	2.0	0.4	1.6
Duck Habitat	85.7	63.6	22.1	85.7	51.1	34.6	85.7	41.5	44.2	85.7	30.6	55.1	85.7	28.2	57.4
Industrial	7.9	7.2	0.7	7.5	6.7	0.8	7.3	5.8	1.5	7.1	4.8	2.3	6.9	4.6	2.2
Crop Irrigation	7,380.0	6,520.1	859.9	8,011.8	5,511.6	2,500.2	8,424.9	4,235.1	4,189.8	8,499.8	3,282.8	5,216.9	8,517.8	2,812.1	5,705.7
Livestock	0.8	0.7	0.1	0.9	0.7	0.2	0.9	0.7	0.2	0.9	0.6	0.3	0.9	0.6	0.3
Mining	0.2	0.1		0.2	0.2		0.2	0.2		0.2	0.2		0.2	0.2	
Municipal	28.2	19.9	8.3	27.3	14.9	12.5	26.9	12.9	14.0	26.9	12.6	14.4	27.4	11.8	15.6
Thermoelectric	1.4	0.8	0.6	1.6	0.8	0.8	1.6	0.8	0.8	1.7	0.7	1.0	1.7	0.7	1.0
Total	**7,608.4**	**6,700.8**	**907.7**	**8,239.2**	**5,658.1**	**2,581.1**	**8,651.7**	**4,353.0**	**4,298.7**	**8,726.3**	**3,379.4**	**5,346.9**	**8,744.7**	**2,899.2**	**5,845.5**

Units: Million Gallons/Day

Table 5-6 Summary of Groundwater Demands and Supply Gaps for the Sparta Aquifer - Dry Scenario 1 Allowing Dewatering

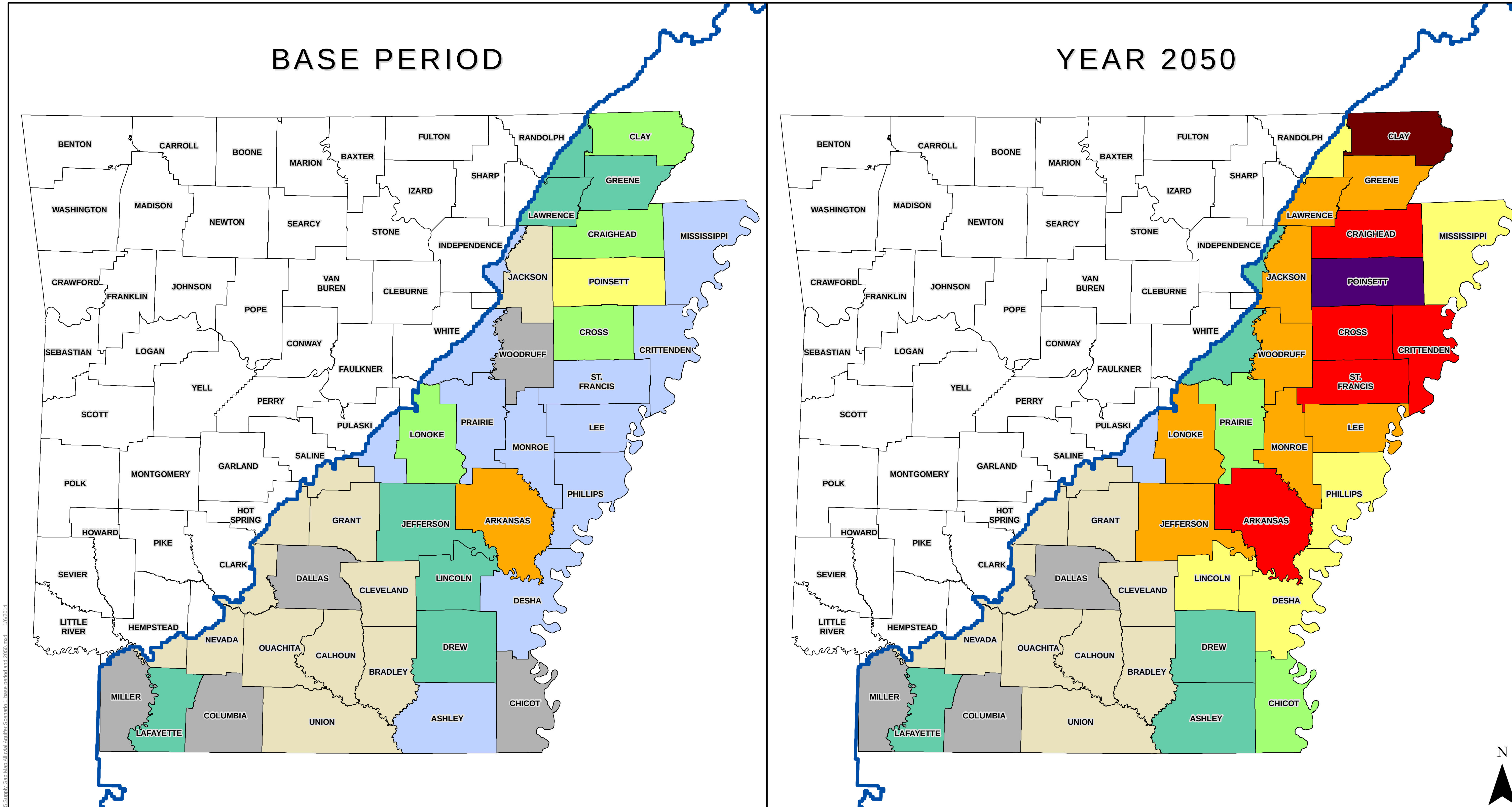
	Base Period			2020			2030			2040			2050		
Water Use Sector	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**
Aquaculture	0.8	0.8		0.8	0.8		0.8	0.7		0.8	0.7		0.8	0.6	0.2
Self-Supplied Commercial	0.2	0.2		0.2	0.2		0.1	0.1		0.1	0.1		0.1	0.1	
Self-Supplied Domestic	0.6	0.6		0.6	0.6		0.5	0.5		0.5	0.5		0.5	0.5	
Duck Habitat	1.6	1.6		1.6	1.6		1.6	1.6		1.6	1.6		1.6	1.6	
Industrial	44.8	42.7	2.2	40.8	38.6	2.1	39.5	37.4	2.0	38.0	35.9	2.1	36.5	34.5	2.1
Crop Irrigation	74.9	71.1	3.8	76.3	70.9	5.3	76.6	70.2	6.5	76.7	69.1	7.6	76.8	68.7	8.0
Livestock	0.5	0.5		0.6	0.5		0.6	0.5		0.6	0.5		0.6	0.5	
Mining	0.3	0.3		0.3	0.3		0.4	0.4		0.3	0.3		0.3	0.3	
Municipal	40.5	36.6	4.0	39.4	33.3	6.0	38.2	30.3	7.9	37.6	28.2	9.4	37.6	26.9	10.8
Thermoelectric	1.1	0.8	0.3	1.3	0.8	0.5	1.3	0.7	0.5	1.3	0.7	0.6	1.4	0.7	0.7
Total	**165.4**	**155.1**	**10.3**	**161.7**	**147.7**	**14.0**	**159.5**	**142.5**	**17.0**	**157.6**	**137.7**	**19.9**	**156.1**	**134.4**	**21.8**

Units: Million Gallons/Day

Table 5-7 Summary of Groundwater Demands and Supply Gaps for the Wilcox Aquifer - Dry Scenario 1 Allowing Dewatering

	Base Period			2020			2030			2040			2050		
Water Use Sector	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**
Aquaculture	0.4	0.4		0.4	0.4		0.4	0.4		0.4	0.4		0.4	0.4	
Self-Supplied Commercial	0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0	
Industrial	0.1	0.1		0.1	0.1		0.1	0.1		0.1	0.1		0.1	0.1	
Crop Irrigation	0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0	
Livestock	20.4	13.5	7.0	20.3	13.1	7.3	20.5	12.9	7.6	20.9	12.8	8.1	21.4	12.7	8.7
Mining	0.5	0.5		0.3	0.3		0.3	0.3		0.4	0.4		0.4	0.4	
Municipal	31.5	23.2	8.4	32.5	23.6	8.9	32.9	23.6	9.4	33.3	23.5	9.9	33.9	23.3	10.6
Thermoelectric	1.1	0.8	0.3	1.3	0.8	0.5	1.3	0.7	0.5	1.3	0.7	0.6	1.4	0.7	0.7
Total	**54.1**	**38.4**	**15.7**	**54.9**	**38.2**	**16.6**	**55.6**	**38.0**	**17.5**	**56.5**	**37.9**	**18.5**	**57.7**	**37.7**	**20.0**

Units: Million Gallons/Day



Legend

- MERAS Outline
- County Boundary

Supply Gap

- No significant supply gap
- < 1 MGD
- 1 - 10 MGD
- 10 - 50 MGD
- 50 - 100 MGD
- 100 - 200 MGD
- 200 - 300 MGD
- 300 - 400 MGD
- 400 - 500 MGD
- > 500 MGD

Figure 5-15
Supply Gap Map for Alluvial Aquifer Scenario 1 Base Period and 2050

Arkansas State Water Plan Update
Groundwater Availability

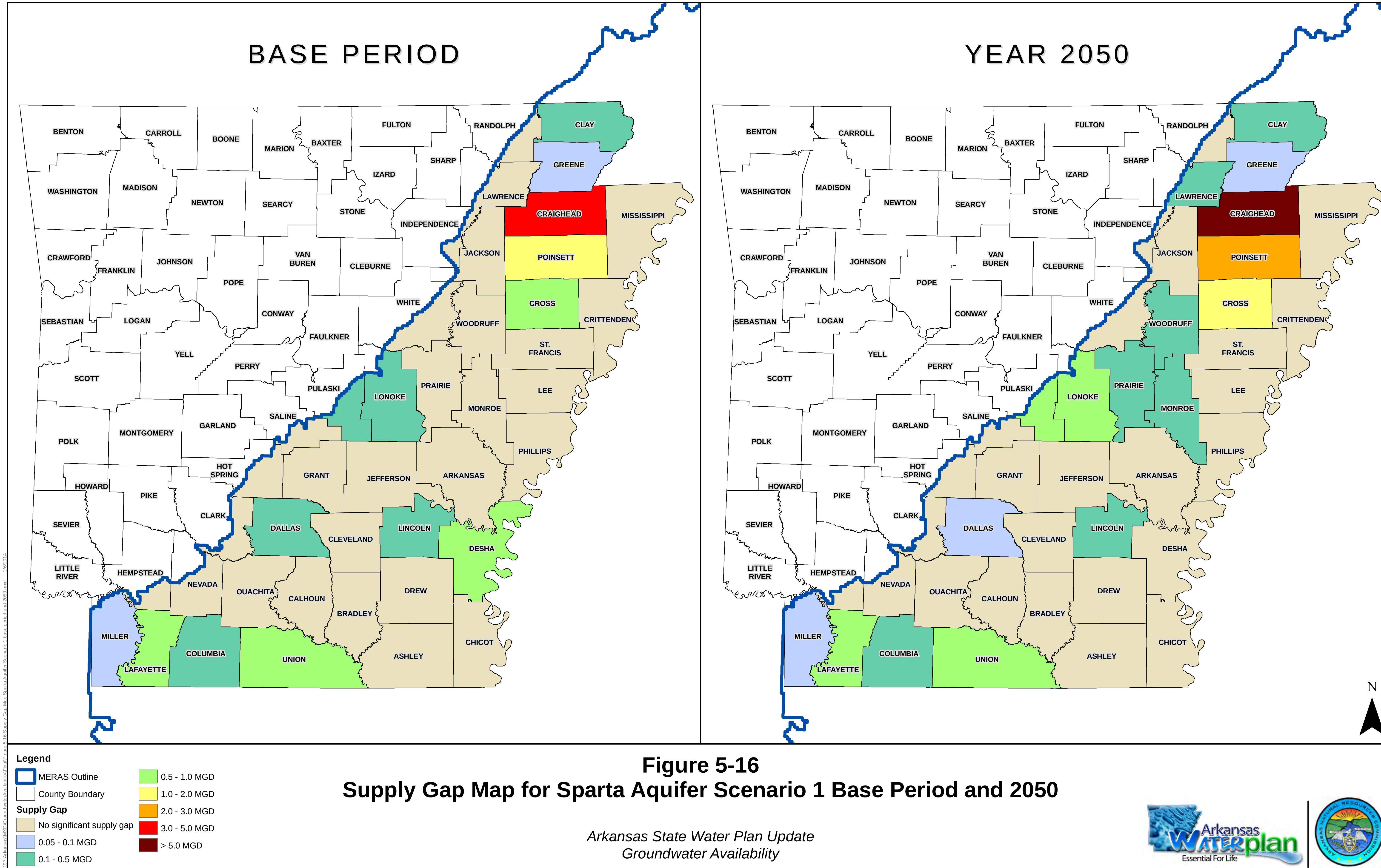


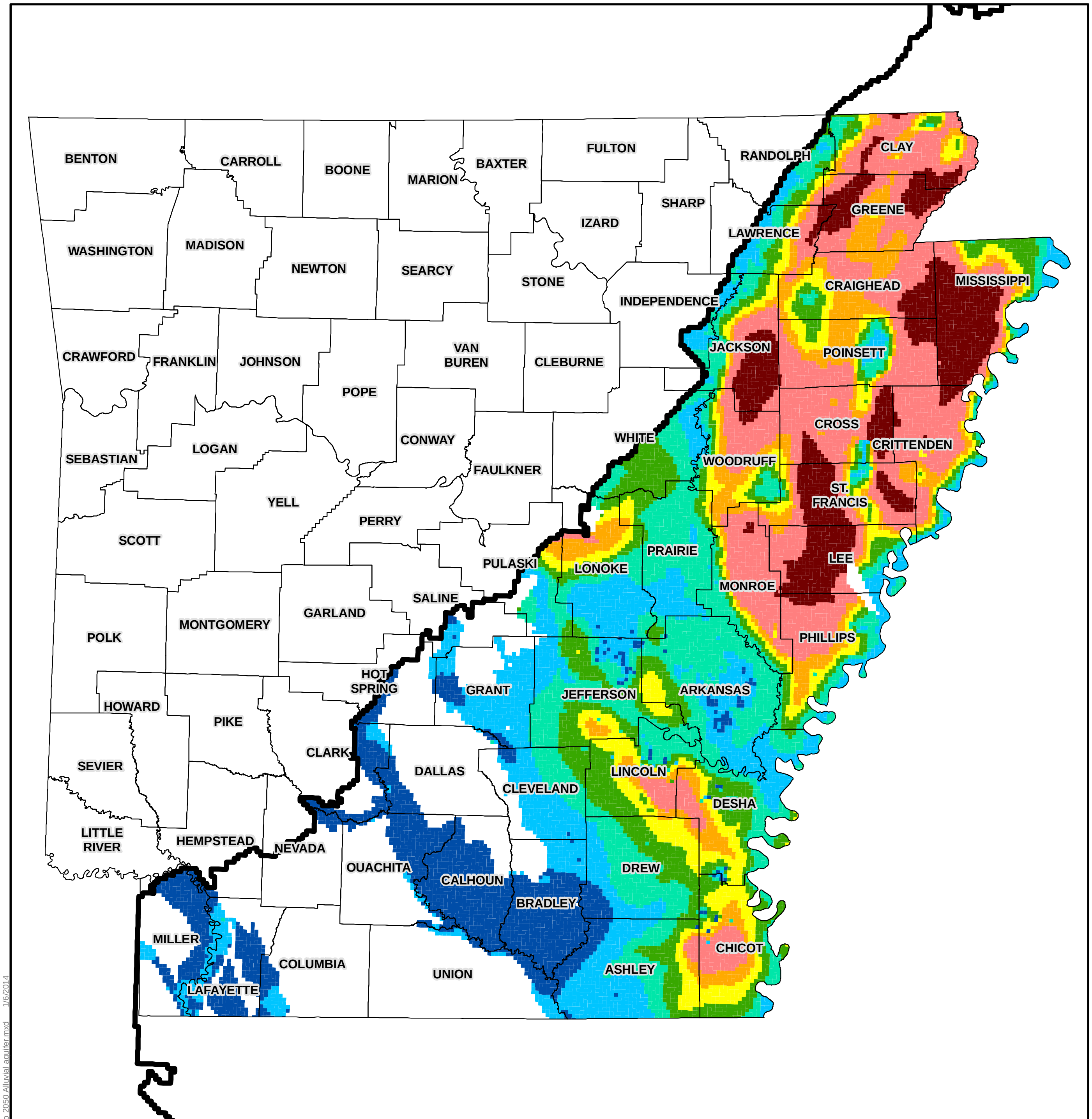
Figure 5-16

Supply Gap Map for Sparta Aquifer Scenario 1 Base Period and 2050

Arkansas State Water Plan Update

Groundwater Availability

Arkansas WATERplan Essential For Life



Legend

MERAS Outline

County Boundary

Decline in Water Levels

- < 0 (Water Rise)
- 0 - 10 feet
- 10 - 20 feet
- 20 - 30 feet
- 30 - 40 feet
- 40 - 50 feet
- 50 - 75 feet
- > 75 feeet

Figure 5-17
Decline in Water Levels
Base Period to 2050
Alluvial Aquifer, Scenario 1

Arkansas State Water Plan Update
Groundwater Availability

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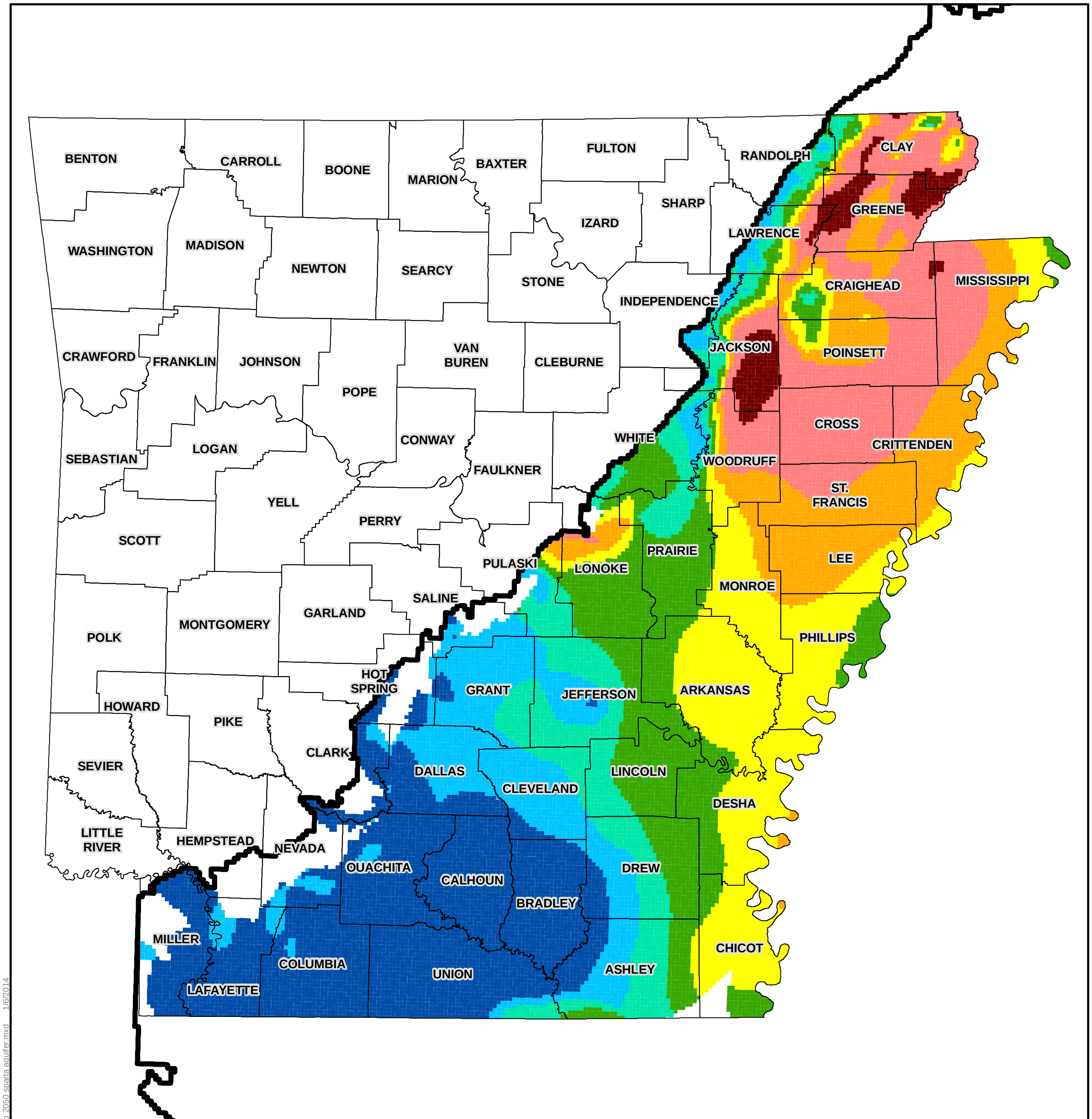
O:\91107-Arkansas\MXD\GroundwaterAvailability\Final\Figure 5-17 Decline in water levels base period to 2050 Alluvial aquifer.mxd 1/6/2014



Legend

MERAS Outline

County Boundary

Decline in Water Levels

- < 0 (Water Rise)
- 0 - 10 feet
- 10 - 20 feet
- 20 - 30 feet
- 30 - 40 feet
- 40 - 50 feet
- 50 - 75 feet
- > 75 feeet

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Figure 5-18
Decline in Water Levels
Base Period to 2050
Sparta Aquifer, Scenario 1

Arkansas State Water Plan Update
Groundwater Availability

Q:\91107-Arkansas\MXD\GroundwaterAvailability\Final\Figure 5-18 Decline in water levels base period to 2050 sparta aquifer.mxd 1/6/2014

Table 5-8 Summary of Groundwater Demands and Supply Gaps for the Alluvial Aquifer - Wet Scenario 2 Allowing Dewatering

	Base Period			2020			2030			2040			2050		
Water Use Sector	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**
Aquaculture	101.8	86.2	15.6	101.8	72.9	28.9	101.8	57.9	43.9	101.8	50.2	51.6	101.8	43.1	58.7
Self-Supplied Commercial	0.2	0.1		0.2	0.1	0.1	0.3	0.0	0.2	0.3	0.0	0.2	0.3	0.0	0.2
Self-Supplied Domestic	2.3	1.9	0.4	2.1	1.5	0.7	2.0	1.0	1.1	2.0	0.5	1.5	2.0	0.4	1.6
Duck Habitat	85.7	62.0	23.7	85.7	53.9	31.8	85.7	47.4	38.3	85.7	34.2	51.5	85.7	30.6	55.1
Industrial	7.9	7.2	0.7	7.5	6.7	0.7	7.3	5.6	1.7	7.1	4.7	2.4	6.9	4.5	2.4
Crop Irrigation	7380.0	6525.4	854.6	8011.8	5673.1	2338.6	8424.9	4532.6	3892.3	8499.8	3540.2	4959.5	8517.8	3061.4	5456.4
Livestock	0.8	0.7	0.1	0.9	0.6	0.2	0.9	0.6	0.2	0.9	0.6	0.3	0.9	0.6	0.3
Mining	0.2	0.1		0.2	0.2		0.2	0.2		0.2	0.2		0.2	0.2	
Municipal	28.2	19.7	8.4	27.3	15.2	12.1	26.9	13.3	13.7	26.9	12.8	14.1	27.4	11.6	15.8
Thermoelectric	1.4	0.9	0.5	1.6	0.8	0.8	1.6	0.8	0.8	1.7	0.7	1.0	1.7	0.6	1.0
Total	**7608.4**	**6704.2**	**904.2**	**8239.2**	**5825.1**	**2414.0**	**8651.7**	**4659.4**	**3992.3**	**8726.3**	**3644.1**	**5082.2**	**8744.7**	**3153.1**	**5591.5**

Units: Million Gallons/Day

Table 5-9 Summary of Groundwater Demands and Supply Gaps for the Sparta Aquifer - Wet Scenario 2 Allowing Dewatering

	Base Period			2020			2030			2040			2050		
Water Use Sector	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**
Aquaculture	0.8	0.7		0.8	0.7		0.8	0.7	0.1	0.8	0.6	0.1	0.8	0.6	0.1
Self-Supplied Commercial	0.2	0.2		0.2	0.2		0.1	0.1		0.1	0.1		0.1	0.1	
Self-Supplied Domestic	0.6	0.6		0.6	0.6		0.5	0.5		0.5	0.5		0.5	0.5	
Duck Habitat	1.6	1.6		1.6	1.6		1.6	1.6		1.6	1.6		1.6	1.6	
Industrial	44.8	42.7	2.1	40.8	38.7	2.1	39.5	37.6	1.9	38.0	36.3	1.8	36.5	34.7	1.8
Crop Irrigation	74.9	70.3	4.6	76.3	69.8	6.5	76.6	69.4	7.2	76.7	68.0	8.7	76.8	67.7	9.1
Livestock	0.5	0.5		0.6	0.5		0.6	0.5		0.6	0.6		0.6	0.6	
Mining	0.3	0.3		0.3	0.3		0.4	0.4		0.3	0.3		0.3	0.3	
Municipal	40.5	37.4	3.1	39.4	34.4	5.0	38.2	31.1	7.1	37.6	28.8	8.8	37.6	27.2	10.4
Thermoelectric	1.1	0.7	0.4	1.3	0.7	0.5	1.3	0.7	0.5	1.3	0.7	0.6	1.4	0.7	0.7
Total	**165.4**	**155.0**	**10.4**	**161.7**	**147.4**	**14.2**	**159.5**	**142.7**	**16.8**	**157.6**	**137.5**	**20.1**	**156.1**	**134.1**	**22.1**

Units: Million Gallons/Day

Table 5-10 Summary of Groundwater Demands and Supply Gaps for the Wilcox Aquifer - Wet Scenario 2 Allowing Dewatering

	Base Period			2020			2030			2040			2050		
Water Use Sector	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**
Aquaculture	0.4	0.4		0.4	0.4		0.4	0.4		0.4	0.4		0.4	0.4	
Self-Supplied Commercial	0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0	
Industrial	0.1	0.1		0.1	0.1		0.1	0.1		0.1	0.1		0.1	0.1	
Crop Irrigation	0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0	
Livestock	20.4	13.5	7.0	20.3	13.1	7.3	20.5	12.9	7.6	20.9	12.8	8.1	21.4	12.7	8.7
Mining	0.5	0.5		0.3	0.3		0.3	0.3		0.4	0.4		0.4	0.4	
Municipal	31.5	23.2	8.4	32.5	23.6	8.9	32.9	23.6	9.4	33.3	23.5	9.9	33.9	23.3	10.6
Thermoelectric	0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0	
Total	**53.0**	**37.6**	**15.3**	**53.7**	**37.5**	**16.1**	**54.3**	**37.3**	**17.0**	**55.1**	**37.1**	**17.9**	**56.3**	**36.9**	**19.4**

Units: Million Gallons/Day

5.5.2.3 Scenario 3

Scenario 3 represents a sustainable groundwater production condition, with the model configured to restrict pumping such that the water levels cannot go lower than the center of the alluvial aquifer and to the top of the confined aquifers. The groundwater demand is specified at the same levels as scenarios 1 and 2. Pumping rates are automatically decreased to maintain these levels. The dry climatic conditions are specified for this scenario. **Tables 5-11, 5-12, and 5-13** summarize the results of the gap analysis for the alluvial, Sparta, and Wilcox aquifers. The supply gap increases significantly for the alluvial aquifer, since less drawdown is allowed in the wells, reducing the quantity of water removed from storage; however, the primary control on the quantity of pumping that can be supported is the quantity of recharge. The supply gap for the alluvial aquifer ranges from 8,240 mgd for the base period to 7,125 mgd for 2050. The supply gap for the Sparta aquifer reaches 25 mgd in 2050, while the Wilcox aquifer gap is 17 mgd. The areas of high agricultural use are the most impacted by moving to the sustainable criteria for pumping levels. **Figure 5-19** shows the supply gap for the alluvial aquifer by county. **Figure 5-20** shows the supply gap for the Sparta aquifer. **Figures 5-21 and 5-22** show the decline in water level between the base period and 2050 for the alluvial and Sparta aquifers. Under Scenario 3, the water level declines in the alluvial aquifer are highest in Mississippi, St. Francis, and Chicot counties. In many areas through the center of the embayment water levels are projected to remain near the 2010 levels, and in some areas water levels are projected to recover. Water levels in the Sparta aquifer follow a similar trend with relatively stable levels through most of the embayment area, except in the Northeast in Greene and Mississippi counties.

5.5.2.4 Scenario 4

Scenario 4 uses conditions and well pumping level criteria that are the same as Scenario 3, using the wet climate conditions. The results are very similar to those observed for Scenario 3 and are provided in Appendix B.

5.5.3 Summary

The modeling results show that current and projected demands for groundwater in the Mississippi embayment in eastern Arkansas are not sustainable, similar to the findings of the USGS in their modeling evaluations. Pumping at higher rates may persist for some time into the future by mining groundwater that is stored in pore space in the aquifer. Even with this mining approach to groundwater development, production rates decline rapidly as this storage is depleted. The sustainable pumping approach, where water level declines are managed by maintaining higher water levels will converge to an equilibrium condition where sustainable pumping rates are a function of the recharge quantity entering the aquifers. The proportion of the groundwater demand that is projected to be met with the model for the alluvial aquifer is shown on **Figure 5-23** for the base period and 2050 for the mining condition. **Figure 5-24** shows the same information for the Sparta aquifer. **Figures 5-25 and 5-26** show the same information for the sustainable water level scenario.

The implications of the continued decline in achievable pumping rates and falling water levels have the potential for severe economic impacts. As water levels decline and pumping lifts increase, wells may need to be deepened and pumps replaced. The cost of pumping will also increase due to the increased lift. For example, in Mississippi County, water levels are projected to decline by about 45 feet in the alluvial aquifer in the area of highest use. The modeled achievable pumping in Mississippi County in 2050 is about 205 mgd. The additional energy required over 1 year for this additional pumping lift is about 17,000,000 kilowatt-hours.

Table 5-11 Summary of Groundwater Demands and Supply Gaps for the Alluvial Aquifer - Dry Scenario 3 Sustainable Pumping Level

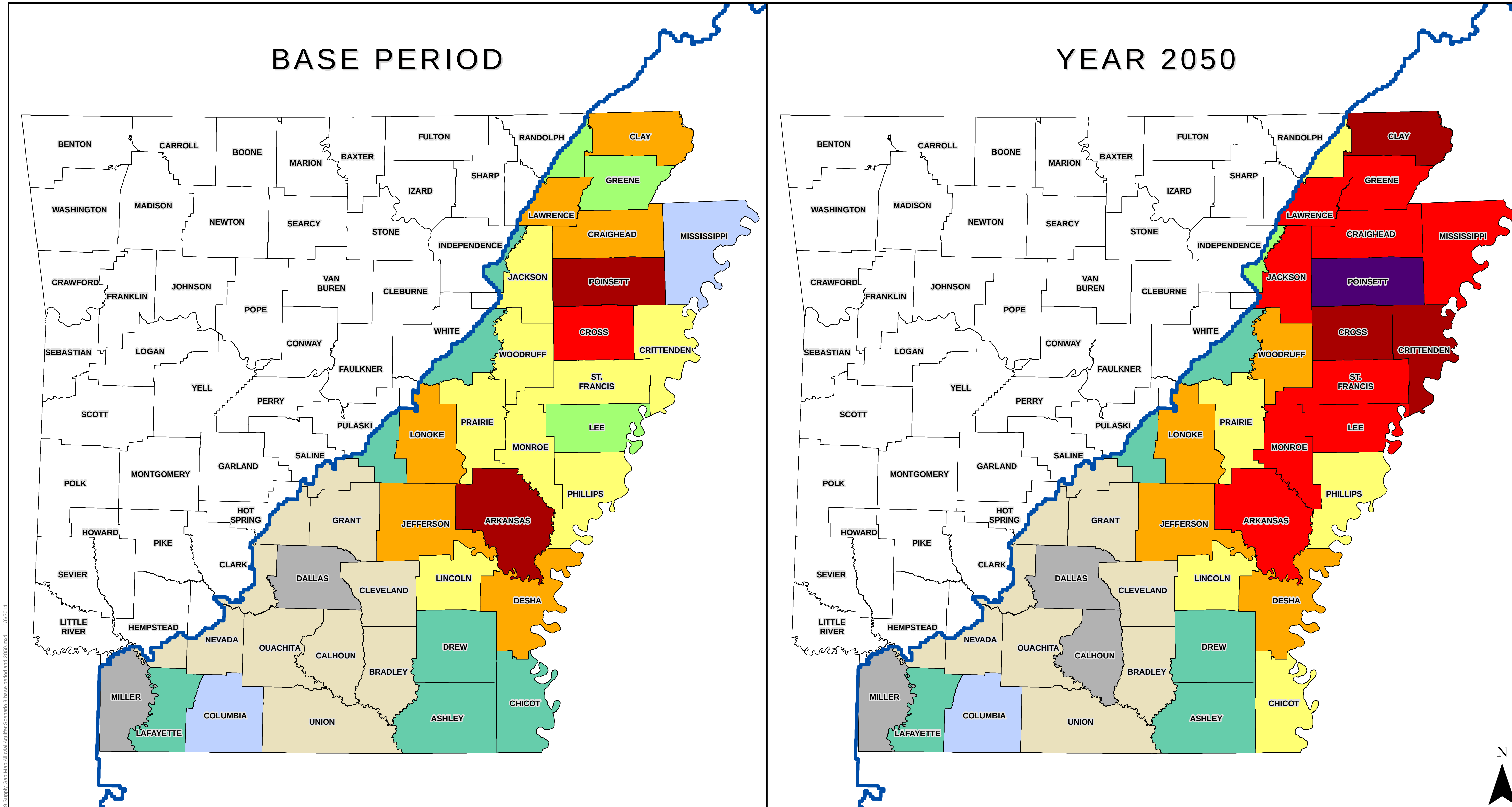
	Base Period			2020			2030			2040			2050		
Water Use Sector	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**	**Groundwater Demand (MGD)**	**Groundwater Demand Met (MGD)**	**Supply Gap (MGD)**
Aquaculture	101.8	23.3	78.5	101.8	17.1	84.8	101.8	14.0	87.8	101.8	12.5	89.3	101.8	12.1	89.7
Self-Supplied Commercial	0.2	0.0	0.2	0.2	0.0	0.2	0.3	0.0	0.2	0.3	0.0	0.2	0.3	0.0	0.3
Self-Supplied Domestic	2.3	0.4	1.9	2.1	0.3	1.9	2.0	0.2	1.8	2.0	0.2	1.8	2.0	0.1	1.9
Duck Habitat	85.7	24.1	61.6	85.7	15.6	70.1	85.7	19.6	66.1	85.7	21.8	63.9	85.7	21.8	63.9
Industrial	7.9	1.8	6.1	7.5	1.2	6.3	7.3	1.1	6.2	7.1	1.1	6.0	6.9	3.1	3.8
Crop Irrigation	7,380.0	3,171.2	4,209.0	8,011.8	2,102.6	5,909.3	8,424.9	1,839.0	6,586.0	8,499.8	1,661.0	6,838.9	8,517.8	1,579.3	6,938.6
Livestock	0.8	0.3	0.5	0.9	0.4	0.5	0.9	0.4	0.5	0.9	0.3	0.5	0.9	0.3	0.5
Mining	0.2	0.1	0.0	0.2	0.2	0.0	0.2	0.2	0.1	0.2	0.2	0.1	0.2	0.1	0.1
Municipal	28.2	6.4	21.8	27.3	3.7	23.7	26.9	1.7	25.3	26.9	1.3	25.7	27.4	1.1	26.3
Thermoelectric	1.4	0.3	1.0	1.6	0.2	1.4	1.6	0.2	1.4	1.7	0.2	1.4	1.7	0.2	1.5
Grand Total	**7,608.4**	**3,228.0**	**4,380.6**	**8,239.2**	**2,141.1**	**6,098.1**	**8,651.7**	**1,876.4**	**6,775.3**	**8,726.3**	**1,698.5**	**7,027.9**	**8,744.7**	**1,618.2**	**7,126.4**

Table 5-12 Summary of Groundwater Demands and Supply Gaps for the Sparta Aquifer - Dry Scenario 3 Sustainable Pumping Level

	Base Period			2020			2030			2040			2050		
Water Use Sector	Groundwater Demand (MGD)	Groundwater Demand Met (MGD)	Supply Gap (MGD)	Groundwater Demand (MGD)	Groundwater Demand Met (MGD)	Supply Gap (MGD)	Groundwater Demand (MGD)	Groundwater Demand Met (MGD)	Supply Gap (MGD)	Groundwater Demand (MGD)	Groundwater Demand Met (MGD)	Supply Gap (MGD)	Groundwater Demand (MGD)	Groundwater Demand Met (MGD)	Supply Gap (MGD)
Aquaculture	0.8	0.5	0.3	0.8	0.5	0.3	0.8	0.5	0.3	0.8	0.5	0.3	0.8	0.5	0.3
Self-Supplied Commercial	0.2	0.1	0.0	0.2	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0
Self-Supplied Domestic	0.6	0.4	0.2	0.6	0.3	0.2	0.5	0.3	0.2	0.5	0.3	0.1	0.5	0.3	0.1
Duck Habitat	1.6	1.6	0.0	1.6	1.6	0.0	1.6	1.6	0.0	1.6	1.6	0.0	1.6	1.6	0.0
Industrial	44.8	39.0	5.8	40.8	35.0	5.8	39.5	34.0	5.4	38.0	33.0	5.0	36.5	31.9	4.7
Crop Irrigation	74.9	68.7	6.2	76.3	69.4	6.9	76.6	69.6	7.0	76.7	69.6	7.1	76.8	69.6	7.1
Livestock	0.5	0.4	0.1	0.6	0.5	0.1	0.6	0.5	0.1	0.6	0.5	0.1	0.6	0.5	0.1
Mining	0.3	0.3	0.0	0.3	0.3	0.0	0.4	0.4	0.0	0.3	0.3	0.0	0.3	0.2	0.0
Municipal	40.5	31.6	8.9	39.4	30.0	9.4	38.2	28.1	10.1	37.6	26.7	10.9	37.6	25.7	11.9
Thermoelectric	1.1	0.5	0.6	1.3	0.5	0.7	1.3	0.5	0.7	1.3	0.5	0.8	1.4	0.5	0.9
Grand Total	**165.4**	**143.2**	**22.2**	**161.7**	**138.3**	**23.4**	**159.5**	**135.7**	**23.9**	**157.6**	**133.2**	**24.4**	**156.1**	**131.0**	**25.1**

Table 5-13 Summary of Groundwater Demands and Supply Gaps for the Wilcox Aquifer - Dry Scenario 3 Sustainable Pumping Level

	Base Period			2020			2030			2040			2050		
Water Use Sector	Groundwater Demand (MGD)	Groundwater Demand Met (MGD)	Supply Gap (MGD)	Groundwater Demand (MGD)	Groundwater Demand Met (MGD)	Supply Gap (MGD)	Groundwater Demand (MGD)	Groundwater Demand Met (MGD)	Supply Gap (MGD)	Groundwater Demand (MGD)	Groundwater Demand Met (MGD)	Supply Gap (MGD)	Groundwater Demand (MGD)	Groundwater Demand Met (MGD)	Supply Gap (MGD)
Aquaculture	0.4	0.4	0.0	0.4	0.4	0.0	0.4	0.4	0.0	0.4	0.4	0.0	0.4	0.4	0.0
Self-Supplied Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Industrial	3.0	2.8	0.2	3.8	3.4	0.4	3.8	3.4	0.4	3.8	3.4	0.4	3.8	3.4	0.4
Crop Irrigation	7.0	3.8	3.3	7.5	3.8	3.7	7.7	3.7	4.0	7.8	3.7	4.1	7.8	3.6	4.2
Livestock	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1
Mining	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Municipal	20.4	9.7	10.8	20.3	9.4	11.0	20.5	9.2	11.3	20.9	9.0	11.8	21.4	8.9	12.5
Thermoelectric	0.5	0.5	0.0	0.3	0.3	0.0	0.3	0.3	0.0	0.4	0.4	0.0	0.4	0.4	0.0
Grand Total	**31.5**	**17.2**	**14.4**	**32.5**	**17.3**	**15.1**	**32.9**	**17.1**	**15.8**	**33.3**	**16.9**	**16.5**	**33.9**	**16.7**	**17.2**



Legend

- MERAS Outline
- County Boundary

Supply Gap

- No significant supply gap
- < 1 MGD
- 1 - 10 MGD
- 10 - 50 MGD
- 50 - 100 MGD
- 100 - 200 MGD
- 200 - 300 MGD
- 300 - 400 MGD
- 400 - 500 MGD
- > 500 MGD

Figure 5-19
Supply Gap Map for Alluvial Aquifer Scenario 3 Base Period and 2050

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Groundwater Availability

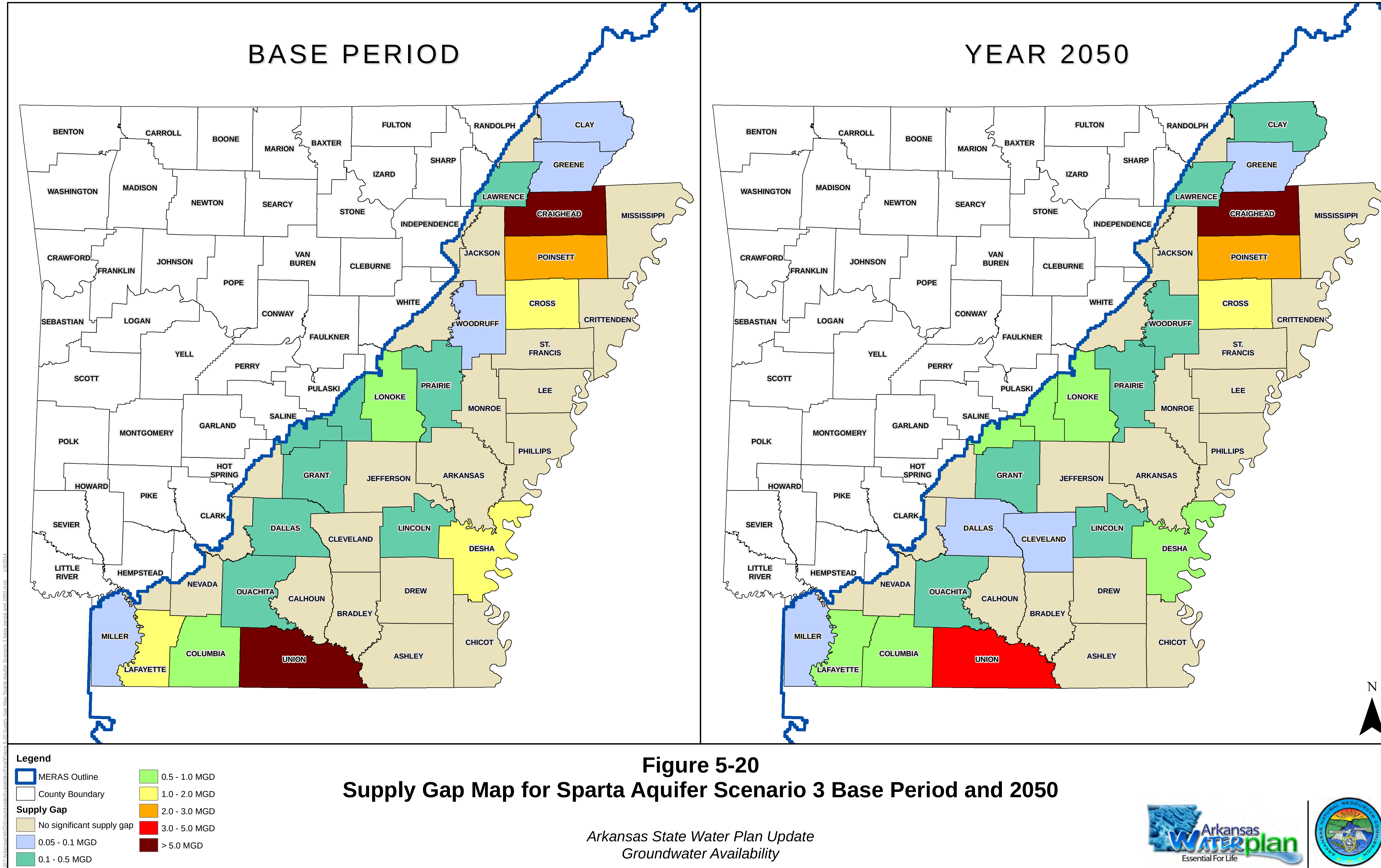
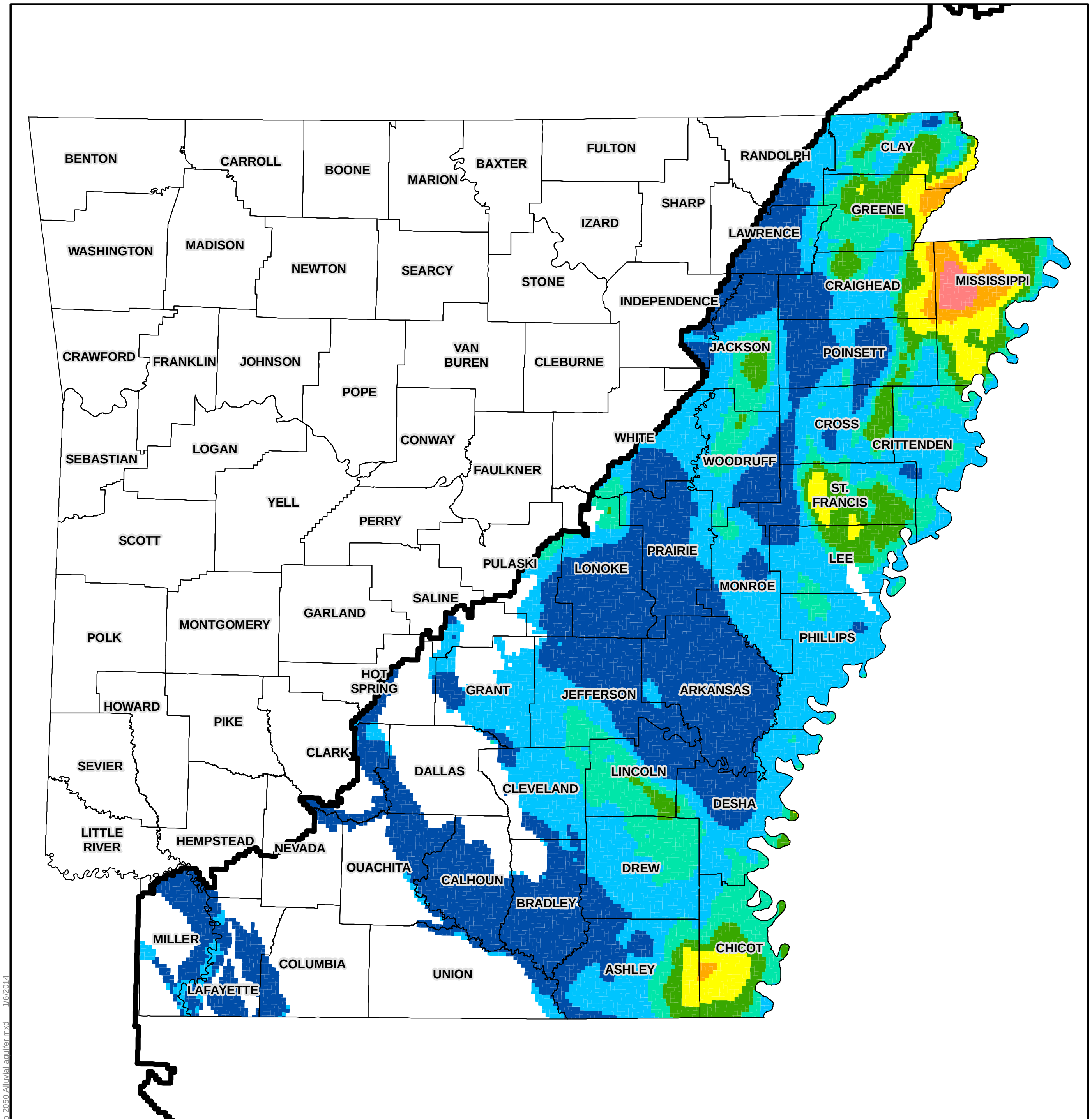


Figure 5-20
Supply Gap Map for Sparta Aquifer Scenario 3 Base Period and 2050

Arkansas State Water Plan Update
Groundwater Availability



Legend

MERAS Outline

County Boundary

Decline in Water Levels

- < 0 (Water Rise)
- 0 - 10 feet
- 10 - 20 feet
- 20 - 30 feet
- 30 - 40 feet
- 40 - 50 feet
- 50 - 75 feet
- > 75 feeet

Figure 5-21
Decline in Water Levels
Base Period to 2050
Alluvial Aquifer, Scenario 3

Arkansas State Water Plan Update
Groundwater Availability

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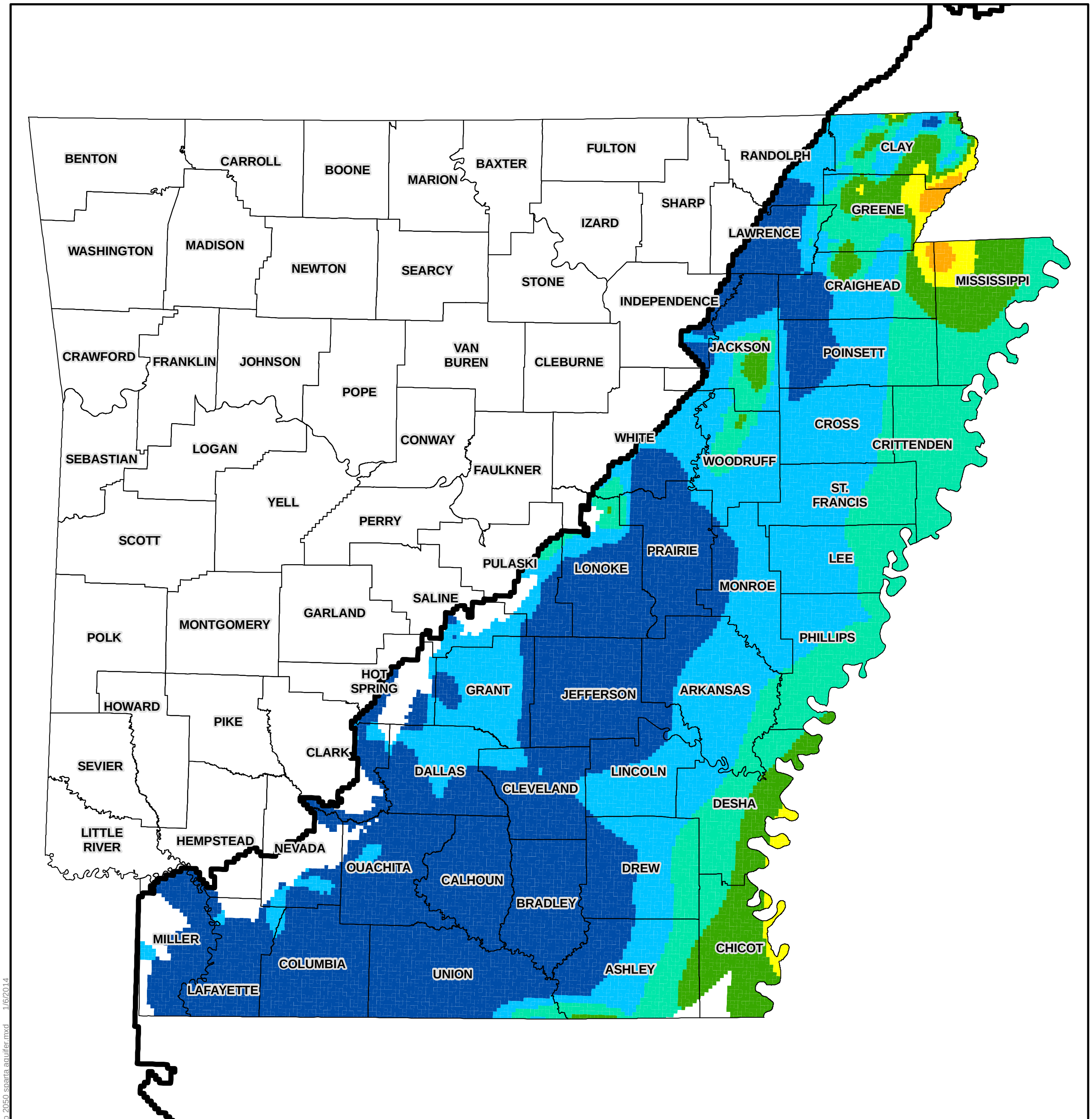
O:\91107-Arkansas\MXD\GroundwaterAvailability\Final\Figure 5-21 Decline in water levels base period to 2050 Alluvial aquifer.mxd 1/6/2014



Legend

MERAS Outline

County Boundary

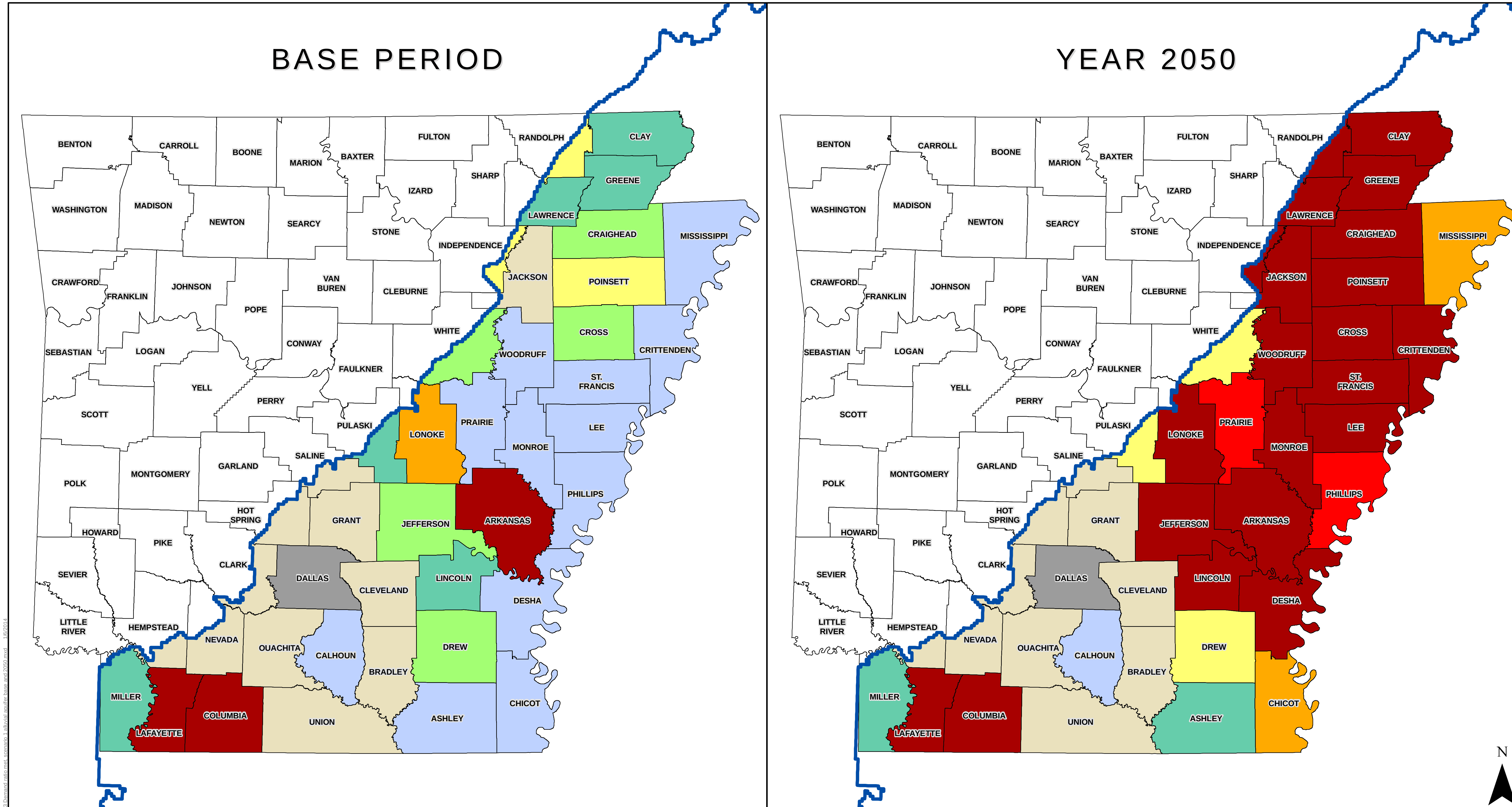
Decline in Water Levels

- < 0 (Water Rise)
- 0 - 10 feet
- 10 - 20 feet
- 20 - 30 feet
- 30 - 40 feet
- 40 - 50 feet
- 50 - 75 feet
- > 75 feeet

N

Figure 5-22
Decline in Water Levels
Base Period to 2050
Sparta Aquifer, Scenario 3

Arkansas State Water Plan Update
Groundwater Availability



Legend

- MERAS Outline
- County Boundary

Demand Ratio Met

- No significant demand
- NA (not applicable)
- < 50%
- 50 - 60%
- 60 - 70%
- 70 - 80%
- 80 - 90%
- 90 - 95%
- > 95%

Figure 5-23
Demand Ratio Met, Scenario 1 Alluvial Aquifer Base and 2050

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Groundwater Availability

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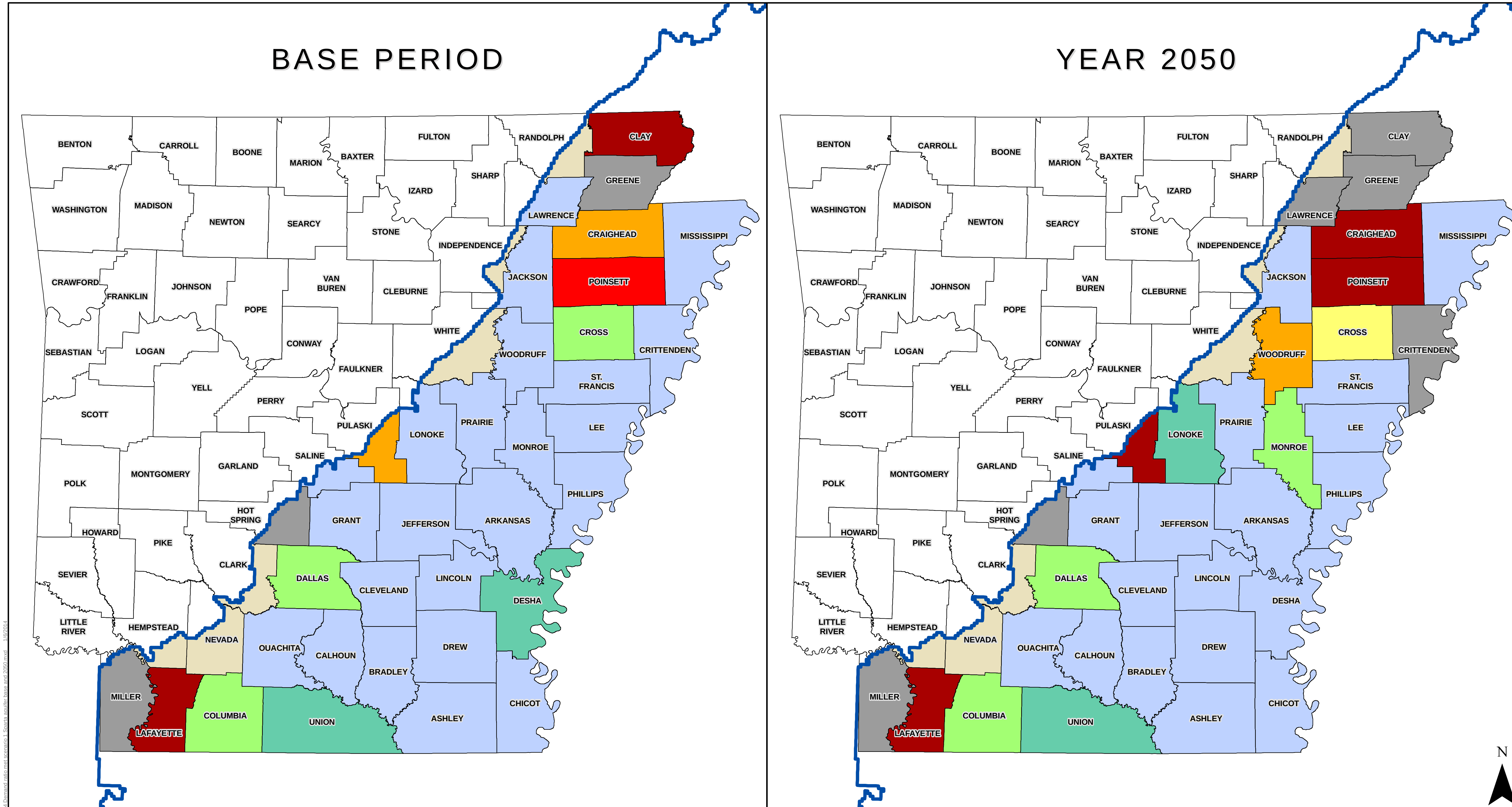


Legend

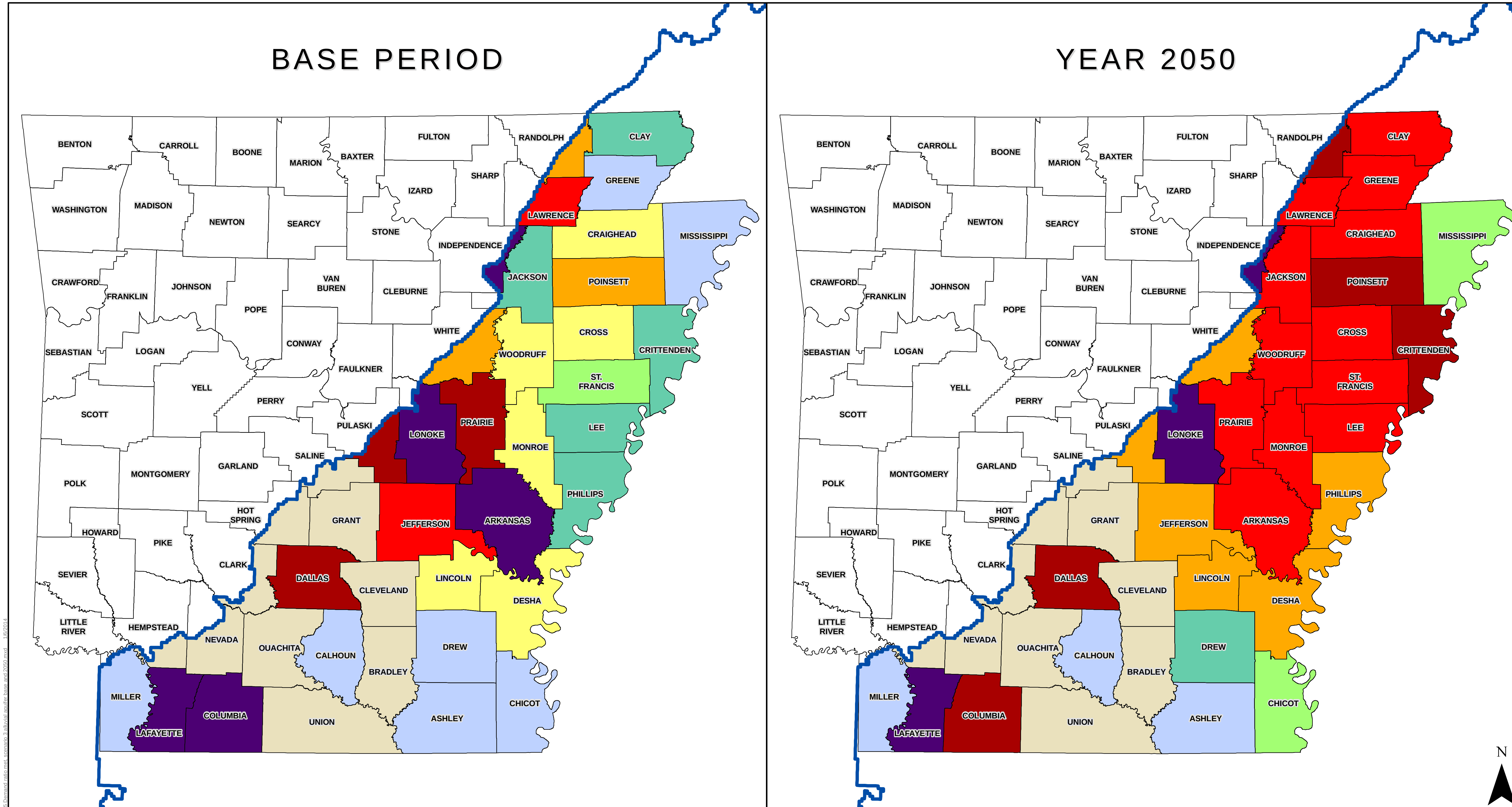
- MERAS Outline
- County Boundary

Demand Ratio Met

- No significant demand
- NA (not applicable)
- < 50%
- 50 - 60%
- 60 - 70%
- 70 - 80%
- 80 - 90%
- 90 - 95%
- > 95%

Figure 5-24
Demand Ratio Met, Scenario 1 Sparta Aquifer Base and 2050

Arkansas State Water Plan Update
Groundwater Availability



Legend

- MERAS Outline
- County Boundary

Demand Ratio Met

- No significant demand
- < 5%
- 5 - 10%
- 10 -20%
- 20 - 30%
- 30 - 40%
- 40 - 50%
- 50 - 75%
- > 75%

Figure 5-25
Demand Ratio Met, Scenario 3 Alluvial Aquifer Base and 2050

Arkansas State Water Plan Update
Groundwater Availability

Arkansas Waterplan
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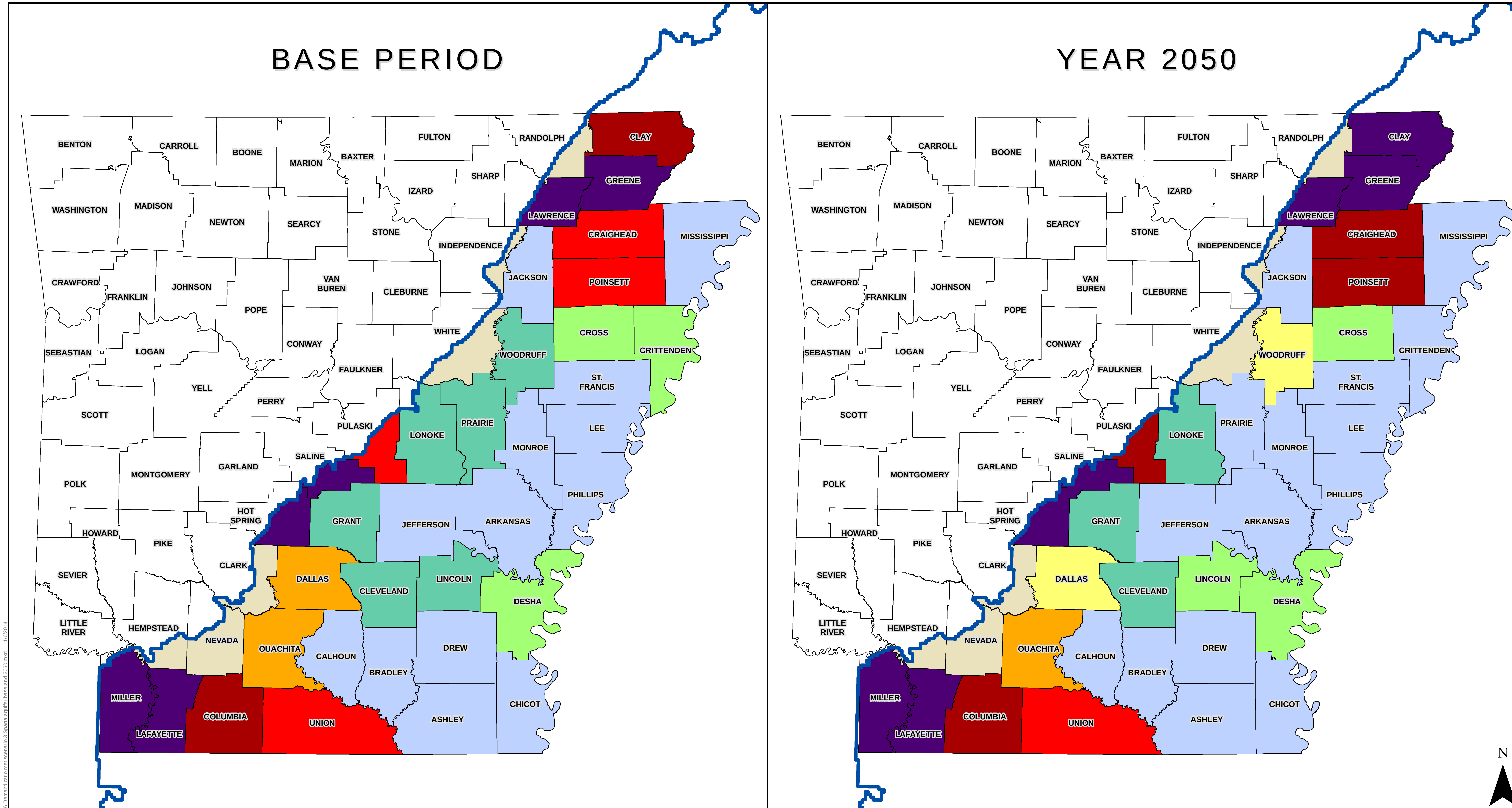

Legend

- MERAS Outline
- County Boundary

Demand Ratio Met

- No significant demand
- < 25%
- 25 - 50%
- 50 - 60%
- 60 - 70%
- 70 - 80%
- 80 - 90%
- 90 - 95%
- > 95%

Figure 5-26
Demand Ratio Met, Scenario 3 Sparta Aquifer Base and 2050

Arkansas State Water Plan Update
Groundwater Availability

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As with all models, the results are subject to limitations and uncertainties. Predictions of long-term climatic trends, which are a significant control on recharge, are highly speculative. The wet and dry scenarios that were simulated are intended to bracket the range of probable conditions in the model area. The impact of changes in land use, crop patterns, and irrigation practices will also impact the quantity of recharge in the system. The model is a regional scale model that is not capable of assessing small scale conditions, but does provide a reasonable means to assess the availability of groundwater at the scale of this study.

5.6 Qualitative Evaluation of Water Supply Availability in Northwest Arkansas

The Interior Highlands of western Arkansas has less reported groundwater use than other areas of the state, reflecting a combination of effects—prevalent and increasing use of surface water, less intensive agricultural uses, lower population and industry densities, lesser potential yield of the resource, and lack of detailed reporting.

The various aquifers of the Interior Highlands generally occur in shallow, fractured, well-indurated, structurally modified bedrock of this mountainous region of the state, as compared to the relatively flat-lying, unconsolidated sediments of the Coastal Plain. The greater porosity of the pervasive, coarse-grained, uncemented sands and gravels serving as aquifers in the Coastal Plain results in greater storage and yields as compared to secondary, relatively low-porosity fractures and bedding planes characteristic of rocks in the Interior Highlands. In addition, the laterally expansive and relatively continuous extents of Coastal Plain sediments provides aquifers that contrast markedly with the more discontinuous aquifers of the ancient bedrock of the highlands, which has experienced multiple episodes of structural modification, uplift, and erosion causing truncation, dissection, and excision. As such, the overall lower yields of aquifers of the Interior Highlands result in domestic supply as the dominant use, with minor industrial, small municipal, and commercial supply use. Where greater volumes are required for growth of population and industry, surface water is the greatest supplier of these water needs in the Interior Highlands.

In terms of age from youngest to oldest, the aquifers of the Interior Highlands are discussed in the following sections—the Arkansas River Valley alluvial aquifer, Ouachita Mountains aquifer, Western Interior Plains confining system, the Springfield Plateau aquifer, and the Ozark aquifer. The Western Interior Plains confining system, Springfield Plateau aquifer, and Ozark aquifer are regional hydrogeologic units, and regional nomenclature is adhered to for purposes of this report.

5.6.1 Arkansas River Valley Alluvial Aquifer

Groundwater derived from alluvial deposits of the Arkansas River is one of the most important sources of water in the Arkansas Valley section of the Ouachita Province and provides a valuable source of irrigation and municipal water supply.

5.6.1.1 Hydrologic Characteristics

Recharge to the aquifer is primarily by downward percolation of precipitation, in addition to leakage from the river (Bedinger et al. 1963; Kilpatrick and Ludwig 1990a). Recharge to the alluvium in the vicinity of the Atkins well field, which is underlain largely by backswamp deposits, was determined to be about 3 in/yr, whereas the average rate of recharge in some nearby channel deposits was about 10 in/yr (Bedinger et al. 1963). Although absent locally beneath some channel-fill deposits, in most places 30 to 60 feet of saturated sand and gravel is present; the saturated thickness generally increasing with distance downstream from Fort Smith.

Wells completed in the sands and gravels in the lower part of the ARV alluvial aquifer are capable of yielding 300 to 700 gpm of water and are used predominantly for irrigation and municipal water supply (Bedinger et al. 1963; Kilpatrick and Ludwig 1990a). Water levels range from approximately 5 to 30 feet below ground surface (Kilpatrick and Ludwig 1990a). Reported transmissivity values range from 40,000 to 160,000 (gal/d)/ft , and storage coefficient ranges from 0.0001 to 0.009 (Bedinger et al. 1963).

Groundwater in the ARV alluvial aquifer is largely unconfined. During normal and low river stages, the water table surface slopes toward the river and larger tributary streams. Local water table highs are common beneath the more permeable surface materials where recharge rates are high. During high river stages, the groundwater gradient is reversed near the river, and water table troughs form along each side of the river. Locally, pumping can modify the shape of the water table. Pumping for irrigation has little effect, because irrigation wells are widely spaced and pumpage is small.

Withdrawals for municipal supply are near continuous and are concentrated in small areas. Bedinger et al. (1963) noted that pumping at the Atkins municipal well field had a pronounced effect on the groundwater table, and that the well fields of Ozark and Dardanelle, which are near the river, had cones of depression extending from the well fields to the river, inducing recharge from the river.

5.6.1.2 Groundwater Flow Simulation Models

Kline (2003) simulated the groundwater flow system of the ARV alluvial aquifer south of Dardenelle, Yell County, Arkansas. A two-layer model was developed for the study to characterize groundwater flow characteristics and to investigate the degree of groundwater connectivity with the Arkansas River. Model results indicated that groundwater pumping induced flow from the river into the alluvial aquifer. Further work by Kline et al. (2006) and Kresse et al. (2006) used hydrographs and geochemical data to quantify the interaction between groundwater and the Arkansas River and validate the results of the model.

5.6.1.3 Water Use

Groundwater from the ARV alluvial aquifer is and historically has been an important source of irrigation and municipal supply. Currently, only the cities of Dardanelle and Maumelle, Arkansas, are using the ARV alluvial aquifer as a source of municipal supply water.

- Dardanelle, Arkansas, continues to depend solely upon groundwater for municipal supply, and in 2012 the city reported the capability of pumping greater than 3.0 mgd (Bill Smith, Dardanelle Water Works, personal communication, March 2012).
- Maumelle, Arkansas pumps from 13 wells completed in the ARV alluvial aquifer reported average use of 2.74 mgd in 2010.

In addition to the important use as a source of municipal supply water, the ARV alluvial aquifer continues to be a valuable source of irrigation water for cropland along the Arkansas River. For 2010, the reported use for irrigation from the ARV alluvial aquifer was 2.6 mgd, which was pumped from 34 wells supplying approximately 2,960 acres of cropland (Terry Holland, written communication, March 26, 2013).

5.6.2 Ouachita Mountains Aquifer

A thick sequence of Paleozoic rock formations in the Ouachita Mountains serves as an important source of groundwater supply for domestic users, in addition to a limited number of small commercial- and community-supply systems. The shallow saturated section of the combined formations in the Ouachita Mountains are referred to as the Ouachita Mountains aquifer.

5.6.2.1 Hydrologic Characteristics

Formations in the Ouachita Mountains are predominated by thick sequences of clastic rocks—shale, siltstones, and quartz formations (i.e., sandstone, chert, novaculite), with minor occurrences of carbonates and other rocks. The rocks have low porosity and low permeability because the dominant porosity is secondary porosity provided by faults, joints, fractures, bedding planes, and other structural features. Groundwater yields generally are sufficient for domestic use only.

Yields from wells completed in the Ouachita Mountains aquifer have a fairly large range depending on individual formations and lithology, but are typically low throughout the aquifer. Albin (1965) noted that most wells in the Ouachita Mountains aquifer yielded less than 10 gpm, and yields greater than 50 gpm were rare; although one well completed in the Bigfork Chert was recorded as yielding 350 gpm. Large yields can be obtained in some areas, particularly from the Bigfork Chert and other quartz formations.

Reported specific-capacity values ranged from 0.1 to 9.0 gpm/ft of drawdown (Albin 1965; Halberg 1968) and reported transmissivity values ranged from 1,000 to 20,000 gal/d/ft (Albin 1965). Aquifer tests for several wells in both types of shale and quartz formations confirmed that yields, in addition to storage characteristics, were substantially lower in shale formations than quartz formations. However, groundwater should not be considered as a source of supply for municipal growth and economic development unless the required quantity was small (Albin 1965; Halberg et al. 1968; Stone and Bush 1984).

Most wells in the Ouachita Mountains aquifer are less than 100 feet deep, but can range up to approximately 700 feet deep, with static water levels generally less than 20 feet below land surface, and flowing-artesian wells found throughout the region (Albin 1965; Kresse and Hays 2009); pumping water levels may be as much as 150 feet below land surface in deeper wells. Within this region there is a high degree of topographic control on shallow groundwater flow, and groundwater flow is confined to individual synclinal and anticlinal basins, adding support to the conceptual model of groundwater flow of topographically controlled, short flow paths within local watersheds.

5.6.2.2 Water Use

As noted above, the greatest use of groundwater from the Ouachita Mountains aquifer is for domestic-supply purposes. A review of community-supply wells from the ADH resulted in 72 wells used by various entities including camps and other recreational areas, conference centers, rest areas, stores, and even sources of public supply; five separate communities used wells completed in the Atoka, Bigfork Chert, Stanley Shale, and Arkansas Novaculite Formations for purpose of public supply, demonstrating that many formations constituting the Ouachita Mountains aquifer are capable of supplying volumes sufficient for small community-supply sources of water.

5.6.3 Western Interior Plains Confining System

The Boston Mountains comprise the Western Interior Plains (WIP) Confining System. They consist of a group of formations that comprise dominantly fractured shale and sandstone rocks, which are characterized by low secondary porosity and permeability with resulting low yields. Although the accepted regional designation of WIP is as a hydrologic confining system, locally the WIP is an important aquifer system within the Boston Mountains region of the state.

5.6.3.1 Hydrologic Characteristics

The WIP confining system lies in the Boston Mountains plateau and consists of alternating sequences of low-permeability shale and siltstone, and low-permeability to moderately permeable sandstone, with minor occurrences of limestone and coal. Regionally, this system of rocks impedes the flow of water to and from the underlying Springfield Plateau aquifer (Imes and Emmett 1994). The designation of rocks forming the Boston Mountains Plateau as a "confining system" is a consequence of the marked permeability contrast between the high-porosity karst limestone of the Springfield Plateau aquifer compared to small-aperture fracture porosity and low primary porosity found in the shale and sandstone rocks of the Boston Mountains. Porosity in well-indurated clastic rock sequences such as the WIP confining system often is dependent upon weathering and resultant fracture development.

Hydrologic properties for rocks of the WIP confining system compare closely to that of the shale- and sandstone-dominated Ouachita Mountains aquifer—little primary porosity, secondary porosity from fractures associated with compression, uplift and weathering, and low yields that rarely exceed 1-5 gpm and decreases with depth (Cordova 1963; Kilpatrick and Ludwig 1990b, Imes and Emmett 1994; Kresse et al. 2013). Imes and Emmett (1994) note that local groundwater flow systems in the WIP confining system are present dominantly in the upper 300 feet of the weathered confining system. Kresse and others (2013) reported on well depths from 58 wells located in the central part of the WIP confining system and noted depths ranging from 25 to 385 feet, with a median depth of 87 feet. Many wells in the WIP confining system often go dry during pumping, particularly during drought periods (Cordova 1963; Kresse and others 2013). As such, the quantity of groundwater available in the WIP confining system is related directly to the density, size, openness, and degree of interconnection of fractures (Cordova 1963).

Generally, groundwater is replenished by precipitation that infiltrates the ground in upland areas, percolates to the water table, flows downgradient toward lowland areas, and discharges into perennial streams (Imes and Emmett 1994). Regional hydraulic heads probably have changed little since predevelopment, because of the poor hydraulic connection between lower and higher permeability zones, and water-level measurements in any one well represent averages of all the water-yielding layers in the WIP confining system (Imes and Emmett 1994).

Because of the low porosity in rocks of the WIP confining system, wells yields generally are sufficient only for household, small municipal, and nonirrigation farm use. Cordova (1963) noted that most wells yielded less than 60 gpm, which represents a maximum yield in the WIP confining system. Thicker sandstone units in the Atoka Formation and the Batesville Sandstone in the eastern part of the aquifer commonly can yield 5-10 gpm to wells less than 300 feet deep (Albin et al. 1967a). Kilpatrick and Ludwig (1990) also noted that yields typically are less than 10 gpm. Tests conducted on 16 shallow wells that penetrated the WIP confining unit in southwestern Washington County, Arkansas, show that well yields in this area are small, ranging from 2 to 19 gpm (Muse 1982). Water levels in the WIP confining system typically range from near land surface to approximately 50 feet below land surface; however, pumping can substantially lower these levels. Seasonal fluctuations are approximately 10 feet with drawdowns from pumping as much as 45 feet (Albin et al. 1967a; Cordova 1963).

5.6.3.2 Water Use

Because domestic and water-supply systems serving less than 50,000 gal/d are not required to report their groundwater use, there is no way to accurately quantify the number of domestic and livestock wells currently in use. Thirteen wells were reported in the Atoka aquifer of WIP Confining System in 2010 (Terrance W. Holland, U.S. Geological Survey, written commun., 2013). These wells were mainly used for public supply or supplied parks. Several schools, stores, parks, and some commercial businesses also withdraw water from this system (Lyle Godfrey, Arkansas Health Department, written commun., 2012).

5.6.4 Springfield Plateau Aquifer

The Springfield Plateau aquifer lies within the Springfield-Salem Plateaus Section of the Ozark Plateaus province. A sequence of limestone and cherty limestone of Mississippian age comprise this aquifer. The Ozark Plateaus (Ozarks) are a region of unique and complex hydrogeology and physiography and are characterized by a predominantly mantled karst terrain, where aquifer anisotropy and heterogeneity, drastic contrast, and variability in aquifer characteristics are the norms, and the full spectrum of groundwater behaviors can be observed. The behavior of groundwater flow and groundwater quality within the Ozark Plateaus is controlled by regional and local geology, including lithologies of the rocks exposed at the surface that convey groundwater flow and stratigraphic relations of these different lithologies, and geologic structure—the physical modifications to the rocks that have occurred over time.

5.6.4.1 Hydrologic Characteristics

The Springfield Plateau aquifer and is generally unconfined across the Springfield Plateau and confined in the Boston Mountains. The highly soluble nature of the carbonate rocks of the Boone Formation has given rise to development of the distinctive karst terrain and pervasive occurrence of karst features—e.g., caves, springs, and sinkholes, and the intimate connection of surface water and groundwater as well as the dramatically variable aquifer characteristics that typify the area.

In the Springfield Plateau aquifer, high hydraulic conductivity values (up to 10−3 ft/s; Stanton, 1993) associated with the aquifer are a result of development of secondary porosity through diagenetic processes, particularly dissolution of bedrock along joints, fractures, and bedding planes rather than from primary, matrix-type porosity. Enhancement or enlargements of fractures, bedding planes, and conduits by carbonate dissolution is an active, ongoing process (Adamski et al. 1995). Hydraulic conductivity values of matrix porosity blocks are much lower, on the order of 10−12 ft/s or even less (Van den Heuvel 1979; Peterson et al. 2002). Development of secondary porosity has produced anisotropic and heterogeneous hydraulic characteristics for the aquifer. The presence of smaller-scale matrix, small-aperture fracture, and small-conduit porosity combined with the dissolution-enhanced conduits result in a bimodal permeability distribution and in water movement that may be described relative to the two flow end members defined above—diffuse flow and focused (conduit) flow. Diffuse flow refers to overland water flow that is spread out over the landscape, rather than concentrated in a defined channel or pipe. Groundwater storage, hydraulic conductivity, and well yields decrease with depth in the Springfield Plateau aquifer (Lamonds 1972). As such, well depths are generally less than 200 feet and rarely exceed 300 feet in the Springfield Plateau aquifer (Imes and Emmett 1994).

Average values of horizontal conductivity modeled from groundwater simulations are 22 ft/d (Imes and Emmett 1994) with vertical conductivities about an order of magnitude lower (Adamski et al. 1995). However, hydraulic conductivities range greatly, and values as high as 886 to 2,100 ft/d occur locally (Vandike 1994). Transmissitivies range from approximately 1,700 to 8,600 ft^2/d (Imes and Emmett 1994). Wells yields in the area reflect the porosity types: where wells intersect highly porous and permeable zones, yields of 10 to greater than 100 gpm are observed; where wells are completed in zones with little secondary development of porosity and permeability, well yields are typically less than 10 gpm. The lower end of the range is most common, with most wells yielding less than 20 gpm throughout the extent of the aquifer (Adamski et al. 1995; Peterson et al. 2002; McFarland and Prior, 2005; Gillip et al. 2007).

Most recharge to the aquifer is by infiltration of precipitation across the aquifer's outcrop area; where confined, recharge occurs via leakage through overlying units (Adamski et al. 1995). Recharge to the Springfield Plateau aquifer occurs as both diffuse and focused recharge (Alley et al. 2002; Healy 2010). Recharge from diffuse input likely amounts to a small percentage of the total recharge as compared to focused recharge through karst features such as sinkholes, fractures and conduits, and losing stream reaches (Alley et al. 2002; Brahana et al. 2011). The proportionality of recharge is not well constrained for the Springfield Plateau aquifer.

Discharge from the Springfield Plateau aquifer is primarily through springs, withdrawals by wells, and inter-aquifer flow to the underlying Ozark aquifer system (Branner 1937; Harvey 1980; Brahana and Davis 1998; Czarnecki et al. 2009; Hudson et al. 2011; Vardy 2011). Seeps and springs make up the predominant discharge mechanism from the aquifer with springs generally occurring near the base of the Boone Formation coincident with structural lows and the underlying Ozark confining unit (Kilpatrick and Ludwig 1990a; Adamski et al. 1995; Murray and Hudson 2002; Bolyard 2007; Hudson et al. 2011). Where the underlying Ozark confining unit is absent or incompetent, transmission of groundwater to the underlying Ozark aquifer takes place (Imes and Emmet 1994). Lastly, discharge also takes place as a function of groundwater withdrawal from wells; however, withdrawals do not appear to have caused distinguishable differences in potentiometric surfaces over time in northern Arkansas (Gillip 2007).

5.6.4.2 Water Levels

Groundwater-level measurements for the Springfield Plateau aquifer available in Arkansas include only one record of more than 15 years, measured at an interval adequate to capture seasonal variability. Water levels generally reflect topography and exhibit a strong correlation with elevation. Potentiometric surfaces (Imes and Emmet 1994) depict relatively higher groundwater levels in high-elevation areas such as Benton, Carroll, Boone, Washington, Madison, and Newton counties and lower groundwater levels in lower elevations areas west towards Oklahoma, south towards the Arkansas River Valley, and east towards the Mississippi Alluvial Plain. Hydrograph of water levels in a well completed in the Springfield Plateau aquifer in northern Arkansas.

5.6.4.3 Water Use

The Springfield Plateau aquifer is widely used throughout its extent in northwestern Arkansas. Numerous domestic and livestock wells are in use in Carroll and Boone Counties (Brahana et al. 1991, 1993), although commercial and municipal surface-water systems have largely supplanted use of the Springfield Plateau aquifer as a general source of water supply. There were three public-supply wells in Carroll County reporting use from the Springfield Plateau in 2010. Also, a small number of small community-supply systems, including restaurants, resorts, RV parks, and shops, are registered with the Arkansas Department of Health (Lyle Godfreys, Arkansas Department of Health, written communication, 2012).

5.6.5 Ozark Aquifer

The Ozark aquifer is exposed and generally unconfined within the Salem Plateaus section of the Ozark Plateaus (Ozarks) province (Fenneman 1938) and underlies and is confined below the Springfield Plateau aquifer in the Springfield Plateau and Boston Mountains regions of the Ozarks.

5.6.5.1 Hydrologic Characteristics

The upper Ozark aquifer is generally unconfined across the Salem Plateau and confined in the Springfield Plateau and Boston Mountains. The highly soluble nature of the carbonate rocks of the dolostones and the limestones that are the primary constituent lithologies of the upper Ozark aquifer has resulted development of the hydrologically heterogeneous karst terrain and prevalence of karst features (for example, caves, springs, and sinkholes) and the intimate connection of surface water and groundwater as well as the highly variable aquifer characteristics that typify the area. In the upper Ozark aquifer, high hydraulic conductivity values typically are a result of development of secondary porosity through dissolution of bedrock along joints, fractures, and bedding planes. Enhancement of fractures, bedding planes, and conduits by carbonate dissolution is an active, ongoing process (Adamski et al. 1995).

In the unconfined upper Ozark aquifer, precipitation provides recharge to the aquifer where exposed. As such, recharge can be rapid and result in highly variable water-level elevations, substantial seasonal changes, and groundwater gradient reversals (Aley 1988). In areas where the Ozark aquifer is overlain by the Springfield aquifer, most recharge occurs through down-gradient flow originating in the outcrop area; recharge by way of exchange of water between the Springfield and Ozark is impeded by shales (primarily the Chattanooga Shale) and dense, low-permeability limestones and dolostones, although some leakage does occur (Imes and Emmett 1994; Adamski et al. 1995).

Well yields and depths within the upper Ozark aquifer are comparable to those of the exposed Springfield Plateau aquifer, with relatively low yields that are reflective of generally low permeability. Wells within the upper Ozark aquifer are generally less than 300 feet in depth (Lamonds 1972) and have yields of approximately 5 to 10 gpm (Leidy and Morris 1990b; Lammonds 1972). The hydraulic conductivity of the Ozark aquifer as a whole is estimated to range between more than 1.0x10-3 ft/sec to less than 1.0x10-8 ft/sec (Imes and Emmet 1994).

The lower portion of the Springfiled Plateau aquifer consists of the Roubidoux Formation, Gunter Member of the Gasconade Dolomite, and Eminence Dolomite, Potosi Dolomite which form aquifers of generally high yield (Harvey 1980). In Arkansas, the lower Ozark aquifer is under confined conditions (Prior et al. 1999) and receives recharge from rainfall and stream-flow interception in their outcrop areas in southern Missouri (Lamonds 1972; Melton 1976; MacDonald et al. 1977; Harvey 1980; Prior et al. 1999). Harvey (1980) further detailed important recharge components, listing sinkholes, infiltration through conduits, and losing streams as the primary mechanisms of recharge. Some recharge moves into the lower Ozark aquifer as leakage from the upper Ozark aquifer (Imes and Emmett 1994; Adamski et al. 1995); however, the majority of recharge to the confined lower Ozark aquifer is attributed to lateral flow from the unconfined areas (Imes and Emmett 1994; Adamski et al. 1995). The direction of groundwater flow generally follows regional dip toward the south. Wells in the lower Ozark aquifer are among the most productive in the region (Lamonds 1972), with yields ranging from less than 10 gpm to about 600 gpm (Caplan 1960; Melton 1976; MacDonald 1977; Lamonds 1972; Kilpatrick and Ludwig 1988; Prior et al. 1999)

The hydraulic conductivity of the Ozark aquifer as a whole is estimated to range between more than 1.0x10-3 ft/sec to less than 1.0x10-8 ft/sec (Imes and Emmet 1994). MacDonald et al. (1977) and Melton (1976) reported specific capacity values ranging from 0.1 to 3.8 gpm/ft from the Roubidoux Formation, and noted that several wells experienced no measurable drawdown while pumping.

5.6.5.2 Water Levels

Water-level data available for the Ozark aquifer in Arkansas are scarce in many areas. Water levels in wells in Arkansas average about 700 to 1,000 feet of altitude (Adamski et al. 1995). Where the upper Ozark aquifer is exposed and unconfined, water levels generally are a subdued reflection of topography (Lamonds 1972; Leidy and Morris 1990b). Groundwater-flow directions are lateral and outward from areas of high elevation with discharge occurring at lower elevations at streams and springs.

The character of water level responses are different in the upper and lower Ozark aquifers. The upper Ozark aquifer generally shows greater and more rapid water level change in keeping with the shallower, exposed nature and direct infiltration of locally recharging precipitation. Water-level changes in the lower Ozark are more subdued and slower in response, showing a lag time as compared with the upper Ozark. Periodic water levels in the Ozark aquifer currently are measured on a 3-year rotational basis in Arkansas. No continuous water-level monitoring sites are active for the Ozark aquifer.

5.6.5.3 Water Use

There were 108 wells reported in the Ozark aquifer in 2010; of those, 79 wells were reported withdrawing groundwater from the lower Ozark aquifer (comprising the Rubidoux Formation and Gunter Member of the Gasconade Formation), and the remaining wells withdrew groundwater from formations composing the upper Ozark aquifer (Terrance W. Holland, U.S. Geological Survey, written commun., 2013). Primary use of the Ozark aquifer is for public supply; 76.45 mgd was withdrawn for public supply in 2010.

For public supply, wells identified as withdrawing groundwater from the Rubidoux Formation constitute the highest reported use in the Ozarks; 50.73 mgd were withdrawn in 2010 (Terrance W. Holland, U.S. Geological Survey, written commun., 2012). The Gunter Sandstone had approximately half the reported use as that from the Rubidoux in 2010, at 26.58 mgd. Cherokee Village in Fulton County withdrew the most water from lower Ozark aquifer in 2010, 9.72 mgd, all from wells listed as completed in the Rubidoux (Terrance W. Holland, U.S. Geological Survey, written commun., 2013). Decatur (Benton County) withdrew the most water from the Gunter Member in 2010, 5.08 mgd (Terrance W. Holland, U.S. Geological Survey, written commun., 2013). Other large users include the municipal supplies of Holiday Island, Corning, and Mammoth Spring.

Groundwater use has recently been on the decline and surface water use has increased dramatically, and the vast majority of the population in northern Arkansas is served by surface water, especially in Benton and Washington counties. Many communities have sought out surface water for the public supply source because of quantity and quality issues. Some municipalities have struggled to provide a growing demand with limited groundwater sources, while other areas tapping the lower Ozark aquifer have naturally occurring radon, radium, fluoride, and other undesirable constituents that has impaired use in some areas and increase costs of treatment (Adamski 1996).

Irrigation use was estimated approximately 20 mgd from the Ozark aquifers in 2010 (Terrance W. Holland, USGS, written commun., 2012). About 70 percent of irrigation water use is from the upper Ozark aquifer occurs in counties in the aquifer's far eastern extent, where row crops like cotton, rice, and soybeans are commonly grown. Depth to water in most of these wells is approximately 100 feet. Agriculture water use throughout the rest of the Ozark Plateaus is likely to be smaller in scale, due to primarily growing fruit (Lammonds 1972) that does not have the large water requirements of row crops. In addition, small amounts water were withdrawn for two fisheries—approximately 6 mgd in 2010 from the Gunter Member of the lower Ozark aquifer.

Commercial use was estimated at 0.1 mgd in 2010 (Terrance W. Holland, U.S. Geological Survey, written commun., 2013). Most use in the Ozarks is seasonal, for recreational activities including resorts, parks, campground, and golf courses.

Section 6

Groundwater Quality

The information on groundwater quality comes entirely from the draft "Aquifers of Arkansas: Protection, Management, and Hydrologic and Geochemical Characteristics of Arkansas' Groundwater Resources" (Kresse et al. in review). Groundwater quality information was compiled from more than 500 historical and recent publications and from greater than 8,000 sites with groundwater quality data. The water quality data measurements were obtained from the USGS National Water Information System database and the ADEQ and entered into a spatial database to investigate distribution and trends in groundwater quality constituents for each of the aquifers.

6.1 General Geochemistry

The 16 aquifers of the state were divided into two major physiographic regions of the state—the Coastal Plain of eastern Arkansas and the Interior Highlands of western Arkansas. Aquifers in the Coastal Plain Province consist of various geologic units with generally good water quality for all aquifers in the Coastal Plain, except for elevated iron concentrations and localized areas of high salinity. In the Coastal Plain, the prevalence of long regional flow paths resulted in regionally predictable and mappable geochemical changes along these flow paths. Trends for individual water quality constituents were generally elevated iron and nitrate concentrations with lower pH values and dissolved solids in the outcrop areas, transitioning to lower iron and nitrate and higher pH and dissolved solids downgradient in the formations. Water type generally trended from a calcium- to a sodium-bicarbonate groundwater with increasing cation exchange along the flow path.

The aquifers in the Interior Highlands region of western Arkansas generally occur in shallow, fractured, well-indurated, structurally-modified bedrock of this mountainous region of the state, as compared to the relatively flat-lying, unconsolidated sediments of the Coastal Plain. Spatial trends in groundwater geochemistry in the Interior Highlands differed greatly from trends noted for aquifers of the Coastal Plain. In the Interior Highlands, short, topographically controlled flow paths (from hilltops to valleys) within small watersheds represent the predominant groundwater flow system. Changes in geochemistry are dominantly noted to be related to rock type and residence time along individual flow paths. Dominant changes in geochemistry for the Ouachita Mountains aquifer and the Western Interior Plains confining system are attributed to rock-water interaction and changes in redox zonation along the flow path. In the Ozark and Springfield Plateau aquifers, rapid influx of surface-derived contaminants, especially nitrogen, coupled with little to no attenuation processes are attributed to the karst landscape developed on Mississippi and Ordovician age carbonate rocks of the Ozark Plateaus.

6.2 Geochemistry in Coastal Plain Aquifers

Aquifers in the Coastal Plain comprise Cenozoic-age strata consisting primarily of Cretaceous, Tertiary, and Quaternary sands, gravels, silts, and clays, with groundwater primarily produced from coarse-grained sands and gravels within these deposits. The geochemistry of the Coastal Plain Aquifers is presented from youngest to oldest in the following sections.

6.2.1 Mississippi Valley Alluvial Aquifer

In general, the overall quality of groundwater from the Mississippi River Valley (MRV) alluvial aquifer throughout eastern Arkansas is good compared to the EPA primary drinking water standards (EPA 2009). Certain common water quality characteristics of the aquifer groundwater limit its use for domestic, industrial, and municipal supply purposes. Elevated concentrations for hardness, iron, and manganese often are found to exceed secondary drinking water standards. Further, concentrations of arsenic exceed federal primary drinking water standards in deeper parts of the MRV alluvial aquifer. Use of the water for drinking water or industry would require treatment to remove these constituents.

The MRV alluvial aquifer water is predominantly used as a source of irrigation water supply. Localized areas contain concentrations of chloride that can affect crops including soybeans and rice. Areas of poor water quality can result from natural processes, including microbial-mediated changes in reduction/oxidation (redox) conditions, basic rock-water interactions, or upwelling of high salinity water from underlying formations.

Because row-crop agriculture is the dominant land use in eastern Arkansas, use of pesticides and fertilizers is the most prevalent and ubiquitous anthropogenic threat to groundwater quality in the shallow alluvial aquifer. Small urban communities are present throughout the Mississippi alluvial plain that include numerous sources of contamination (i.e., underground storage tanks, pesticides and fertilizers, small industry, and other sources); however, contaminant plumes normally are present at small local scales and do not affect large regional areas.

Groundwater from the MRV alluvial aquifer is dominantly a calcium-bicarbonate water type throughout most of the extent of the aquifer, with sodium, magnesium, chloride, sulfate, silica, and iron comprising the remaining major (by weight) ions in solution. Most constituents show a wide variability based on residence time of groundwater along a flow path, thus allowing more time for mineral dissolution and rock-water interactions affecting the chemical composition of groundwater, and where groundwater has been impacted by anthropogenic sources or upwelling of high-salinity water from underlying formations.

Water quality problems in the MRV alluvial aquifer generally are related to elevated concentrations of iron and manganese concentrations that are widespread throughout the aquifer, in addition to salinity problems and elevated arsenic concentrations that are found in isolated parts of the aquifer. Because the primary use of the alluvial aquifer is for irrigation, practical issues related to elevated iron and manganese concentrations primarily are fouling of pumps and well screens and the need for treatment prior to use in industrial or municipal supply, whereas elevated concentrations of chloride potentially can affect crop yields. Although arsenic concentrations exceed primary drinking water regulations in some areas, this problem has been documented only in irrigation wells completed in the deeper part of the aquifer, and use of the groundwater for irrigation presents minimal health risks. Pesticide monitoring since the early 1990s has resulted in an approximate 14 percent pesticide detection rate; however, pesticide concentrations typically are low and are 3 to 5 orders of magnitude lower than published maximum contaminant levels (MCLs) and health advisory standards.

6.2.2 Minor Alluvial Aquifers in Coastal Plain Province

The MRV alluvial aquifer is limited to roughly the eastern third of Arkansas. However, smaller deposits of alluvium can be an important local water source. Within the West Gulf Coastal Plain in southern Arkansas, the Red River and Ouachita River alluvial deposits are an important source of water.

The principal source or recharge to Quaternary aquifers is precipitation (Boswell et al. 1968). Both the Red and Ouachita Rivers are in hydraulic connection with the alluvium deposited along their course (Ludwig 1973; Halberg et al. 1968), and as such the rivers may act to drain or recharge the aquifer.

Like the Quaternary alluvium of the Mississippi River Valley, the Quaternary alluvium of the Red River and Ouachita River Valleys are the result of Pleistocene and later erosion and deposition. As sea level rose, the gradient of the streams were reduced and aggradation of sediments began. The depositional processes were complex, with alluvium being eroded, dissected, and terraced with changing flow conditions (Boswell et al. 1968). The smaller scale drainage of these basins is reflected in the thinner nature of the alluvium compared to that of the Mississippi River Valley.

Groundwater-quality data from the Red River alluvial aquifer for this report show pH values generally greater than 7.0 and ranging upward to 9.4. Most samples revealed a strongly calcium-bicarbonate except as affected by salinity issues in Miller County. Iron concentrations were mostly less than 1,000 micrograms per liter (μg/L) throughout the extent of the aquifer. Nitrate concentrations dominantly were less than 1 milligram per liter (mg/L) except in western Little River County, where four wells had concentrations exceeding the MCL for nitrate of 10 mg/L.

Locally, the alluvium of the Ouachita and Saline Rivers provides readily available groundwater. The geochemistry and general water quality of groundwater from the Ouachita-Saline Rivers alluvial aquifer might be expected to be similar to groundwater in the Pleistocene-age deposits of the MRV alluvial aquifer.

6.2.3 Cockfield Aquifer

The Cockfield aquifer contains groundwater of a high quality that is used throughout southeastern Arkansas. The Cockfield Formation crops out extensively over south-central Arkansas. It is exposed over practically all of Union County and parts of Bradley, Cleveland, Dallas, Grant, and Saline Counties (Hosman et al. 1968; Hosman 1982; Petersen et al. 1985). The Cockfield Formation has not been observed in outcrop or identified in the subsurface north of 35°north latitude (Hosman et al. 1968).

Overlying the Cockfield aquifer is the Jackson Group, which is considered a confining bed between the Quaternary alluvium and the Cockfield aquifer (Hosman and Weiss 1991; Petersen et al. 1985). In spite of its designation as a regional confining system, groundwater contained in thin sandy sections of the Jackson Group served a large number of users, primarily as a source of domestic and small farm supply, up through the 1990s. Groundwater from the Jackson Group has some of the poorest water quality of any aquifer system in the state. Sulfate concentrations are especially elevated in the aquifer. Residents previously using groundwater from the Jackson Group are now supplied by municipal supply sources, and the combined effects of poor yields, undesirable water quality, and available municipal supply have rendered the Jackson Group effectively obsolete as a viable water supply.

Data extracted from the combined USGS NWIS and ADEQ databases revealed 257 sites with water quality data for the Cockfield aquifer. A review of the data revealed very good water quality throughout most of the extent of the Cockfield aquifer, with isolated areas of poorer quality groundwater. A geospatial information system analysis of the water quality sites showed distinct patterns for many of the water-quality constituents of interest. Several of the water-quality constituents revealed spatial trends and differences related to groundwater chemistry in the outcrop area, reflecting younger, less geochemically evolved water compared to groundwater downgradient along the flow path, or trends related to leakage of poor quality groundwater from overlying or underlying formations.

Groundwater quality throughout the extent of the Cockfield aquifer is good, except for isolated areas with elevated sulfate and chloride concentrations as a result of influx of poor quality groundwater from overlying and underlying formations. The groundwater typically is a calcium-bicarbonate in the outcrop and subcrop, but transitions to a sodium-bicarbonate downdip as a result of cation exchange processes, and ultimately to a sodium-chloride water type in areas of mixing of poor quality, high salinity groundwater from underlying formations. Nitrate concentrations generally were low throughout the extent of the aquifer.

6.2.4 Sparta Aquifer

The Tertiary-age Sparta Sand is the thickest sand in the Mississippi embayment and its importance as an aquifer is recognized by the fact that it is second in use only to the Mississippi River Valley alluvial aquifer. The Sparta aquifer ranks first in groundwater used for public supply in Arkansas. It is a sand-dominated aquifer generally bearing fresh water of very high quality throughout its extent in Arkansas. Sparta aquifer groundwater supports users requiring water of exceptional quality, including a chemical industry built upon abundant availability of high quality water in Union County and numerous municipal suppliers across the aquifer's extent.

Spatial analysis of water quality revealed an overall pattern of low percent sodium—calcium-bicarbonate water type where sodium is less than 50 percent of total cations (calcium, sodium, magnesium, and potassium) in milliequivalents per liter—occurring dominantly in the area of outcrop, with an overall increasing trend in sodium percentage in the downgradient direction of flow. This finding suggests that cation exchange along the flow path accounts for the transitioning of initial calcium-bicarbonate to a sodium-bicarbonate water type with increased residence time in the aquifer.

The quality of groundwater from the Sparta aquifer throughout the state is very good. The groundwater generally is a sodium-bicarbonate water type throughout most of the extent of the aquifer; however, a calcium-bicarbonate water type is found in northeastern Arkansas and in the outcrop area for the Sparta Formation in south Arkansas. Elevated iron and nitrate groundwater concentrations are found dominantly in the outcrop area of the Sparta Formation, with lower concentrations in the downgradient direction of flow. Generally, pH values, in addition to bicarbonate and dissolved solids concentrations, increase in the Sparta aquifer with increased residence time along the flow path moving downgradient from the outcrop (and shallow subcrop in the northeast part of the state) area for the Sparta Formation; effects attributed to increased dissolution of carbonates. Areas of high salinity are noted in isolated areas of the Sparta aquifer, predominantly as a result of inferred upwelling from high-salinity groundwater in underlying formations.

6.2.5 Cane River Aquifer

The Cane River Formation (hereinafter referred to as the Cane River aquifer when referring to the saturated part of the formation) comprises an aquifer of mixed clastic lithology with resultant variable water quality and water yield. Areas where good quality water can be extracted from the Cane River aquifer are generally in or very near the outcrop in southwestern Arkansas. The outcrop area extends in a narrow, elongated band from the very southwestern corner of the state up through central Arkansas. Changes in lithology and sand thickness throughout the extent of the Cane River Formation affect water yields and water quality as the formation dips to greater depths below the land surface. In the southern and southeastern part of the state, the fine-grained nature of the deposits does not support yields adequate for use, and data from electric logs indicate the water as too saline for most uses (Onellion and Criner 1955; Hewitt et al. 1949; Broom et al. 1984). In northeastern Arkansas, the

Cane River Formation changes from a clay-dominated to sand-dominated facies and cannot be differentiated from the Sparta Formation or the Carrizo Sand.

A review of data available on the Cane River aquifer from the USGS NWIS and ADEQ databases yielded 45 groundwater sites with associated water quality data. Water quality from the Cane River aquifer is good with respect to federal drinking water standards. Groundwater from the Cane River aquifer generally is a calcium-bicarbonate water type in the outcrop area, but transitions at short distances from the outcrop area to a sodium-bicarbonate water type as a result of cation exchange processes. Nitrate concentrations were less than the maximum contaminant level of 10 mg/L as nitrogen for all samples. Salinity increases downdip of the outcrop area, and chloride concentrations can exceed the federal secondary drinking water regulation of 250 mg/L in some areas.

6.2.6 Carrizo Aquifer

The Carrizo Sand (called the Carrizo aquifer where referring to the saturated part of the formation) comprises an aquifer of limited use only in and near the outcrop area in southwestern Arkansas. Although hydrologic characteristics were deemed the most favorable future development in south-central Arkansas (Hosman et al. 1968), abundant groundwater from overlying formations supply water needs in that area of the state. In the northeast part of the state, sand units within the Carrizo cannot be differentiated from those of the overlying Cane River Formation and Sparta Sand; these sands become part of the Sparta aquifer.

Available databases contained water quality results for only 12 wells completed in the Carrizo aquifer. Groundwater samples from the Carrizo aquifer reveal an overall good quality, sodium-bicarbonate groundwater with low iron concentrations as compared to many other aquifers of the Coastal Plain. Nitrate concentrations from data compiled for this report were extremely low throughout the extent of the aquifer. Sulfate and chloride concentrations generally are low for areas near the outcrop, but increase appreciably at large distances from the outcrop area.

6.2.7 Wilcox Aquifer

The Wilcox Group contains a major lower aquifer, termed the lower Wilcox aquifer, and minor aquifers associated with sands of the upper Wilcox Group. The saturated part of the Wilcox Group is referred to as the Wilcox aquifer. The distinctive lithologic characteristics of the sand-rich lower Wilcox unit and the clay-rich upper Wilcox unit, coupled to the relative thickness of the two units across Arkansas, exercise a strong control on yields and water quality. Because of these stratigraphic differences, a distinct trend is noted in the distribution of producing wells and in aquifer water quality from the northeastern extent of the Wilcox aquifer to the western extent. Producing wells completed in the Wilcox aquifer in the southwest and central part of the state from Miller County to approximately Lonoke are completed almost solely in the outcrop area. In the extreme northeastern part of the state and east of Crowleys Ridge, numerous wells have been completed in a broad area downgradient from the outcrop and subcrop areas.

Groundwater from the Wilcox aquifer is of very good quality, with the exception of high salinity and elevated dissolved solids noted for groundwater downgradient of the outcrop and subcrop areas for most of the western extent of the aquifer. Numerous groundwater samples had iron concentrations that exceed the secondary drinking water limit of 300 μg/L, which could present problems for various users, including commercial, industrial, and public supply. Overall, better water quality is located in the eastern extent of the aquifer in northeastern Arkansas, as compared to groundwater in the western extent. Generally groundwater evolves from a calcium-bicarbonate water type to a sodium-bicarbonate water type at dissolved-solids concentrations greater than 100 mg/L. For dissolved-solids concentrations greater than 800 mg/L, groundwater is represented by strongly sodium-chloride water type.

6.2.8 Nacatoch Aquifer

The Nacatoch aquifer is one of the Cretaceous aquifers in Arkansas (Nacatoch Sand, Ozan Formation, Tokio Formation, and the Trinity Group). The Nacatoch Sand outcrops in Southwest Arkansas along a belt 3 to 8 miles wide that extends from central Clark County southwestward to the west edge of Hempstead County. Groundwater from the Nacatoch aquifer is most important in the southwestern part of the state, although it is also an available and good quality source of water in the extreme northeastern part of the state.

The Nacatoch aquifer is a viable and important source of water for parts of the southwestern and extreme northeastern parts of the state. In the southwestern extent, fresh water mainly is obtained from areas in or near to the area of outcrop, especially for the eastern and western parts of the outcrop area, and salinity increases in a downgradient direction from the outcrop area to a point where the groundwater is not suitable for most uses. Gradients of increasing chloride concentration are sharpest in the western and eastern parts of the outcrop, with a larger area of fresh water downgradient of the outcrop area in the central part of the aquifer. Concentrations of sulfate, iron, and nitrate generally are very low throughout the extent of the Nacatoch aquifer, where water quality data were available from producing wells. Values for pH, concentrations of bicarbonate, and percent sodium (of total cations in milliequivalents per liter) tend to increase downgradient of the outcrop area as a result of mineral dissolution coupled to cation exchange.

6.2.9 Ozan Aquifer

The Cretaceous-age Ozan Formation comprises an aquifer that is used solely in isolated parts of southwestern Arkansas. This aquifer is not listed in any regional reports, is one of the least used aquifers, and contains some of the poorest quality groundwater of any aquifer in the state.

Inspection of available databases produced only 14 sites with water quality data. Of the 14 sites, the data dominantly were populated for major anions (bicarbonate, chloride, sulfate), nitrate, and field parameters including pH and specific conductance, with only 2 sites containing information related to major cations (calcium, magnesium, sodium, potassium). As such, no meaningful analysis can be made with regard to water type or distribution of geochemical constituents. Several historical reports mentioned that use of the aquifer as a domestic source was predicated on the fact that in many areas no other water source was available. High chloride concentrations can occur in groundwater within the outcrop area of the Ozan aquifer, which is atypical of most Cretaceous and Tertiary aquifers of the Coastal Plain. Elevated sulfate concentrations in high-pH samples from wells located in the northeastern extent of the aquifer are attributed to possible gypsum dissolution coupled to calcite precipitation.

6.2.10 Tokio Aquifer

The Tokio aquifer is one of the Cretaceous aquifers in Arkansas (Nacatoch Sand, Ozan Formation, Tokio Formation, and the Trinity Group). The Tokio aquifer crops out in a narrow band from southeastern Sevier County through western Clark County with a small, isolated outcrop located in extreme western Little River County. Most producing wells are located within the larger outcrop belt.

Good quality water is obtained from the Tokio aquifer throughout much of its extent. Sharp increases in salinity are noted in the extreme southwestern and northeastern parts of the aquifer, limiting use at distances greater than approximately 5 miles downdip of the outcrop area. In the central part of the aquifer, salinity increases are more gradual (with concentrations in the aquifer at less than 300 mg/L as far as 20 miles from the outcrop area), affording a larger area of low salinity, high quality water for multiple uses. In the southwestern part of the aquifer, sulfate is the dominant anion in the aquifer. Dedolomitization is a likely process that may account the high sulfate, low bicarbonate groundwater in this area of the aquifer; however, this theory requires further analysis to achieve greater confidence.

6.2.11 Trinity Aquifer

The Trinity aquifer is the lowest-most Cretaceous aquifer in Arkansas (Nacatoch Sand, Ozan Formation, Tokio Formation, and the Trinity Group). The Trinity aquifer crops out in an east-west trending band from western Sevier County through Central Howard County to near the southeastern extent of Pike County. Wells for which water quality data were available were located only in Sevier and Howard Counties. A paucity of water quality data exists for the Trinity aquifer; only 32 wells with limited water quality data were available.

Good quality groundwater is found throughout the extent of the Trinity aquifer. Sulfate concentrations can be slightly elevated in some locations, although all concentrations were less than the 250 mg/L secondary drinking water regulation. Groundwater samples with elevated sulfate concentrations dominantly had correspondingly low bicarbonate concentrations, and this situation is explained by possible dedolomitization processes. All chloride concentrations, except one, were less than 15 mg/L at distances as great as 15 miles from the outcrop area, demonstrating the low overall salinity in the aquifer.

6.3 Aquifers of the Interior Highlands

The Interior Highlands of western Arkansas has less reported groundwater use than any other areas of the state, reflecting a combination of effects—prevalent and increasing use of surface water, less intensive agricultural uses, lower population and industry densities, lesser potential yield of the resource, and lack of detailed reporting. The various aquifers of the Interior Highlands generally occur in shallow, fractured, well-indurated, structurally modified bedrock of this mountainous region of the state. Rocks in the Interior Highlands characteristically have secondary, relatively low-porosity fractures and bedding planes in the discontinuous aquifers of the ancient bedrock of the highlands. The highlands have experienced multiple episodes of structural modification, uplift, and erosion causing truncation, dissection, and excision.

In terms of age from youngest to oldest, the aquifers of the Interior Highlands are discussed in the following sections: the Arkansas River Valley alluvial aquifer, Ouachita Mountains aquifer, Western Interior Plains confining system, the Springfield Plateau aquifer, and the Ozark aquifer.

6.3.1 Arkansas River Valley Alluvial Aquifer

Groundwater derived from alluvial deposits of the Arkansas River is one of the most important sources of water in the Arkansas Valley section of the Ouachita Province and provides a valuable source of irrigation and municipal water supply. For purposes of this report, groundwater contained in the alluvium of the Arkansas River Valley, called the Arkansas River Valley (ARV) alluvial aquifer, is considered a distinct aquifer from approximately the state border at Fort Smith to Little Rock, Arkansas. In the Mississippi alluvial plain in eastern Arkansas, making a distinction between groundwater from the alluvial deposits of the Arkansas River and those of the Mississippi alluvial plain is difficult, and all alluvial deposits east of Little Rock in the Mississippi alluvial plain are for all practical purposes considered part of the Mississippi River Valley alluvial aquifer.

Groundwater in the ARV alluvial aquifer has overall good water quality, with the exception of elevated iron concentrations, which often requires treatment for use as a municipal supply system. Chloride concentrations can be slightly elevated in backswamp areas or where influenced by influx of water from the Arkansas River; however, only 4 of 661 samples with chloride analyses exceeded the federal secondary drinking water regulation of 250 mg/L. Reducing conditions in various parts of the aquifer were theorized as controls on the distribution and concentration of nitrate, iron, and sulfate.

6.3.2 Ouachita Mountains Aquifer

A shallow saturated section of the combined formations in the thick sequence of Paleozoic rock formations in the Ouachita Mountains serves as an important source of groundwater supply for domestic users, in addition to a limited number of small commercial- and community-supply systems. The Ouachita Mountains aquifer includes all formations extending north to the Arkansas River (and associated alluvial deposits), west to the state line, and south and east to the boundary with the Coastal Plain Province.

Groundwater quality in the Ouachita Mountains aquifer is good with respect to federal primary drinking water standards. Problems in regard to taste, staining, and other aesthetic properties are related to elevated levels of iron, which is a common complaint among domestic users. Geochemical data indicate that an important control on iron solubility is sulfate reduction, which occurs dominantly in groundwater with dissolved solids concentrations greater than 250 mg/L. Nitrate was somewhat elevated (greater than 1.0 mg/L) in numerous wells, although only 4 of 101 samples exceeded the federal MCL of 10 mg/L, and concentrations greater than 1.0 mg/L generally occurred in wells less than 200 feet in depth. As such, increased vulnerability to surface sources of contamination is related to well depth.

6.3.3 Western Interior Plains Confining System

The Boston Mountains is represented by a group of formations that comprise dominantly fractured shale and sandstone rocks, which are characterized by low secondary porosity and permeability with resulting low yields. Regional hydrogeological models (Imes and Emmett 1994) characterize this system of formations as a regional confining unit, referred to as the Western Interior Plains (WIP) confining system. Although designated as a confining system, it is a valuable water supply to residents and small communities throughout the area. Unfortunately, there are no reports that view this collection of rocks as an aquifer, although historical reports discuss hydrologic characteristics and water quality for individual formations in this system of rocks.

Generally, very little groundwater quality monitoring was performed in the past related to the WIP confining system, as most water resource investigations in the Ozark Plateaus have concentrated on the Springfield Plateau and Ozark aquifers. Recent groundwater studies (Kresse and Hays 2008; Kresse et al. 2013) collected a more extensive and comprehensive geochemical database, in addition to analysis of isotopic compositions, to better understand rock-water interactions and evolution of groundwater geochemistry with respect to rock type in the Interior Highlands. These studies confirmed poorer water quality for groundwater from shale formations and showed marked differences in the geochemistry of groundwater from quartz formations, including sandstone and shale formations in the Interior Highlands.

General water quality is good throughout the WIP confining system. Groundwater with elevated iron, nitrate, sulfate, and chloride can be encountered in localized areas dependent on rock type and position in a localized flow path for a particular well. Water type can vary from a soft, slightly acidic groundwater, typically encountered in wells completed in sandstone rocks, to a calcium-and sodium-bicarbonate water type dependent on the amount of cation exchange in the groundwater system. Reducing conditions are found throughout the WIP confining system, dominantly related to groundwater from shale rock, and a complete redox zonation from nitrate-reducing conditions to production of methane is apparent in the data compilation.

6.3.4 Springfield Plateau Aquifer

The Springfield Plateau aquifer lies within the Springfield-Salem Plateaus section of the Ozark Plateaus province and comprises a sequence of limestone and cherty limestone of Mississippian age. The Ozark Plateaus (Ozarks) are a region of unique and complex hydrogeology and physiography and are characterized by a predominantly mantled karst terrain, where aquifer anisotropy and heterogeneity, drastic contrast, and variability in aquifer characteristics are the norms, and the full spectrum of groundwater behaviors can be observed. The behavior of groundwater flow and groundwater quality within the Ozark Plateaus is controlled by regional and local geology, including lithologies of the rocks exposed at the surface that convey groundwater flow and stratigraphic relations of these different lithologies, and geologic structure—the physical modifications to the rocks that have occurred over time.

Groundwater from natural rock-water interaction in the Springfield Plateau aquifer is generally of good quality. Agriculture in the form of cattle (beef and dairy), swine, and poultry operations accounts for the greatest land use activity in this region. Because of the steep topography and poor soils in the Ozarks, the nutrients, bacteria, and pesticides from agricultural activities, home septic systems, and infiltration of urban runoff are the dominant threats to groundwater quality in the aquifer. Numerous studies have documented elevated nitrate concentrations and fecal bacteria in groundwater from springs and wells issuing from or completed in the Springfield Plateau aquifer. A positive correlation between agricultural land use and nitrate concentrations validates concerns over agricultural waste and vulnerability of the Springfield Plateau aquifer. Recent studies have shown that in addition to agricultural land use, areas of greater karst development increase the vulnerability of the aquifer to these waste sources. Other inorganic constituents, including chloride, sulfate, and iron, generally were low throughout the aquifer, revealing a relatively high quality of groundwater from natural rock-water interaction for all water supply uses.

6.3.5 Ozark Aquifer

The Ozark aquifer is exposed and generally unconfined within the Salem Plateaus section of the Ozark Plateaus (Ozarks) province (Fenneman 1938) and underlies and is confined below the Springfield Plateau aquifer in the Springfield Plateau and Boston Mountains regions of the Ozarks. In Arkansas, the Ozark aquifer comprises a sequence of formations predominated by dolostones along with minor limestone, sandstone, and shale intervals of Ordovician age. The Ozark aquifer and associated formations contribute to the unique and complex hydrogeology and physiography of the Ozarks, with the karst of the carbonates of the upper Ozark aquifer presenting a physiographic and hydrologic environment in the Salem Plateau similar in aspect and complexity to that seen for the Springfield Plateau.

The Ozark aquifer is one of two major aquifers of the Ozark Plateaus, together with the Springfield Plateau aquifer. The Ozark aquifer, similar to the Springfield Plateau aquifer, comprises carbonate formations that have weathered to form a karst terrain that increases vulnerability to surface-derived contaminants. Because agriculture in the form of cattle (dairy and beef), poultry, and swine operations is the dominant land use in the Ozark Plateaus, nutrients, bacteria, and pesticides pose the greatest threat to groundwater quality. Elevated nitrate concentrations were noted in groundwater from the upper and lower Ozark aquifer, in spite of the fact that the lower Ozark aquifer is confined and well depths generally are greater than 1,000 feet below ground surface. The thin soils and karst features associated with formations constituting the Ozark aquifer coupled to inadequate casing appear to facilitate transport of agricultural contaminants to the upper and lower Ozark aquifer. An important protection and management conclusion based on these data is that sufficient casing for isolating groundwater from the more vulnerable Springfield Plateau aquifer should prevent influx of surface-derived contaminants into the upper Ozark aquifer in this area of the Ozark Plateaus.

6.4 Summary

The 16 aquifers of the state are divided into two major physiographic regions of the state—the Coastal Plain of eastern Arkansas and the Interior Highlands of western Arkansas. The water quality characteristics of 16 aquifers in Arkansas that currently serve or have served as important sources of water supply have been described. Data from more than 8,000 sites with groundwater quality data were obtained from the USGS NWIS and the ADEQ databases and entered into a spatial database to investigate distribution and trends in groundwater quality constituents for each of the aquifers.

The Mississippi River Valley alluvial aquifer is one of the most important aquifers in terms of total groundwater use in Arkansas. Water quality generally is good throughout the extent of the aquifer; however, elevated iron concentrations in most areas preclude use of the aquifer for commercial, industrial, and municipal use without treatment. Elevated salinity additionally occurs in different areas of eastern Arkansas, resulting from upwelling of high salinity water from underlying formations or evapotranspiration in clay-rich backswamp areas.

The Cockfield aquifer is a principal aquifer in southeast Arkansas. Groundwater in the outcrop area is represented by lesser-evolved, early flow-path, recharging water chemistry, resulting in overall lower pH values and dissolved solids, higher nitrate and iron concentrations, and a calcium-bicarbonate water type. Groundwater downdip from the outcrop area is affected by cation exchange and transitions to a sodium-bicarbonate water type, with higher pH and increasing dissolved solids, and lower concentrations of nitrate and iron occurring with more reducing conditions further along the flow path.

The Sparta aquifer is the second most important aquifer in terms of volume of use. Groundwater from the Sparta aquifer generally is of very high quality; isolated areas contain slightly elevated chloride concentrations resulting from upwelling of high-salinity water from underlying formations. Changes in geochemistry, similar to that in the Cockfield aquifer, involve a transitioning of calcium to a sodium-bicarbonate water type along the flow path, with concomitant increases in dissolved solids and decreases in iron and nitrate with greater reducing conditions.

Other aquifers of the Coastal Plain, including the Cane River, Carrizo, Wilcox, Nacatoch, Ozan, Tokio, and Trinity aquifers, generally are used as important local sources of domestic, industrial, and municipal supply. These aquifers all exhibit increasing salinity at various distances downdip from the outcrop areas that renders the groundwater unusable for most purposes. However, where there is a higher percentage sand in the formations comprising these aquifers in the northeast part of the state, the aquifers are of high quality and resulting greater use in this area of the state.

The Interior Highlands region of western Arkansas has less reported groundwater use than other areas of the state. Spatial trends in groundwater geochemistry in the Interior Highlands differ greatly from trends noted for aquifers of the Coastal Plain. In the Interior Highlands, short, topographically controlled flow paths (from hilltops to valleys) within small watersheds represent the predominant groundwater-flow system.

Dominant changes in geochemistry for the Ouachita aquifer and the Western Interior Plains confining system were attributed to rock type, residence time along individual flow paths, and resultant rock-water interaction and changes in redox zonation. Generally, groundwater evolved from a calcium- to a sodium-bicarbonate water type, with increasing reducing conditions resulting in denitrification, elevated iron and manganese concentrations, and production of methane in the more geochemically evolved and strongest reducing conditions.

In the Ozark and Springfield Plateau aquifers, rapid influx of surface-derived contaminants, especially nitrogen, coupled with little to no attenuation processes was attributed to the karst landscape developed on Mississippian- and Ordovician-age carbonate rocks of the Ozark Plateaus. Agriculture in the form of cattle (beef and dairy), swine, and poultry operations is the predominant land use in this region of steep topography and thin soils. As such, the high degree of connectivity between the surface and groundwater, expressed in the occurrence of sinkholes, solution fractures, caves, losing streams, large springs, and other karst features, leads to nutrients, bacteria, and other surface-derived contaminants associated with these agricultural activities posing the greatest threat to groundwater quality in the Ozark aquifer. A direct correlation was noted for increasing nitrate concentrations with increasing percentage of agricultural land use for the Springfield Plateau and Ozark aquifers. Additionally, areas with higher density of karst features, using density of sinkholes as a surrogate indicator, were shown to have higher nitrate concentrations than areas with no mapped sinkholes.

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Section 7

Approach to Future Development of Fish and Wildlife Flows

7.1 Background

In the spring of 2013, the Fish and Wildlife Flow Subgroup, a subgroup of the Water Supply Availability Group, met to discuss approaches for incorporating fish and wildlife flows in the AWP Update. Currently, different approaches are used to estimate fish and wildlife flow requirements for different purposes. The Arkansas Method is used for estimating fish and wildlife flows for the purpose of calculating excess flow available for allocation to nonriparian withdrawals. A modified Tennant method is used for estimating safe yield and minimum streamflows for fish and wildlife for allocating water among riparian users during times of declared water shortage.

The general opinion of the subgroup was that a new method is needed to determine fish and wildlife flow requirements; one that better addresses relationships between ecology and hydrology. In addition, a single method, rather than two different methods (i.e., Arkansas Method, modified Tennant Method) for estimating fish and wildlife flows was desired. Understanding that it will take time to develop a new method, the workgroup recommendation was to continue to use the Arkansas Method in the interim while a new method is developed. Therefore, the Arkansas Method will be used to determine minimum fish and wildlife flows for estimating excess water for allocation to nonriparian users in the 2014 update of the AWP. Stream safe yield, which guide allocation of water to riparian users during declared water shortages, will be defined in the 2014 AWP, but not calculated. The Arkansas and modified Tennant Method are briefly described below.

The Arkansas Method uses wetted perimeter as a surrogate for flow-fisheries relationships (Filipek et al. 1987). The Arkansas Method considers flow magnitude, but does not consider frequency, rate of change, or duration of flows and their potential effects on fish assemblages. Timing might is considered through seasons. The water year is divided into three seasons based on flow and ecological function. November through March represents a clean and recharge season, where sediment and other accumulated debris on spawning beds are cleaned through elevated flows, and groundwater, which contributes to base flow, is recharged. Recommended minimum flows during this period are 60 percent of the mean monthly flow for these months. April through June represents the spawning season for fish. Recommended minimum flows during this period are 70 percent of the mean monthly flows for these months. June through October reflect the period when most of the fisheries production occurs. Recommended minimum flows are 50 percent of the mean monthly flows during these months.

The original Tennant Method, developed for western streams, recommended minimum low streamflows be 10 percent of the average annual flow (Tennant 1976). The modified Tennant Method uses 10 percent of the mean seasonal flows, where the seasons are those described above for the Arkansas Method.

The Fish and Wildlife Flows Subgroup recommended shifting from using presumptive flow standards (i.e., Arkansas Method, modified Tennant Method) to using empirical, risk-based ecological response/flow relationships as the foundation for determining fish and wildlife flows in the future. In addition, it was recommended that the 2014 update of the AWP outline a process by which the current policy can be revised so that improved methodologies for estimating fish and wildlife flows can be used in preparing future updates to the AWP, and for implementation of the 2014 AWP. After a new method is developed for a specific flow regime(s) within a specific drainage basin(s), and the fish and wildlife flows are approved by stakeholders, the ANRC could then utilize the method in evaluating permits for nonriparian withdrawals, pre-allocation studies, and allocation in times of water shortages within those basins.

Fish and wildlife flows have been negotiated for two regulated stream systems—White River below Bull Shoals and Norfork Lake; and the Ouachita River below Remmel Dam. It was recommended that negotiated flows on regulated streams be retained pending additional evaluation.

This section describes a proposed framework and process for developing and confirming new methodologies for estimating fish and wildlife flows that could subsequently be used to replace the Arkansas Method, or other methods in use in the future, for implementing the AWP as scientific and technological advances are made in estimating fish and wildlife flows.

7.2 Proposed Framework for Developing and Confirming Improved Methodology

7.2.1 Framework Elements

The proposed framework provides a process for developing and adopting new methods for estimating fish and wildlife flows across the entire flow regime, from minimum low flows to flood flows. Over the past 20 years, there have been significant advances not only in the concepts of sustainable streamflows, but also in the methodologies for estimating fish and wildlife flows (Baron et al. 2002; Hill et al. 1991; King et al. 2003; NRC 2005; Poff et al. 1997; Poff et al. 2009; Richter et al. 2006). Current thinking about the process for estimating fish and wildlife flows, generally accepted within the scientific community, is described by Poff et al. (2009) and is called the Ecological Limits of Hydrologic Alteration (ELOHA). This ELOHA framework or process is proposed as the framework for developing and confirming alternative methods for estimating fish and wildlife flows and implementing the AWP. The elements required to evaluate proposed alternative methods are:

1. Establish the hydrologic foundation for the method development,
2. Specify the applicable stream class(es),
3. Document the current hydrologic status of the systems for which the method was developed,
4. Confirm that the flow-ecological response relationships of the method that are scientifically appropriate for these stream classes,
5. Use a stakeholder driven process to refine flow thresholds for designated stream uses, and
6. Monitor and periodically assess the adequacy of the method in protecting fish and wildlife.

Each of the steps in the framework or process is described below.

7.2.2 Establish the Hydrologic Foundation for the Method Development

The hydrologic foundation for a method consists of the source(s) of hydrologic data and hydrologic analyses. For example, the data source might be continuous USGS streamflows over a 40-year period of record. USGS gaging stations, with continuous stage recorders, serve as a primary hydrologic foundation (i.e., source of flow information) in the state. However, other entities have used other methods to collect flow information on Arkansas streams (e.g., ANRC, ADEQ, USACE, AGFC, The Nature Conservancy [TNC], etc.). At a minimum, any method proposed for use in implementing the AWP must document how the flow information was obtained, at what frequency, and over what period this information was collected. Greater confidence in the hydrologic foundation of the method is gained through frequent or continuous sampling over a long period of record. In addition, the hydrologic analyses used in method development also need to be documented. These analyses might consist of establishing comparative reference streams (Carlisle et al. 2010a, b), calculating different hydrologic metrics using the Hydrologic Assessment Tool (Henricksen et al. 2006), Indicators of Hydrologic Alteration (Richter et al. 1996), or other analytical approaches. A conceptual model is useful in describing the important structural and functional elements being considered in the method development and creating a shared understanding of how these stream systems are assumed to function (NRC 2005).

7.2.3 Specify the Applicable Stream Class(es) for the Method

The Arkansas Method was developed primarily on medium to larger sized streams in eastern and central Arkansas, including the White River, Arkansas River, Saline River, and Ouachita River (Filipek et al. 1987), and is considered applicable for these sized streams. The method has also been evaluated relative to 10 important hydrologic metrics (i.e., magnitude of flow, frequency, rate of change) and found to significantly maintain these metrics at recommended flow rates (Magoulick personal communication). It has not been applied for different categories of streams, such as "Extraordinary Resource Water," "Ecologically Sensitive Waterbody," or "Natural and Scenic Waterbody" streams, so its applicability for these stream classes is unknown.

Recent studies by Magoulick identified seven potential stream classes for Arkansas streams, excluding Delta streams, with the following hydrologic characteristics: Groundwater Stable; Groundwater; Groundwater Flashy; Runoff Perennial; Runoff Flashy; Intermittent; and Intermittent Flashy. Other stream classes have been based on geomorphic characteristics, such as braided, meander, or straight (Leopold and Wolman 1957), erosion, transport, and deposition reaches (Schumm 1977), or stream order (Strahler 1952). Rosgen (1994) proposed a classification scheme based on landform and fluvial characteristics, which combined channel relief, shape, and dimension profiles. Because there are multiple approaches for classifying streams, any proposed method should document the stream classes, and classification approach, for which it is applicable.

7.2.4 Document the Current Hydrologic Status of the Systems for Which Method was Developed

Many stream systems in Arkansas have been hydrologically altered. The intent of this step is not to imply that streams will be restored to a pre-alteration status, but rather to determine if the stream is currently subject to withdrawals or has been significantly altered hydrologically. Streams that currently have significant withdrawals or that have been altered hydrologically might not have the capacity to sustain withdrawals that other streams without these conditions have. One approach that has been used is to compare observed flows in the stream of interest with expected flows in a reference stream (Carlisle et al. 2010 a,b).

7.2.5 Confirm Flow-Ecological Response Relationships Used in the Method are Scientifically Appropriate for These Stream Classes

The recommendation of the Fish and Wildlife Flows Subgroup was to move from presumptive relationships to empirical, risk-based flow-ecology relationships. Any proposed method should confirm that flow-ecology relationships form the basis of the methodology, rather than a presumed or inferred relationship between flow and some other stream attribute such as wetted perimeter. The procedures for developing the flow-ecology relationships should be clearly described, including estimates of uncertainty. Estimates of risk, damage, or vulnerability of the ecosystem or appropriate ecological indicator (fish species, guilds, etc.) from changes in the flow regime should be documented, along with the scientific peer-review process.

7.2.6 Use a Stakeholder Driven Process to Refine Flow Thresholds for Designated Stream Uses

Fish and wildlife flows represent one desired or designated stream use, but there are other stream uses that also require protection. If fish and wildlife flows estimated by the new or refined method become the most protective flow category, the proposed method should also describe the stakeholder process that was used to achieve societally acceptable flow thresholds for withdrawal and allocation among these stakeholders.

7.2.7 Monitor and Periodically Assess the Adequacy of the Method in Protecting Fish and Wildlife

Stream ecosystems continue to change over time so it is critical that additional information on flow/ecology relationships continue to be collected over time and periodically used to assess the flow/ecology relationships and associated thresholds that were developed and adopted. If the relationships change over time, the method needs to be refined to accommodate these changing relationships.

7.3 Proposed Framework

This framework is offered as a guide in providing needed information to support the adoption of any new or refined method for estimating fish and wildlife flows consistent with the existing method(s) used in implementing the AWP.

Section 8
Conclusions

The vision statement for the AWP Update recognizes that water is vital to the prosperity and health of Arkansas's people and their natural surroundings. As such, water must be managed in a sustainable manner to support local and state economies, protect public health and natural resources, and enhance the quality of life of all citizens by applying appropriate policies and best practices with limited regulation and preservation of private property rights. This report demonstrates that water in Arkansas is not necessarily available where and when it is needed. This scarcity of water, spatially and temporally, will likely require managing water resources between competing uses to maintain the long-term sustainability of the resource. Arkansas water resource management will have to consider the three major conclusions can be drawn from the information provided in this report. These conclusions are broad and individual exceptions to them are present anywhere. However, they are presented here as an overall context in which to begin the analysis of gaps and development of issues and recommendations that are the ultimate purpose of the 2014 AWP.

8.1 Conclusion 1

There is an abundance of water available on an average annual basis in all of the surface water basins in the State of Arkansas. However, the demands for that water do not necessarily correlate to the times of year when that water is available in a stream. Maintaining sufficient water in the streams to meet all needs all of the time is a primary goal of the 2014 AWP.

8.2 Conclusion 2

The groundwater availability based on modeling results show that meeting the current and projected demands for groundwater in the Mississippi embayment in eastern Arkansas is not sustainable. The USGS modeling evaluations (Kresse et al. in review) came to a similar conclusion based on their modeling evaluations. Pumping at higher rates may persist for some time into the future by mining groundwater that is stored in pore space in the aquifer. Even with this mining approach to groundwater development, production rates decline rapidly as this storage is depleted. The sustainable pumping approach, where water level declines are managed by constraining pumping to maintain higher water levels in the aquifers, results in pumping rates that are approximately equal to recharge quantity entering the aquifers. The implications of the continued decline in achievable pumping rates and falling water levels have the potential for severe economic impacts. As water levels decline and pumping lifts increase, wells may need to be deepened and pumps replaced. The cost of pumping will also increase due to the increased lift.

8.3 Conclusion 3

Surface water and groundwater quality is not currently impacting the water supply use of water in Arkansas. However, human activities have a demonstrated impact on water quality as evidenced by the number of impaired stream segments and groundwater contamination from residential and industrial uses, which impact do impact other uses of water. Future impacts on all water uses are expected as the projected gaps in water availability are manifested. The ability to fill those gaps with alternate sources of water may be limited by the quality of that water. The economic impacts of treating water before it can be used could be severe. Improving the water quality by controlling the contribution of pollutants to surface and groundwater is the most effective approach to ensuring the goal of sufficient water supply for Arkansas can be met.

Section 9

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