Arkansas Groundwater Protection and Management Report for 2013

A Supplement to the Arkansas Water Plan

Ground-Water Protection Mission:

To manage and protect ground-water resources in Arkansas for human, environmental, and economic benefits.

January 2014

STATE OF ARKANSAS

ARKANSAS NATURAL RESOURCES COMMISSION
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LITTLE ROCK, ARKANSAS 72201

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Abstract

The Arkansas Groundwater Protection and Management Report (AGWPM) is produced annually by the Arkansas Natural Resources Commission (ANRC) pursuant to the Arkansas Water Plan. The 2013 AGWPM report has been produced as a coordinated effort with the update of the Arkansas Water Plan. Therefore, the report includes current groundwater-level and water-use reports, as well as sections on Arkansas groundwater policy history and development. This reports data covers water level data from the spring of 2012 to the spring of 2013. The general trend in Arkansas' long-term water level change is that the groundwater levels are declining in response to continued withdrawals at a rate which is not sustainable. The continued unsustainable pumping rates have caused cones of depression in both the alluvial and Sparta/Memphis aquifers in the state. (fig. 4 and 5)

Arkansas Water Plan:

The Arkansas Groundwater Management and Protection Reports are produced annually by the Arkansas Natural Resources Commission (ANRC) pursuant to Act 154 of 1991, Arkansas Code section 15-22-901. This act was passed in response to the Arkansas Water Plan of 1990. The statute directed the ANRC to define critical groundwater areas, sustainable yield, and groundwater level trends within the state's aquifers. This report is an update to the Arkansas Water Plan, and provides hydrogeologic information needed for statewide water resources planning and management programs. As a result, three critical groundwater areas have been designated in Arkansas and resources have been focused on those areas through tax incentives, education programs, and priority ranking for federal conservation program funding such as the Environmental Quality Incentive Program, and the funding of large scale diversion projects for agricultural water supply.

In 2012, the Arkansas Natural Resources Commission (ANRC) began the process of updating the Arkansas Water Plan, which was last updated in 1990. The Plan will be completed by November of 2014.

During 2013 the ANRC performed several tasks including:

- An internal Water Management Division workgroup was formed to guide the Water Plan update process. Meetings were held approximately every other week.

- The ANRC formed a Water Plan committee which continued to be utilized as a part of the core planning tasks.
- The CDM Smith team, including subcontractors FTN and Associates, worked closely with ANRC to accomplish Water Plan tasks in accordance with the initial work plans and schedules.
- Tasks were completed such as the development of public stakeholder work groups, gathering of information on statewide water issues, available hydrogeologic data, and water resources modeling tools availability.
- Fact sheets were developed on current water resources programs as well as the Water Plan update process.
- A Water Plan web site has been created to provide general information, schedules and updates. Refer to http://www.arwaterplan.arkansas.gov.
- The US Geological Survey, Arkansas District, has worked closely with the ANRC Groundwater Section to produce a report to be titled Aquifers of Arkansas. This report has been drafted, and hydrogeologic data has been utilized in all phases of the Water Plan development.
- Over twenty (20) public hearings were held by CDM, FTN and ANRC in order to educate the public about the planning process and to get input on the Plan, as well as input on demand, availability, and some general input on gap analysis and water issues. Public meetings were held in key locations including – Arkadelphia, Batesville, Clinton, El Dorado, Fayetteville, Forrest City, Fort Smith, Harrison, Heber Springs, Jonesboro, Little Rock, Mount Ida, North Little Rock, Pine Bluff, Russellville, Searcy, Smackover, Stuttgart, and Texarkana.
- Technical committees were utilized for water demand and availability tasks, including the categories of public supply, industry, navigation, irrigation, fish and wildlife, recreation, and power generation.

Summary of Groundwater Availability, by Aquifer, in Arkansas

This summary provides a general, qualitative evaluation of Arkansas's aquifers based on water-quantity and quality. Specific information on hydrogeology, aquifer locations, stratigraphy, and geochemistry/water quality is found in the "Aquifers of Arkansas" report, and the 2013 Groundwater Protection and Management Report, along with references cited in those reports.

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.

Springfield Plateau aquifer - The Springfield Plateau aquifer (>30 gpm), 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.

Ouachita Mountain aquifer system - 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.

Arkansas River Valley alluvial aquifer - 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.

Trinity aquifer - The Trinity aquifer (100 – 200 gpm) is an excellent source of groundwater for domestic, poultry, and livestock wells of modest size in and near its outcrop area in southwestern Arkansas. Water-quality becomes restrictive down-gradient.

Tokio aquifer - The Tokio aquifer (150 – 300 gpm) is a reliable source of groundwater for public supply, industry, poultry and livestock, and other uses in and near its outcrop area in southwestern Arkansas. Water-quality becomes restrictive down-gradient due to salinity. Some water-level declines and the development of at least one cone-of-depression indicate that aquifer currently may be used at a rate that is near an optimal sustainable yield.

Ozan aquifer – The Ozan aquifer (< 10 gpm) is a minor aquifer in southwestern Arkansas that is no longer a reliable source of water to wells due to declines and poor water quality. Historically, the aquifer was of importance to domestic well owners in need of a shallow water supply. Future available supply is not adequate, and other sources should be pursued.

Nacatoch aquifer – 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.

Wilcox aquifer - The Wilcox aquifer (100 – 500 gpm) is a reliable source of groundwater for public supply, industrial, and other purposes primarily in northeastern Arkansas. The aquifer also provides limited amounts of water to wells in the outcrop and sub crop area of southern Arkansas. The water-quality of the aquifer generally if good, with well yields of over 500 gpm; however, water-level declines and the development of cones of depression indicate that the aquifer may be nearing maximum sustainable yield levels.

Carrizo aquifer - The Carrizo aquifer (50 – 150 gpm) is not a major source of groundwater in Arkansas, but does yield modest amounts of water to wells in southwestern Arkansas. However, this aquifer may be of future significance in Dallas, Grant, and eastern Saline counties where the transmissivity of the aquifer is much greater than in the outcrop area. Limited groundwater is available for future use from this aquifer.

Cane River aquifer - The Cane River aquifer (<50 gpm) of southern Arkansas is a limited source of water to small public supply and domestic users, and primarily functions as a confining unit with restricted availability for groundwater use. In northern Arkansas, the formation composes the middle sand layer of the Memphis Sand.

Sparta/Memphis aquifer - The Sparta/Memphis aquifer (500 – 1500 gpm), including the Cane River and Carrizo Sand formations, is a reliable groundwater source for current and future water use needs within sustainable water use volumes over most of eastern and southern Arkansas. Continued withdrawals above sustainable levels are not reliable, and availability is of uncertain duration. The sustainable use estimates of this report and previous ANRC/USGS reports should be relied on for all future groundwater policy decisions in Arkansas. Locally, water-quality constraints may restrict the use of this water or limit use altogether. High salinity concentrations severely limit the use of the aquifer in southeastern Arkansas. A lithofacies change occurs at about 35 degrees latitude, above which, the Cane River Formation has a large percentage of high permeability sand, and contributes to the overall thickness of the Memphis aquifer, locally called the 500 foot sand.

Cockfield aquifer - The Cockfield aquifer (100 – 350 gpm) is a reliable source of groundwater for current and future domestic, small public supply and industrial wells in southern Arkansas. Groundwater quality constraints, primarily chloride concentrations, greatly restrict the use of the aquifer in southeastern Arkansas.

Jackson Group confining unit - The Jackson Group, though not typically known to be an aquifer is a minor source of groundwater to small yielding wells. Poor groundwater quality also restricts use from these strata to shallow domestic well supply. It is not considered to be a reliable source for future water supply needs.

Mississippi River Valley alluvial aquifer - The Mississippi River valley alluvial aquifer (1,000 – 3,000 gpm) may be relied on for current and future water use needs within sustainable water use volumes over much of eastern Arkansas. Continued withdrawals above sustainable levels are not reliable, and availability is of uncertain duration. The sustainable use estimates of this report and previous ANRC/USGS reports should be relied on for all future groundwater policy decisions in Arkansas. Locally, water-quality constraints may restrict the use of this water or limit use altogether.

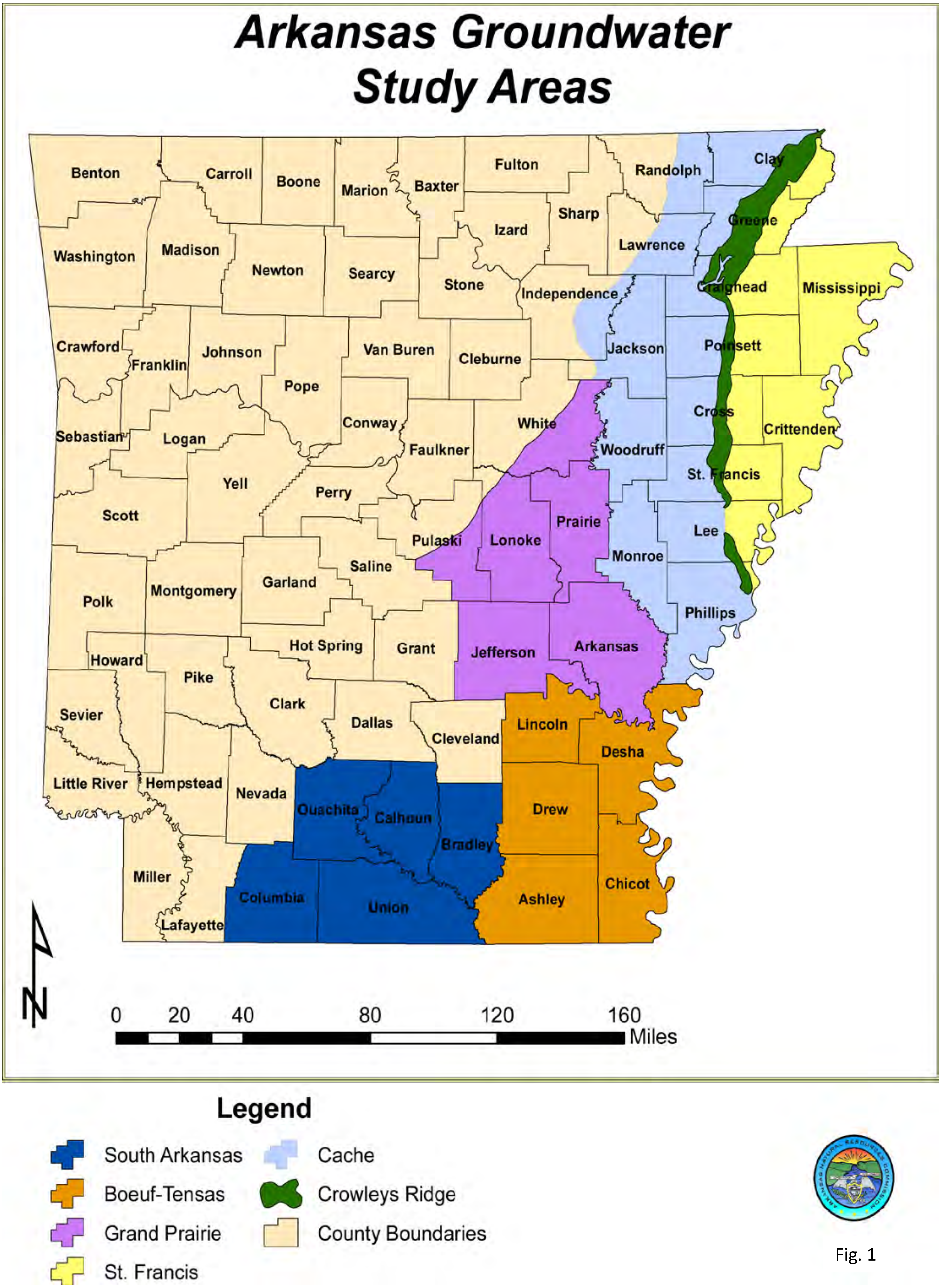

Arkansas Groundwater Study Areas
Benton
Carroll
Boone
Marion
Baxter
Fulton
Randolph
Clay
Washington
Madison
Newton
Searcy
Izard
Sharp
Lawrence
Greene
Stone
Independence
Craighead
Mississippi
Crawford
Franklin
Johnson
Pope
Van Buren
Cleburne
Jackson
Poinsett
Sebastian
Logan
Conway
Faulkner
White
Woodruff
Cross
Crittenden
Yell
Perry
St. Francis
Scott
Pulaski
Lonoke
Prairie
Lee
Monroe
Saline
Polk
Montgomery
Garland
Phillips
Howard
Hot Spring
Grant
Jefferson
Arkansas
Pike
Sevier
Clark
Dallas
Cleveland
Lincoln
Desha
Little River
Hempstead
Nevada
Ouachita
Calhoun
Drew
Bradley
Miller
Chicot
Columbia
Union
Ashley
Lafayette
N
0
20
40
80
120
160
Miles
Legend
South Arkansas
Boeuf-Tensas
Grand Prairie
St. Francis
Cache
Crowleys Ridge
County Boundaries

Fig. 1

Update on Alluvial Aquifer and Sparta/Memphis Aquifer, Spring 2013

Alluvial Aquifer

During the spring 2012 to Spring 2013 monitoring period the U.S. Geological Survey (USGS), Natural Resource Conservation Service (NRCS) and Arkansas Natural Resources Commission (ANRC) monitored static groundwater levels throughout the Mississippi River Alluvial aquifer. During this time 73.3% of the 307 wells monitored showed declines in water level. Over the 10-year monitoring period 79.7% of the 232 wells monitored showed declines in static water levels. The drawdown of the alluvial aquifer from spring 2012 to spring 2013 was calculated for the entire alluvial aquifer. It was an average change of -1.44 feet, which is historically less than the typical change observed during the irrigation season. There is approximately 2.00 feet recharge during the fall-winter months leaving a long-term historical drawdown of approximately 1.00 foot per year. Many counties in the delta that utilize alluvial aquifer water for irrigation of crops continue to withdraw an amount of water that is not sustainable. These counties can be seen on figure 9. Precipitation during 2012 was reported by the National Climatic Data Center as 39.95 inches which is typical. The average over the last 10 years is 50.23 inches which included one of the wettest periods in one hundred and thirteen years. Precipitation and average aquifer change can be seen on figure 2.

Sparta Aquifer

Data was also collected by ANRC and USGS in the Sparta/Memphis Aquifer during the 2012-2013 monitoring period. Of the 150 wells monitored 63 (42.0%) showed declines during this time. All the data collected on the Sparta/Memphis aquifer is also attached in appendix III. The Sparta/Memphis aquifer monitoring network was also calculated for the spring to spring change 2012-2013. The average change observed during this time was +0.95 feet. During the 10-year monitoring period (2003-2013) 82 of the 105 wells monitored (78.1%) showed declines, however the aquifer wide average change was +6.75 feet primarily due to the recovery of the Sparta Aquifer in the South Arkansas Study Area. Union County alone had an average change of +36.83 feet over the last 10-year period (fig.8). Continued monitoring of the Sparta Aquifer in the South Arkansas Study Area indicates that some groundwater levels in this area have stabilized or risen. This study area is comprised of Ouachita, Calhoun, Bradley, Columbia and Union counties, and was the first area to be designated as a Critical Groundwater Area in 1996. The diminishing declines in average change seem to indicate that the education, conservation, and development of excess surface water from the Ouachita River in Union county have made an impact of groundwater levels.

Figure 3 illustrates the general hydrogeologic budget of the primary aquifers of the Mississippi Embayment in eastern and southern Arkansas. The flow budget has been derived from the average withdrawals and recharges from 2000-2005, and indicates that withdrawals from wells is much greater than recharge from stream capture and precipitation at land surface. This is not a sustainable scenario and water level declines will continue to occur under these conditions.

Figure 2 shows both total yearly precipitation, as well as the overall alluvial aquifer change, in feet, for the specific monitoring period in the Spring of the respective year. It illustrates that under typical conditions, there is little change or even an increase in average water-levels following a year of generally higher precipitation.

The USGS Mississippi Embayment Regional Aquifer Study (MERAS) has developed and utilized a numerical groundwater flow model for the primary aquifers of the Mississippi Embayment. This model has been utilized as a part of the update of the Arkansas Water Plan as described in the USGS SIR 2013-5161. For the planning purposes of the Arkansas Water Plan, three scenarios were developed to evaluate potential future conditions: simulation of previously optimized pumping values within the Mississippi River Valley alluvial and the Sparta aquifers, simulated prolonged effects of pumping at average recent rates (2005), and simulation of drawdown constraints on most pumping wells. These scenarios indicate significant water-level declines in the future; however, much of these declines, especially those east of Crowley's Ridge, may occur after the 2050 study period of the current Water Plan update. These scenarios as well as their respective figures and maps can be found in appendix IV of this report *Enhancements to the Mississippi Embayment Regional Aquifer Study (MERAS) Groundwater-Flow Model and Simulations of Sustainable Water-Level Scenarios.*

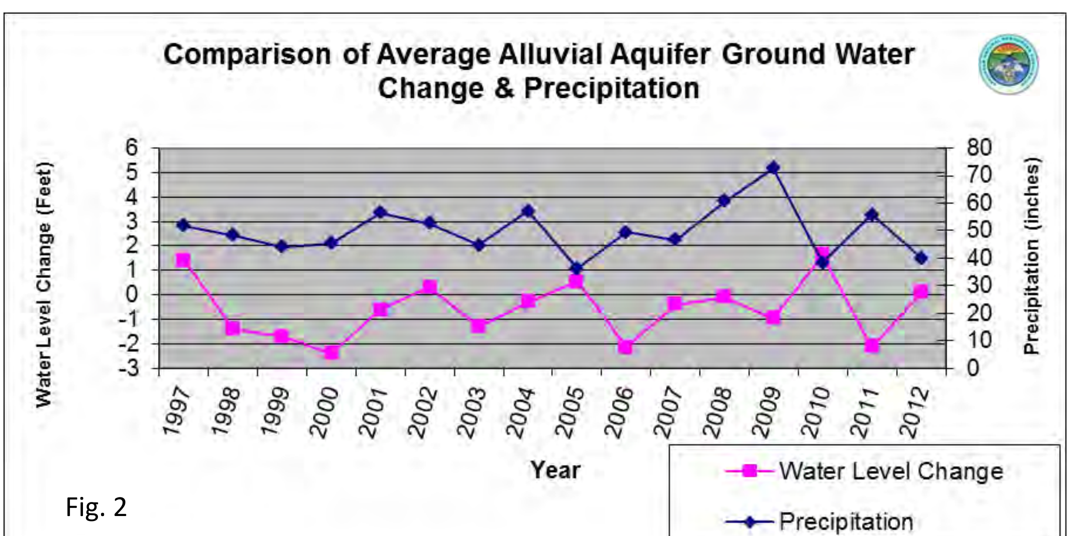


Fig. 2

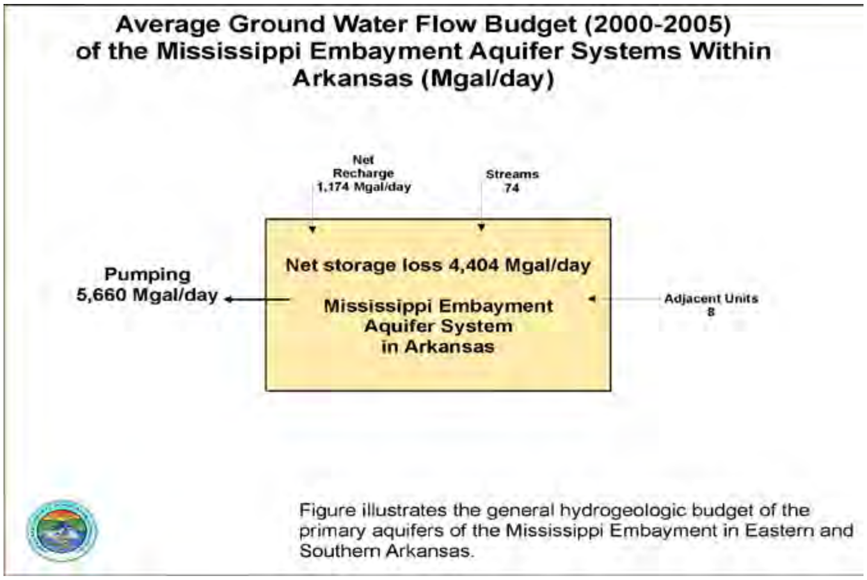


Fig. 3

The most recent water-use data available from the USGS is 2010, and is attached as appendix I to this report. In 2010 an estimated 7873.74 million gallons per day (Mgal/d) of water were reported to be withdrawn from the State's aquifers. The greatest reported volume is pumped from the alluvial aquifer and used primarily for irrigation. Poinsett County, Cross County, and Arkansas County used the most alluvial water of all counties, with 842.99 Mgal/d, 519.32 Mgal/d, and 504.90 Mgal/d respectively. The reported total ground-water use from the alluvial aquifer during 2010 was 7592.33 Mgal/d. The estimated total sustainable use for the alluvial aquifer is 3374.33 Mgal/d, which is only 44.4% of the reported 2010 use. The percentage of 2010 alluvial aquifer water use that is sustainable, per county, is seen in figure 9.

The Sparta/Memphis aquifer is the second largest aquifer in terms of withdrawals. The reported ground-water use from the Sparta/Memphis aquifer for 2010 was 191.78 Mgal/d, mostly used for municipal and industrial purposes. The Sparta/Memphis aquifer had a reported average withdrawal of 191.78 Mgal/d during the 2010 reporting period. It is important to note that mainly due to increases in the Sparta/Memphis aquifer for irrigation in the area, Arkansas County is now the largest user of this aquifer's resources, with a withdrawal of 58.29 Mgal/d. Jefferson County is the second largest user of Sparta/Memphis groundwater, with a withdrawal of 45.50 Mgal/d. The 2010 reported ground-water use from the Sparta/Memphis aquifer was an estimated 32.8% for agricultural uses, 43.2% for public supply use, and 22.8% for industrial uses, which combine with other uses for an estimated total use of 191.78 Mgal/d. The estimated sustainable use for the entire aquifer is 87 Mgal/d based on 1997 reported water use. This leaves a deficit of 104.8 Mgal/day, or 38.9% of the 1997 rate that is an unmet demand. (Holland, 2003, 2007, 2013)

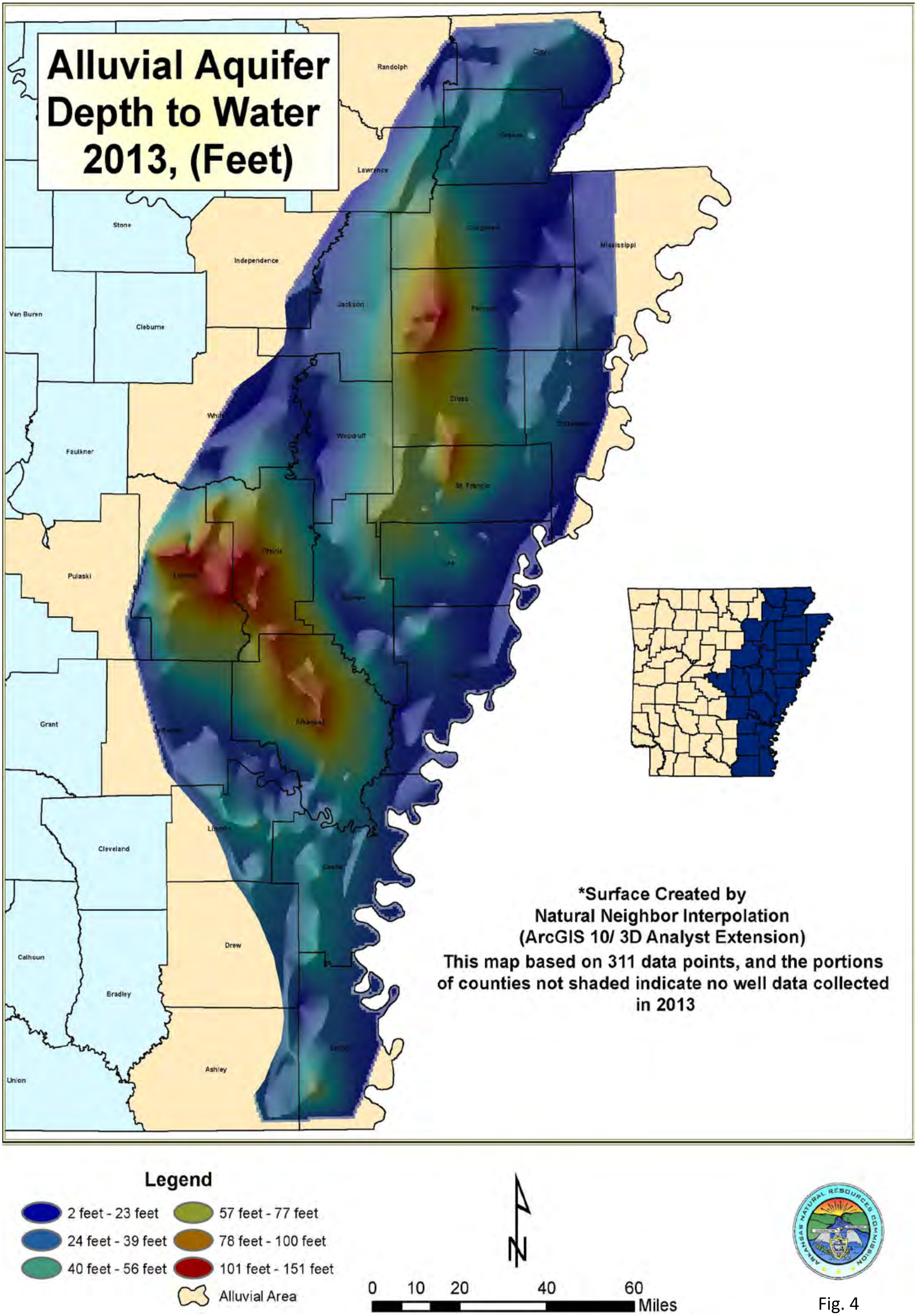
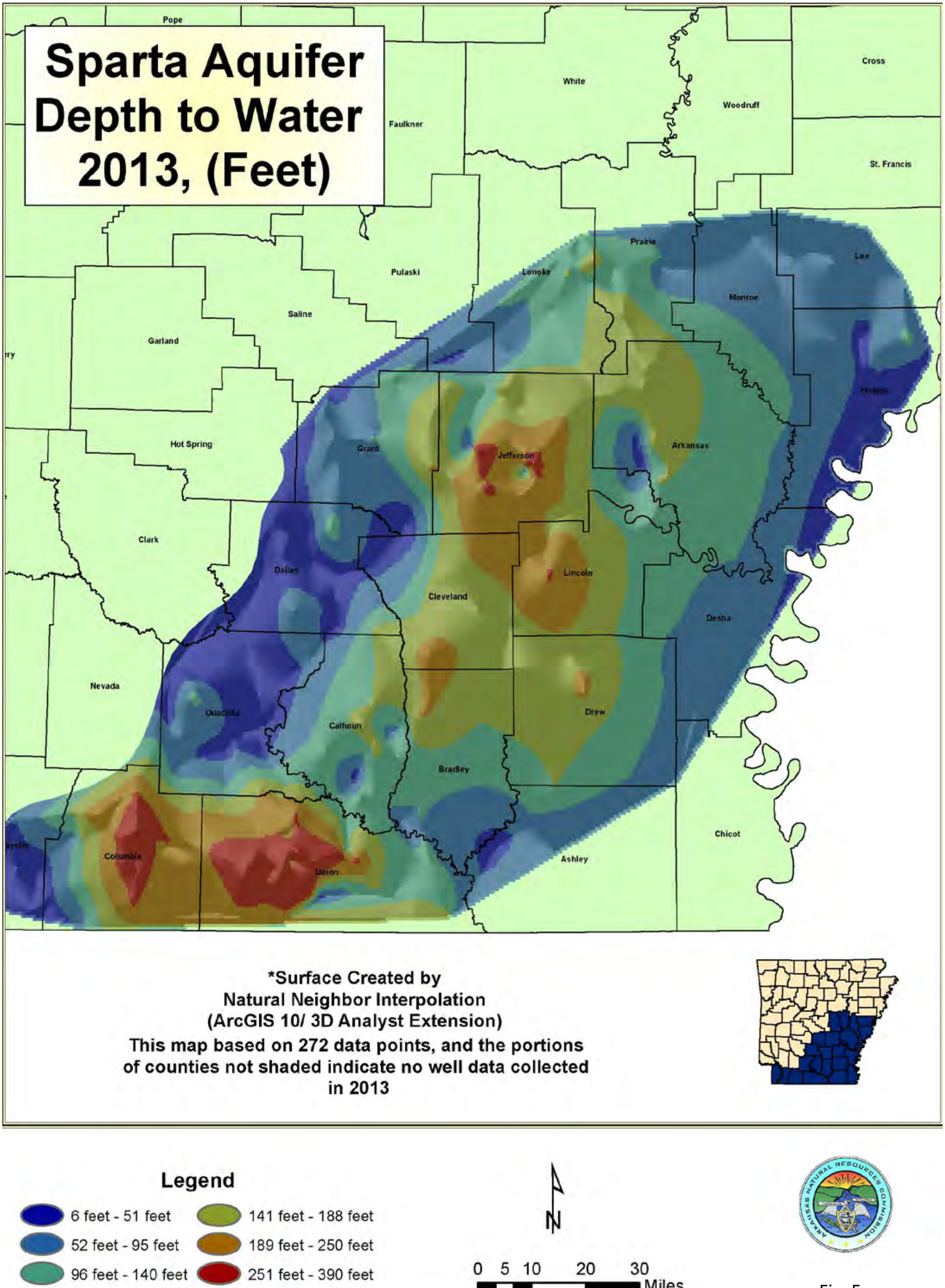

Alluvial Aquifer Depth to Water 2013, (Feet)
Randolph
Lawrence
Stone
Independence
Mississippi
Van Buren
Jackson
Cleburne
Faulkner
Woodruff
St. Francis
Pulaski
Grant
Arkansas
Cleveland
Drew
Calhoun
Bradley
Ashley
Union
*Surface Created by
Natural Neighbor Interpolation
(ArcGIS 10/ 3D Analyst Extension)
This map based on 311 data points, and the portions of counties not shaded indicate no well data collected in 2013
Legend
2 feet - 23 feet
24 feet - 39 feet
40 feet - 56 feet
57 feet - 77 feet
78 feet - 100 feet
101 feet - 151 feet
Alluvial Area
N
0 10 20 40 60
Miles

Fig. 4



Sparta Aquifer Depth to Water 2013, (Feet)
Pope
White
Cross
Woodruff
Faulkner
St. Francis
Prairie
Lonoke
Pulaski
Lee
Monroe
Saline
Garland
Phillips
Hot Spring
Grant
Jefferson
Arkansas
Clark
Dallas
Lincoln
Cleveland
Desha
Nevada
Ouachita
Calhoun
Drew
Bradley
Chicot
Columbia
Union
Ashley
*Surface Created by
Natural Neighbor Interpolation
(ArcGIS 10/ 3D Analyst Extension)
This map based on 272 data points, and the portions
of counties not shaded indicate no well data collected
in 2013
Legend
6 feet - 51 feet
52 feet - 95 feet
96 feet - 140 feet
141 feet - 188 feet
189 feet - 250 feet
251 feet - 390 feet
N
0 5 10 20 30
Miles

Fig. 5

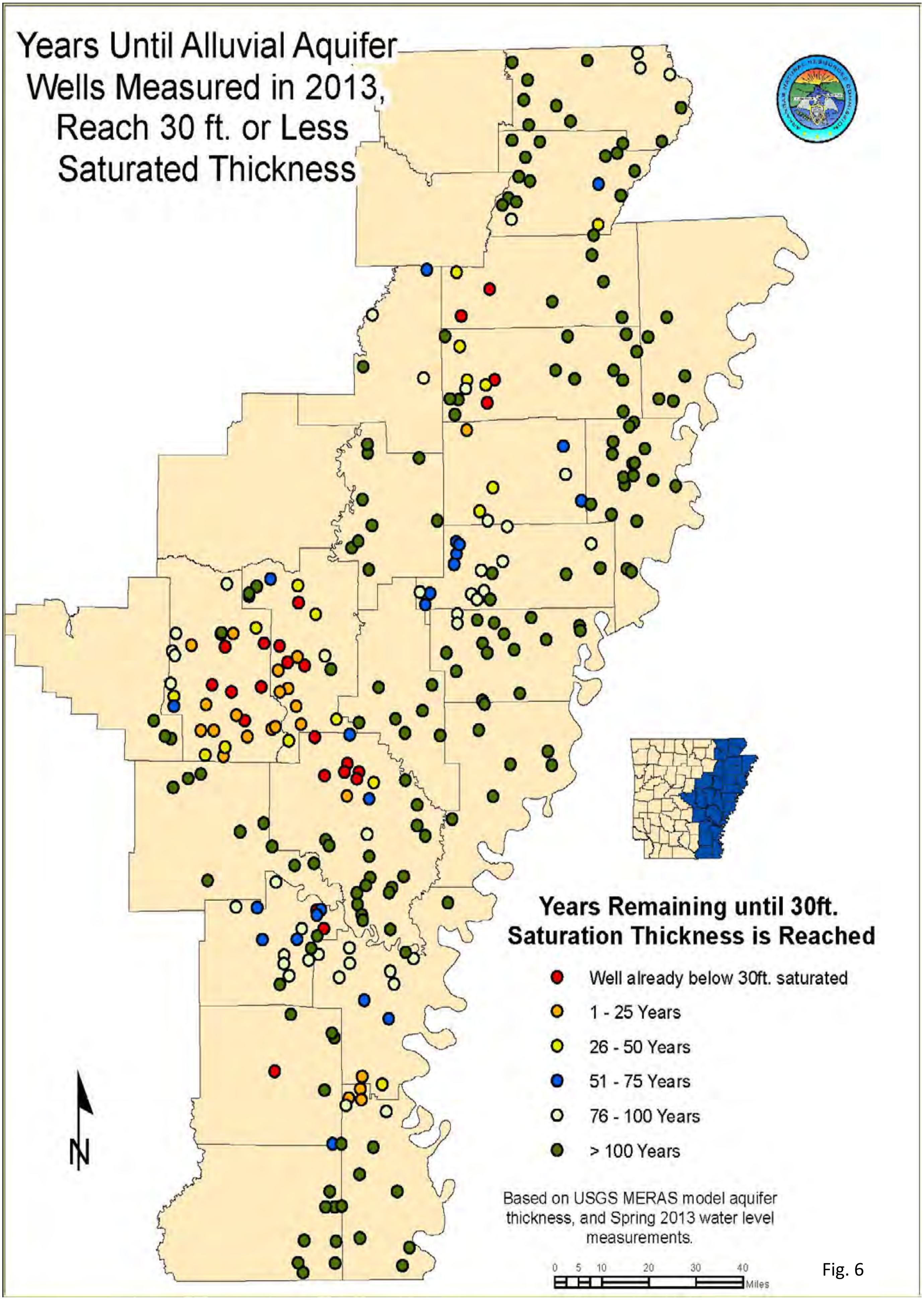
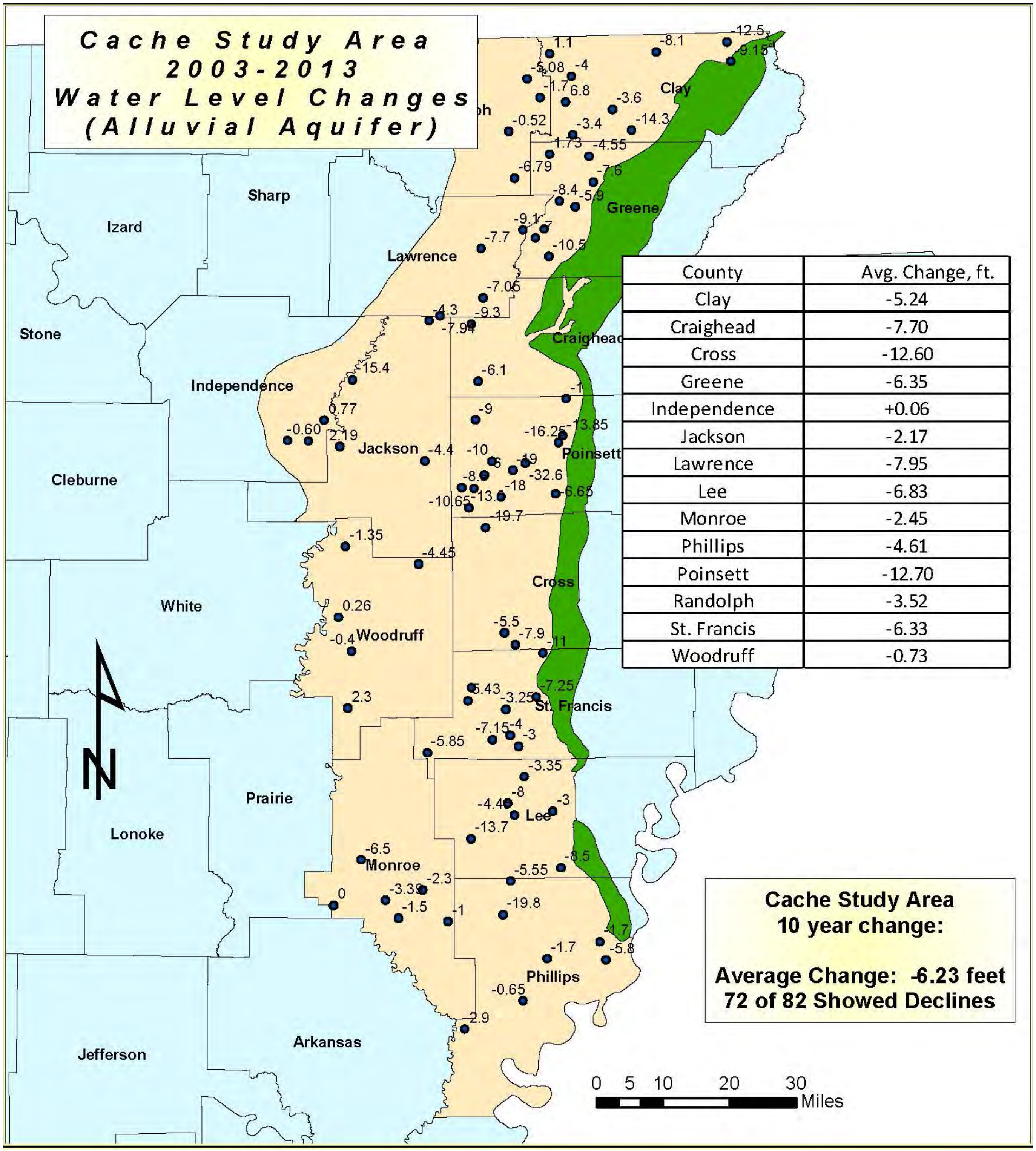

Years Until Alluvial Aquifer Wells Measured in 2013, Reach 30 ft. or Less Saturated Thickness
Years Remaining until 30ft. Saturation Thickness is Reached
Well already below 30ft. saturated
1 - 25 Years
26 - 50 Years
51 - 75 Years
76 - 100 Years
> 100 Years
Based on USGS MERAS model aquifer thickness, and Spring 2013 water level measurements.
0 5 10 20 30 40
Miles
N

Fig. 6

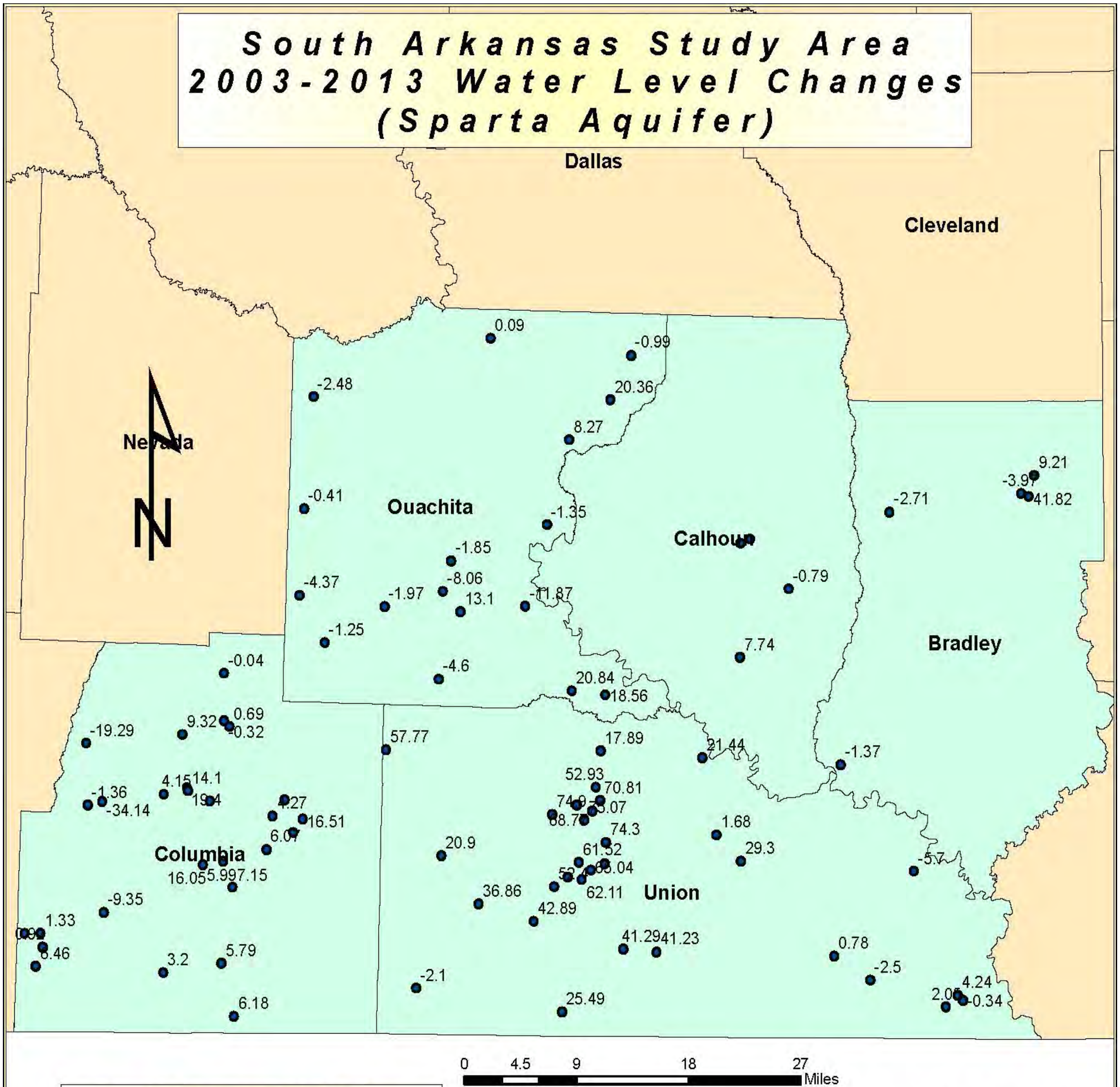


County	Avg. Change, ft.
Clay	-5.24
Craighead	-7.70
Cross	-12.60
Greene	-6.35
Independence	+0.06
Jackson	-2.17
Lawrence	-7.95
Lee	-6.83
Monroe	-2.45
Phillips	-4.61
Poinsett	-12.70
Randolph	-3.52
St. Francis	-6.33
Woodruff	-0.73

Legend

- Wells
- Crowleys Ridge
- Cache Study Area

Fig. 7



South Arkansas Study Area
10 Year Change:

Average Change: +15.84 feet
27 of 85 Wells Showed Declines

County	Avg. Change, ft
Bradley	+8.60
Calhoun	+0.50
Columbia	+3.64
Ouachita	+1.32
Union	+36.83

Legend

- Wells
- South Arkansas Study Area

Fig. 8

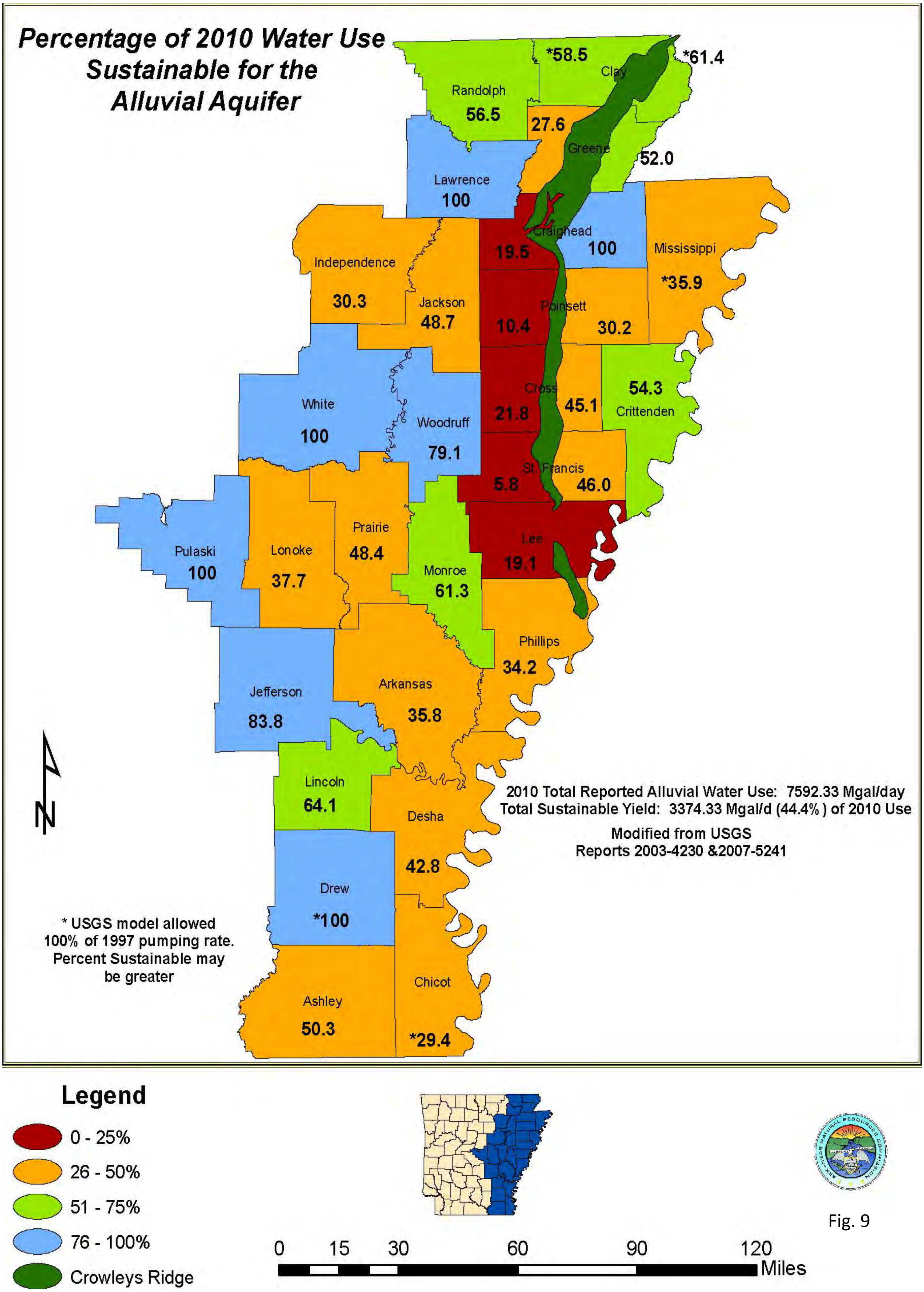

Percentage of 2010 Water Use
Sustainable for the
Alluvial Aquifer
Randolph
56.5
*58.5
Clay
*61.4
27.6
Greene
52.0
Lawrence
100
Craighead
19.5
100
Mississippi
*35.9
Independence
30.3
Jackson
48.7
Poinsett
10.4
30.2
White
100
Woodruff
79.1
Cross
21.8
45.1
54.3
Crittenden
St. Francis
5.8
46.0
Pulaski
100
Lonoke
37.7
Prairie
48.4
Monroe
61.3
Lee
19.1
Phillips
34.2
Jefferson
83.8
Arkansas
35.8
Lincoln
64.1
Desha
42.8
Drew
*100
Ashley
50.3
Chicot
*29.4
2010 Total Reported Alluvial Water Use: 7592.33 Mgal/day
Total Sustainable Yield: 3374.33 Mgal/d (44.4%) of 2010 Use
Modified from USGS
Reports 2003-4230 &2007-5241
* USGS model allowed
100% of 1997 pumping rate.
Percent Sustainable may
be greater
N
Legend
0 - 25%
26 - 50%
51 - 75%
76 - 100%
Crowleys Ridge
0 15 30 60 90 120
Miles

Fig. 9

The following section of the Arkansas Groundwater Protection and Management Report was produced during 2013 as a part of the update of the Arkansas Water Plan. This section provides valuable background information on groundwater quantity, quality, use, sustainability and the development of Arkansas water policy and law. This information has been utilized in planning activities including water demand, availability, and gap analysis.

ARKANSAS WATER RESOURCES CONSERVATION AND PROTECTION PROGRAMS AND POLICY DEVELOPMENT

(Contributions to the Arkansas Water Plan Report – Aquifers of Arkansas)

1. Geology, Hydrogeology, and the Fall Line of Arkansas
2. Groundwater Policy Development and Critical Groundwater Areas
3. Long-term Groundwater Trends
4. Historic Groundwater Use
5. Potable Groundwater Use in Arkansas
6. Water Rights Authority
7. Water Resources Statutory Authority
8. Institutional Framework
9. Sustainable Yield and Groundwater Flow Modeling
10. Groundwater Monitoring Programs
11. Artificial Recharge
12. Groundwater and Climate Change

Arkansas Natural Resources Commission, Mission Statement:

"To manage and protect our water and land resources for the health, safety, and economic benefit of the State of Arkansas."

Major Geologic Subdivisions and Hydrogeology of Arkansas

Arkansas is typically divided into two major geologic subdivisions. These are 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. These subdivisions are further divided into smaller geophysical units based on geologic characteristics such as topography, petrology, and stratigraphy. Formations of Arkansas range in stratigraphic order from the earliest deposited layers of the Cambrian Period to the Quaternary alluvium. The only recognized Cambrian formation in Arkansas is the Collier Shale located in a valley in Montgomery County between the watersheds of the Ouachita and the Little Missouri Rivers. The Quaternary alluvial and terrace deposits are located across much of the Mississippi River Valley alluvial plain of eastern Arkansas.

The major geophysical subdivisions of Arkansas are separated by the "fall line" which generally is defined in geologic terms as the contact of the consolidated Paleozoic formations with the unconsolidated formations of the Cretaceous, Tertiary, and Quaternary Systems.

The outline below shows the relationship of the major geophysical regions of Arkansas.

- Interior Highlands Division
  - Ozark Plateau Province
    - Salem Plateau
    - Springfield Plateau
    - Boston Mountains
  - Ouachita Mountain Province
    - Arkansas Valley
    - Fourche Mountains
    - Central Ouachita Mountains
    - Athens Plateau
- Gulf Coastal Plain Province
  - West Gulf Coastal Plain
  - Mississippi Embayment

Interior Highlands – Ozark Plateau Province

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, dolostone, sandstone, shale, chert, novaculite and some shallow alluvial deposits along the Arkansas River and other streams. The surface rocks of the Salem Plateau are the oldest of the Ozark Mountains, younger ones having been removed by erosion. They are predominantly dolomite and limestone with some sandstone and shale. The Cotter dolomite of Lower Ordovician age, a massive formation 500 feet thick, covers most of the eastern and northern portions of this region. The Everton Limestone is the prominent formation in the western and southern areas. The Calico Rock Sandstone, a white colored sand, is at the base of the Everton. Dolomite and silica-rich sand are quarried. The former zinc-producing area of Arkansas is centered in the Ordovician rocks of Marion County but zinc was mined in numerous other areas where the same strata were exposed by stream cutting. Some lead is associated with the zinc deposits.

The Ozark Plateaus cover northern Arkansas and extend into eastern Oklahoma and to the Missouri River to the north. They consist of consolidated sedimentary rock which has undergone massive uplift and which remains relatively horizontal with only minor deformations. Stream erosion has removed much of the original surface rock and has dissected the area into hills and low mountains although some plains occur.

The Salem Plateau is mainly north and east of the White River in Arkansas. Elevations are generally 500 to 1,000 feet above sea level. Streams are gradually dissecting the broad uplands and the area is undulating to hilly, relief seldom exceeding 200 feet. The Springfield Plateau is found in northwestern Arkansas and in a narrow belt eastward. Elevations generally are from 1,000 to 1,500 feet. Extensive relatively level areas exist in Washington and Benton counties but relief of 200 to 300 feet occurs along major streams. Outliers of the Boston Mountains appear as isolated low mountains on the Plateau, the most notable being the Boat Mountain group near Harrison.

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

The Springfield Plateau is the surface feature of northwestern and north-central Arkansas. It is commonly recognized at land surface as the Boone Formation, consisting of limestone and chert. Weathering more easily reduces the limestone, leaving large pieces of chert which are especially prominent on hillsides where the finer materials have been eroded away. The limestone is quarried in many localities. The St. Joe marble member is at the base of the Boone and is locally quarried for commercial purposes. The St. Joe Member is also the source rock for the majority of springs flowing in the Springfield Plateau. Outliers of the Boston Mountains are especially common in the western part of the region. They consist largely of sandstone and shale found in the Boston Mountains but lack the Atoka formation which caps the mountains.

The Boston Mountains and the eastern part of the Arkansas Valley are surfaced primarily in sandstone and shale. The massive Atoka Formation, over 1,500 feet thick, is the most prominent. The Atoka sandstone forms the bluffs at the top of the Boston Mountains.

Interior Highlands – Arkansas River Valley

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

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

The Arkansas River Valley is bordered on the north and south by consolidated formations of the Ouachita Mountains. These formations yield small quantities of groundwater to wells and are susceptible to seasonal and weather variations in precipitation. Drilling records from water well construction reports indicate a trend of well depths in the range of 150 to 250 feet, with the highest yields being found along the flanks of anticlines, synclinal valleys (AWWCC records, 1969 – 2012). Well yields of up to 35 gallons per minute can be developed where there is significant fracturing and bedding plane intersection. The best source of groundwater, with respect to quantity, is the Arkansas River Valley alluvium which commonly yields 300 to 700 gallons per minute to wells of 100 feet in depth. (Bedinger and others, 1963) The alluvium consists of clay, sand and gravel ranging in thickness from 60 feet in the western portion of the

State, to slightly over 100 feet where the valley opens into the Mississippi Embayment near Little Rock.

Interior Highlands – Ouachita Mountains

The Ouachita Mountains are also of sedimentary rock but here it has been folded to create generally parallel ridges and valleys which have an east-west orientation. Most of the mountain ridges are narrow, with steep slopes; crests tend to be sharp; valleys are generally rather broad. Within the Ouachita Mountains, the sections are distinguished largely by the spacing of the folds.

Fourche Mountains contain several major ridges. The crest of Rich Mountain is 2,500 feet, while Fourche and Poteau mountains are little lower. The folding is closer than in the Arkansas Valley, but valley floors are broad and often of considerable elevation, around Mena reaching 1,100 feet at the center.

The Central Ouachitas are very closely folded. Some principal mountains are the Caddo, Cossatot, Trap, Crystal, and Zigzag. Elevations of 2,000 feet are common toward the center and the west and local relief is between 300 and 900 feet.

The Athens Plateau is a very narrow belt extending along the southern edge of the Ouachita. Elevation is little above 500 feet and it has an undulating appearance. Occasional hills are remnants of an older surface.

The Fourche Mountains and the Athens Plateau of the Ouachitas are dominant range geophysical features of western Arkansas. The Jackfork Sandstone is particularly important in the major mountain ridges. The Stanley Shale is the most widespread formation.

The Central Ouachitas are closely folded ridges and valleys of Ordovician and Silurian sandstone and shale. Two prominent formations are the Crystal Mountain sandstone which is overlain by the Mazarn shale. Arkansas novaculite is exposed along the outer edge of the Central Ouachitas, sometimes referred to as the Novaculite Uplift. The novaculite is Devonian in age and is situated below the Hot Springs sandstone. It is a very hard, fine-grained silica-rich rock, which has been broken by the folding of the Ouachita Mountains producing a large amount of secondary porosity that contains groundwater.

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

However, with respect to surface water supplies, the topography of the area is especially conducive to the development of lakes. Construction of dams in the narrow valleys produces reservoirs with large volumes of water storage, such as Beaver, Bull Shoals, Norfork, Ouachita, Greers Ferry, Hamilton, DeGray, Greeson, and others. In general, if a quantity of water over 35 gallons per minute is needed in the Ouachita Mountains, the potential user should develop surface water supplies.

Gulf Coastal Plain – West Gulf Coastal Plain

The Gulf Coastal Plain of eastern and southern Arkansas generally consists of unconsolidated sands, clays, marls, and gravels. Lignite is also located within the strata of these regions. The Gulf Coastal Plain is most commonly divided into the Western Gulf Coastal Plain and the Mississippi Embayment of eastern and southern Arkansas.

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

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

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

Gulf Coastal Plain – Mississippi Embayment

The Mississippi Embayment of eastern Arkansas is a geosyncline, a trough filled by fluvial (stream) sediments of great depth. The surface is generally flat, with local relief of less than 100 feet. 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.

The recent alluvium has been deposited by flood waters of the streams and consists of a variety of water-washed material, especially clay, silt, sand, and gravel. The terrace deposits are frequently older, often Pleistocene, representing former levels of bottomland below which streams have now cut.

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

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

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

Plain include the Nacatoch, Wilcox, Sparta/Memphis, Cockfield, and Mississippi River Valley alluvial aquifers.

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

Groundwater 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. (Bedinger and Jeffrey, 1964) "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. (USGS, 1968) These early observations of stream capture were realized before the construction of the lock and dam system on the Arkansas River.

Purely by coincidence, the McClellan Kerr Navigation System on the Arkansas River has functioned for years as one of the most efficient all-time artificial recharge projects in the world. Water-level change data in the form of tables, maps, and hydrographs all indicate that the Grand Prairie water supply has been augmented by the development of the navigation pools on the Arkansas River. The contrast between river stage elevation and the potentiometric surface of the groundwater system creates a hydraulic gradient in which water flows from the river to the alluvial aquifer. The water moves into the aquifer through riverbank storage and floodplain percolation, then flow down-gradient toward the center of the cone of depression in the Grand Prairie near Stuttgart and DeWitt.

Another observed case of stream capture is in the alluvial aquifer along the Cache River west of Crowley's Ridge. As early as 1981, digital-model analysis indicated that 430,000 acre-feet per year of water was being removed from the Cache River basin into the alluvium as a direct result of agricultural pumping. (Broom and Lyford, 1981)

In 2003, the USGS groundwater flow model reported data was evaluated to determine the volume of White River flow being diverted/intercepted by irrigation wells in the Mississippi River Valley alluvial plain. 20,231,644 cubic feet per day is the volume of river flow that is indirectly withdrawn from the White River due to stream capture and reduced base flow to the river from the aquifer. (ANRC file data, 2003)

Wetlands may best be understood to be a natural expression of a high water table, often in an area where the surface material is of low permeability. The role of wetlands as a source of groundwater recharge is minor compared to other factors in the overall water budget. In one wetland study in the Cache River Basin, groundwater flow was a minor component of the water budget, accounting for less than one percent of both inflow and outflow. (Gonthier and Kleiss, 1996)

The Fall Line

One of the most significant geophysical features found in Arkansas is commonly referred to as the "fall line". "This line is one of the most strongly marked physiographic and cultural lines on the surface of the globe." (McGee, American Journal of Science, 1888) This line (Figure 11) generally runs from near Pocahontas in northeastern Arkansas through the center of the State at Little Rock, then southwest to just north of De Queen on the Oklahoma border. The line represents a very important geological, topographical and hydrological transition within our State, and has impacted every aspect of it including the development of cities, roads, railroads, power generation, agriculture, and even our cultural development.

The fall line has been defined in many different ways for many years. It is most typically observed as a line on a map of Arkansas which separates the consolidated formations of the Interior Highlands from the typically unconsolidated formations of the Gulf Coastal Plain and the Mississippi River Valley alluvial plain. Perhaps the best

and earliest documented definition is – the **"fall line of rivers"**, which is the demarcation between the Piedmont Plateau (Interior Highlands) and the Coastal Plain (McGee, 1888). It seems to be most easily defined as the upper limit of navigation, and the lower limit of water power. Keep in mind that when originally discussed, the navigation referred to was steamboats, and the water power was not hydroelectric plants, but rather was referring to saw mills and grist mills powered by large water wheels. An interesting description has been provided by Mr. Gilbert Thompson, with the Philosophical Society of Washington, April 24, 1886. It reads as follows:
"If we follow the course of any river in the eastern part of the United States, south of New England, from its source to the sea, we discover that at a certain point is ceases to be rapid and turbulent, and becomes broad and slow moving, and in many cases an estuary of the sea. At this point where this change occurs there is usually a fall or rapid. The familiar local example is the Potomac at Little Falls. I have traced this fall line from near Troy, N.Y., southward by the interior cities of Washington, Richmond, Columbia and Montgomery, and thence to the Muscle Shoals of the Tennessee River. It is always the lower limit of water power and often the upper limit of navigation, and is therefore marked, and destined to be marked, by cities and towns of importance."

Mr. Thompson, comments further on the nature of the fall line in the southern U.S. that - "This line becomes less distinguishable southward, so that instead of a constant fall line there are many rapids extending over a long distance of the river's course." (Thompson, 1888)

Some geologists define the fall line based on stratigraphy and petrology. In this case, the fall line is defined as the eastern most outcrop of consolidated Paleozoic formation. In northeastern Arkansas, the fall line can be described in terms of stratigraphy and lithology as the contact of the Ordovician limestone, dolostone, and chert with the sand and clay of the Mississippi Embayment. Further to the southwest, the contact of the Bloyd shale and the alternating flysh deposits, of sand and shale of the Atoka formation.

Though by purest definition the fall line is a hydrologic feature, the extent of consolidated formation does in fact directly influence the occurrence of the "fall line of rivers".

In Arkansas, from Arkadelphia to the Oklahoma state line, the fall line ceases altogether as a stable feature, and is replaced by a series of slight rapids that are obliterated in highest water (Branner, AGS, 1888). It should be noted that the alteration of hydrologic basins can change the fall line location and significance. For instance, the construction of the McClellan-Kerr Navigation System on the Arkansas River has significantly changed the prominence of the fall line in the Arkansas River Valley. The fall line was once in the vicinity of Little Rock as evidenced by the location of sites such as the historic "Old Mill" in North Little Rock. The development of navigational pools on the river has more or less created a series of artificial falls where the lock and dams are now located and at some of these, hydroelectric plants are in place. In this sense, Murray Lock and Dam (#7) could now be the most exact representation of the fall line. Another easily observed expression of the fall line is the series of rapids which occur just a few hundred yards northwest of Interstate 30 at Rockport, Arkansas.

At the fall line of rivers, the topography becomes less mountainous and more fitting for travel. Therefore, early Native Americans traveled along the fall line marking a trace later to be known as the Southwest Trail. In time this trail would be used by early travelers explorers like the Spanish explorer DeSoto. "Spanish diggings" are noted along the trail in Saline and Hot Springs Counties (Griswold, 1890), and some accounts state that DeSoto panned for gold near the strange rocks along the Little Missouri River near Murfreesboro. He seems to have had the right location, but looked for the wrong mineral. As history has since revealed, the igneous intrusion of kimberlite/lamproite in this area was found to produce diamonds of excellent quality. The first of these diamonds were found by John Huddleston in 1906. (Howard, 1989) In 1819, naturalist Thomas Nuttall noted the existence of a "great road to the southwest" which connected St. Louis to what is today Monroe, LA. (Nuttall, 1821) The trail also became a major travel corridor as part of the "Trail of Tears", and for Civil War soldiers along a portion known as the Old Military Road.

Groundwater Policy Development

"In wealth of natural resources, no kingdom of Europe can compare with the Mississippi Valley… It is politically and commercially more important than any other valley on the face of the globe." President Theodore Roosevelt, October 4, 1907, Memphis Tennessee.

Arkansans have long recognized the value of all its natural resources including its water resources. Water policy has developed around the strong desire to use, conserve, and protect these valuable water resources. The Arkansas Natural Resources Commission is the State's primary water resources planning and management agency. Its purpose is defined as follows:

The commission establishes policy that makes funding and regulatory decisions relative to soil conservation, nutrient management, water rights, dam safety and water resources planning and development.

The Arkansas General Assembly enacted the nation's first conservation district law in 1937. This law provided landowners with a mechanism for creating local political subdivisions of the State of Arkansas to conserve land and water resources.

The organization that became the Arkansas Natural Resources Commission resulted from the General Assembly's decision to abolish the Water Conservation Commission and the Water Compact Commission in 1963. This Act transferred all functions, powers, and duties of those commissions and the Arkansas Geological and Conservation Commission's authority with regard to soil conservation and flood control, to the Arkansas Soil and Water Conservation Commission.

In 1971, the General Assembly reorganized the Arkansas government and transferred the Commission to the Department of Commerce. However, the Department of Commerce was abolished in 1983, and the Soil and Water Conservation Commission became an independent agency, functioning in the same manner as it had prior to its transfer.

Because the Commission already had responsibility for other state water and sewer infrastructure loan and grant programs, the construction Assistance Revolving Loan Fund Program of the Arkansas Department of Environmental Quality was transferred to the Arkansas Soil and Water Conservation Commission in 2001.

In 2005, at another time when state re-organization of the executive branch seemed imminent, the Arkansas Soil and Water Conservation Commission remained the Arkansas Natural Resources Commission.

The Arkansas Natural Resources Commission is composed of nine members appointed by the Governor and confirmed by the Senate. The members serve staggered seven-year terms of office. Each of Arkansas's four congressional districts is represented by two commissioners with the ninth commissioner holding an at-large position.

The Executive Director is appointed by, serves at the will of, and reports to the Governor. Commission employees are divided into three major divisions, Conservation, Water Resources Development and Water Resources Management, which are assisted by the Legal and Fiscal Sections.

Arkansas water resources policy, and related programs, has developed largely in response to issues such as drought, overdraft, and flooding. With an average rainfall of approximately 50 inches per year, Arkansas is a water-rich state. However, many catastrophic water-resources events have occurred and water policy has emerged in response to these. Long-term unsustainable water use for industry, municipal water supply, and the agricultural economy of eastern Arkansas has also brought about water depletion issues. Water law, policy, and programs were developed accordingly, and a summary of this development is described here.

One of the first documented water resources reports was published in 1939 by the Arkansas State Planning Board. This report titled "Arkansas Water Resources" identified the social and economic importance of our State's water resources, and recognized the lack of basic hydrologic data. At this time there was only a minimal amount of data being gathered. The United States Geological Survey worked in cooperation with the Arkansas Geological Survey and the State Highway Department to collect stream gage data, while the State Board of Health collected some water-quality data. The report stated that – "Present data, in the hands of State governmental agencies, are entirely too meager to make possible the preparation of a complete plan, and this deficiency has been indicated at several places in this report." This report is one of the first documents to identify a groundwater depletion problem in the Grand Prairie, and to suggest a study of augmenting well water in the rice producing area with a diversion and importation of water. Also of great importance, the report called for the establishment of a permanent Water Resources Commission.

Arkansas water policy has evolved over the past few years in response to significant groundwater level declines observed in the eastern Arkansas alluvial plain and southern Arkansas Gulf Coastal Plain region. Water law has been developed by working closely with Arkansas water users and with a strong underlying desire to reach the necessary goals of a sustainable yield by voluntary, incentive based methods.

The most current version of the Arkansas Water Plan was developed in 1990, and advocates conservation, education, and the development of excess surface water as the primary means of groundwater protection in the State. However, it is also recognized that regulation should always be reserved as a last-resort for water-resources protection. In February of 1991, the Arkansas Ground Water Protection and Management Act was signed into law. This law provided the Arkansas Soil and Water Conservation Commission, the Arkansas Natural Resources Commission since 2005, with authority to designate critical groundwater areas. This law mandated that the Arkansas Soil and Water Conservation Commission (ASWCC) evaluate the condition of the State's aquifers on a biennial basis, and make recommendations concerning safe yield and the designation of critical ground water areas. The ASWCC works with the Arkansas District of the U.S. Geological Survey, the Natural Resource Conservation Service, and the Arkansas Geological Commission to monitor water levels and water quality in a network of over 1200 wells Statewide, in order to make this evaluation of the State's ground water resources.

Current state policy, as outlined by the 1975 and 1990 water plans, is to provide for the unmet demand through the practices of conservation, education, and the use of excess surface water. Arkansas utilizes approximately 3 percent of the surface water that flows through the State, and excess surface water has been calculated. To achieve a sustainable yield pumping rate from groundwater in Arkansas, excess surface water must be utilized. Without this surplus water, the only option identified by groundwater flow modeling (Czarnecki, 2008) is to voluntarily reduce, or restrict pumping from an estimated 25,000 of the 49,558 registered irrigation wells in eastern Arkansas.

The Arkansas Water Plan from 1990 has guided water policy toward conservation, education, and the use of excess surface water in a conjunctive use pumping strategy in an effort of achieving water use needs without adversely impacting in-stream flow or the sustainable yield of groundwater. It must be noted that the implementation of this policy, especially with respect to the use of excess surface water, has progressed quite slowly. Therefore, the withdrawal of groundwater remains at a rate that is not sustainable and water-levels continue to decline at a critical rate throughout much of the State. The success of Union County in using excess surface water is proof that this policy is extremely successful. However, this water use strategy has not yet been fully-implemented in Arkansas.

Historically, the Arkansas Soil and Water Conservation Commission (ASWCC) has been an advocate of voluntary conservation programs as a proper response to water resources depletion issues. At the February 18, 1999 meeting of the ASWCC, Commissioner Neal Anderson of Lonoke made a motion for a unanimous vote by the ANRC to "encourage continued voluntary conservation efforts pursuant to the Arkansas Water Plan and the Arkansas Ground Water Protection and Management Act, and opposes any efforts to enhance the regulatory powers available to it under the Ground Water Protection and Management Act". The motion passed as stated and was termed Resolution 99-2. In so doing, the ANRC established precedent of opposition against water use allocation, and indirectly, of support for the policy of development of excess surface water to meet water use needs. This action emphasized the ASWCC commitment made to individuals in the agricultural areas of the state, that it would not advocate water use regulation, but would continue to support conservation, education, and the use of excess surface water to reach our state's water resources goals.

As Arkansas water resources policy and law continue to develop, important issues must be considered. These issues will benefit Arkansas best, if they are framed with good science and knowledge of the complex hydrology of this State. Any effective water policy will continue to recognize and build on the process of the Arkansas Water Plan, relying on conservation, education, and the conjunctive use of groundwater and excess surface water, both within sustainable levels that protect all water users and water use needs. Future water policy in Arkansas must recognize that the State's aquifers are still being pumped at a rate that is above sustainable levels. Current groundwater use trends rely on stream capture late during the irrigation season when base flow to streams is extremely vulnerable with respect to in-stream flow needs. The current Arkansas Water Plan (1990) advocates the use of excess surface water, which would provide alternate agricultural water supply during the "wet season" when Arkansas has a great abundance of surface water flow through its stream channels and over its floodplains. During such periods of high-flow, surface water is available for capture and on-farm storage, therefore protecting the in-stream flow needs during the more-vulnerable times of the year.

In the absence of such alternative water supply, agricultural practices will have to adapt to reduced groundwater availability. In areas of the most significant groundwater decline, litigation between water users will occur. At some point in the future, there may be increased interest in a legislated solution, such as state issuance of permits for groundwater use.

Critical Groundwater Areas:

On February 20, 1991 the General Assembly of the State of Arkansas enacted the Arkansas Groundwater Protection and Management Act (Arkansas Code sec. 15-22-901 et seq.). This Act provided the Arkansas Soil and Water Conservation Commission (Commission) with additional groundwater protection and management authority to: designate critical groundwater use areas, establish the authority for withdrawals, establish ground water rights, set fees, and provide a mechanism for local ground water management. As a result of this action, the Commission began updating the Arkansas Water Plan on a yearly basis focusing on ground water protection concerns. This is accomplished through annual data collection and analysis from a statewide monitoring network of approximately 1200 wells. This information is presented in an annual report, and includes recommendations to the Commission concerning critical ground water areas.

Critical groundwater area criteria are evaluated by the Commission staff each year, to determine if water levels are declining or if water quality is becoming degraded. The specific criteria include; water levels declining at a rate of one foot per year or more, water levels have declined to below the top of the formation (below 50 percent saturated thickness for an unconfined aquifer), and water quality is becoming degraded. These criteria were selected by a group of geologists and hydrologists in Arkansas who had extensive background working with groundwater programs. Agencies represented included the Arkansas Natural Resources Commission, Arkansas Geological Survey, Arkansas Department of Environmental Quality, Arkansas Department of Health, and the US Geological Survey. Each criterion was selected based on observation of hydrologic trends in areas where cones of depression had developed, and a long-term history of water-level declines. Other factors considered are ground water flow model projections and the safe yield of the aquifer.

Once a critical area designation is recommended, the Commission conducts public hearings in accordance with the Administrative Procedure Act. These hearings are held in each critical area county, and where requested by interested parties. Comments are taken in oral or written form and evaluated by the staff. After consideration or these comments, the Commission decides on whether or not it is appropriate to designate the proposed area as critical. Once in place, the Commission is able to focus resources in the critical area and provide greater protection and management of the resource. Critical area designation is a positive step toward ground water protection which emphasizes prevention, and a coordinated effort focusing on conservation and education programs. Groundwater modeling efforts are enhanced, and additional monitoring is conducted.

Regulation is not automatic with critical area designation. This is a separate process requiring another round of analysis, reporting, and public hearings. The Commission has always hoped to protect our state's valuable ground-water resource through conservation programs, and the development of excess surface water to sustain future water use needs.

Since enactment of the Arkansas Ground Water Protection and Management Act, the ANRC has designated three critical ground water areas in Arkansas. The first critical ground water area was delineated in 1996, in a five county area in South Arkansas for the Sparta Sand formation. The second area was designated in 1998 for a six county area surrounding the Grand Prairie in East-Central Arkansas for the alluvial and Sparta Sand formations, and the latest critical area was designated in 2009 for the Cache area west of Crowley's Ridge for both the alluvial and Sparta/Memphis aquifers. The designation of a critical ground water area allows federal, State, and local groups to work together in providing a managed and protected resource for current and future water users by focusing on conservation and education. Critical area designation also allows State and federal agencies to focus cost share and tax incentives for conservation projects within those areas. Critical area designation does not involve regulation of water use or well drilling. It is a proactive action, which focuses on the prevention and mitigation of problems associated with ground-water level declines and groundwater quality degradation. The most effective tools, which the State is currently using, are education programs, conservation tax incentives, and the development of alternative surface water supplies and a conjunctive use strategy.

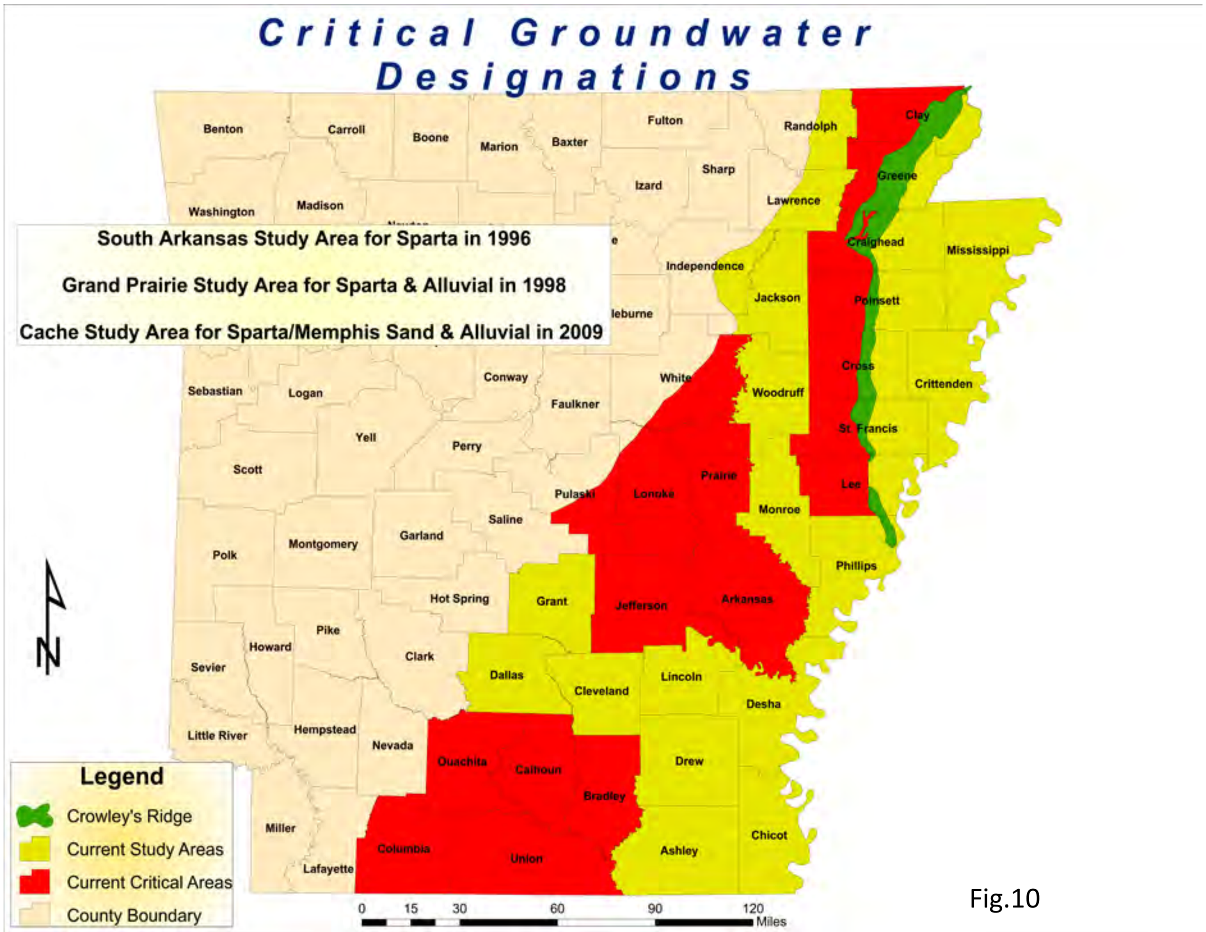


Fig.10

Long-term Groundwater-level Trends

Groundwater flow models have been used to determine the predevelopment-potentiometric surface of the Mississippi River Valley alluvial aquifer. Such model scenarios have shown that water levels in non-pumping wells generally were within 20 feet of land surface. (Broom and Lyford, 1981) Early records show significant withdrawals beginning around 1910, and drawdowns in the potentiometric occurred in response. As early as 1929, water-level declines were attributed to irrigation water use. (Engler, 1945)

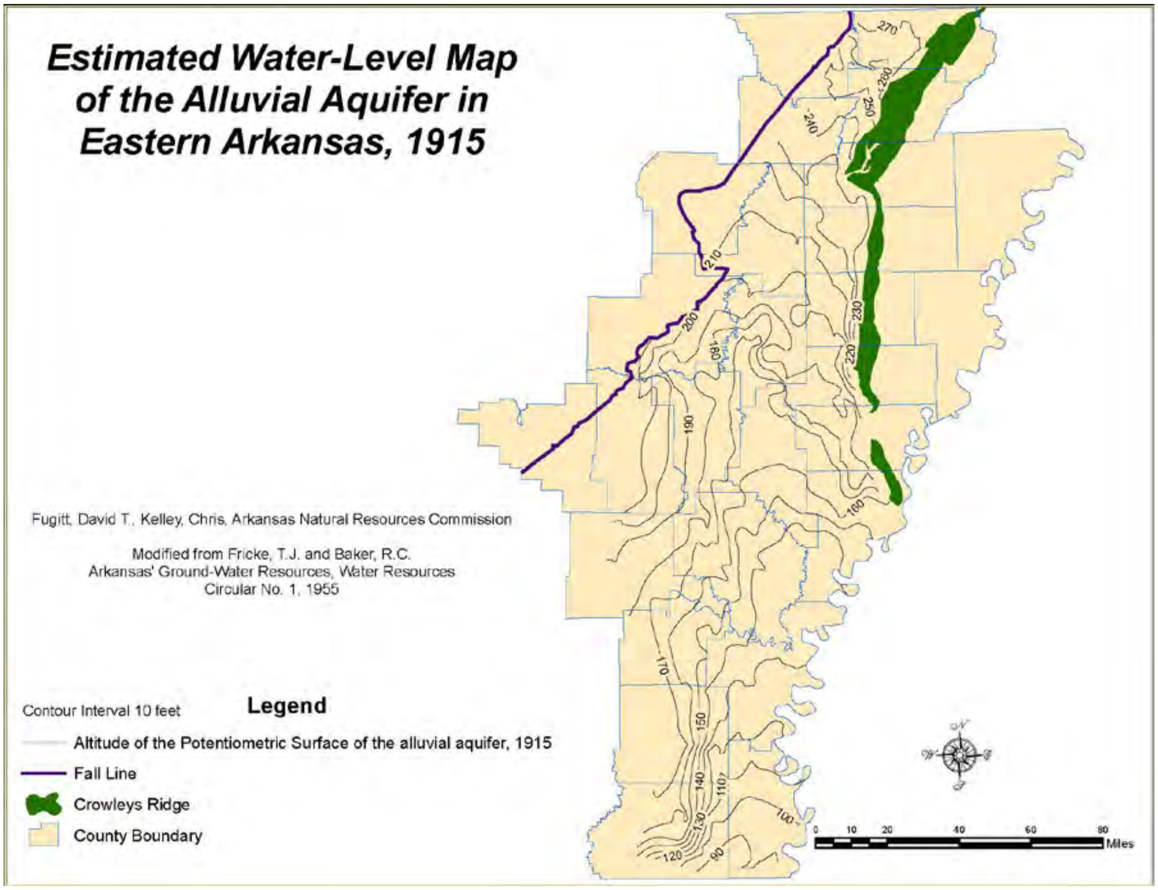


Fig. 11

Figure 12 is a water-level change map for the alluvial aquifer in the Grand Prairie area of eastern Arkansas. This map was produced from an unpublished potentiometric surface map of the alluvial aquifer in 1915, as compared to the 1953 surface for the same area. (Baker, 1955) Figure 15 is a water level change map for the alluvial aquifer from 1938 to 1953 in all of the Mississippi Embayment north of the Arkansas River.

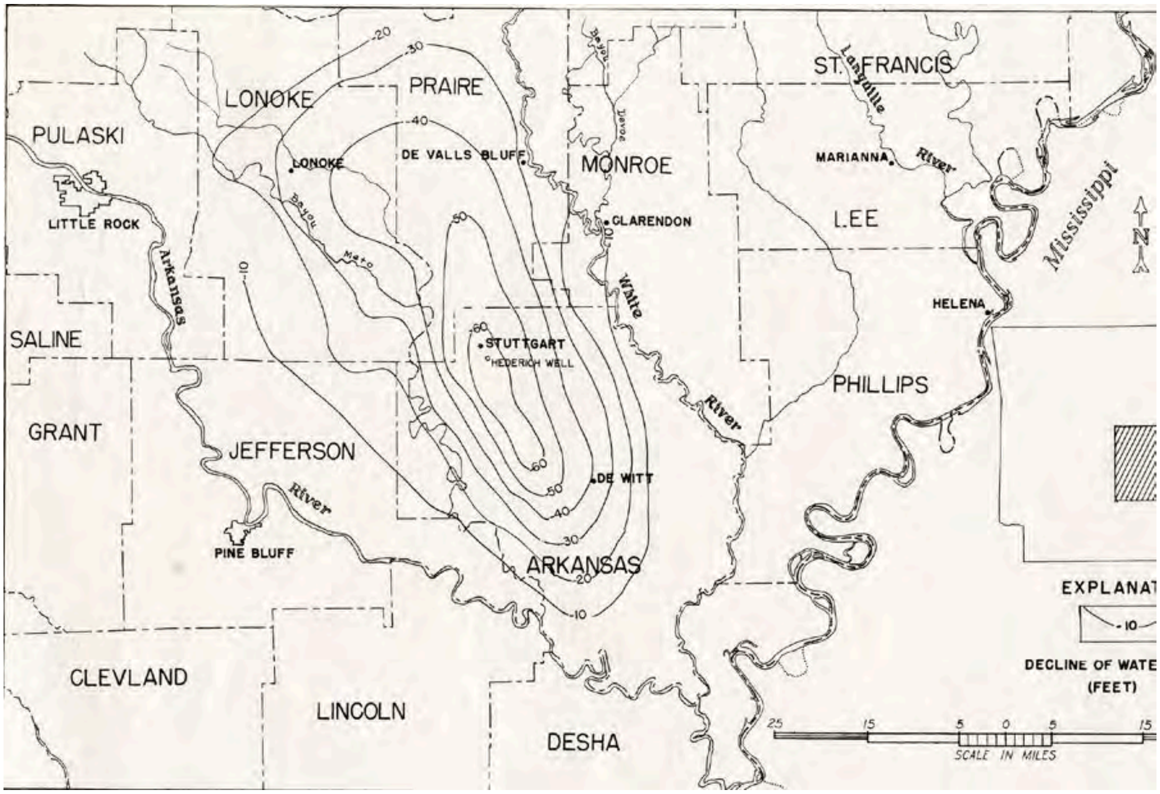


Fig. 12

An early source of documented groundwater level declines is from unpublished maps produced by T.J. Fricke, as referred to by R. C. Baker in the 1955 US Geological Survey Report "Arkansas' Ground-Water Resources." In this report, Fricke compares groundwater levels from 1953 to estimated levels from 1915. These observations indicated groundwater declines throughout much of the Grand Prairie, with some as much as 60 feet.

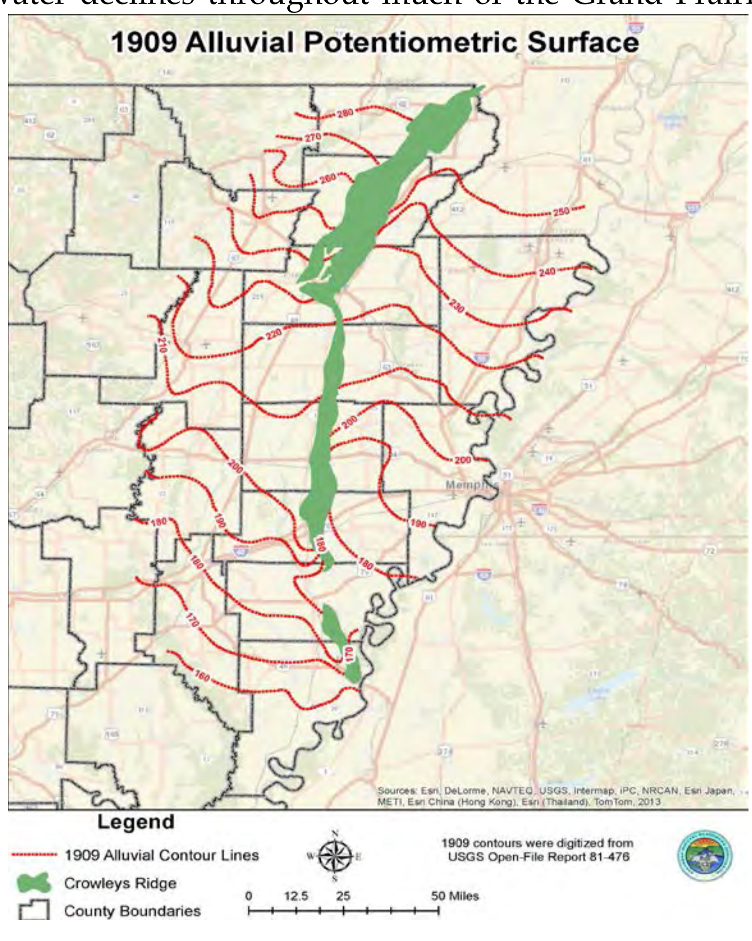


Fig. 13

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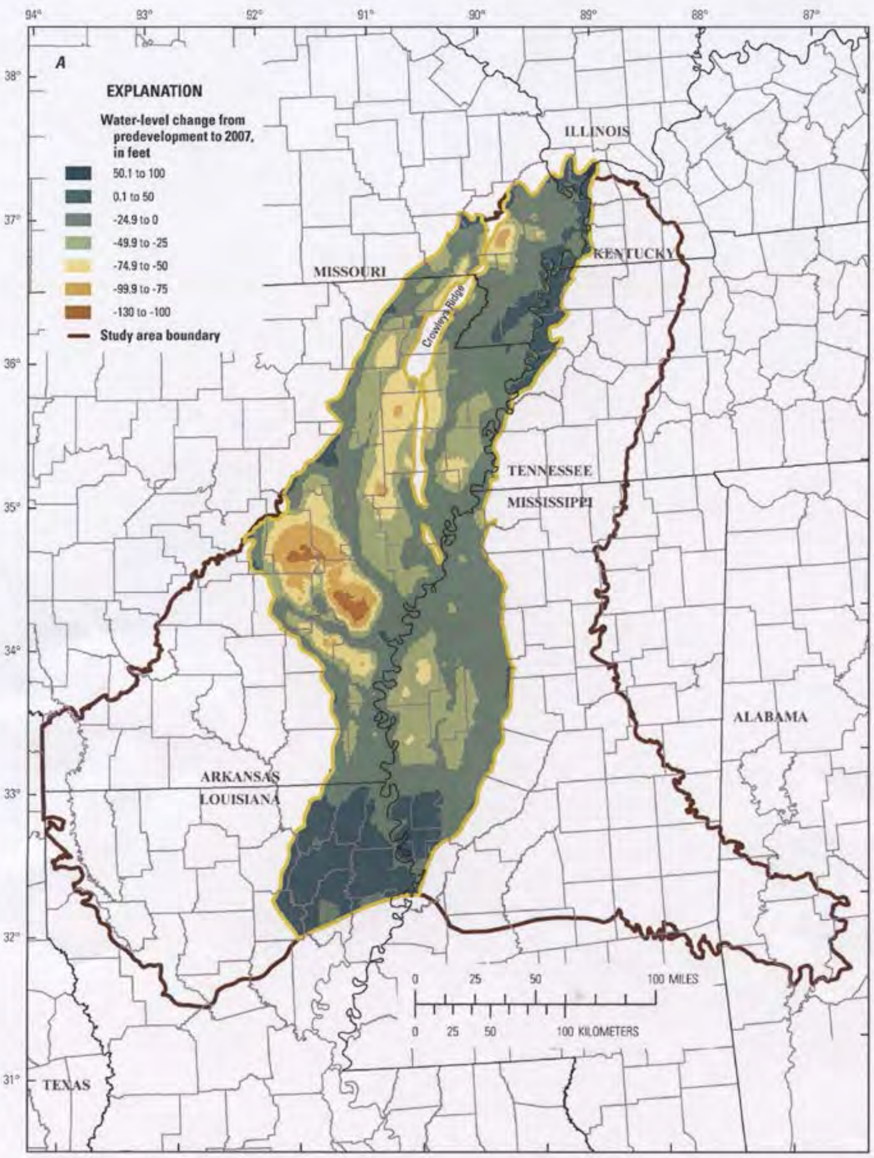

Base from U.S. Geological Survey digital data, 1:100,000

Figure 14. Water-level change from predevelopment to 2007 in the *A*, Mississippi River Valley alluvial aquifer and *B*, the middle Claiborne aquifer.

Fig. 14

As early as 1927, the US Geological Survey was approached by Arkansas Senator Caraway, with concerns that some farmers are saying - “well water levels had been going down more or less continuously” in the Grand Prairie. In 1929 and again in 1931, US Geological Survey, Senior Geologist David Thompson, released hydrogeologic reports including a “Memorandum for the Press”, a report on groundwater supplies for rice irrigation in the Grand Prairie. In these reports, Thompson stated that by 1929 water levels had been lowered over a large portion of the prairie, and a big depression in this water surface was observed in which "water was flowing in from all sides". This is the first description of the cone of depression that exists in the Grand Prairie until the present time. Mr. Thompson actually identifies that there were two initial cones of depression, one north of Stuttgart, and another a few miles to the southeast. Mr. Thompson goes on to say that "water was being pumped out here faster than it could flow in from the outer lying areas".

One indication of historically higher groundwater levels comes from the report "Arkansas Water Resources" published in 1939 by the Arkansas State Planning Board. This report indicates that there are 1,000 wells in the Grand Prairie "rice producing" are of eastern Arkansas, and that these wells are all in the range of 85 to 100 feet in depth and have very high yields. Water well construction reports from 2010 – 2012 indicate an average depth for this same area that is consistently over 110 feet, and often much deeper.

One of the first known potentiometric maps of the alluvial aquifer of eastern Arkansas was produced by H. B. Counts and Kyle Engler of the U.S. Geological Survey and the Arkansas Agricultural Experiment Station respectively (Figure 15). This water level map shows the existence of a cone of depression in the Grand Prairie area in 1939. The accompanying map for 1953 shows the cone of depression and how it has grown in the 14 year period. This figure shows the change in water levels in the alluvial aquifer over this period including a large area with declines of 20 feet or more. This report identifies that the major reason for these declines is withdrawal for rice production.

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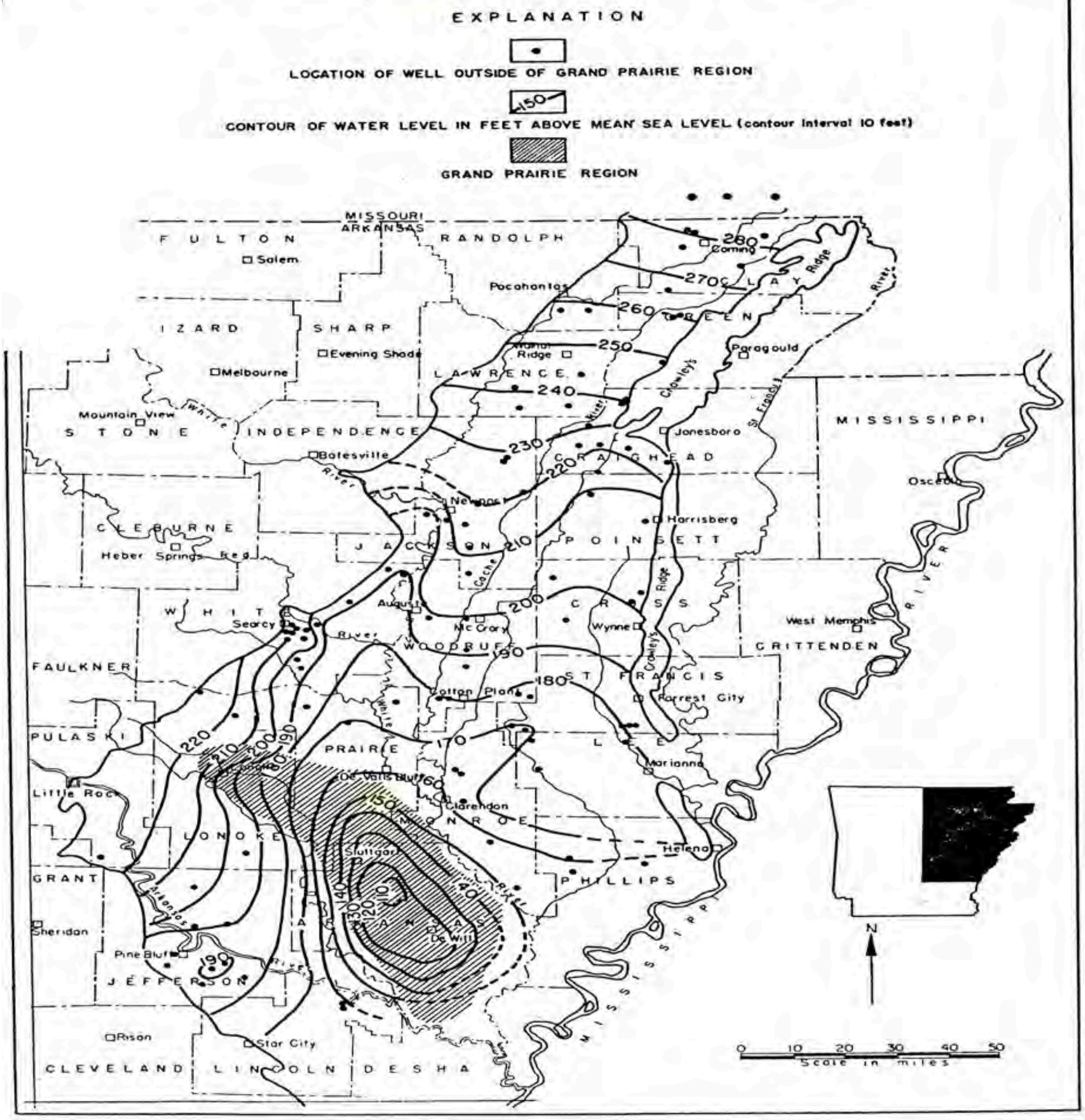


FIG. I. ALTITUDE OF WATER LEVELS IN DEPOSITS OF QUATERNARY AGE IN A PART OF EASTERN ARKANSAS IN 1938

Fig. 15

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. For the same approximate time period 157 hydrographs were produced for wells in the Sparta aquifer. The mean change for this 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.

In 2011, a US Geological Survey groundwater-flow model of the Mississippi embayment was used to evaluate changes in water-level altitudes in response to the addition of wells in the Bayou Meto – Grand Prairie area. This scenario was developed to evaluate the trend of developing deep water wells in the study area, as an alternative to the alluvial aquifer as an irrigation water supply. The increase in deep, Sparta wells, in the study area created a significant decrease in water-levels. Declines averaged from 40 to 50 feet in the Sparta aquifer, with a maximum of 102 feet in Lonoke County. These declines were shown to directly impact public supply wells in the area. (Clark, Westerman, and Fugitt, 2011)

Groundwater Use Trends

Arkansas groundwater use became important on a large-scale with the development of the rice industry of eastern Arkansas.

According to Thomas Nuttall (Nuttall, 1821), rice and other grains had already been grown in the vicinity of Arkansas Post by the time of his journey through the Mississippi River Valley alluvial plain of eastern Arkansas. According to Nuttall, "…rice has been tried on a small scale and found to answer every expectation. Under the influence of a climate mild as the South of Europe, and a soil equal to that of Kentucky, wealth will ere long flow, no doubt, to the banks of the Arkansa."

In 1896 W.H. Fuller observed a successful rice operation in southern Louisiana and was so impressed that he bought rice seeds and brought them back to the Carlisle area of eastern Arkansas and in 1897, planted 3 acres which he irrigated with two 4-inch wells. By 1904 Fuller had planted 70 acres of rice and proved once and for all that the conditions were right for its production. This was the beginning of rice-based economic development in the Grand Prairie of eastern Arkansas. In 1906 about 4,000 acres of rice were harvested in the area producing an average of 55 to 60 bushels per acre. The region's first mill, the Stuttgart Rice Mill, opened in October, 1907. (Gates, 2005)

By 1915 there was an estimated 135,000 acres of rice being produced in the Grand Prairie. By 1954 there were 450,000 acres. (Baker, USGS, 1955) Rapid growth was observed throughout all of eastern Arkansas and Stuttgart became known as the rice capitol of the world. By 2008, 6.5 million acres were being cultivated annually for crops in eastern Arkansas with an average of 1.3 to 1.6 million acres of irrigated rice (NASS, 2007).

According to the report "Arkansas Water Resources", by the Arkansas Planning Board, 1939, groundwater withdrawals in Arkansas in 1936 were about 321 million gallons per day (mgd). 301 million gallons per day were used for irrigation of rice. Most of the remaining groundwater use was used to provide drinking water for 304,989 individuals statewide. Total groundwater use had increased to 685 mgd by 1953 and continued to increase until the maximum withdrawal amount reached 7510 mgd in 2005. It should be noted that the estimated sustainable yield for the State's major aquifers was reached in the late 1970's.

By 1980 Arkansas groundwater use had exceeded its estimated sustainable yield from its two major aquifers, the Mississippi River Valley alluvial aquifer (alluvial aquifer) and the Sparta/Memphis Sand aquifer. In 1980 withdrawals from the alluvial aquifer were approximately 3860 mgd. This same year, withdrawals from the Sparta aquifer were approximately 142 mgd.

In 2009, Arkansas groundwater use had increased to 6070 mgd with about 5900 mgd being used for irrigation. There are currently 49,558 registered wells in Arkansas. Of these, 48,599 are irrigation wells, 699 are public supply wells, and the rest are for industrial, commercial, and mining purposes. There are also an estimated 170,000 private domestic wells serving about 680,000 individuals in Arkansas. These wells are exempt from registration requirements.

Recent water use trends can also be evaluated by comparing water well construction reports, as submitted by law, to the Arkansas Water Well Construction Commission program staff. The chart below categorizes the reports for 1975 and 2012.

Table 1. Statewide Water Well Construction Reporting

	1974	2012
Domestic	4491	523
Irrigation	548	1971
Municipal	35	12
Miscellaneous	150	265
Total	5224	2771

These numbers indicate a decline in water well construction in Arkansas for this 38 year period. Though the construction of large irrigation wells increased significantly, it was not enough to match the dramatic decrease in rural domestic well construction. This is the direct result of the drastic increase in the development of public water supply systems statewide.

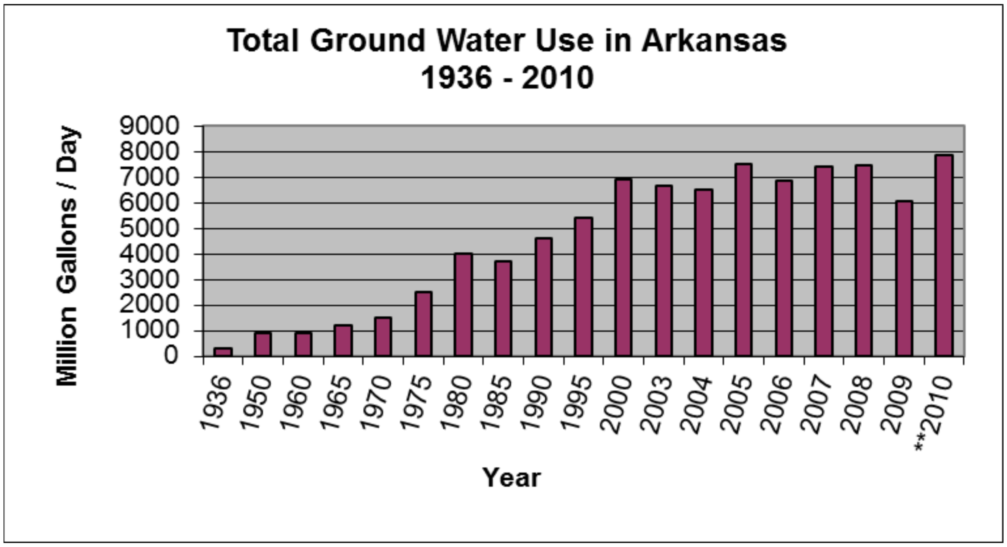


Fig. 16

Of great concern to groundwater program managers and water users is the trend of drilling deep wells in the Grand Prairie, as an alternative supply for alluvial aquifer wells which have become unproductive due to water-level declines. This practice will place greater stress on an aquifer that has much less capability of providing water to wells due to its low storage as compared to the high specific yield of the unconfined alluvial aquifer.

A comparison of the volume of water available to wells developed in the Sparta and alluvial aquifers is summarized in the following table. Based on these basic calculations the volume of water available from the Sparta aquifer, with a storage coefficient of .0001 is .06 acre-feet per square mile with one foot of saturated thickness. While the alluvial aquifer, with a specific yield of .3, yields 192 acre-feet of water for the same area and saturated thickness. This simple comparison shows the vast difference in available water from the confined Sparta aquifer and the unconfined alluvial aquifer.

Fig. 17

Table 2 shows the number of wells constructed in the Grand Prairie counties during selected years. This data indicates a trend of drilling more of the deep wells into the Tertiary formations such as the Cockfield and Sparta/Memphis aquifers. Likewise, table 3 shows a 45 percent increase in the number of deep registered wells in these counties from 1985 to 2012.

Table 2. Deep Water Wells Constructed in Grand Prairie Area

County	1974	1995	2000	2012
Arkansas	4	0	1	2
Lonoke	1	12	32	17
Prairie	1	12	11	4
Total	6	24	44	23

Table 3. Registered Groundwater withdrawals from the Sparta/Memphis aquifer in Arkansas, Lonoke, and Prairie counties, 1985-2010.

County	1985	1990	1995	2000	2005	2010
Arkansas	100	99	97	94	98	196
Lonoke	29	29	41	47	58	67
Prairie	42	42	45	43	43	48
Total	171	170	183	184	199	311

Source: US Geological Survey/ANRC water use registration data

Summary of Potable Groundwater Use in Arkansas

ALLUVIAL AQUIFER

The Alluvial aquifer (alluvial aquifer), mainly used for irrigation, serves a combined retail population of 291,887 Arkansans in seventy-eight (78) community public water systems (CPWS) in twenty-four (24) counties—Arkansas, Ashley, Clay, Craighead, Cross, Desha, Faulkner, Hempstead, Independence, Jackson, Lawrence, Little River, Logan, Lonoke, Mississippi, Pike, Phillips, Poinsett, Prairie, Pulaski, St. Francis, White, Woodruff, and Yell (55 independents and 23 buyers).

This number includes a few CPWS, like Lonoke, with a roughly equal number of wells in the Alluvial and other aquifer systems. It also includes Jacksonville and Cabot, which either obtain or will obtain over 50% of their water supply from Lakes Maumelle and Winona through Central Arkansas Water after 2010. [Both utilities will continue to use their wells indefinitely.]

The combined average water demand from the 55 independent CPWS is 48,981,900 GPD. However, this excludes Arkansans who rely solely on private household wells in the alluvial. According to a 2012 ANRC study, there are an estimated 210,982 Arkansans who use private wells instead of public water, and 10%, or 21,000, of them tap into the alluvial, which would bring the total to 312,000 Arkansans. (Some sources place the percentage of private well owners in the alluvial aquifers high as 20%.)

As much as 250 feet thick in parts, the alluvium is composed of coarse sand and gravel at the base that grades upward to silt and clay near the surface. Alluvial wells are generally 100 to 150 feet deep (maximum depth 200 feet) and generally yield 1,000 to 2,000 GPM (480,000 to 960,000 gallons in 8 hours)—up to a maximum rate of 5,000 GPM.

The hard ground water averages 246 parts per million (ppm) in calcium carbonate, and over 1 ppm in iron. In parts of Chicot, Desha, Lincoln, Monroe, and White Counties, the water may contain as much as 3,750 ppm of dissolved solids, restricting its usefulness for irrigation.

COCKFIELD AQUIFER

The Cockfield aquifer serves a combined retail population of 21,752 Arkansans in eighteen community public water systems (CPWS) in seven counties—Ashley, Bradley, Chicot, Cleveland, Columbia, Dallas, and Grant (ten independents and eight buyers). This number includes a few CPWS that buy water from one or more utilities with a roughly equal number of wells in the Cockfield and other aquifers. However, it does not include Arkansans who own private household wells in the Cockfield. The combined average water demand from the ten independent CPWS is 2,586,000 GPD.

The Cockfield formation consists of inter-bedded fine to medium sand, clay, and lignite, and may be up to 400 feet thick in Chicot and Desha Counties. It is confined (except in the outcrop). The water is soft, of a sodium bicarbonate or sodium chloride type, and generally suitable for most industrial uses as well as drinking water. But it may contain more than 0.3 mg/L of iron in places. In parts of extreme southeastern Arkansas, it contains over 1,800 parts per million of chloride.

Wells in the Cockfield are typically 350 to 500 feet deep but may be up to 700 feet in depth. They typically yield 100 to 350 GPM (48,000 to 168,000 gallons in 8 hours)—but may exceed 500 GPM.

SPARTA AQUIFER

The Sparta Sand aquifer serves a combined retail population of 380,741 Arkansans in one hundred sixty-nine (169) community public water systems (CPWS) in thirty-three counties—Arkansas, Ashley, Bradley, Calhoun, Chicot, Cleveland, Columbia, Cross, Dallas, Desha, Drew, Grant, Hot Spring, Independence, Jackson, Jefferson, Lafayette, Lee, Lincoln, Lonoke, Miller, Mississippi, Monroe, Nevada, Ouachita, Phillips, Poinsett, Prairie, Pulaski, Saint Francis, Saline, Sharp, and Union—one hundred twenty-one (121) independents and forty-eight (48) buyers. The combined average water demand on the Sparta from the independent CPWS is 49,057,000 GPD. (NOTE: Lonoke and Magnolia obtain only about half their water from the Sparta.)

The Sparta formation is the middle stratum of the Claiborne Group, made of massive fine to medium sands with inter-bedded clay lenses and lignite, and is up to 800 feet thick. It is confined between the overlying Cook Mountain Formation and underlying Cane River Formation. Sparta wells are generally between 500 and 1,000 feet deep (maximum depth 1,200 feet) and typically yield 500 to 1,500 GPM (240,000 to 720,000 gallons in 8 hours)—up to a maximum rate of 3,000 GPM.

The Sparta not only covers eastern Arkansas and northern Louisiana, but also western Tennessee and western Mississippi, where it is often referred to as the Memphis Sand or the "500-foot sand". The increased thickness of the Memphis Sand is the result of a lithofacies change which occurs approximately at the 35^{th} latitude line in eastern Arkansas. Here the Cane River formation changes from a clay confining strata to a primarily sand layer, therefore combining with the overlying Sparta Sand and the underlying Carrizo Sand to form the thicker stratum. The Sparta is the second most productive aquifer in Arkansas (after the alluvial), and by far the most productive among confined aquifers. About 70% of all Sparta wells in Arkansas are used for irrigation or paper production.

Some of the utilities listed below, such as Fountain Hill, have a problem with color in their water.

Unfortunately, the irrigation wells and paper mill wells have led to overdrawals or "mining" (forcing the aquifer to produce above its sustainable yield). The Arkansas Natural Resources Commission and U.S. Geological Survey have recorded 320-foot declines in the Sparta water level since well records were first kept in Columbia, Jefferson, and Union Counties. In some cases, saline water has contaminated the Sparta due to these declines.

WILCOX AQUIFER

The Wilcox aquifer is the principal source of residential drinking water for an estimated 136,062 Arkansans in fifty-five (55) community public water systems (CPWS) in twelve counties—Clark, Clay, Craighead, Crittenden, Greene, Lawrence, Mississippi, Nevada, Poinsett, Randolph, St. Francis, and Saline (43 independents and 12 buyers). The combined average water demand from the 44 independent CPWS is 17,810,000 GPD.

This number includes a handful of CPWS that buy water from one or more utilities with a roughly equal number of wells in the Wilcox and other aquifers. However, it does not include Arkansans who rely solely on private household wells in the Wilcox.

Though it runs throughout most of the Coastal Plain in Arkansas, this generally confined aquifer of fine to medium sand, silt, clay, and lignite is a major water source only in eastern and northeastern Arkansas, where it is referred to as the "1,400-foot sand." The water is a soft, sodium bicarbonate type but saline in down-gradient areas. Withdrawals are primarily for public and industrial supplies.

Wells in the Wilcox are typically 750 to 1,100 feet deep (maximum depth 1,500 feet). They typically yield 50 to 500 GPM (24,000 to 240,000 gallons in 8 hours)—up to a maximum rate of 2,000 GPM in Crittenden and Mississippi Counties.

NACATOCH SAND AND TOKIO AQUIFERS

The Cretaceous sands of the Nacatoch aquifer and the Tokio aquifer are the principal sources of residential drinking water for an estimated 43,591 Arkansans in 26 community public water systems (21 independents and five buyers) in six counties—Clay, Greene, Hempstead, Howard, Randolph, and Sevier. The 26 independents have a combined average water demand of 5,395,300 gallons per day (GPD).

This number includes Hope, a special case, which obtains most of its water supply from Lake Millwood but still depends on its nine wells in the Nacatoch Sand and Tokio formation to supplement its supply, especially during summer months. However, this number does not include Arkansans who rely on private household wells in the Nacatoch Sand or Tokio.

The Nacatoch Sand and Tokio are confined aquifers, consisting of massive cross-bedded sand, limestone lenses, and calcareous clay. During the 1970s, water level declines exceeding 40 feet were observed at Prescott in Nevada County as a result of large municipal withdrawals, prompting Prescott to switch to the Little Missouri River.

The typical Nacatoch or Tokio well is 500 to 800 feet deep (but may exceed 1,100 feet) and yields 150 to 300 GPM (up to 500 GPM). It is equivalent to the McNairy aquifer in Missouri. The ground water is of a soft, sodium bicarbonate type (less than 30 ppm of hardness as calcium carbonate) and contains less than 500 ppm dissolved solids in the freshwater areas, but may be saline in downdip areas.

ATOKA AND MISSISSIPPIAN AQUIFERS

The Pennsylvanian stratigraphic system, which includes the Atoka aquifer, and the Mississippian system aquifer, serves a combined retail population of 6,878 Arkansans in seven independent community public water systems (CPWS) in six counties—Cleburne, Craighead, Cross, Newton, Perry, and Poinsett—not including Arkansans who rely on private household wells in the Carboniferous. The combined average water demand from the seven CPWS is 631,000 GPD.

OZARK AQUIFER

The Ozark Aquifer System, which includes the Gasconade-Van Buren (Gunter Sandstone member), Roubidoux, Everton, Cotter Dolomite, Potosi Dolomite, Powell Dolomite, and other formations, is the principal source of residential drinking water for an estimated 73,863 Arkansans in eighty-five (85) community public water systems (CPWS) in thirteen counties—Baxter, Benton, Boone, Carroll, Fulton, Izard, Lawrence, Marion, Newton, Randolph, Searcy, Sharp, and Stone—consisting of eighty-one (81) independents and four (4) buyers. This number does not include Arkansans who rely on private household wells in the Ozark Aquifer.

The aquifer system consists primarily of dolomite, sandy dolomite, and sandstone, and is the only significant aquifer system in the Interior Highlands. The Gunter sandstone member, which belongs to the Van Buren Formation, and the Roubidoux formation do not crop out in Arkansas.

The Roubidoux is 100 to 250 feet thick and ranges from 600 feet deep at the Missouri state line to 2,300 feet deep at its southern limit around longitude 36o. The Gunter is 50 feet thick and lies 300 to 600 feet below the Roubidoux. The massive dolomites between these two formations do not yield significant water.

Wells in the Ozark are typically 600 to 2,400 feet deep (maximum depth 3,000 feet) and typically yield 150 to 300 GPM (up to a maximum of 500 GPM). Ground water in the Ozark aquifer system in Arkansas contains up to 1,000 parts per million of dissolved solids and is of a hard or very hard calcium-bicarbonate type. (Polk, 2012)

Water Rights Summary

With respect to Arkansas water rights, Arkansas follows the "reasonable use" theory of water use by riparian--landowners whose property borders a watercourse, stream, or lake. See *Meriweather Sand and Gravel Co. v. State*, 181 Ark. 216, 26 S.W. 2d 57 (1930). Landowners may beneficially use water as long as they do not cause unreasonable damage to fellow riparian land owners. See *Id*. The right to use surface water is incident to the ownership of riparian property. *Id* at 226. It is appropriate to note that riparian rights are usufructuary, not actual ownership of the water, but a property right that is shared and protected by constitutional due process. *Id at* 230-31. Arkansas Statutory law delineates water use priorities in the order of sustaining life, maintaining health, and increasing wealth (Ark. Code Ann. §15-22-217(c)). Household use is given the highest priority, and use of over 1 acre-foot of water per year requires registration through the Commission or your local conservation district. Ark. Code Ann. §15-22-301, et. seq.

Groundwater is also subject to some regulation under the Arkansas Groundwater Protection and Management Act, which provides for the establishment of "critical groundwater areas" and under certain circumstances, the initiation of a regulatory program. Ark. Code Ann. §15-22-901, et seq. Groundwater is also subject to the reasonable use doctrine. The common law of groundwater rights and the reasonable use concept was defined in 1957 when the Arkansas Supreme Court decided on a case, *Jones vs. Ozark-Val Poultry Co.* In this case the court directly applied the riparian rights reasonable use rule to groundwater by stating, "As to water rights of riparian owners, this State has adopted the reasonable use rule. We see no good reason why the same rule should not apply to a true subterranean stream or to subterranean percolating waters." . *Jones vs Ozark-Val Poultry Co.*, 228 Ark. 76, 79, 306 S.W. 2d 111, 113 (1957). This wording clearly identifies that all groundwater, vadose and phreatic, is being addressed here. Unlike the English Rule (capture), the American Rule described in *Jones* is defined as a correlative right among property owners in which each has the right to a reasonable amount up to the full extent of the water use need if the supply is sufficient such that other users are not adversely impacted.

For drainage, the "common enemy doctrine" applies, allowing a landowner to prevent damage to property by runoff without causing damage to neighbors. See *Honey v. Bertig Co.*, 202 Ark. 370, 150 S.W.2d 214 (1941).

The Arkansas Natural Resources Commission is charged with the responsibility of helping the people of the State solve "water rights" problems. When a water shortage occurs, the Commission has the power to allocate use. Ark. Code Ann. §15-22-201, et. seq. To prevent excessive litigation, the Arkansas courts have ruled that a person must exhaust all administrative remedies through the Commission before filing a lawsuit.

If a problem is not one of "water rights," it does not fall directly under the Commission's jurisdiction. In such cases the Commission may be able to provide technical assistance, though it would have no power to order any action. The Commission can also provide information to you about regulation by other state and federal agencies.

Water rights law and policy have evolved over many years, and the text provided here is for summary purposes only. Water rights law is covered in much greater depth in other sources such as:

Kenneth S. Gould, Water Rights in the 21st Century: The Challenges Move East, 25 U. Ark. Little Rock L. Rev. 3 (2002)

J. W. Looney, Water Law in Arkansas, J.W. Looney (University of Arkansas 1998)

Water Resources Statutory Authority

Act 81 of 1957 created the Arkansas Water Conservation Commission and required the reporting of all surface water use above one acre-foot per year. This law also gave the AWCC authority to regulate surplus stream flow storage facilities, inspect dams, allocate surface water, and have oversight of regional water districts. In 1963, the Arkansas Legislature transferred the water conservation functions of Act 81 of 1957 to the Arkansas Soil and Water Conservation Commission, now the Arkansas Natural Resources Commission, including stream allocation authority and water use data collection. Interstate compact authority and flood control authority were also transferred to the ASWCC this same year. Flood control authority previously existed under Arkansas, Irrigation, Drainage and Watershed Improvement District Act of 1949. These transfers specifically enable the ANRC to cooperate with the Federal government in the development of water supplies for the purpose of flood control, navigation, and irrigation. These laws are now codified at Ark. Code Ann. §15-22-201, et. seq., §15-24-100, et. seq., §15-20-201, et. seq.

The ASWCC received statutory authority to begin work on the first Arkansas State Water Plan in 1969. Act 217 gave specific authority to the ASWCC to serve as the designated State agency responsible for water resources planning at the state level. The plan was to be comprehensive and coordinated for the protection, development and utilization of the State's water and related land resources. The ASWCC was also directed to collect data, determine areas of need, facilitate planning, and administer the water development funding, and oversee drainage and levee district plans. In 1985, the Arkansas General Assembly passed Act 1051 which broadened the ASWCC planning responsibilities to include preparing an inventory of surface- and groundwater resources, determining water requirements to satisfy in-stream flow needs, determine excess surface water volumes, establish minimum stream flows, and delineate critical water areas. In response, the ASWCC undertook a major revision and update of the Arkansas Water Plan. Eight basin reports and a supplement covering the entire State were prepared along with several special water resources reports and an executive summary. These basin reports inventory the water resources of each major basin, identify current and future water problems, and recommend actions necessary to resolve or minimize these problems. The Executive Summary of the Arkansas Water Plan is a compilation of the information gained in the basin reports into a concise volume of statewide interest. This plan currently serves as the State's primary guidance document for water resources planning, management, and development. These Acts are now codified at Ark. Code Ann. §15-22-201, et. seq., §15-22-501, et. seq.

Act 641 of 1969 created the Arkansas Committee on Water Well Construction whose purpose was to regulate the water well drilling industry such that wells will be constructed that provide good quality water. The Arkansas Water Well Construction Act is codified at Ark. Code Ann. §17-50-101, et. seq. The Arkansas Committee on Water Well Construction is now the Arkansas Water Well Construction Commission.

The Arkansas Water Resources Development Act of 1981 authorized the ASWCC to assist cities, towns, improvement districts, water associations, and counties in financing the construction of water, sewer, and solid waste systems and to issue water resources development general obligation bonds. This Act is now codified at Ark. Code Ann. §15-22-601, et. seq.

The Arkansas Groundwater Protection and Management Act passed as Act 154 of 1991 and provided the ASWCC with authority to designate critical groundwater use areas (CGWA), to establish the authority for groundwater withdrawals within the CGWA, the authority to set groundwater rights, establish water use registration fees, and to establish a mechanism for local groundwater management. The Act provided specific authority to the ASWCC to develop a comprehensive groundwater protection program, assess and monitor groundwater quantity and quality, develop a groundwater classification system and water-quality standards, to regulate groundwater use through the issuance of water rights within a CGWA, and to establish an information/education program statewide. In 2001, the Arkansas Groundwater Protection and Management Act was expanded by Act 1426 which stated that any non-domestic water well constructed after September 30th of 2001 to withdraw groundwater from a sustaining aquifer shall be equipped with a properly functioning metering device. Likewise, any non-domestic well used to withdraw groundwater from a sustaining aquifer after September 30th, 2006, regardless of when constructed, must be properly metered. Sustaining aquifers include the Roubidoux, Gunter, Nacatoch, Wilcox, Carrizo, Cane River, Memphis, Sparta, and Cockfield aquifers. The Arkansas Groundwater Protection Management Act is now codified at Ark. Code Ann. §15-22-901, et. seq.

In 2005, Act 1243 officially changed the name of the Arkansas Soil and Water Conservation Commission to the Arkansas Natural Resources Commission. Ark. Code Ann. §15-20-201. ANRC's water related authorities can be found throughout Title 15 of the Arkansas Code Annotated. The following chapters are specifically related to water resources: §15-22-201, §15-22-301, et. seq., §15-22-401, et. seq., §15-22-501, et. seq., §15-22-601, et. seq., §15-22-701, et. seq., §15-22-801, et. seq., §15-22-901, et. seq., §15-22-1001, et. seq., §15-22-1101, et. seq., §15-22-1201, et. seq., §15-22-1301, et. seq.

INSTITUTIONAL FRAMEWORK

1980s Water Policy

The policy of the ANRC in the area of water management was defined early on as a policy of providing Arkansans with sufficient quantity of water of a quality satisfactory for the intended beneficial use. During the 1980's groundwater management in Arkansas was in the data collection and planning stages. Several state and local agencies have limited or inferred jurisdiction over groundwater (Bennett and Young, 1985). State water resources protection authority has generally been described as being divided, with the ANRC having comprehensive planning, and water quantity authority, with ADEQ having primary water quality protection authority, and ADH having authority over public drinking water supply programs. Other agencies have specific authority over various protection needs such as the Arkansas Geological Survey which provides analysis, mapping, and development of the State's geologic resources.

The list below identifies the primary water resources protection agencies and appropriate programs.

Federal Agencies

Department of Agriculture
Natural Resources Conservation Service (NRCS)
Natural Resources Conservation Service (NRCS) - In the future, NRCS plans to examine interrelated issues that have implications for U.S. agriculture and forestry: climate change, biofuels production, and the quality and availability of water. The Soil and Water Resources Conservation Act (RCA) of 1977, provides the United States Department of Agriculture (USDA) broad strategic assessment and planning authority for the conservation, protection, and enhancement of soil, water, and related natural

resources. Through RCA, USDA: appraises the status and trends of soil, water, and related resources on non-Federal land and assesses their capability to meet present and future demands; evaluates current and needed programs, policies, and authorities; and develops a national soil and water conservation program to give direction to USDA soil and water conservation activities.

The 2011 RCA Appraisal provides an overview of land use and the U.S. agricultural sector; of the status, condition, and trends of natural resources on non-Federal lands; and of USDA's program for soil and water resources conservation.

National Water Management Center (of NRCS)
The National Water Management Center (NWMC) serves as a focal point for water resources information exchange. It is a production support center for NRCS helping to address water resource problems across the nation by providing leadership, direct assistance, information, and technology for natural resources conservation. The NWMC also provides expertise in and guidance with the application of water resource technologies to assess watershed health and plan watershed-scale solutions. NWMC responds to internal and external customer-identified needs and/or requests. Emphasis on collaborating with other Federal water resource agencies to collectively support locally led conservation processes. The NWMC has six major areas in which they provide support and training: Environmental compliance, Hydrology and hydraulics, stream geomorphology and restoration, water quality and quantity, watershed and dam rehabilitation, and technology outreach. The support and training provide assistance in various topics associated with watershed planning and other water resource applications, stream health and restoration, water management, and through enhancing conservation and sustainable farming.

US Forest Service – Groundwater concerns for the USFS are associated with recharge/discharge relationship of groundwater and its effects on National Forests and Grasslands. The mission of the USDA Forest Service is to sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations. The goal is to achieve quality land management under the sustainable multiple-use management concept to meet the diverse needs of people including: Advocating a conservation ethic in promoting the health, productivity, diversity, and beauty of forests and associated lands, providing technical and financial assistance to State and private forest landowners, encouraging good stewardship and quality land management, providing technical and financial assistance to cities and communities to improve their natural environment, and providing international technical assistance and scientific exchanges to sustain and enhance global resources to encourage quality land management.

United States Department of Agriculture, National Agricultural Statistics Service -

Department of the Interior - US Geological Survey (USGS) – Ecosystems, Climate and Land Use Change, Natural Hazards, Water, Energy and Minerals, Environmental Health, and Core Science Systems.

US Geological Survey (USGS) - USGS's mission is to collect and disseminate reliable, impartial, and timely information that is needed to understand the Nation's water resources.

The USGS Water Mission Area actively promotes the use of this information by decision makers to: Minimize loss of life and property as a result of water-related natural hazards, such as floods, droughts, and land movement; effectively manage groundwater and surface water resources for domestic, agricultural, commercial, industrial, recreational, and ecological uses; protect and enhance water resources for human health, aquatic health, and environmental quality; and contribute to the wise physical and economic development of our Nation's resources for the benefit of present and future generations.

US Fish and Wildlife Service (FWS) The FWS Office of Law Enforcement contributes to Service efforts to manage ecosystems, save endangered species, conserve migratory birds, preserve wildlife habitat, restore fisheries, combat invasive species, and promote international wildlife conservation.
Groundwater resource objectives include groundwater recharge/discharge concerns in wetlands or streams of the state, and the resulting impact on fish and wildlife species or their food sources and habitat. FWS law enforcement today focuses on potentially devastating threats to wildlife resources, illegal trade, unlawful commercial exploitation, habitat destruction, and environmental contaminants. The Office investigates wildlife crimes, regulates wildlife trade, helps Americans understand and obey wildlife protections laws, and works in partnership with international, state, and tribal counterparts to conserve wildlife resources. This work includes: Breaking up international and domestic smuggling rings that target imperiled animals; Preventing the unlawful commercial exploitation of protected U.S. species; Protecting wildlife from environmental hazards and safeguarding critical habitat for endangered species; Enforcing Federal migratory game bird hunting regulations and working with States to protect other game species from illegal take and preserve legitimate hunting opportunities; Inspecting wildlife shipments to ensure compliance with laws and treaties and detect illegal trade; Working with international counterparts to combat illegal trafficking in protected species; Training other Federal, State, tribal, and foreign law enforcement officers; Using forensic science to analyze evidence and solve wildlife crimes; Distributing information and outreach materials to increase public understanding,

Environmental Protection Agency – Water and Air Pollution Control and Regulation, delegates NPDES State Permit Program, Drinking Water, Hazardous Waste Disposal, Toxic Waste Clean-up, Pesticide Regulation and Applicator Training, and Research.

The mission of EPA is to protect human health and the environment. EPA's purpose ensures that: all Americans are protected from significant risks to human health and the environment where they live and work; national efforts to reduce environmental risk are based on the best available scientific information; environmental protection is an integral consideration in U.S. policies concerning natural resources, human health, economic growth, energy, transportation, agriculture, industry, and international trade, and these factors are similarly considered in establishing environmental policy. EPA believes that all aspects of society should have access to accurate information sufficient to effectively participate in managing human health and environmental risks, and environmental protection contributes to making our communities and ecosystems diverse, sustainable and economically productive. EPA also strives to allow the United States to play a leadership role in working with other nations to protect the global environment.

Department of Defense, US Army Corp of Engineers – Water Resource Development, Bank Stabilization, Navigation Channel Maintenance, Dredge and Fill Permits, Wetland Regulation and Permitting, and Flood Control.

Since the Corps formation in 1775, the U.S. Army Corps of Engineers (USACE) has played an integral part in the development of the country. Serving as the Nation's environmental engineer, the USACE owns and operates more than 600 dams (11 in Arkansas), which not only provides valuable surface water and hydroelectric power, but also decreases demand for groundwater in areas served by these lakes. USACE also restores, creates, enhances or preserves tens of thousands of acres of wetlands in the nation annually under the Corps' Regulatory Program. The Clean Water Act (CWA) requires no net loss of wetlands, which are important contributing areas for recharge of Arkansas' aquifers. USACE also supports Army and Air Force installations, provides technical and construction support to more than 100 countries, and researches and develops technologies to protect the nation's environment and enhance the quality of life.

Federal Emergency Management Association – Disaster Assistance and Flood Response, including the National Flood Insurance Program.
The agency's primary purpose is to coordinate the response to a disaster that has occurred in the United States that overwhelms the resources of local and state authorities.

Federal Energy Regulatory Commission - Oversees environmental matters related to natural gas and hydroelectricity projects.

State Agencies

Forestry Commission -_AFC's groundwater concerns are associated with aquifer recharge/discharge relationship to the water table and its associated impact on the state's forests.

The Arkansas State Plant Board works to control of destructive plant insects; control of pests and plant diseases; and to

Arkansas Natural Resources Commission (ANRC) – The ANRC serves as the State's primary water resources planning and management agency with authority to develop the State Water Plan and other appropriate policy documents. Other authority includes financial assistance for water resource and wastewater development, dam safety, registration of water use, adjudication of water rights, the authorization of non-riparian water use, interstate water compacts, soil conservation, and floodplain management. With respect to groundwater authority, the ANRC operates under the Groundwater Protection and Management Act of 1991, which directs the agency to study the State's groundwater resources, designate critical groundwater areas, and provide conservation and education technology and training.

The Water Well Construction Commission (AWWCC) – This Commission basically serves as a technical advisory board over matters involving the licensing and registration of water well contractors/drillers and pump-installers, issues regulations on construction, repair and abandonment of water wells, and performs inspections on well complaints.

Department of Health - As regulatory agency for public water systems in the State, groundwater mission objectives include preservation of aquifer water quality and yield sustainability. The Department of Health's mission is to protect and improve the health and well-being of all Arkansans and promote the optimal health for all Arkansans to achieve maximum personal, economic, and social impact.

Department of Environmental Quality - ADEQ's regulatory programs set pollution limits, determine compliance, and enforce environmental laws and regulations. ADEQ's regulatory divisions include Air, Water, Solid Waste, Hazardous Waste, Regulated Storage Tanks and Mining. ADEQ protects the air, water and land from the threat of pollution through programs of regulation, education and assistance. ADEQ also oversees training and standards for various licensed professionals. ADEQ offers citizens the tools and resources to protect natural resources by showing businesses and communities, alternatives to waste disposal and how to prevent pollution, and involving students in environmental projects. ADEQ also implements understanding of environmental requirements and responsibilities through workshops for teachers and businesses, and helps citizens understand permitting issues. ADEQ's authority is bound and limited by federal and state laws and regulations. ADEQ maintains partnerships with other agencies and stakeholders, sharing knowledge and expertise to solve environmental problems. ADEQ depends on, and responds to, citizens' concerns, because they are often the first to witness environmental problems.

University of Arkansas Cooperative Extension Service – The U of A Cooperative Extension Service provides technical assistance to the citizens of Arkansas on multiple water-resources conservation and protection issues. The Cooperative Extension Service is part of the University of Arkansas' Division of Agriculture. With offices in all 75 counties, its faculty and staff provide educational programs and research-based information to the people of Arkansas. From agricultural programs to family financial management to youth education, The UA CES offers educational programs that have immediate and practical applications.

The Arkansas Water Resources Research Center (AWRC) has worked, since 1964, to arrange for competent research addressing water-resources issues, and enhanced understanding. The AWRC has also aided in the entry of new scientists and engineers, along with the transfer of newly developed scientific research and technology to water-resources managers and the public.

Natural Heritage Commission - Since 1973, the Arkansas Natural Heritage Commission (ANHC) has been working to conserve Arkansas' natural landscape. ANHC's professionals locate and evaluate occurrences of natural communities and rare, threatened, and endangered species. Research findings and results are often published in scientific journals and presented at national, regional and state forums. This information is analyzed and housed in the Arkansas Heritage Program biodiversity database. Their field surveys and research projects have provided a wealth of information on more than 900 rare species and are used to evaluate the relative imperilment of native species and shared for environmental planning purposes. ANHC provides data to organizations and individuals involved with Arkansas conservation efforts, economic development, scientific research and education. Based on sound scientific research, ANHC evaluates the state's ecologically important sites to set priorities for conservation in Arkansas and provide stewardship of these lands to preserve and sometimes restore unique and diverse ecosystems.

Arkansas Geological Survey - The AR Geological Survey (AGS) provides geological information to develop and enable effective management of the State's mineral, fossil fuel and water resources while protecting the environment.

Arkansas Game and Fish Commission - Groundwater resource concerns include groundwater recharge/discharge concerns in wetlands or streams of the state, and the resulting impact on fish and wildlife species or their food sources and habitat.

The Game and Fish Commission manages protection, conservation and preservation of various species of fish and wildlife in Arkansas through habitat management, fish stocking, hunting and fishing regulations, and many additional programs. Intrinsic to this goal, the AG&FC works diligently to protect in stream flow and other water resources interests that directly impact the States game and fish resources. Through agency programs focused toward the public, the Commission works to generate awareness of ethical and sound management principles by enforcing fishing and hunting regulations and promoting environmental awareness through educational programs.

The Forestry Commission (AFC) works with agencies, organizations and residents to prevent and suppress wildfires, control forest insects and disease, grow and distribute trees, and gather and disseminate information concerning the growth, use and renewal of forests. In addition to wildfire suppression, AFC crews respond to all other natural disasters, from tornadoes to ice storms to floods. Crews are often called upon to clear roadways to allow emergency access, and organize incident command centers used to provide a staging area for emergency responders. AFC County Foresters and Rangers also work with non-industrial private landowners to manage for their forested property. Since 1991, AFC Foresters have worked with more than 1,150 landowners to help them earn Forest Stewardship recognition. Arkansas regulates services used in agricultural production. The Plant Board has been monitoring groundwater since 2004 using an EPA approved Pesticide Management Plan, which allows the agency to work with the Arkansas Department of Health to determine response actions in the event pesticide groundwater contamination of a well (or wells) is confirmed. The Plant Board's groundwater monitoring program targets agricultural wells susceptible to contamination and investigates potential causes of contamination when pesticides are detected in groundwater samples. 271 wells have been sampled since inception of the program. The agency recommends implementation of Best Management Practices (BMPs) as a preventative method to protect the groundwater resources and avoid potential for both point source and non-point sources of groundwater contamination. Pesticide use in Arkansas is regulated by the State Plant Board's Pesticide Division in accordance with the Arkansas Pesticide Control Act and Regulations. This allows the Plant Board to confirm that all pesticides used in the State meet State and Federal requirements to provide for both human and environmental protection. Each year the Pesticide Division registers approximately 11,000 pesticides for use in the State. Dealers who sell pesticides and applicators must receive proper training and follow approved Best Management Practices to retain a license from the Board. The goal of the Arkansas

State Plant Board's groundwater monitoring program is to prevent the state's groundwater from being polluted by agricultural chemicals and, if pollution is found, to respond appropriately.

Oil and Gas Commission (AOGC) - The purpose of the Arkansas Oil and Gas Commission is to serve the public regarding oil and gas matters, prevent waste, encourage conservation, and protect the correlative rights of ownership associated with the production of oil, natural gas and brine, while protecting the environment during the production process, through the regulation and enforcement of the laws of the State of Arkansas. The commission: issues permits to drill oil, natural gas and brine production wells and other types of exploratory holes; issue authority to operate and produce wells through approval of well completions, establishes production volumes, performs compliance inspections during drilling and the operational life of wells, and issues authority to plug and abandon wells to insure protection of fresh water zones and production intervals. AOGC also issue permits to conduct seismic operations for exploration of oil and natural gas, issue permits to drill and operate Class II UIC enhanced oil recovery injection wells and saltwater disposal wells, and issue permits to drill and operate Class V UIC brine injection wells for the disposal of spent brine fluids following removal of bromine and other minerals.

Waterways Commission -The Waterways Commission develops, promotes, and protects the commercially navigable waterways of Arkansas for waterborne transportation and economic development to benefit the people of Arkansas. The Commission is concerned specifically with navigation activities, port development, and the use and protection of the navigable streams within or adjacent to the State. Groundwater concerns relate to planned irrigation projects on the White and Arkansas Rivers which could reduce demand for groundwater in eastern Arkansas.

<u>Other Entities</u>

The entities listed below should be considered for stakeholder involvement regarding future groundwater programs associated with conservation, resource use, and/or educational programs, particularly in critical recharge or karst areas of the state. Groundwater resource objects include preservation of aquifer water quality and yield sustainability throughout the state. Municipal and County Governments, Regional Water Distribution or Planning Districts, Water Associations, or the Rural Development Commission or Department of Rural Services are other local or regional groups, or State agencies that could also be included in groundwater conservation or educational programs.

The ANRC Conservation Districts provide for the control and prevention of soil erosion, for the prevention of floodwater and sediment damages, and for furthering the conservation, development, and utilization of soil and water resources and the disposal of water, and to preserve natural resources, control floods, prevent impairment of dams and reservoirs, assist in maintaining the navigability of rivers and harbors, preserve wildlife, assist in the control of nonpoint source pollution, protect the tax base, protect public lands, and protect and promote the health, safety, and general welfare of the people of the state.

The drainage, levee, and irrigation districts in Arkansas originated through federal programs which constructed levees following the extensive flooding of the early 20th century. Various drainage and irrigation districts have been formed in the past, and many have been less active in recent years. Most were focused on drainage concerns, and with recent concerns regarding conservation associated with aquifer depletion, some have become more active associated with conservation projects.

The Arkansas Farm Bureau's mission is to advocate the interests of agriculture in the public domain, disseminate information concerning the value and importance of agriculture; and provide products and services which improve the quality of life for its members. Farm Bureau is an independent, voluntary organization of farm and ranch families united for the purpose of analyzing their problems and formulating action to achieve educational improvement, economic opportunity, and social advancement and promote the national well-being. Farm Bureau is county, state, national and international in its scope and influence. Farm Bureau is nonpartisan, nonsectarian, nongovernmental and open in character. Farm Bureau strives to be the voice of agricultural producers at all levels.

Sustainable Yield and Groundwater Flow Modeling

Scientists, water users, and state officials have recognized that Arkansas groundwater use was at a rate that is severely impacting water-levels in the state's major aquifers. Therefore, water users and managers alike have realized the importance of understanding the groundwater flow systems of the State and the need to identify what yields are safe or sustainable.

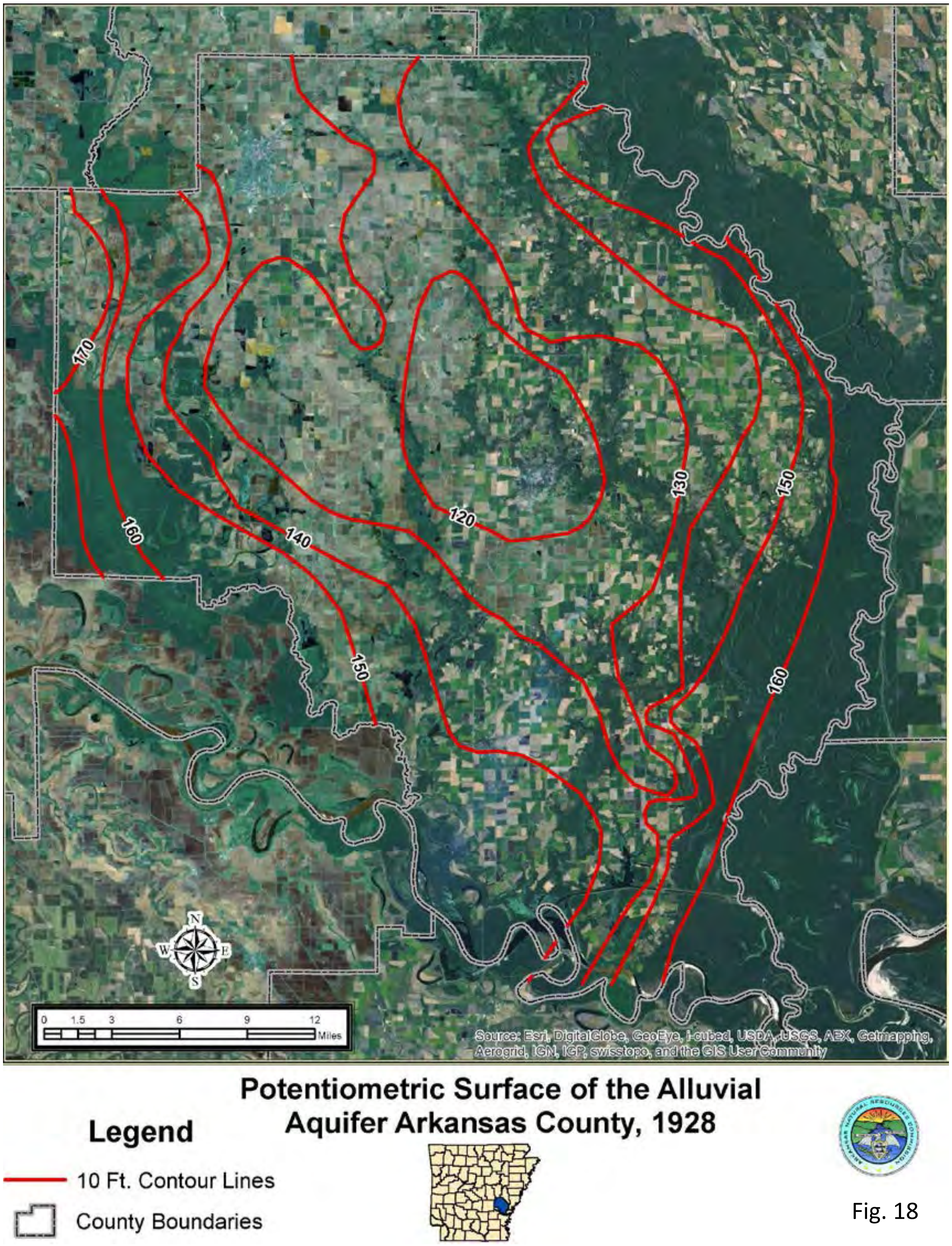
"In the Grand Prairie region as a whole, the present pumpage is roughly twice the rate of recharge." (USGS, Research Series No.19, June 1950)

Arkansas water resources policy and programs have developed with a goal of conjunctive use or the State's surface- and groundwater resources at optimized levels that are sustainable. This sustained yield/conjunctive use strategy has been estimated using groundwater flow models developed largely through the ANRC/USGS cooperative program. Additional federal funding, such as through the Mississippi Embayment Regional Aquifer Study have also greatly benefited the State.

The ANRC has been an advocate for sustainable yield groundwater protection as a means of achieving specific goals such as preventing groundwater-level declines, preventing litigation, insuring a certain volume of groundwater, providing groundwater supplies for drought, preventing groundwater-quality degradation, protecting riparian rights, and providing courts with an objective means for determining reasonable, and unreasonable, use.

Somewhat by default, Arkansas water policy has adopted a deferred perennial yield strategy which accepts that current groundwater levels are reasonable or at least, acceptable. The alternative of requiring the complete recovery of our state's aquifers to pre-development levels is viewed as being extreme and unreasonable.

The earliest potentiometric surface maps prepared in Arkansas identified significant cones of depression in our State's aquifers. One such example is the 1938 alluvial aquifer potentiometric surface map (Counts and Engler, 1954).



Potentiometric Surface of the Alluvial Aquifer Arkansas County, 1928

Fig. 18

Once the depletion of the alluvial aquifer was recognized in the Grand Prairie in the 1920s, hydrologists, geologists, and engineers began immediately trying to estimate the "safe yield" of the aquifer. Perhaps one of the earliest estimates of safe yield is from preliminary report by Thompson in which he provides an estimate for the Grand Prairie. Thompson states that around 60,000 acres, out of 117,000 acres, of land can use irrigation from the alluvial aquifer in this area. This is roughly a 50 percent sustainable level, with 50 percent of the water use being unmet demand.

In a report titled “Breaking the Land, Water Levels in Rice Irrigation Wells in the Grand Prairie Region” Engler documents withdrawals from the alluvial aquifer of around 200,000 acre-feet per year and further comments that this volume is overdrawing the aquifer by about 50,000 acre-feet, inferring a safe yield of 200,000. (Engler, 1958).

An early estimate of sustainable yield for the Sparta aquifer in the El Dorado area was set at 15 mgd. This represents one of the first sustainable yield estimates for the Sparta aquifer in Arkansas.

In 2003, an optimization and sustainable yield scenario was produced for the Sparta aquifer in all of southeastern Arkansas. This report estimated a sustainable yield of 87 mgd for the Sparta aquifer in Arkansas (McKee, Clark, Czarnecki, 2003). Current (2010) withdrawals from the Sparta in Arkansas are about 150 mgd, of which about 58 percent is sustainable.

Such cones of depression indicate, in a qualitative way, that groundwater withdrawals may be above safe yield or sustainable levels, especially if the aquifers do not achieve equilibrium, and the cones continue to expand. With this in mind, water-resources managers, engineers, and planners have adopted the concept of “sustainable yield” as defined here. Though many definitions of sustainable yield exist throughout Arkansas and the world, the most common and accepted version in Arkansas is as follows:

“The development and use of groundwater resources in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences.” (Alley and Leake, USGS, 2004) Another definition that is very similar and compatible is “the quantity of water that can be withdrawn indefinitely by reaching a system equilibrium, or steady state, without compromising the integrity of the aquifer or with respect to agreed-upon criteria.” (McKee, Clark, and Czarnecki, USGS, 2004) One of the most succinct definitions is “the amount of water which can be withdrawn from it annually without producing an undesired result” (Todd, 1959).

Hydrologists today recognize that water resources sustainability is not a purely scientific concept or mathematical algorithm, but rather a perspective that embraces adaptive management, and frames scientific analyses. Groundwater flow modeling should remain a valuable tool in this effort to quantify sustainable yield, emphasizing optimization of water use while protecting both a minimum saturated thickness of the aquifer, as well as the base flow to streams necessary for instream flow needs. Though historical debates on the subject of sustainable yield indicate that a consensus on a firm number may never be reached, it is possible to achieve a workable definition and a functioning process.

The original definition of safe yield has become obsolete in regards to water resources protection goals and policies. As originally used, safe yield calculations were strictly linked to water budget calculations. A more mature understanding of water resources and associated program management now views the original concept as a "water budget myth". It is a common misperception that the development of a groundwater system is "safe" if the average rate of groundwater withdrawal does not exceed the average rate of natural recharge. Safe yield concepts historically focused attention on the water budget, as well as the economic and legal aspects of groundwater development. Sustainability concerns have brought more of the environmental aspects to the forefront. (Alley, 2004) Sustainable yield concepts more accurately view this issue from a perspective of how much water can be captured from increased recharge and decreased discharge, without causing adverse impacts to the groundwater system, the physical formation, or base flow to streams. Sustainability recognizes the complex nature of water resources, and that no single environmental, or legitimate water use, can be addressed in isolation. (Alley and Leake, 2004) From these concepts we realize the need to stop trying to calculate a fixed safe yield, and rather to design groundwater management system that is sustainable, adaptive, and responsive.

Calculation of a sustainable yield estimate for the state's primary aquifers required a quantitative definition. So, as conjunctive-use optimization modeling and sustainable yield estimation was performed, the modelers referred to State policy which defined unacceptable consequences as those conditions which defined an aquifer as critical. Therefore, sustainable yield has been calculated as the level which maintains the water level of an aquifer above critical area criteria in accordance with the Groundwater Protection and Management Act. An aquifer is determined to be critical and above sustainability when the ANRC determines that an area has significant groundwater depletion or degradation. Factors that go into the determination include: 1) water levels are declining at an average rate of one foot per year or more, or 2) the saturated thickness of the formation is 50 percent or less, or 3) water-quality trends indicate degradation. When a confined aquifer is evaluated, it is determined to be critical if the potentiometric surface is below the top of the formation, rather than the saturated thickness criterion. (Arkansas Code sec15-22-901 et seq)

Figures 19(a) and 19(b) illustrate Arkansas' groundwater use as compared to the estimated sustainable yield for the alluvial and Sparta aquifers.

Fig. 19a

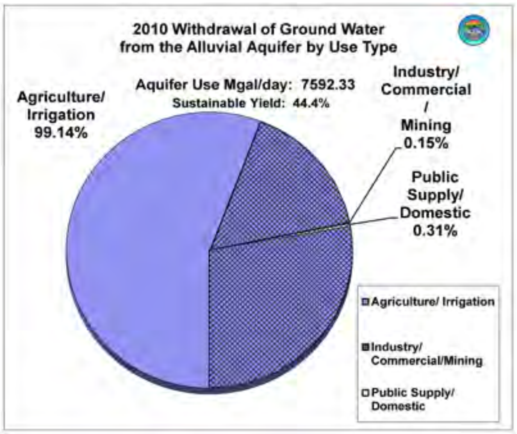
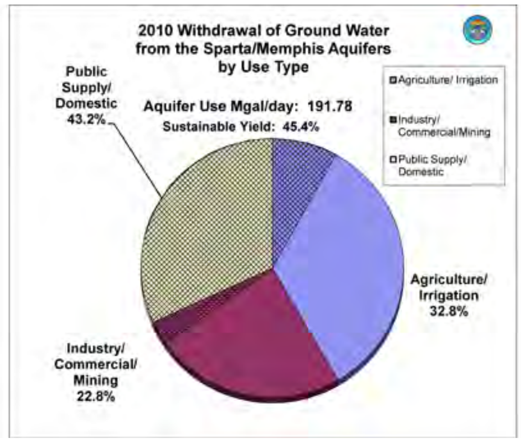


Fig. 19b



The value of a sustainable yield pumping strategy is the goal of reaching a steady-state potentiometric surface, or water table. Such a target level will assure an adequate saturated thickness for existing or planned wells, adequate saturated thickness to sustain water use needs during time of drought, a stable groundwater flow system with respect to quality concerns, protection of base flow to streams and wetlands, and protection of legal water compact requirements.

During the 1980s, the Arkansas Department of Agricultural Engineering produced several reports, mostly by Richard C. and Ann W. Peralta. Initial boundary conditions were developed and a saturated thickness was evaluated for effectiveness in protection from drought and litigation. Results indicated that a minimum of 13 feet of saturated thickness are desirable for the center of cells to provide for a drought season. (Peralta, 1986) However, the report goes on to identify a previous recommendation of a 20 foot saturated thickness requirement for a conjunctive use/sustainable yield strategy. Even so, Peralta reports that 20 feet might be inadequate and that future determinations would be wise. It must be noted that a sustainable yield can only be achieved through a pumping strategy that has a specified rate and pattern of groundwater withdrawals. Implementation of such a strategy will establish a specific target potentiometric surface.

Peralta and Kilian (Peralta, 1985) state that alternative sources of water will have to be developed to meet current water needs in the Grand Prairie.

The Grand Prairie area of eastern Arkansas is typically defined as area of about 1,000 square miles. The total optimum steady-state pumping rate is approximately 5,053 million cubic-feet (mcf) per year which is about 41 percent of the 1982 pumping rate in the Grand Prairie. (Peralta and Yazdanian, 1986) Englar estimated approximately 5,227 mcf for this area which is comparable. (Counts and Engler 1954)

In accordance with the Arkansas Water Plan, the ANRC has supported the policy of utilization of excess surface water to meet unmet demands for agricultural use. The University of Arkansas, Department of Agricultural Engineering has provided estimates of water use needs and alternatives for the Bayou Meto area. Bayou Meto irrigation demand is about 1.9 percent of the total yearly discharge, of 14,360,000 acre-feet per year, at Murray Lock and Dam in Little Rock. In an extremely dry year, the irrigation demand has been calculated to be about 12.7 percent of the discharge. (Peralta and Dutram, 1985)

Early modeling efforts through the U of A, Engineering Department, focused on target levels and a safe yield pumping strategy, which centered on providing a minimum saturated thickness for irrigation wells during pumping season, especially droughts. As this concept evolved into a more desirable sustainable yield strategy, the ANRC worked closely with the US Geological Survey to develop scenarios that would provide optimization estimates along with sustainable yield values.

At the 1984 Summer Meeting of the American Society of Agricultural Engineers, Professor Peralta stated that potentiometric surface of the alluvial aquifer in the Grand Prairie in 1982 was about 36 feet below the optimal surface level, according to his modeling efforts. (Peralta, Kilian, and Dixon, 1984)

Once a sustainable yield optimization yield was quantified, the unmet demand of water use was also easily calculated for each aquifer. The unmet demand is estimated as water use that is above sustainable yield amounts.

In 1983, the Arkansas House of Representatives passed a resolution directing the ASWCC (ANRC) to conduct studies to determine the feasibility of diverting water for agricultural irrigation purposes throughout the Grand Prairie Region to include diversions from the Arkansas and White Rivers. Subsequently, the ASWCC began working closely with the U.S. Army Corps of Engineers, Little Rock and Vicksburg Districts, and the University of Arkansas, Agricultural Engineering Department to study these areas and evaluate the water budget, hydrogeology, and economics of the area.

In accordance with Arkansas Code section 15-22-901 et seq, the Arkansas Groundwater Protection and Management Act, authority to establish safe yield values for Arkansas rest with the Arkansas Natural Resources Commission. Since 1991, the ANRC has worked closely with the Arkansas District of the U.S. Geological Survey to develop and calibrate groundwater flow modeling tools to assist the State with water use scenarios, management decisions, and estimating optimization. Initial modeling efforts were focused on the alluvial and Sparta aquifers, but have evolved into the development of today's Mississippi Embayment Regional Aquifer Study (MERAS) model, which is a three-dimensional multi-aquifer model of the Mississippi Embayment and much of the Western Coastal Plain of south Arkansas.

Current State policy, as defined by the 1975 and 1990 water plans, is to provide for the unmet demand through the practices of conservation, education, and the use of excess surface water. Arkansas utilizes approximately 3 percent of the surface water that flows through the State, and excess surface water has been calculated. To achieve a sustainable yield pumping rate from groundwater in Arkansas, excess surface water must be utilized. Without this surplus water, the only option identified by groundwater flow modeling (Czarnecki, 2008) is to voluntarily reduce, or restrict pumping from an estimated 25,000, of 49,558 registered irrigation wells in eastern Arkansas (Figure 20). Such a decrease in water availability would drastically change agricultural practices, and severely impact the agricultural economy of the State and the country.

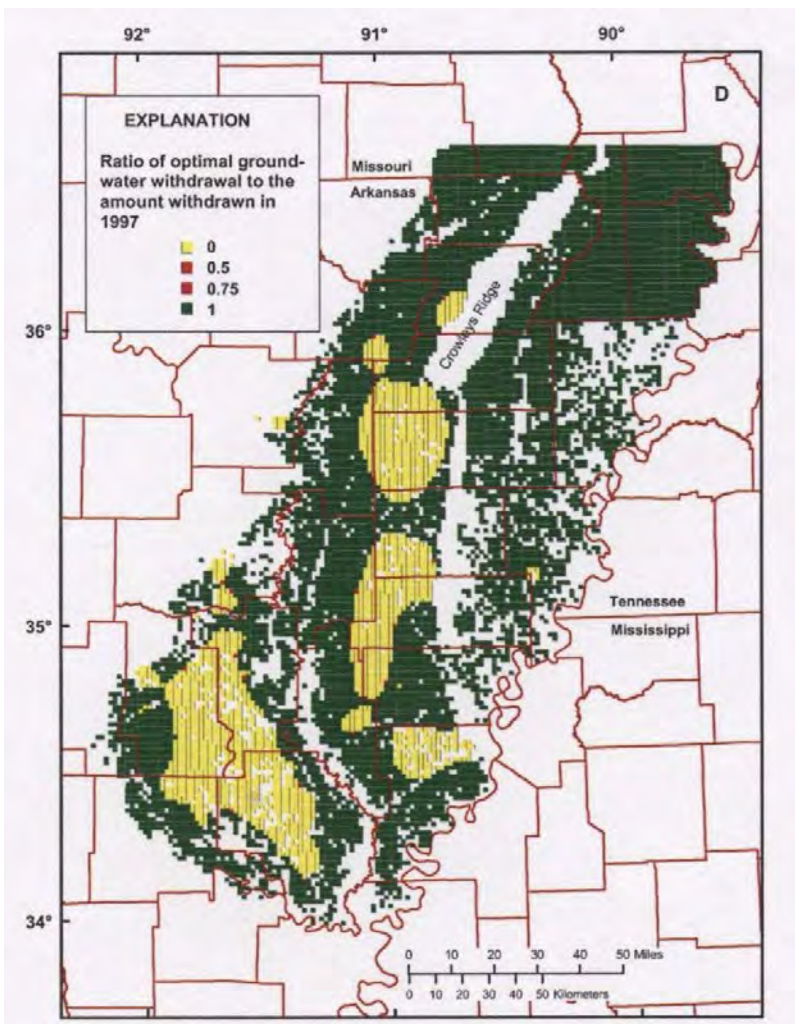


Fig. 20

The sustainable yield for the Mississippi River Valley alluvial aquifer, north of the Arkansas River has been estimated to be approximately 2693 mgd, which is about 57 percent of the 1997 withdrawal amount. The other 43 percent is unmet demand. Optimal sustainable yields from within the Bayou Meto irrigation project area and within the Grand Prairie irrigation project area are 135.4 and 68.1 mgd respectively. (Czarnecki, Clark, and Reed, 2003) These values represent a sustainable yield estimate for both areas of less than 50 percent of the current (2010) water use. Unless agricultural water demand is drastically reduced in this area, an alternative supply will be needed. In the absence of excess surface water, water use reductions can only be achieved through voluntary reductions and a change in cropping patterns, or government restriction through water use permits.

If groundwater use from the alluvial aquifer in the Grand Prairie to be restricted to sustainable levels, without surface water available to make up the difference, it would require a shared reduction of 86 percent of the 1982 water use. This would result in a severe economic loss. (Peralta, 1985)

Since 1990, the US Geological Survey has developed the groundwater flow and optimization modeling tools to estimate the sustainable yield of the State's aquifers, unmet demand, and to determine excess surface water available in the streams. As stated by Czarnecki, 2006, the optimization model does provide estimates of sustainable yield from both the groundwater and surface-water sources that result in hydraulic-head values remaining at or above an altitude corresponding to half the thickness of the aquifer throughout the bulk of the model area, and maintaining streamflows at or above specified minimum amounts (Czarnecki, USGS, 2006). CDM Smith and FTN and Associates are using this same groundwater flow models to determine future needs and unmet demand based on projected use, economic, and population growth forecasting methods. These modeling efforts are being accomplished through the use of groundwater flow modeling and optimization efforts, which build on years of data collection and scenario development.

The ANRC has long been an advocate for conservation, education, and the use of excess surface water, with water-use allocation being the last alternative. However, most hydrologists and water managers recognize that ultimately, sustainable yield implies some form of control of water use, usually resulting in the requirement for withdrawal permits. (Alley and Leake, 2004).

The ANRC is continuing to work with the Arkansas District of the US Geological Survey and CDM Smith and Associates, as a part of the Arkansas Water Plan update, to further define sustainable yield for the State's alluvial and Sparta/Memphis aquifers. Previous estimated sustainable yield values have been produced through the ANRC and USGS cooperative program, but the water plan process is providing a more comprehensive data set, and better forecasting methodology than was available for these estimates.

Groundwater Monitoring Programs

The US Geological Survey began monitoring groundwater levels in eastern Arkansas as early as 1927. As water-level declines, primarily in the Grand Prairie of eastern Arkansas, were observed by farmers, State officials and legislators began to set up monitoring sources at the State level. Over a period of many years, State agencies developed a strong water resources partnership with the Arkansas District of the U.S. Geological Survey. This State/Federal partnership and its monitoring network remain as the primary source of water resources data statewide.

In the early 1960s, the U.S. Geological Survey 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. Measurements were collected from 208 wells in the alluvial aquifer, and 75 wells in the Sparta aquifer. These measurements were mapped, analyzed, and reported.

By 1970, a strong cooperative program had developed between the Arkansas District of the U.S. Geological Survey, and the State's primary water-resources agencies such as the Arkansas Soil and Water Conservation Commission, the Arkansas Department of Environmental Quality, and the Arkansas Geological Survey.

Arkansas experienced a severe drought in 1980, and many farmers in eastern Arkansas were forced to lower pumps in irrigation wells as much as 20 to 30 feet. As a result, Jackson County, and soon afterwards Arkansas, Prairie, and Woodruff counties worked with the Arkansas Soil and Water Conservation Commission, today's ANRC, to initiate a well monitoring program that would try to evaluate the condition of the groundwater system. This study was designed to answer the question "Will our water supply recover or are we steadily diminishing the available supply?" The project area included 26 counties in eastern Arkansas with over 6.5 million acres of agricultural land.

Funding for the Eastern Arkansas Water Conservation Project was made available through the USDA Soil Conservation Service, todays NRCS, and has resulted in one of the broadest cooperative efforts of federal, state, and local entities on record. This project along with the USGS and ANRC cooperative program has evolved into the groundwater monitoring network that we have today. This program relies on the use of mostly existing wells for water-level and water-quality data collection, but some dedicated monitor wells are found throughout the State. US Geological Survey monitoring protocol is relied on to insure the best possible quality control.

The groundwater monitoring network in Arkansas is obviously concentrated where the aquifers of the state are utilized the most. The data collection sites are primarily existing irrigation and domestic wells, with a few public supply wells included. Some wells have been installed by ANRC and USGS to serve only as a data collection points in specific aquifers.

The USGS currently has 28 real-time monitoring wells which can be accessed on-line at http://groundwaterwatch.usgs.gov . These wells are spread across the state and monitor Quaternary alluvium, Sparta/Memphis Sand, Hot Springs Sandstone, Arkansas Novaculite, the Silurian System, Bigfork Chert, Stanley Shale, the Boone Formation and the Atoka Formation. There are a total of 928 active monitoring locations on this USGS web site including the wells monitored cooperatively with ANRC on a yearly basis as well as the USGS Master Wells. USGS also has a Northern Lonoke County Groundwater Monitoring Network consisting of 3 Memphis aquifer wells and 21 wells in the Quaternary alluvium. There are also the 42 ANRC wells installed specifically for data collection, and the data is collected on this web site. This web site has become the best location to access all ANRC/USGS groundwater data collected. Everything ANRC, USGS, and NRCS measures is compiled there showing historical measurements, graphs, and trends.

ADEQ has approximately 430 sites that have been historically used since the beginning of their monitoring program in the mid to late 80’s, of these approximately 250 are “active” monitoring sites. ADEQ primarily utilize domestic wells for their groundwater monitoring, but also sample municipal, irrigation and industrial supply wells. They also use springs where available. ADEQ’s network is broken down into 10 monitoring areas with 30-35 sites in each area; each area is sampled on a 3 year cycle.

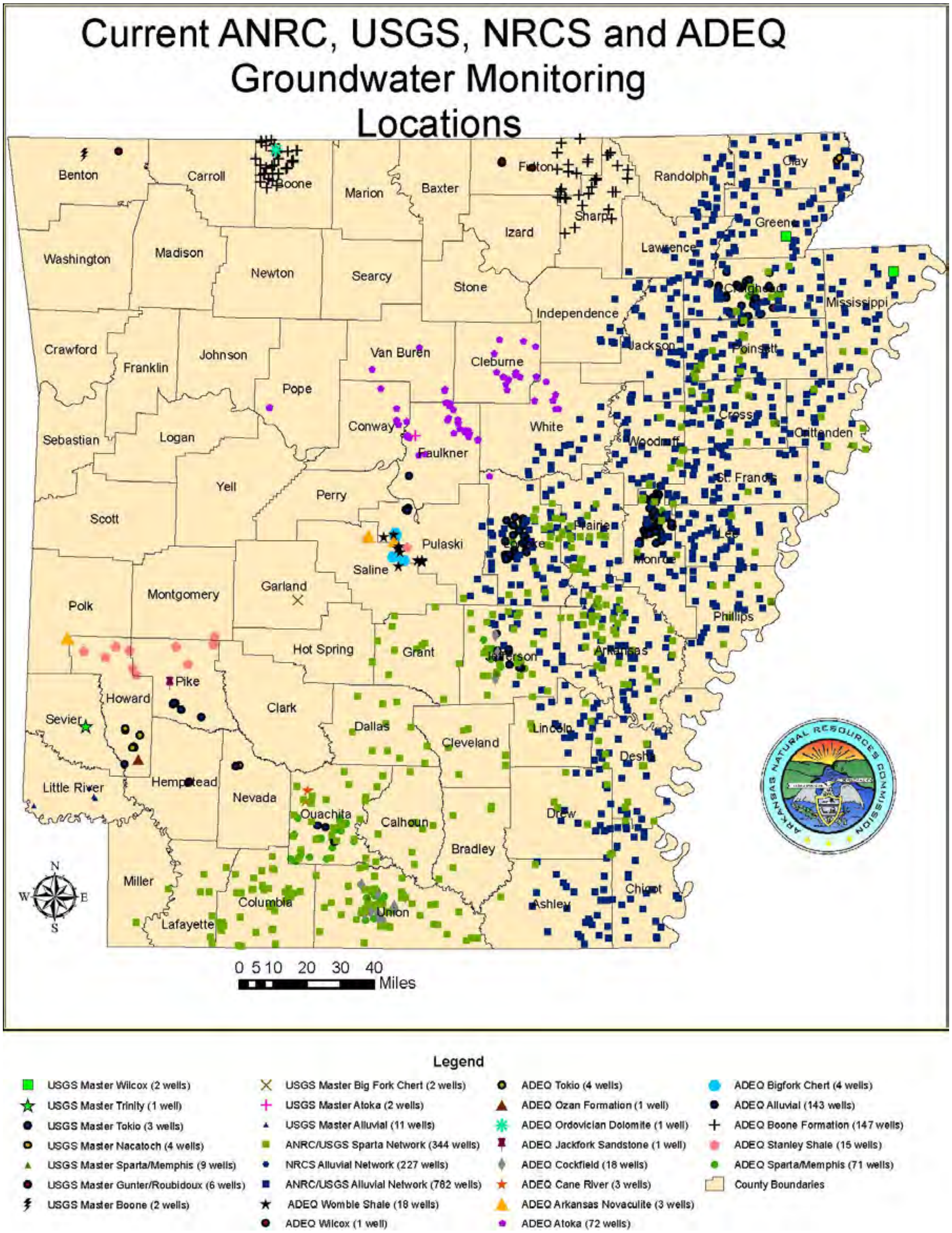


Fig. 21

Each year ANRC staff, works closely with the US Geological Survey (USGS) and the Natural Resource Conservation Service to collect water-level data from a network of approximately 1500 wells and springs statewide. This data is analyzed and reported in the annual Ground-Water Protection and Management Report; a report generated as part of the Arkansas Water Plan activities since the early 1990s. This section also provides data, presentations, and hydrogeologic evaluation to other agencies and the public as requested.

Artificial Recharge

The benefits of artificial recharge include seasonal and long-term storage, supplemental use, and prevention of saline water encroachment, water-quality enhancement, and improvement in well production, restoration of groundwater levels and subsidence prevention, and deferral of expanding water facilities where this option may be problematic. Various techniques exist that allow for the artificial recharge of aquifers. However, these techniques are not as efficient in all settings due to geologic, groundwater quality, and economic factors.

A University of Arkansas published an abstract of aquifer recharge studies 1954 (Steinbruegge and others, 1954) which provides a summary of the three basic methods of artificial recharge – surface spreading, recharge pits, and recharge wells. A team of hydrologists from various backgrounds inspected artificial recharge sites at Richmond and Los Angeles, California, and at El Paso, Austin, and King Ranch in Texas. Abstracts from approximately 100 aquifer recharge investigations were collected and evaluated as a part of this work. Though all three of these artificial recharge methods can work if the conditions are favorable, the cost-effectiveness may be unfeasible. For example, in the Grand Prairie of Arkansas, the clay cap of 50 to 80 feet in thickness prevents surface spreading and recharge pits, and recharge wells only work at great cost.

The 1965 US Geological Survey report "Testing Procedures and Results of Studies of Artificial Recharge in the Grand Prairie Region Arkansas"(Sniegocki and others, 1965) provided information on this process. Seventeen recharge tests were made with a well design similar to irrigation wells, and six tests were made with specially designed recharge wells. The results were less than satisfactory.
According to this study, artificial recharge was found to be unsuccessful due primarily to the high cost of water treatment. Without water quality treatment, the recharge wells clogged rapidly and ceased to function. If recharge through wells is to be done under hydrogeologic conditions similar to those at the test site, is recommended that the injected water be chlorinated, contain less than 5 ppm turbidity and no entrained air, be chemically compatible with the native groundwater and aquifer, and have approximately the same temperature as the native groundwater. It was also noted that redevelopment of the clogged wells was difficult and the original specific capacity of the well could not be achieved.

All of these studies reach the same conclusion, that the cost of well recharge is excessive due primarily to initial well drilling costs, well rehabilitation, and the cost of water treatment for water injected into wells. "It is the general opinion that the cost of well recharge is excessive and can only be justified in special cases." (Steinbruegge, 1954)

It is common for artificial recharge to be utilized as part of an overall aquifer storage and recovery (ASR) program such as the ones observed in the San Antonio and El Paso Texas areas where it is used to supplement public supply needs.

At the Twin Oaks ASR facility in the San Antonio, Texas area it has been successfully demonstrated implemented to meet the growing public supply needs of that area. However, it must be noted that this area has a different hydrogeologic and economic setting. The Edwards aquifer is primarily composed of limestone which has a greater transmissivity than the fine sediments of eastern Arkansas. Also, unlike a large-scale agricultural area, the Twin Oaks facility targets a specific well field area and water use need. Economically it must be considered that the Twin Oaks facility can provide 30 million gallons per day for $185 million dollars. However, during the irrigation season, agricultural wells in Poinsett County, Arkansas, alone provide about 585 mgd for crop production. Therefore, it would take many such ASR plants at a great cost to utilize this technology to provide supplement for Arkansas' agricultural use, and this at an extremely high cost.

Though artificial recharge and ASR can both be made to work in Arkansas, the hydrogeologic setting is not conducive, and therefore, not economically feasible. The ideal hydrogeologic setting for these technologies is a highly permeable formation found close to the surface, where the water use is for public supply wells, usually with a single well field area. Large agricultural areas typically are not ideal due to the areal extent of the water use and economic factors associated with the required water-quality treatment. However, though limited in its applicability to Arkansas with its enormous agricultural demands, ASR and artificial recharge may have a future in certain smaller scale scenarios, such as those areas where surface water diversion is not possible, the saturated thickness of the aquifer has been depleted, and the well field area is relatively confined.

One summary of artificial recharge was produced in 1990 (Fitzpatrick, 1990). Though recharge basins are less expensive to other forms of artificial recharge methods, they rarely coincide with hydrologically favorable areas. Recharge wells are the only functional alternative, but have serious cost drawbacks due to the cost of the well construction, water treatment, conveyance of the water, well rehabilitation, pumping, and energy consumption. For example, to maintain a minimum saturated thickness of 20 feet in the alluvial aquifer would require about 220 artificial recharge wells in the groundwater depletion area west of Crowleys Ridge, and about 500 in the Grand Prairie, representing a significant expense with a marginal benefit, especially when compared to the use of excess surface water.

Perhaps the early documented professional evaluation of artificial recharge wells in eastern Arkansas was close to being accurate. "I can't find any place in the country, where recharge wells under conditions similar to what you have here are functioning satisfactorily." (Thompson, 1931) However, the use of artificial recharge may yet serve as a valuable tool in Arkansas within certain site-specific locations where the hydrogeology and economics are favorable.

Groundwater and Climate Variation

Groundwater-level change and the volume of water stored in our State's aquifers are a result of the long-term precipitation patterns and the recharge characteristics of the aquifer's area of outcrop/sub crop. Though the groundwater system is very robust with respect to its response to floods and droughts, it is very slow to recharge once water-levels are depleted. The State's groundwater management policies and management programs must take into account the normal variation of precipitation and temperature within the State.

Global climate change could affect these variations in precipitation and temperature. However, such planning should not overreact, but respond accordingly to good science. Therefore, State water planners should not strive to define the causes of this matter, but rather to prepare for the varying weather patterns that may result from it.

The following charts identify the historical rainfall averages for Arkansas on a monthly basis. (Herndon, Dallas T., Centennial History of Arkansas, 1922)

	1879 – 1920	1879 – 1937
January	4.12	4.91
February	3.49	3.7
March	4.75	4.54
April	4.65	4.93
May	4.52	4.74
June	4.06	3.66
July	4.02	3.44
August	3.79	3.54
September	3.36	3.11

October	2.65	2.79
November	3.58	4.02
December	4.15	4.22
Statewide Total	47.14	47.6

From 1951 to 1980 the average statewide precipitation was 49.0 inches. (Friewald, 1987)

During this same time period the average temperature was 57.7 in northern Arkansas, 62 in the Little Rock area, and 64 in southern Arkansas. The growing season ranged from 169 to 241 days.

In 2012, John Czarnecki and Tony Schrader published US Geological Survey scientific investigations report 2012-5258 titled "Drought and Deluge: Effects of Recent Climate Variability on Groundwater Levels in Eastern Arkansas". This report provides valuable insight to the effects of the precipitation extremes observed in Arkansas from 2005 through 2010. The year 2009 has been documented as the wettest year in the meteorological records going back to 1878. 2005 and 2010 were the 7th and 14th driest years in Arkansas. During this time, groundwater-levels generally responded to the annual precipitation change. From 2004 to 2008, groundwater levels in the alluvial aquifer decreased by an average of 1.62 feet. This represents an especially dry period of time including 2005, the 7th driest year in historical records of Arkansas precipitation. However, water levels increased an average of 1.36 feet from 2006 to 2010, resulting from the record rainfall (89.71 inches) in 2009. This report demonstrates the value of the groundwater – monitoring network and the need for additional sites in Arkansas, both periodic and real-time continuous sites for the purpose of a better understanding of the State's water resources availability and limitations.

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Appendix I

Withdrawals of ground water from aquifers in Arkansas, 2010

(In million gallons per day: ---, no data available)

County	Deposits of Quaternary Age	Cockfield Formation	Cane River Formation	Sparta-Memphis Sand	Wilcox Group undifferentiated	Clayton Formation	Nacatoch Sand	Tokio Formation	Trinity Group	Rocks of Paleozoic age undifferentiated	County total
ARKANSAS	504.90	0.38	--	58.29	--	--	--	--	--	--	563.57
ASHLEY	129.16	10.02	--	--	--	--	--	--	--	--	139.18
BAXTER	--	--	--	--	--	--	--	--	--	1.37	1.37
BENTON	--	--	--	--	--	--	--	--	--	5.68	5.68
BOONE	--	--	--	--	--	--	--	--	--	1.79	1.79
BRADLEY	--	0.1	--	1.88	--	--	--	--	--	--	1.98
CALHOUN	--	--	--	0.63	--	--	--	--	--	--	0.63
CARROLL	--	--	--	--	--	--	--	--	--	2.09	2.09
CHICOT	201.24	1.96	--	0.48	--	--	--	--	--	--	203.68
CLARK		--	--	--	--	--	0.48	0.12	--	0.01	0.61
CLAY-TOTAL	**396.27**	--	--	0.12	0.8	--	1.22	--	--	1.44	399.85
CLAY-WEST	289.70										
CLAY-EAST	106.57										
CLEBURNE	0.37	--	--	--	--	--	--	--	--	--	0.37
CLEVELAND	--	--	--	1.16	--	--	--	--	--	--	1.16
COLUMBIA	0.04	--	--	4.36	--	--	--	--	0.02	--	4.42
CONWAY	1.66	--	--	--	--	--	--	--	--	--	1.66
TOTAL	**358.49**	--	--	13.38	0.77	--	--	--	--	--	372.64
CRAIGHEAD-WEST	183.14										
CRAIGHEAD-EAST	175.35										
CRAWFORD	0.87	--	--	--	--	--	--	--	--	--	0.87
CRITTENDEN	211.99	--	--	--	7.12	--	--	--	--	--	219.11
CROSS-TOTAL	**519.32**	--	--	5.21	0.35	--	--	--	--	--	524.88
CROSS-WEST	373.97										
CROSS-EAST	145.35										
DALLAS		--	--	0.78	--	--	--	--	--	--	0.78
DESHA	366.48	2.05	--	4.36	--	--	--	--	--	--	372.89

County	Deposits of Quaternary Age	Cockfield Formation	Cane River Formation	Sparta-Memphis Sand	Wilcox Group undifferentiated	Clayton Formation	Nacatoch Sand	Tokio Formation	Trinity Group	Rocks of Paleozoic age undifferentiated	County total
DREW	31.34	--	--	2.56	--	--	--	--	--	--	33.9
FAULKNER	4.53	--	--	--	--	--	--	--	--	--	4.53
FRANKLIN	0.47	--	--	--	--	--	--	--	--	0.01	0.48
FULTON	0.01	--	--	--	--	--	--	--	--	1.89	1.89
GARLAND	--	--	--	--	--	--	--	--	--	0.05	0.05
GRANT	3.39	--	--	1.73	--	--	--	--	--	--	5.12
GREENE-TOTAL	350.73	--	--	--	5.78	--	0.46	--	--	--	356.97
GREENE-WEST	280.58										
GREENE-EAST	70.15										
HEMPSTEAD		--	--	--	--	--	1.29	2.12	--	--	3.41
HOT SPRING		--	--	0.24	--	--	--	--	--	0.23	0.47
HOWARD		--	--	--	--	--	--	0.54	--	--	0.54
INDEPENDENCE	58.77	--	--	--	--	--	--	--	--	--	58.77
IZARD	--	--	--	--	--	--	--	--	--	1.3	1.3
JACKSON	422.96	--	--	0.33	--	--	--	--	--	--	423.29
JEFFERSON	237.94	1.12	--	45.5	--	--	--	--	--	--	284.56
JOHNSON	0.35	--	--	--	--	--	--	--	--	--	0.35
LAFAYETTE	25.43	0.01	0.65	0.75	0.02	--	--	--	--	0.01	26.87
LAWRENCE	179.35	--	--	--	--	--	0.01	--	--	0.55	179.91
LEE-TOTAL	308.86	--	--	0.94	0.05	--	--	--	--	--	309.85
LEE-WEST	263.80										
LEE-EAST	45.07										
LINCOLN	194.22	--	--	3.23	--	--	--	--	--	--	197.45
LITTLE RIVER	4.12	--	--	--	--	--	--	--	--	--	4.12
LOGAN	0.71	--	--	--	--	--	--	--	--	--	0.71
LONOKE	351.08	--	--	16.5	1.92	--	--	--	--	--	369.5
MADISON	--	--	--	--	--	--	--	--	--	0.93	0.93
MARION	--	--	--	--	--	--	--	--	--	0.84	0.84
MILLER	9.08	--	--	0.01	0.02	--	--	0.15	--	--	9.26
MISSISSIPPI	364.73	--	--	--	9.92	--	--	--	--	--	374.65

County	Deposits of Quaternary Age	Cockfield Formation	Cane River Formation	Sparta-Memphis Sand	Wilcox Group undifferentiated	Clayton Formation	Nacatoch Sand	Tokio Formation	Trinity Group	Rocks of Paleozoic age undifferentiated	County total
MONROE	293.63	0.95	--	1.33	--	--	--	--	--	--	295.91
MONTGOMERY	--	--	--	--	--	--	--	--	--	0.26	0.26
NEVADA	--	--	--	--	0.22	--	0.21	--	--	--	0.43
NEWTON	--	--	--	--	--	--	--	--	--	0.15	0.15
OUACHITA	--	--	0.08	1.3	--	--	0.01	--	--	--	1.39
PERRY	0.49	--	--	--	--	--	--	--	--	--	0.49
PHILLIPS	261.19	--	--	3.75	--	--	--	--	--	--	264.94
PIKE	0.64	--	--	--	--	--	--	--	--	0.01	0.65
POINSETT-TOTAL	842.99	1.97	--	2.4	3.32	--	--	--	--	--	850.68
POINSETT-WEST	419.64										
POINSETT-EAST	423.35										
POLK	--	--	--	--	--	--	--	--	--	1.16	1.16
POPE	0.71	--	--	--	--	--	--	--	--	1.01	1.72
PRAIRIE	227.82	--	--	10.32	2.17	--	--	--	--	--	240.31
PULASKI	15.27	--	--	0.93	--	--	--	--	--	0.03	16.23
RANDOLPH	111.64	--	--	--	--	--	--	--	--	0.05	111.69
SALINE	1.32	--	--	0.49	2.74	--	--	--	--	--	4.55
SCOTT	--	--	--	--	--	--	--	--	--	0.6	0.6
SEARCY	--	--	--	--	--	--	--	--	--	1.54	1.54
SEBASTIAN	0.24	--	--	--	--	--	--	--	--	--	0.24
SEVIER	0.81	--	--	--	--	--	--	--	0.14	--	0.95
SHARP	0.01	--	--	--	--	--	--	--	--	1.28	1.29
ST FRANCIS-TOTAL	346.72	0.67	--	0.09	0.56	--	--	--	--	--	348.04
ST FRANCIS-WEST	229.75										
ST FRANCIS-EAST	116.97										
STONE	0.07	--	--	--	--	--	--	--	--	0.61	0.68
UNION	0.05	--	--	7.59	--	--	--	--	--	--	7.64
VAN BUREN	--	--	--	--	--	--	--	--	--	0.25	0.25
WASHINGTON	--	--	--	--	--	--	--	--	--	1.09	1.09
WHITE	34.62	--	--	--	0.76	0.15	--	--	--	--	35.53

County	Deposits of Quaternary Age	Cockfield Formation	Cane River Formation	Sparta-Memphis Sand	Wilcox Group undifferentiated	Clayton Formation	Nacatoch Sand	Tokio Formation	Trinity Group	Rocks of Paleozoic age undifferentiated	County total
WOODRUFF	214.81	--	--	1.14	--	--	--	--	--	--	215.95
YELL	0.45	--	--	--	--	--	--	--	--	--	0.45
Total	7592.33	19.23	0.73	191.78	36.52	0.15	3.68	2.93	0.16	26.23	7873.74

Totals in Yellow boxes not included in grand total for Quaternary Alluvial.

Appendix II

Alluvial Aquifer 2013

County	Station ID	latitude	longitude	LSA	Date Measured	13 DTW	Aq Thickness	Saturated (ft)	% Saturated	12 DTW	08 DTW	03 DTW	Δ12-13	Δ08-13	Δ03-13
Arkansas	02S04W11DBB1	343232.89	912415.21	213.04	3/20/2013	100.95	145.3	44.35	30.5	100.08	100.74	101	(0.87)	(0.21)	0.05
Arkansas	02S05W15AAB1	343212.68	913126.72	213	3/19/2013	119.3	131.6	12.30	9.3	123.23	107.38	109.65	3.93	(11.92)	(9.65)
Arkansas	03S02W27ABB1	342447.92	911251.01	197.00	3/21/2013	64.20	155.6	91.40	58.7	62.76	65.92	69.6	(1.44)	1.72	5.40
Arkansas	03S03W05CCD1	342737.02	912131.83	201.00	5/3/2013	100.42	128.9	28.48	22.1	99.78	99.78	97.6	(0.64)	(0.64)	(2.82)
Arkansas	03S03W18CCC1	342553	912251	196.00	3/27/2013	100.94	116.5	15.56	13.4	101.04	102.24		0.10	1.30	
Arkansas	03S03W27BBC1	342454.73	911944.08	195.00	3/21/2013	95.75	134.0	38.25	28.5	93.09	93.04	90.8	(2.66)	(2.71)	(4.95)
Arkansas	03S04W02BBB1	342831	912454	197.63	3/20/2013	93.5	121.4	27.90	23.0	93.35	93.22	91.3	(0.15)	(0.28)	(2.20)
Arkansas	03S04W03DCA16	342753.04	912515.37	205	1/14/2013	101.29	126.5	25.21	19.9	101.55	101.14	99.85	0.26	(0.15)	(1.44)
Arkansas	03S05W13CBA2	342630	913007	211	2/25/2013	106.79	130.5	23.71	18.2	106.79	107.39		0.00	0.60	
Arkansas	04S01W19AAD1	342011.71	910919.34	196	3/26/2013	64.45	160.8	96.35	59.9	62.44		63.6	(2.01)		(0.85)
Arkansas	04S01W31DCB1	341753.45	910949.34	179	3/26/2013	49.95	147.3	97.35	66.1	50.04	52.42	53.25	0.09	2.47	3.30
Arkansas	04S03W17ADD1	342101.87	912058.11	200	3/26/2013	110.25	154.7	44.45	28.7	111.77	109.98	106.7	1.52	(0.27)	(3.55)
Arkansas	04S04W02ABB1	342313.2	912423.69	200	3/26/2013	111.36	142.9	31.54	22.1	110.06	109.89	108.4	(1.30)	(1.47)	(2.96)
Arkansas	05S01W16BAB1	341551.59	910729.49	183	3/26/2013	50.08	152.7	102.62	67.2	45.9	51.37	50.2	(4.18)	1.29	0.12
Arkansas	05S03W09CBA1	341624	912046	196	3/27/2013	115.66	167.9	52.24	31.1	114.71	113.09		(0.95)	(2.57)	
Arkansas	05S04W07CCC1	341555.36	912931.61	194	4/17/2013	73.49	176.4	102.91	58.3	73.88	75.05	76.8	0.39	1.56	3.31
Arkansas	05S04W32BBA1	341315.97	912821.81	191	4/17/2013	55.83	173.0	117.17	67.7	56.62	58.75	59.3	0.79	2.92	3.47
Arkansas	06S02W23DCD1	340852.62	911206.48	188	4/23/2013	62.4	170.0	107.60	63.3	74.2	70.61	65.3	11.80	8.21	2.90
Arkansas	06S03W10BBA1	341135.97	911953.82	184	4/23/2013	83.4	178.1	94.70	53.2	79.36	82.25	82.6	(4.04)	(1.15)	(0.80)
Arkansas	06S03W27AAA1	340857.58	911912.78	183.14	4/23/2013	71.15	173.1	101.95	58.9	68.28	68.55	68.6	(2.87)	(2.60)	(2.55)
Arkansas	06S03W32DDA1	340740	912115	180	3/27/2013	58.81	159.8	100.99	63.2	56.82	57.35		(1.99)	(1.46)	
Arkansas	07S02W04BBB1	340707.15	911451.89	176	4/23/2013	45.1	156.3	111.20	71.1	49.26	50.5	34.9	4.16	5.40	(10.20)
Arkansas	07S02W17BBA1	340529.84	911538.62	184	4/23/2013	51.13	164.3	113.17	68.9	48.89	54.05	52.9	(2.24)	2.92	1.77
Arkansas	07S03W18CCD1	340435.28	912316.09	186.18	4/23/2013	41.19	142.1	100.91	71.0	41.34	44.17		0.15	2.98	
Arkansas	07S03W32BBC1	340240	912216	176.92	4/23/2013	24.09	154.1	130.01	84.4	24.22	26.45		0.13	2.36	
Arkansas	07S04W01DDD1	340625.25	912327.15	186	4/23/2013	23.4	145.8	122.40	84.0	21.91			(1.49)		
Arkansas	08S02W08ACA1	340041.03	911505.57	179	4/23/2013	42.55	146.2	103.65	70.9	40.66	42.67		(1.89)	0.12	
Arkansas	08S03WT2299	340147.45	912202.5	178	4/23/2013	24.5	162.1	137.60	84.9	20.53	22.09	21.6	(3.97)	(2.41)	(2.90)
								Average %	49.9	Declines/ Wells			16/28	13/26	12/20
										Average Change:			(0.33)	0.23	(1.23)
Ashley	15S04W26DCC1	332231.97	912902.22	127	2/27/2013	33.65	84.5	50.85	60.2	32.72	32.17	30.2	(0.93)	(0.55)	(3.45)
Ashley	15S07W21CBA1	332315.7	915001.37	210.00	3/4/2013	5.50				7.54	4.52	6.5	2.04	(3.02)	1.00
Ashley	16S06W25DDD1	331640	913958	182	3/5/2013	80.4				79.42	78.47		(0.98)	(0.95)	
Ashley	17S04W03ABB1	331528	913010	124	2/27/2013	36.45	159.9	123.45	77.2	35.26	30.77	30.1	(1.19)	(4.49)	(6.35)
Ashley	17S04W15DDC1	331252.48	912954.09	116	2/28/2013	34.57	187.9	153.33	81.6	31.83	27.7	23.3	(2.74)	(4.13)	(11.27)
Ashley	17S04W21ABA1	331252	913108	117	3/6/2013	29.8	188.2	158.40	84.2	28.17	22.97	22.90	(1.63)	(5.20)	(6.90)
Ashley	17S06W35CAC1	331049	914136	179	3/5/2013	73.1				72.42	72.41	71.8	(0.68)	(0.01)	(1.30)
Ashley	18S04W23DDD1	330658	912856	103	4/16/2013	35	155.2	120.20	77.4		30	16			(19.00)
Ashley	18S05W11CCD1	330841	913538	118	4/16/2013	28				21	27	15	(7.00)	6.00	(13.00)
Ashley	18S05W22DDA1	330712	913555	125	4/16/2013	25	163.2	138.20	84.7	23	22	12	(2.00)	(1.00)	(13.00)
Ashley	18S08W28DDD2	330624.8	915528.46	163	3/26/2013	85.2				85.15	85.11		(0.05)	(0.04)	
Ashley	19S04W14BBB1	330310	912913	107	4/16/2013	33	142.6	109.60	76.9	32.2	31	21	(0.80)	(1.20)	(12.00)

Alluvial Aquifer 2013

County	Station ID	latitude	longitude	LSA	Date Measured	13 DTW	Aq Thickness	Saturated (ft)	% Saturated	12 DTW	08 DTW	03 DTW	Δ12-13	Δ08-13	Δ03-13
Ashley	19S05W08ACA1	330405	913815	111	4/16/2013	20				22	18	11	2.00	(4.00)	(9.00)
Ashley	19S05W16ABB1	330323	913718	116	4/16/2013	35	141.1	106.10	75.2	27	28	15	(8.00)	1.00	(20.00)
Ashley	19S05W22DCD1	330139	913615	107	4/16/2013	29	126.6	97.60	77.1	28.4	26	14	(0.60)	(2.40)	(15.00)
Ashley	19S06W07BCC1	330403.56	914607.92	134.7	3/5/2013	32.7				31.56	32.46		(1.14)	0.90	
								Average %	77.2	Declines/ Wells			13/15	13/16	12/13
										Average Change:			(1.58)	(1.27)	(9.94)
Chicot	13S03W27AAA1	333253	912310	138	4/25/2013	50	86.2	36.20	42.0	49.3			(0.70)		
Chicot	13S03W34BAA1	333110.24	912539.38	133	5/15/2013	43.26	74.0	30.74	41.5	45.26		39	2.00		(4.26)
Chicot	13S03W35BAC1	333154.05	912245.53	134	5/15/2013	43.11	80.5	37.39	46.4	44.4	41.29		1.29	(1.82)	
Chicot	14S02W09BDD1	332859	911729	135	4/25/2013	31	89.6	58.60	65.4		30	29		(1.00)	(2.00)
Chicot	14S03W07BBD1	333011.09	912620	134	5/21/2013	32.77	90.5	57.73	63.8	30.9	27.62		(1.87)	(5.15)	
Chicot	15S02W20DDC1	332226.59	911919.83	126	4/25/2013	32	104.2	72.20	69.3	31.75	28.12		(0.25)	(3.88)	
Chicot	16S03W15DAD1	331818	912334	118	2/21/2013	31.9	108.3	76.40	70.5	33.94			2.04		
Chicot	17S01W06BCC1	331501.18	911505.22	115	2/20/2013	23.15	139.3	116.15	83.4	23.21	21.57		0.06	(1.58)	
Chicot	17S03W18CBC1	331257	912736	115	4/25/2013	38	174.0	136.00	78.2	35.6	35	32.00	(2.40)	(3.00)	(6.00)
Chicot	18S01W33BDA1	330543	911245	115	4/25/2013	13	134.5	121.50	90.3	10	14		(3.00)	1.00	
Chicot	18S03W22ABA2	330728	912341	103	2/20/2013	65.6	146.0	80.40	55.1						
Chicot	19S01W17BCC1	330250.36	911406.24	106	2/19/2013	14.3	122.9	108.60	88.4		20.57			6.27	
								Average %	66.2	Declines/ Wells			5/9	6/8	3/3
										Average Change:			(0.31)	(1.15)	(4.09)
Clay	18N08E03DAB1	361323.23	901153.03	257	4/30/2013	6.15	129.2	123.05	95.2	7.27	4.29	4.68	1.12	(1.86)	(1.47)
Clay	19N04E19BAA1	361649	904125		5/29/2013	24.4	138.3	113.90	82.4		31.56	21.00		7.16	(3.40)
Clay	19N05E15BBD1	361716	903152	289	5/29/2013	46.9	130.0	83.10	63.9		39	32.60		(7.90)	(14.30)
Clay	20N03E25BAA1	362112	904225	288	5/29/2013	15.1	141.4	126.30	89.3		23	21.90		7.90	6.80
Clay	20N04E06BB1	362444.34	904131.25		5/1/2013	22.7	137.0	114.30	83.4			18.70			(4.00)
Clay	20N05E30CAC1	362003	903454	283	5/29/2013	19.9	124.9	105.00	84.1	18.5	17.4	16.30	(1.40)	(2.50)	(3.60)
Clay	20N09E33DDC1	361904	900628	270	5/20/2013	6.1	106.7	100.60	94.3	6.4	5	6.40	0.30	(1.10)	0.30
Clay	21N03E15CBC1	362738	904453	292	5/29/2013	10.8	142.6	131.80	92.4	10.8	5	11.90	0.00	(5.80)	1.10
Clay	21N06E28BB1	362604.92	902607.97	292.5	4/30/2013	26	105.7	79.70	75.4	19.9	19.38	17.90	(6.10)	(6.62)	(8.10)
Clay	21N07E01DDC1	362835	901607	303	5/29/2013	30.8	96.3	65.50	68.0	25.5	33.2	18.30	(5.30)	2.40	(12.50)
Clay	21N08E18CCC1	362650.9	901550.33	324	4/30/2013	45.25	111.9	66.65	59.6		40.71	36.10		(4.54)	(9.15)
Clay	21N09E31BDA1	362447	900851	284	5/20/2013	6.9	71.3	64.40	90.3	5.2	1	5.00	(1.70)	(5.90)	(1.90)
								Average %	81.5	Declines/ Wells			4/7	8/11	9/12
										Average Change:			(1.87)	(1.71)	(4.19)
Craighead	13N01E23CAB1	354430	905736	242	3/12/2013	71	92.7	21.70	23.4	72.2		64.90	1.20		(6.10)
Craighead	13N04E12ABB1	354635	903656	231	4/23/2013	27.7	108.0	80.30	74.4	25.61	24.51	25.40	(2.09)	(3.19)	(2.30)
Craighead	14N01E10BAB1	355204	905828	246	3/12/2013	58	100.8	42.80	42.5	59.4	54	48.70	1.40	(4.00)	(9.30)
Craighead	14N02E27AAA1	354915.7	905124.5	255	4/22/2013	86.1	106.9	20.80	19.5	85.16	82.25		(0.94)	(3.85)	

Alluvial Aquifer 2013

County	Station ID	latitude	longitude	LSA	Date Measured	13 DTW	Aq Thickness	Saturated (ft)	% Saturated	12 DTW	08 DTW	03 DTW	Δ12-13	Δ08-13	Δ03-13
Craighead	14N06E27AAB1	354911.46	902559.08	225.93	4/23/2013	2.7	96.0	93.30	97.2	2.81	0.25		0.11	(2.45)	
Craighead	15N06E04BAD1	355744	902706	239	3/12/2013	18.1	77.9	59.80	76.8	17.5	17.4	11.10	(0.60)	(0.70)	(7.00)
Craighead	15N06E20DDD1	355426	902739	234	4/24/2013	10.23	87.2	76.97	88.3	9.73	9.37	8.35	(0.50)	(0.86)	(1.88)
								Average %	60.3	Declines/ Wells			4/7	6/6	5/5
										Average Change:			(0.20)	(2.51)	(5.32)
Crittenden	05N07E08BDC1	350407	902234		6/5/2013	23						20.50			(2.50)
Crittenden	05N07E28CBA1	350121.32	902139.85	201	4/30/2013	18.55				16.06	17.08	18.70	(2.49)	(1.47)	0.15
Crittenden	05N07E34BAB1	350059.39	902029.86	203	4/30/2013	13.3	136.0	122.70	90.2	14.36	16.27	12.50	1.06	2.97	(0.80)
Crittenden	05N07E34CDD1	350010	902028	205	6/4/2013	11	142.8	131.80	92.3		9.9	12.50		(1.10)	1.50
Crittenden	06N07E14ABA1	350848	901858		6/4/2013	22	128.6	106.60	82.9			20.50			(1.50)
Crittenden	07N06E29CBC1	351152	902914		6/4/2013	42	141.9	99.90	70.4			37.50			(4.50)
Crittenden	07N07E05DAD1	351504	902129	215	4/24/2013	33.2	144.6	111.40	77.0	30.98		29.35	(2.22)		(3.85)
Crittenden	07N07E31CCC1	351041.9	902358.97	207	4/24/2013	39.09	138.2	99.11	71.7	36.53	36.48	33.40	(2.56)	(2.61)	(5.69)
Crittenden	07N08E04BBD1	351538	901505		6/4/2013	21	140.6	119.60	85.1			19.00			(2.00)
Crittenden	07N09E05CDD1	351453.34	900933.58	214	4/30/2013	6.9	117.0	110.10	94.1			5.50			(1.40)
Crittenden	08N06E01DCC1	352021	902408	215	6/5/2013	33.5	123.0	89.50	72.8			33.00			(0.50)
Crittenden	08N07E13CCC2	351828.34	901811.95	221	5/7/2013	31.12	137.1	105.98	77.3	31.13	31.43	29.20	0.01	0.31	(1.92)
Crittenden	08N07E14DAA2	351854.41	901832.68	219.00	4/9/2012	32.62	135.2	102.58	75.9		31.82			(0.80)	
Crittenden	08N07E32DAA1	351618	902146	215	6/4/2013	27.5	138.2	110.70	80.1		31.4	28.50		3.90	1.00
Crittenden	08N07E35BCB1	351630	901933	221	4/20/2013	33.9	147.6	113.70	77.0	32.56	32.58		(1.34)	(1.32)	
Crittenden	08N08E06ABB1	352103	901644	223	6/4/2013	30	135.6	105.60	77.9		31.3	29.00		1.30	(1.00)
Crittenden	09N06E30ADD1	352235	902904	214	6/5/2013	34.5					34			(0.50)	
Crittenden	09N07E02CDB1	352537	901905	225	6/4/2013	32	126.0	94.00	74.6		33.5	29.00		1.50	(3.00)
Crittenden	09N07E10DDA1	352447.58	901924.64	221	4/30/2013	30.15	123.7	93.55	75.6	28.84	29.29	28.30	(1.31)	(0.86)	(1.85)
Crittenden	09N07E31BAB1	352159.85	902326.57	221	6/4/2013	35	124.7	89.70	71.9	33.2	34.06	32.50	(1.80)	(0.94)	(2.50)
Crittenden	09N08E04CDC1	352527	901444		6/5/2013	27.5									
								Average %	79.2	Declines/ Wells			6/8	8/13	14/17
										Average Change:			(1.33)	0.03	(1.79)
Cross	07N02E02CDD1	351508	905113	225	4/10/2013	85.3	156.1	70.80	45.4	84.14			(1.16)		
Cross	07N02E29DDC1	351138.09	905409.17	220	4/10/2013	75.3	152.8	77.50	50.7	72.5	74.14	69.80	(2.80)	(1.16)	(5.50)
Cross	07N05E24CCC1	351232	903121		6/4/2013	40	143.2	103.20	72.1						
Cross	08N05E32ADD1	351631.65	903440.45	204	4/9/2013	28.2	142.0	113.80	80.1	27.23	31.47	26.70	(0.97)	3.27	(1.50)
Cross	09N01E12CBB1	352505	905653		4/9/2013	97.8	148.7	50.90	34.2			78.10			(19.70)
Cross	09N05E32BDB1	352150.53	903512.11	210.00	4/9/2013	30.5	125.7	95.20	75.7	28.99	32.17	30.40	(1.51)	1.67	(0.10)
								Average %	59.7	Declines/ Wells			4/4	1/3	4/4
										Average Change:			(1.61)	1.26	(6.70)
Desha	07S01E19ABA1	340428	910303	154	5/9/2013	14	140.6	126.60	90.0	14	22.5	14.20	0.00	8.50	0.20
Desha	09S01W08BDA1	335608	911234	151	4/9/2013	32	137.8	105.80	76.8	23.4	30	26.00	(8.60)	(2.00)	(6.00)
Desha	09S01W15CBB1	335501	911055	152	4/9/2013	40	138.8	98.80	71.2	38.6	39	35.00	(1.40)	(1.00)	(5.00)

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County	Station ID	latitude	longitude	LSA	Date Measured	13 DTW	Aq Thickness	Saturated (ft)	% Saturated	12 DTW	08 DTW	03 DTW	Δ12-13	Δ08-13	Δ03-13
Desha	09S02W26DDC1	335256.57	911529.64	149.27	2/26/2013	34.38	130.6	96.22	73.7	33.28	31.68	30.20	(1.10)	(2.70)	(4.18)
Desha	09S03W05BAC1	335704	912506	161	4/9/2013	42.8	146.5	103.70	70.8	48.6			5.80		
Desha	09S03W13BAB1	335500	911922		4/9/2013	35.2				36.5			1.30		
Desha	09S03W17DCB1	335448.23	912456.66	155.08	2/27/2013	38.65	139.8	101.15	72.4	37.38	33.68	33.80	(1.27)	(4.97)	(4.85)
Desha	09S04W06BCA1	335756.06	913242.95	161	2/26/2013	38.09	148.0	109.91	74.3	37.66	36.43	33.60	(0.43)	(1.66)	(4.49)
Desha	09S04W06CBB1	335629.1	913256.6	162	4/16/2013	52	148.0	96.00	64.9	44			(8.00)		
Desha	10S01W23CDA1	335305	911032		4/9/2013	30.8				23			(7.80)		
Desha	10S02W11ADD1	335045	911517	148	4/9/2013	29	128.2	99.20	77.4	35	31	27.00	6.00	2.00	(2.00)
Desha	10S02W20ADA1	334916	911825	148	2/26/2013	43.35				42.16	40.85		(1.19)	(2.50)	
Desha	10S03W26CAA1	334806	912144.55	150	2/26/2013	49.68	131.8	82.12	62.3	48.71	47.43	44.03	(0.97)	(2.25)	(5.65)
Desha	10S04W12DBB1	335101.64	912729.27	152	2/26/2013	37.03	132.4	95.37	72.0		31.73			(5.30)	
Desha	11S02W15ADD1	334446	911635	148	4/9/2013	35.4	120.9	85.50	70.7	35.9		33.00	0.50		(2.40)
Desha	11S03W16CBA1	334439	912433	155	4/9/2013	38.3				36			(2.30)		
Desha	13S02W17ADA1	333421	911858		4/9/2013	48.9				47.2			(1.70)		
Desha	13S02W27CAC1	333223.99	911734.76	133	2/26/2013	34.58	89.4	54.82	61.3	33.92	32.43	30.90	(0.66)	(2.15)	(3.68)
Desha	13S03W11CAB1	333503	912241	142	4/9/2013	48.9	96.4	47.50	49.3	56.4	52	47.00	7.50	3.10	(1.90)
								Average %	70.5	Declines/ Wells			12/18	9/12	10/11
										Average Change:			(0.80)	(0.91)	(3.63)
Drew	11S04W35CDD1	334144	912842	154	2/21/2013	31.28	118.3	87.02	73.6	30.11			(1.17)		
Drew	11S05W08CCC1	334546.48	913837.16	185	2/21/2013	40.3	149.2	108.90	73.0	38.52			(1.78)		
Drew	12S04W03ABB1	334133.92	912946.13	155	2/21/2013	28.8	119.1	90.30	75.8	27.2	26.02	24.00	(1.60)	(2.78)	(4.80)
Drew	13S04W33BAA1	333206.47	913100.3	138	2/20/2013	25.59	90.3	64.71	71.7		19.32	15.70		(6.27)	(9.89)
Drew	13S06W03DDC1	333544.69	914201.6	191	2/20/2013	58.49					64.89	58.70		6.40	0.21
Drew	15S04W13DAD1	332338	912730	131	4/25/2013	2	89.1	87.10	97.8	1.3			(0.70)		
								Average %	78.4	Declines/ Wells			4/4	2/3	2/3
										Average Change:			(1.31)	(0.88)	(4.83)
Greene	15N05E34ACC1	350006	903329		3/29/2013	26									
Greene	16N03E03BA1	360315.87	904515.85	260	4/29/2013	37.5	121.0	83.50	69.0	36.38		28.95	(1.12)		(8.55)
Greene	16N03E05BBB1	360316	904750	257.00	4/2/2012	35.90	120.1	84.20	70.1		32.6	28.90		(3.30)	(7.00)
Greene	16N03E16DDD1	360049	904547	258	4/16/2013	37.2	112.7	75.50	67.0	37	28.1	26.70	(0.20)	(9.10)	(10.50)
Greene	16N03E20CDA1	355957	904742		4/16/2013	37.25									
Greene	16N06E28ABB1	355938.31	902657.01	251	4/24/2013	31	83.2	52.20	62.7		25.73	26.65		(5.27)	(4.35)
Greene	17N03E02DCC1	360806	904352	267	4/16/2013	39.1	137.4	98.30	71.5	45.6	30.8	30.70	6.50	(8.30)	(8.40)
Greene	17N03E32CDC1	360317	904735		4/16/2013	36.5									
Greene	17N03E35CB1	360347	904437	259	4/16/2013	38.5	120.7	82.20	68.1	36.5			(2.00)		
Greene	17N04E07AD1	360718	904122	271	4/16/2013	47.8	132.6	84.80	64.0	43.3	38.1	41.90	(4.50)	(9.70)	(5.90)
Greene	17N04E28DAA1	360431	903917	319	4/26/2013	90.9				89.79	87.26		(1.11)	(3.64)	
Greene	17N06E15ABC1	360631	902546	268	4/23/2013	39.2	106.1	66.90	63.1	36.1	30.9	39.90	(3.10)	(8.30)	0.70
Greene	17N07E01BBA1	360832	901724	248	4/23/2013	5.4	125.6	120.20	95.7	5.1			(0.30)		
Greene	17N07E28CBA1	360424	902045	245	4/16/2013	7.5	103.2	95.70	92.7						

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County	Station ID	latitude	longitude	LSA	Date Measured	13 DTW	Aq Thickness	Saturated (ft)	% Saturated	12 DTW	08 DTW	03 DTW	Δ12-13	Δ08-13	Δ03-13
Greene	18N03E24ACA1	361119	904216	270.00	4/16/2013	36.25	136.0	99.75	73.3	36.50	35.1		0.25	(1.15)	
Greene	18N04E04AAC1	361356	903854	273	4/16/2013	36.75	128.6	91.85	71.4		31.3	32.20		(5.45)	(4.55)
Greene	18N04E21CBD1	361052.32	903724.76	294	4/25/2013	60.9					58.57	53.30		(2.33)	(7.60)
Greene	18N06E23ABB1	361109	902402	280	4/23/2013	18.5	128.9	110.40	85.6						
Greene	18N07E05DAB1	361316	902024.5	275	4/23/2013	17.75	125.0	107.25	85.8	14.1			(3.65)		
Greene	18N07E20BBA1	361110.37	902113.23	257	4/25/2013	14.3	109.8	95.50	87.0	10.18	7.23	6.25	(4.12)	(7.07)	(8.05)
Greene	19N03E33DDD1	361418	904516	276	4/16/2013	38.67	144.2	105.53	73.2	40.6	36.5	40.40	1.93	(2.17)	1.73
								Average %	75.0	Declines/ Wells			9/12	12/12	9/11
										Average Change:			(0.95)	(5.48)	(5.68)
Independence	11N04W22BBA1	353409	912506		5/13/2013	3									
Independence	12N04W14DD1	353929.42	912236.26	231	4/22/2013	24.43	124.4	99.97	80.4	22.03	10.54	25.20	(2.40)	(13.89)	0.77
Independence	12N04W34CBB1	353720.1	912512.5	231	4/22/2013	18.9	128.2	109.30	85.3	20.83	4.47	18.90	1.93	(14.43)	0.00
Independence	12N05W36AAA1	353738.04	912827.22	236	5/13/2013	21.6	131.9	110.30	83.6			21.00			(0.60)
Independence	14N03W14CB2	355105	911700	236	5/13/2013	1.9	107.4	105.50	98.2	5.2	6.41		3.30	4.51	
								Average %	86.9	Declines/ Wells			1/3	2/3	1/3
										Average Change:			0.94	(7.94)	0.06
Jackson	11N01W11CBB1	353550	910428		4/22/2013	55.73									
Jackson	11N01W29AAD1	353338.66	910635.27	225	4/22/2013	43	150.6	107.60	71.4	41.4	41.88	38.60	(1.60)	(1.12)	(4.40)
Jackson	11N03W06DAB1	353655.13	912008.5	223	4/22/2013	17.51	127.2	109.69	86.2	12.96		19.70	(4.55)		2.19
Jackson	12N04W10BBC1	354107	912357		5/13/2013	24.6									
Jackson	13N03W15CDD1	354525.9	911749.46	232	4/22/2013	15.4	110.2	94.80	86.0		7.41				(15.40)
Jackson	14N01W09AAA1	355220.36	910515.16	251	4/22/2013	44	114.1	70.10	61.4	45.35		39.70	1.35		(4.30)
								Average %	76.3	Declines/ Wells			2/3	1/1	3/4
										Average Change:			(1.60)	(1.12)	(5.48)
Jefferson	03S09W22AAA1	342639.63	915728.43	218	4/1/2013	45	120.6	75.60	62.7	42	43	39.80	(3.00)	(2.00)	(5.20)
Jefferson	03S09W29CBD1	342516.81	920023.32	216	4/25/2013	28.4	114.2	85.80	75.1	27.08	27.74	25.25	(1.32)	(0.66)	(3.15)
Jefferson	03S10W35BBC1	342449	920358	215	4/1/2013	17	107.9	90.90	84.2	11	8.5		(6.00)	(8.50)	
Jefferson	04S07W35DDB1	341836	914347	185	4/8/2013	35.5	109.6	74.10	67.6	30.6		25.70	(4.90)		(9.80)
Jefferson	05S06W31CAA1	341329.94	914206.1	189.22	4/24/2013	18.1	116.7	98.60	84.5		18.33			0.23	
Jefferson	05S07W29DDD1	341410.52	914653.88		4/12/2013	15.6									
Jefferson	05S08W12DAA1	341712	914907	194.25	4/24/2013	18.85	120.9	102.05	84.4	18.05		16.55	(0.80)		(2.30)
Jefferson	06S05W15BCA1	341022.95	913245	177.14	4/24/2013	17.76	133.9	116.14	86.7	16.69		19.50	(1.07)		1.74
Jefferson	06S06W23AAD1	341006.74	913712.2	189.01	4/24/2013	18	130.0	112.00	86.2	19.37		18.60	1.37		0.60
Jefferson	07S08W06BAA1	340858.53	915647.26	202.31	4/24/2013	20.12	116.7	96.58	82.8	20.62	19.07	18.30	0.50	(1.05)	(1.82)
								Average %	79.4	Declines/ Wells			6/9	4/5	5/7
										Average Change:			(1.90)	(2.40)	(2.85)

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County	Station ID	latitude	longitude	LSA	Date Measured	13 DTW	Aq Thickness	Saturated (ft)	% Saturated	12 DTW	08 DTW	03 DTW	Δ12-13	Δ08-13	Δ03-13
Lawrence	15N01E09ABD1	355714	905900	259	4/23/2013	60.05	117.6	57.55	48.9	58.8	55.25		(1.25)	(4.80)	
Lawrence	15N01E26DDA1	355401.91	905639.34	251	4/23/2013	55.2	106.2	51.00	48.0	54.76	54.07	48.15	(0.44)	(1.13)	(7.05)
Lawrence	15N01E32BAA1	355352	910027	254	4/23/2013	57.95	111.5	53.55	48.0	55.45	53.09		(2.50)	(4.86)	
Lawrence	15N01W35CBB1	355336.15	910356.33	250	4/23/2013	51.19	111.8	60.61	54.2	49.04	46.68	43.25	(2.15)	(4.51)	(7.94)
Lawrence	16N01E11DAC2	360203.04	905639.37	262	4/23/2013	52.5	126.0	73.50	58.3	51.61	48.69	44.80	(0.89)	(3.81)	(7.70)
Lawrence	17N02E25CBD1	360423	904948	265	4/3/2013	44.1	131.9	87.80	66.6			35.00			(9.10)
								Average %	54.0	Declines/ Wells			5/5	5/5	4/4
										Average Change:			(1.45)	(3.82)	(7.95)
Lee	01N01E04AAB1	344358	910015	175	5/14/2013	39	135.5	96.50	71.2	37.5		25.30	(1.50)		(13.70)
Lee	01N02E33CCB1	343851	905433	185	5/14/2013	13.5	143.8	130.30	90.6	15.5	9		2.00	(4.50)	
Lee	01N03E27ADD1	343952	904605	204	5/14/2013	17.5	142.3	124.80	87.7	29		9.00	11.50		(8.50)
Lee	02N01E18ACC1	344708	910222	187	5/14/2013	50	146.1	96.10	65.8						
Lee	02N02E08ADC1	344807.34	905338.75	201	3/19/2013	48.35	151.8	103.45	68.1	46.35	45.92	40.35	(2.00)	(2.43)	(8.00)
Lee	02N02E21ABC1	344621.57	905358.16	200	3/20/2013	42.75	151.6	108.85	71.8		41.25	38.30		(1.50)	(4.45)
Lee	02N03E09DDD1	344723	904707	220	5/14/2013	52	163.1	111.10	68.1	49.6	47	49.00	(2.40)	(5.00)	(3.00)
Lee	02N04E03ABD1	344855	903954	192	5/14/2013	20.5	141.7	121.20	85.5		26	22.00		5.50	1.50
Lee	03N01E10BBB1	345339	905946	205	5/14/2013	75	160.3	85.30	53.2						
Lee	03N01E15CC1	345206	905947	205	3/15/2013	68	157.9	89.90	56.9	66.48	63.96		(1.52)	(4.04)	
Lee	03N02E13BBA1	345237.4	905107.32	212	3/20/2013	52	159.5	107.50	67.4	50.22	51.87	48.65	(1.78)	(0.13)	(3.35)
Lee	03N02E17BBB1	345235	905520	204	5/14/2013	51	153.0	102.00	66.7						
Lee	03N03E32CAB1	344932.65	904926.23	204	3/19/2013	50.9	151.2	100.30	66.3	48.99			(1.91)		
Lee	03N04E07CBB1	345245	904312	200	5/14/2013	18	148.1	130.10	87.8	16			(2.00)		
Lee	03N05E14DDA1	345148.08	903203.25	193	3/14/2013	14.6	149.3	134.70	90.2	11.57	15.79	12.65	(3.03)	1.19	(1.95)
Lee	03N05E26ADC1	345020	903215	185	5/14/2013	8	144.7	136.70	94.5	4.5		5.00	(3.50)		(3.00)
								Average %	74.5	Declines/ Wells			9/11	6/8	7/9
										Average Change:			(0.56)	(1.36)	(4.94)
Lincoln	07S06W03CCA2	340828	914114	190	4/15/2013	20	114.3	94.30	82.5	16	22.00	19.00	(4.00)	2.00	(1.00)
Lincoln	07S07W36CBD1	340411	914529	183	4/15/2013	44	116.2	72.20	62.1	42	38.00	37.00	(2.00)	(6.00)	(7.00)
Lincoln	08S04W06ABD1	340341	913116	171	4/16/2013	14	101.5	87.50	86.2	12	15.00	14.00	(2.00)	1.00	0.00
Lincoln	08S04W08BBB2	340253.92	913100.76	171	3/7/2013	20.4				20.13		19.45	(0.27)		(0.95)
Lincoln	08S04W29ABC1	340021	913044	176	4/15/2013	47				32		46.00	(15.00)		(1.00)
Lincoln	08S04W31CBA1	335901.09	913149.69	161.9	3/7/2013	36.41	161.9	125.49	77.5	35.75	34.00	32.30	(0.66)	(2.41)	(4.11)
Lincoln	08S05W12AAD1	340246	913214	165	4/16/2013	26	109.9	83.90	76.3	32		21.00	6.00		(5.00)
Lincoln	08S05W21DCD1	340027	913533	169	4/16/2013	31	129.7	98.70	76.1	26	36.00	34.00	(5.00)	5.00	3.00
Lincoln	08S05W32DCC1	335840	913644	172	4/15/2013	55	137.3	82.30	59.9	62	45.00	45.00	7.00	(10.00)	(10.00)
Lincoln	08S07W05DDD1	340300.81	914902.72	190	3/7/2013	31.45	133.3	101.85	76.4	31.1	30.40	30.00	(0.35)	(1.05)	(1.45)
Lincoln	09S05W14ABC1	335553.02	913439.08	172.5	3/13/2013	44.88	152.8	107.92	70.6	41.95	39.00	37.05	(2.93)	(5.88)	(7.83)
Lincoln	09S05W17BCB1	335551.59	913819.95	171	3/13/2013	42.2	133.3	91.10	68.3	40.96	38.10		(1.24)	(4.10)	
Lincoln	09S05W19CCC1	335428	913941	171	4/16/2013	38	131.4	93.40	71.1	40			2.00		
Lincoln	09S06W04BCD1	335821.38	914345.83	181	3/7/2013	44.65	123.0	78.35	63.7	43.21	42.40	40.10	(1.44)	(2.25)	(4.55)

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County	Station ID	latitude	longitude	LSA	Date Measured	13 DTW	Aq Thickness	Saturated (ft)	% Saturated	12 DTW	08 DTW	03 DTW	Δ12-13	Δ08-13	Δ03-13
Lincoln	10S05W05BCB1	335228	913833	172	3/13/2013	29.42	134.3	104.88	78.1						
Lincoln	10S05W06DCC1	335155.3	913907.96	175	3/13/2013	29.88	140.9	111.02	78.8	29.82	28.10		(0.06)	(1.78)	
								Average %	73.4	Declines/ Wells			12/15	9/12	11/13
										Average Change:			(1.33)	(2.32)	(3.32)
Lonoke	01N07W27AAD1	344103.48	914410.4	220	3/13/2013	136.35	139.8	3.45	2.5		133.35	129.35		(3.00)	(7.00)
Lonoke	01N08W26CCB1	344034.61	915043.43	212	3/13/2013	105.31	111.9	6.59	5.9		104.60	101.50		(0.71)	(3.81)
Lonoke	01N09W13DAB1	344235.17	915517.01	226	3/13/2013	90.4	102.2	11.80	11.5	84.53	88.00	87.20	(5.87)	(2.40)	(3.20)
Lonoke	01N10W15CDA1	344236	920414	240	5/10/2013	23	124.3	101.30	81.5		27.00	27.00		4.00	4.00
Lonoke	01S06W31ABB1	343459.39	914131.48	200	3/12/2013	81.86	121.1	39.24	32.4	79.94		77.70	(1.92)		(4.16)
Lonoke	01S06W32BBB1	343501	914056	201	5/10/2013	81	123.8	42.80	34.6	80.00	78.00	76.00	(1.00)	(3.00)	(5.00)
Lonoke	01S07W19DDB1	343609	914746	206	3/12/2013	89.11	116.0	26.89	23.2	86.98			(2.13)		
Lonoke	01S08W24CDD1	343605.64	914912.37	210	3/12/2013	86.13	117.9	31.77	26.9	83.64			(2.49)		
Lonoke	01S09W02DDD1	343857	915623	230	5/10/2013	86	121.1	35.10	29.0						
Lonoke	01S09W36CCC1	343435.31	915618.98	220	3/12/2013	65.09	115.5	50.41	43.6	62.94			(2.15)		
Lonoke	01S10W01ACB1	343926.84	920214.96	236	3/12/2013	45.51	119.5	73.99	61.9	43.47			(2.04)		
Lonoke	01S10W11CAB1	343841	920337	235	3/20/2013	31.36	115.5	84.14	72.8						
Lonoke	01N10W15CDA1	344236	920415		3/29/2012	24.00				24.00			0.00		
Lonoke	02S07W05CDC1	343326	914715		5/10/2013	75	116.1	41.10	35.4	75.00	70.20	68.30	0.00	(4.80)	(6.70)
Lonoke	02S07W10CCB1	343246.45	914524.67	201	3/12/2013	69.28				62.69		61.45	(6.59)		(7.83)
Lonoke	02S08W06BAA1	343430	915447	221	3/20/2013	70.57	120.2	49.63	41.3	68.55			(2.02)		
Lonoke	02N08W16ABC1	344806.48	915113.61	230.00	3/20/2012	126.87	143.2	16.33	11.4	126.87	123.30		0.00	(3.57)	
Lonoke	02N08W27DCC	344543	915106	230	3/13/2013	133.97				131.96			(2.01)		
Lonoke	02S08W28CDC1	343007	915237	211	3/20/2013	64.59	116.3	51.71	44.5	62.93	61.60		(1.66)	(2.99)	
Lonoke	02S08W34DBB1	343002.96	915149.75	214	3/12/2013	68.59	131.3	62.71	47.8	68.14	63.76	61.50	(0.45)	(4.83)	(7.09)
Lonoke	02N09W02BDB1	344955.06	915840.93	251	3/20/2013	121.1	159.6	38.50	24.1		123.30			2.20	
Lonoke	02N10W15ACC1	344807	920352	242	5/10/2013	30	136.0	106.00	77.9	28.00	32.50		(2.00)	2.50	
Lonoke	02N10W23BCA1	344725.25	920322.15	242	3/13/2013	11.55	134.0	122.45	91.4		8.10			(3.45)	
Lonoke	02S09W26DC1	343019	915643	216	5/10/2013	53	114.8	61.80	53.8	52.00			(1.00)		
Lonoke	03N07W08BDB1	345406.62	914638.28		5/30/2013	100.55				99.69			(0.86)		
Lonoke	03N07W29ADA1	345128.53	914558.4	234	5/30/2013	94.9	152.7	57.80	37.9	94.22	96.00	97.00	(0.68)	1.10	2.10
Lonoke	03N07W29CDD1	345057	914632		5/10/2013	101				110.00			9.00		
Lonoke	03N07W35CDC2	344957.16	914332.11	232	3/20/2013	118.86	144.6	25.74	17.8	121.76	116.70	114.40	2.90	(2.16)	(4.46)
Lonoke	03N08W03BAA1	345518.54	915053.52		5/28/2013	102.43				101.10			(1.33)		
Lonoke	03N08W03CCC1	345429.86	915123.2		5/28/2013	109.25				107.52			(1.73)		
Lonoke	03N08W08ABA1	345426.98	915247.87		5/28/2013	99.71				98.81			(0.90)		
Lonoke	03N08W10ACB1	345414.65	915052.74		5/28/2013	96.1				95.33			(0.77)		
Lonoke	03N08W10ADD1	345401.06	915022.78		5/28/2013	97.84				97.14			(0.70)		
Lonoke	03N08W11ACA1	345412.72	914934.26		5/28/2013	105.36				104.72			(0.64)		
Lonoke	03N08W21BCC1	345220.21	915220.21	247	3/20/2013	111.6				110.17		102.30	(1.43)		(9.30)
Lonoke	03N08W26CDC1	345100	915007	235	5/10/2013	118	167.1	49.10	29.4	114.00	108.20		(4.00)	(9.80)	
Lonoke	03N08W29BBB1	345147.1	915332.81		5/28/2013	114.62				113.58			(1.04)		
Lonoke	03N08W29BCC1	345125.01	915333.4		5/28/2013	116.33				124.16			7.83		

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County	Station ID	latitude	longitude	LSA	Date Measured	13 DTW	Aq Thickness	Saturated (ft)	% Saturated	12 DTW	08 DTW	03 DTW	Δ12-13	Δ08-13	Δ03-13
Lonoke	03N08W32ABB1	345057	915256	250	4/25/2013	122.67	189.2	66.53	35.2	120.78			(1.89)		
Lonoke	03N08W32ABB3	345058.68	915255.43	250	3/20/2013	50.2	189.2	139.00	73.5		58.10	52.10		7.90	1.90
Lonoke	03N10W34ABB1	345101.07	920351.5	257	3/20/2013	53.68	155.5	101.82	65.5		59.70	56.90		6.02	3.22
Lonoke	04N08W15BCB2	345832.92	915121.25	225	3/20/2013	37	148.3	111.30	75.1	34.54	34.60	32.80	(2.46)	(2.40)	(4.20)
Lonoke	04N08W16DCC1	345757.26	915154.02		5/28/2013	48.85				47.80			(1.05)		
Lonoke	04N08W19BBB1	345753.4	915431.8		5/28/2013	5.55				2.10			(3.45)		
Lonoke	04N08W28CAC1	345620.27	915215.78		5/23/2013	58.58				56.79			(1.79)		
Lonoke	04N08W33ABD1	345558.6	915141.3		5/23/2013	92.51				90.43			(2.08)		
Lonoke	04N08W33ACD1	345546.9	915140.9		5/23/2013	95.92				94.18			(1.74)		
Lonoke	04N08W33ADB1	345552.6	915125		5/23/2013	103.14				106.31			3.17		
Lonoke	04N08W33ADD1	345546.3	915125.5		5/23/2013	105.08				103.06			(2.02)		
Lonoke	04N08W36DBB1	345540.53	914914.42		5/28/2013	96.14				95.06			(1.08)		
								Average %	**42.4**	**Declines/ Wells**			**34/41**	**12/18**	**11/15**
										Average Change:			**(1.03)**	**(1.08)**	**(3.44)**
Mississippi	10N08E22ABA2	352850.89	901312.16	224	5/3/2013	26.56	152.1	125.54	82.5	26.42	24.20		(0.14)	(2.36)	
Mississippi	10N09E08ACC1	352949.05	900925.66	230	5/3/2013	18	174.3	156.30	89.7		16.90			(1.10)	
Mississippi	11N09E34BBB1	353217.73	900715.17	235	5/3/2013	20.8	190.2	169.40	89.1		18.00	16.00		(2.80)	(4.80)
Mississippi	12N08E08BCB1	354047.06	901559.25	225	5/3/2013	10.4	133.4	123.00	92.2	9.64	8.60	6.10	(0.76)	(1.80)	(4.30)
Mississippi	13N09E30CCD1	354247.81	901028.63	230	5/3/2013	15	149.1	134.10	89.9	12.83	10.20	8.70	(2.17)	(4.80)	(6.30)
								Average %	**88.7**	**Declines/ Wells**			**3/3**	**5/5**	**3/3**
										Average Change:			**(1.02)**	**(2.57)**	**(5.13)**
Monroe	01N01W15DBC1	344139	910542	185	3/27/2013	54.06	149.7	95.64	63.9	52.68			(1.38)		
Monroe	01N03W23BAC1	344124	911743	170.00	4/30/2013	18.5	119.9	101.40	84.6	9.50	14.3	12.00	(9.00)	(4.20)	(6.50)
Monroe	01S01W18DCD1	343617.76	910849.2	178	4/9/2013	25.25	147.9	122.65	82.9	23.96	24.52	22.95	(1.29)	(0.73)	(2.30)
Monroe	01S02W20BBB1	343612.7	911456.1	170.00	4/9/2013	13.29	130.5	117.21	89.8	9.68	12.22	9.90	(3.61)	(1.07)	(3.39)
Monroe	01S03W20BBA1	343538.29	912117.73	210	4/30/2013	80	153.4	73.40	47.8	69	75.03	80.00	(11.00)	(4.97)	0.00
Monroe	02S01W01BCD1	343305	910408	176	4/30/2013	20	145.5	125.50	86.3	17	22	19.00	(3.00)	2.00	(1.00)
Monroe	02S02W11DAC1	343208.97	911100.58	164	4/9/2013	10.4	128.9	118.50	91.9	6.8	11.04	8.90	(3.60)	0.64	(1.50)
								Average %	**78.2**	**Declines/ Wells**			**7/7**	**4/6**	**5/6**
										Average Change:			**(4.70)**	**(1.39)**	**(2.45)**
Phillips	01S02E09CBB1	343718.73	905434.06	185	3/25/2013	16.45	146.9	130.45	88.8	14	15.44	10.90	(2.45)	(1.01)	(5.55)
Phillips	01S02E32BCC1	343350	905526	200	4/22/2013	50.8	168.6	117.80	69.9	50.8		31.00	0.00		(19.80)
Phillips	02S04E27AAC1	342931.57	904001.09	179	3/27/2013	9	87.9	78.90	89.8	8.5	9.74	7.30	(0.50)	0.74	(1.70)
Phillips	03S02E35DDA1	342256.24	905129.93	171	3/26/2013	21.35	122.4	101.05	82.6	19.53	22.44	20.70	(1.82)	1.09	(0.65)
Phillips	03S03E04DAA1	342734.52	904709.93	171	3/27/2013	20.5	121.2	100.70	83.1	19.53	20.37	18.80	(0.97)	(0.13)	(1.70)
Phillips	03S04E02CAA1	342732	903918	176	3/27/2013	16.5	119.0	102.50	86.1	11.5	17.48	10.70	(5.00)	0.98	(5.80)
Phillips	04S01E29CDC1	341844	910148	150	5/9/2013	5.6	113.5	107.90	95.1	8.5	7	8.50	2.90	1.40	2.90

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County	Station ID	latitude	longitude	LSA	Date Measured	13 DTW	Aq Thickness	Saturated (ft)	% Saturated	12 DTW	08 DTW	03 DTW	Δ12-13	Δ08-13	Δ03-13
								Average %	85.0	Declines/ Wells			5/7	2/6	6/7
										Average Change:			(1.12)	0.51	(4.61)
Poinsett	10N01E02AAA	353205	905654	235	3/20/2012	103.00	148.90	45.90	30.8		101	97.00		(2.00)	(6.00)
Poinsett	10N01E14CC1	352909.77	905813.38	231	4/11/2013	99.85	150.4	50.55	33.6	98.84	94.91	89.20	(1.01)	(4.94)	(10.65)
Poinsett	10N01E16CCB1	352921.87	910005.35	225	4/11/2013	80.55	146.2	65.65	44.9	80.99	77.67	71.95	0.44	(2.88)	(8.60)
Poinsett	10N01E33ACB1	352746	905931	220	4/8/2013	87.5	142.0	54.50	38.4		81	74.00		(6.50)	(13.50)
Poinsett	10N02E15CAA1	352940	905209	237	3/28/2013	115	143.1	28.10	19.6	112	108		(3.00)	(7.00)	
Poinsett	10N02E20BAB1	352906	905418		4/8/2013	116				111		98.00	(5.00)		(18.00)
Poinsett	10N02E34BBB1	352725.8	905231.3	236	3/6/2013	107.13				104.57	102.08		(2.56)	(5.05)	
Poinsett	10N03E13BCB1	352958	904352	270	3/28/2013	153				144	140		(9.00)	(13.00)	
Poinsett	10N03E14DAB1	352947.21	904404.93	263	4/12/2013	123.35				121.34	119.6	116.70	(2.01)	(3.75)	(6.65)
Poinsett	10N03E19BCB1	352905	904907	239	3/28/2013	112				110	101		(2.00)	(11.00)	
Poinsett	10N03E26BBD1	352816	904449	257	3/28/2013	118				120	115		2.00	(3.00)	
Poinsett	10N07E28CBB1	352733	902128	215	3/28/2013	32	104.9	72.90	69.5	30	31		(2.00)	(1.00)	
Poinsett	11N01E26AA1	353340.33	905653.32	236	4/15/2013	107.65	144.8	37.15	25.7	100.92	96.63		(6.73)	(11.02)	
Poinsett	11N02E26AAB1	353350.31	905034.19	241	4/15/2013	137.5	149.2	11.70	7.8	125.01	110.11	104.90	(12.49)	(27.39)	(32.60)
Poinsett	11N02E30BBB1	353352	905540	239	4/8/2013	112				108	105	102.00	(4.00)	(7.00)	(10.00)
Poinsett	11N02E34CBA1	353238	905222	240	4/8/2013	112	150.0	38.00	25.3	112	110	93.00	0.00	(2.00)	(19.00)
Poinsett	11N03E10DDA1	353545.69	904456.54	243	4/16/2013	119				109.35	106.11	102.75	(9.65)	(12.89)	(16.25)
Poinsett	11N03E17AAB1	353535	904714	243	4/8/2013	150									
Poinsett	11N03E18BAB1	353537.76	904852.42	243	4/16/2013	115.65				113.19	106.53		(2.46)	(9.12)	
Poinsett	11N04E13DDA1	353450	903631	210	3/28/2013	15	67.7	52.70	77.8	15.5	18		0.50	3.00	
Poinsett	11N05E26BDB1	353318	903213	213	3/28/2013	13	91.3	78.30	85.8	13.5	11		0.50	(2.00)	
Poinsett	11N06E34BBC1	353224	902646	211	4/17/2013	9.52				12.36			2.84		
Poinsett	11N07E18CAB1	353435	902320	217	4/17/2013	17.3	107.3	90.00	83.9	15.99	14.04	12.60	(1.31)	(3.26)	(4.70)
Poinsett	11N07E28CBB1	353252	902120	218	3/28/2013	25	111.0	86.00	77.5	23.5	25		(1.50)	0.00	
Poinsett	12N01E07CDA1	354053.69	910141.25	236	4/22/2013	56.7	123.4	66.70	54.1	53.91	55.14		(2.79)	(1.56)	
Poinsett	12N01E22DAB1	353922	905809	235	4/8/2013	81	116.6	35.60	30.5	81	76.5	72.00	0.00	(4.50)	(9.00)
Poinsett	12N02E25DCC1	353820	904944	245	4/8/2013	137									
Poinsett	12N02E26DAD1	353831	905024	245	4/16/2013	118.1				117.5			(0.60)		
Poinsett	12N03E01CBD1	354154	904329	250	4/8/2013	101				102	96	100.00	1.00	(5.00)	(1.00)
Poinsett	12N03E35AD1	353745	904353	245	4/8/2013	102				106			4.00		
Poinsett	12N03E36ACB1	353749.4	904318.72	250	4/16/2013	112.25				104.22	99.86	98.40	(8.03)	(12.39)	(13.85)
Poinsett	12N05E16ABA1	354039	903333	221	3/28/2013	14	89.0	75.00	84.3	14	9.5	10.00	0.00	(4.50)	(4.00)
Poinsett	12N07E04BAA1	354201.95	902059.69	223	4/17/2013	8.5	115.8	107.30	92.7	7.16	2.42	4.20	(1.34)	(6.08)	(4.30)
Poinsett	12N07E10CBB1	354042	902022	228	3/28/2013	9	124.3	115.30	92.8	10	10		1.00	1.00	
Poinsett	12N07E25DC1	353740	901802	226	4/17/2013	19.97	129.3	109.33	84.6	17.11			(2.86)		
								Average %	55.8	Declines/ Wells			20/31	25/28	16/16
										Average Change:			(2.20)	(5.89)	(11.13)
Prairie	01N06W05CCB1	344352.97	914049.08	220	4/3/2013	119.7	155.7	36.00	23.1	118.61	119.27	117.10	(1.09)	(0.43)	(2.60)
Prairie	01N06W26CDD1	344014.88	913707.61	218	4/1/2013	108.6	143.1	34.50	24.1	102.55			(6.05)		

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County	Station ID	latitude	longitude	LSA	Date Measured	13 DTW	Aq Thickness	Saturated (ft)	% Saturated	12 DTW	08 DTW	03 DTW	Δ12-13	Δ08-13	Δ03-13
Prairie	01N06W29DDD1	344017.54	913951.46	223	4/1/2013	118	150.3	32.30	21.5	119.01	118.13		1.01	0.13	
Prairie	01S04W28BDB1	343522.68	912629.73	205	4/3/2013	98.73	138.3	39.57	28.6	98.09	98	97.80	(0.64)	(0.73)	(0.93)
Prairie	01S05W31DDA1	343416.82	913431.69	206	4/1/2013	101.17	137.7	36.53	26.5	94.1	105.57		(7.07)	4.40	
Prairie	01S06W12BAB1	343826	913613	228	3/20/2013	119.09	157.0	37.91	24.1	118.82			(0.27)		
Prairie	02N04W32CCB1	344436.43	912737.79	221	4/3/2013	84.56	150.0	65.44	43.6	83.36	84.84	85.10	(1.20)	0.28	0.54
Prairie	02N05W24BCA3	344659	912937	225	3/13/2013	92.15	147.7	55.55	37.6	90.19			(1.96)		
Prairie	02N05W29DDB2	344545.22	913308.75	228	4/3/2013	125.93	150.8	24.87	16.5	121.52	119.78	118.10	(4.41)	(6.15)	(7.83)
Prairie	02N06W17ABB1	344809.48	913959.44	235	4/10/2013	132.23	148.0	15.77	10.7	127.03	125.82	123.60	(5.20)	(6.41)	(8.63)
Prairie	02S06W14BBB1	343213.38	913728.62	201	4/1/2013	75.39	121.3	45.91	37.8	77.59	75.76	58.25	2.20	0.37	(17.14)
Prairie	02N06W22BCC1	344652.8	913827.4	234.00	4/3/2013	114.75				114.68			(0.07)		
Prairie	02N06W24CAA1	344651	913551	233	3/13/2013	118.77	154.5	35.73	23.1	118.31			(0.46)		
Prairie	03N05W03BDD2	345444.06	913115.35	207	4/12/2013	67.41	113.7	46.29	40.7	63.02	65.25	64.00	(4.39)	(2.16)	(3.41)
Prairie	04N05W07CDC1	345842.62	913440.92	212	4/10/2013	79.2	125.4	46.20	36.8	79.42	79.34	75.10	0.22	0.14	(4.10)
Prairie	04N05W31DDC1	345513.66	913405.83	206	4/10/2013	81.33				79.4	76.25	75.50	(1.93)	(5.08)	(5.83)
Prairie	04N06W05CCC1	345933.76	914017.96	206	4/10/2013	62.36	117.1	54.74	46.7	61.81		59.80	(0.55)		(2.56)
Prairie	04N07W03DCB1	345942.1	914412.48	255	4/10/2013	89.17	170.7	81.53	47.8	88.59	88.73	87.80	(0.58)	(0.44)	(1.37)
Prairie	04N07W20DDB1	345709.23	914607.27	255	4/23/2013	103.24	174.5	71.26	40.8	102.87	103.11		(0.37)	(0.13)	
Prairie	04N07W28BBA1	345700.53	914544.88	258	4/10/2013	98.22	177.5	79.28	44.7	97.9	97.67	94.20	(0.32)	(0.55)	(4.02)
								Average %	**31.9**	**Declines/ Wells**			**17/20**	**9/14**	**11/12**
										Average Change:			**(1.66)**	**(1.20)**	**(4.82)**
Pulaski	01S10W29CC1	343537.78	920707.66	239	5/13/2013	22.2	107.0	84.80	79.3	13.26	14.87	15.85	(8.94)	(7.33)	(6.35)
Pulaski	02S10W14DC1	343204.71	920333.75	225	5/13/2013	22.2	109.2	87.00	79.7	23.8	23.5	22.20	1.60	1.30	0.00
Pulaski	02S10W16CCA1	343216.99	920549.36	230.8	5/13/2013	18.67	106.7	88.03	82.5	23.35	25.33	23.00	4.68	6.66	4.33
								Average %	**80.5**	**Declines/ Wells**			**1/3**	**1/3**	**1/3**
										Average Change:			**(0.89)**	**0.21**	**(0.67)**
Randolph	18N01E11CCC1	361233	905712		3/25/2013	18				13			(5.00)		
Randolph	18N01E16ABA1	361229	905847		3/25/2013	16				13			(3.00)		
Randolph	18N01E21CD1	361054	905852		3/25/2013	18				15.5			(2.50)		
Randolph	18N02E02CBC1	361344	905035		3/25/2013	31.5				30.2			(1.30)		
Randolph	18N02E22DCD1	361045.76	905104.7	273	4/23/2013	42.79	151.6	108.81	71.8	40.53	39.12	36.00	(2.26)	(3.67)	(6.79)
Randolph	18N02E27BA1	361044	905120		3/25/2013	42				40			(2.00)		
Randolph	19N02E09DCA1	361757.27	905157.46	267	4/23/2013	10.92	135.8	124.88	92.0	11.24	0.5	10.40	0.32	(10.42)	(0.52)
Randolph	19N02E22CAB1	361622	905049	266	3/25/2013	5.5	136.2	130.70	96.0	3.5			(2.00)		
Randolph	20N02E01ADD1	362424.21	904811.39	280	4/23/2013	16.43	138.4	121.97	88.1	10.85	2.66	11.35	(5.58)	(13.77)	(5.08)
Randolph	20N02E01ADD2	362424	904811	280	3/25/2013	19	138.4	119.40	86.3						
Randolph	20N02E13CBB1	362232	904912		3/25/2013	10									
Randolph	20N03E07DAA1	362323	904708		3/25/2013	25				14.5			(10.50)		
Randolph	20N03E28BA1	362113.53	904537.97	276	4/23/2013	13.4	134.1	120.70	90.0	10.64		11.70	(2.76)		(1.70)
Randolph	20N03E30DDA1	362030	904717		3/25/2013	8				12			4.00		

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County	Station ID	latitude	longitude	LSA	Date Measured	13 DTW	Aq Thickness	Saturated (ft)	% Saturated	12 DTW	08 DTW	03 DTW	Δ12-13	Δ08-13	Δ03-13
								Average %	87.4	Declines/ Wells			10/12	3/3	4/4
										Average Change:			(2.72)	(9.29)	(3.52)
St. Francis	04N01E20DA1	345630	905439	200	3/29/2013	73	146.1	73.10	50.0						
St. Francis	04N01E20DA2	345630	905439	200	3/30/2013	74	146.1	72.10	49.3						
St. Francis	04N01W17CBC1	345735	910801	208	3/11/2013	63.85	149.0	85.15	57.1	61.91	59.82		(1.94)	(4.03)	
St. Francis	04N01W22BB1	345718	910552	200	3/29/2013	75	142.5	67.50	47.4		63.00			(12.00)	
St. Francis	04N01W28CDD1	345535.26	910633.55	208	3/12/2013	75.6	157.2	81.60	51.9	73.83	72.10	69.75	(1.77)	(3.50)	(5.85)
St. Francis	04N02E11AD1	345827	905117	210	3/29/2013	47					45.00			(2.00)	
St. Francis	04N02E16ACD1	345733	905341	209	3/29/2013	55	153.4	98.40	64.1		51.00	51.00		(4.00)	(4.00)
St. Francis	04N02E19BBB1	345701	905633	209	3/13/2013	64.9	153.8	88.90	57.8	63.23	61.00	57.75	(1.67)	(3.90)	(7.15)
St. Francis	04N02E27AAA1	345604	905220	211	3/29/2013	49	157.0	108.00	68.8		49.00	46.00		0.00	(3.00)
St. Francis	04N02E29BB1	345608	905519	212	3/29/2013	62	157.9	95.90	60.7		58.00			(4.00)	
St. Francis	05N01E15BCB1	350302.57	905942.41	209	3/12/2013	71.98	143.4	71.42	49.8	70.12	66.40	63.50	(1.86)	(5.58)	(8.48)
St. Francis	05N01E27BBA1	350135.73	905928.78	209	5/16/2013	71.23	145.8	74.57	51.1	72.1	68.80	65.80	0.87	(2.43)	(5.43)
St. Francis	05N02E20ADC1	350156.9	905437.16	211	3/13/2013	60.2	150.8	90.60	60.1	58.55	55.70	56.95	(1.65)	(4.50)	(3.25)
St. Francis	05N02E26AAB1	350122	905121	213	3/29/2013	56									
St. Francis	05N02E26CD1	350032	905149	215	3/29/2013	52	157.4	105.40	67.0		51.00			(1.00)	
St. Francis	05N03E20AAA2	350214.31	904800.83	250	3/14/2013	99.4	192.6	93.20	48.4	91.88	93.87	92.15	(7.52)	(5.53)	(7.25)
St. Francis	05N03E32BB2	350100	904851		3/29/2013	52					49.00			(3.00)	
St. Francis	05N05E19DCA1	350127.57	903630.35	203	3/14/2013	32.9				30.57	32.36	33.56	(2.33)	(0.54)	0.66
St. Francis	05N05E33BCC1	350004	903506	196	3/29/2013	26	138.6	112.60	81.2		30.00	29.00		4.00	3.00
St. Francis	05N06E05BBB1	350508	902922	195	3/29/2013	39	130.1	91.10	70.0						
St. Francis	05N06E34CAB1	350025.57	902656.87	200	4/8/2013	26.7	141.8	115.10	81.2	24.99	28.10	26.90	(1.71)	1.40	0.20
St. Francis	06N01E33ACA1	350559	905943	211	3/29/2013	73	142.4	69.40	48.7	71.48	67.10		(1.52)	(5.90)	
St. Francis	06N01E33ACA2	350552.33	905941.6	211	5/16/2013	63.77	142.4	78.63	55.2						
								0.00	#DIV/0!						
St. Francis	06N02E15BDD1	350841.91	905247.31	214.64	3/12/2013	65.6	150.0	84.40	56.3	63.95	61.30	57.70	(1.65)	(4.30)	(7.90)
St. Francis	06N03E17CAA1	350822	904810	258	3/29/2013	113	196.6	83.60	42.5			102.00			(11.00)
								Average %	58.0	Declines/ Wells			10/11	16/19	10/13
										Average Change:			(2.07)	(3.20)	(4.57)
White	05N07W10CCC1	350400.22	914436	203	3/26/2013	8.71	115.2	106.49	92.4	8.28	9.30	8.20	(0.43)	0.59	(0.51)
White	06N06W04BAA1	351047.21	913909.91	220	3/26/2013	22.39	127.6	105.21	82.5	16.37	34.75	26.85	(6.02)	12.36	4.46
White	06N07W17DCC1	350822.47	914634.73	217	3/26/2013	13.08	127.2	114.12	89.7	10.3	12.70	13.40	(2.78)	(0.38)	0.32
White	06N08W13ABA1	350907.73	914824.37	228	3/26/2013	11.37	137.8	126.43	91.7	6.88	10.20	8.10	(4.49)	(1.17)	(3.27)
White	06N08W26DDB1	350639.72	914931.17	230	3/26/2013	16.04	141.7	125.66	88.7	10.59	16.55	16.90	(5.45)	0.51	0.86
White	07N05W01AAA1	351552.59	912858.14	205	3/27/2013	15.67	111.5	95.83	85.9	12.81	5.40	22.55	(2.86)	(10.27)	6.88
White	07N05W32BAB1	351136.63	913406.19	213.7	3/26/2013	29.48	120.1	90.62	75.5	24.58	28.10	28.60	(4.90)	(1.38)	(0.88)
White	08N04W06CCB1	352028.21	912846.51	214	3/27/2013	14.99	121.4	106.41	87.7	13.32	16.10	18.70	(1.67)	1.11	3.71
White	08N05W32CBC1	351615.66	913416.96	199	3/27/2013	2.75	105.7	102.95	97.4	0.49	2.60	1.85	(2.26)	(0.15)	(0.90)
								Average %	87.9	Declines/ Wells			9/9	5/9	4/9

Alluvial Aquifer 2013

County	Station ID	latitude	longitude	LSA	Date Measured	13 DTW	Aq Thickness	Saturated (ft)	% Saturated	12 DTW	08 DTW	03 DTW	Δ12-13	Δ08-13	Δ03-13
										Average Change:			(3.43)	0.14	1.19
Woodruff	04N03W03AB1	350020.93	911819.87	185	4/16/2013	12.9	87.7	74.80	85.3		9.63	15.20		(3.27)	2.30
Woodruff	05N04W12DBA1	350426.78	912210.78	186	4/9/2013	26.7	89.0	62.30	70.0						
Woodruff	06N01W11AAB1	350944	910354	215	4/16/2013	66.25	137.5	71.25	51.8						
Woodruff	06N03W15BAB1	350903.06	911807.41	188.79	4/16/2013	5.5	94.7	89.20	94.2	4.54		5.10	(0.96)		(0.40)
Woodruff	06N03W31BCB1	350623	912144	185	4/16/2013	3.93	88.8	84.87	95.6	2.73	1.5		(1.20)	(2.43)	
Woodruff	07N03W19AAA1	351335	912025.42	202.59	4/16/2013	10.84	109.5	98.66	90.1		8.39	11.10		(2.45)	0.26
Woodruff	08N01W06DDD1	352028	910747	218	4/16/2013	48.15	135.4	87.25	64.4	43.49	46.14	43.70	(4.66)	(2.01)	(4.45)
Woodruff	08N03W04BBB1	352128	911919	221	7/17/2013	17.78	131.3	113.52	86.5	13.58			(4.20)		
Woodruff	09N03W29AAD1	352258	911921	220	4/16/2013	21.85	131.0	109.15	83.3	17.93	18.9	20.50	(3.92)	(2.95)	(1.35)
								Average %	80.1	Declines/ Wells			5/5	5/5	3/5
										Average Change:			(2.99)	(2.62)	(0.73)
								Aquifer Averag	65.6	DECLINED WELLS			225/307	192/260	185/232
										TOTAL % WELL DECLINES			73.3	73.8	79.7
										TOTAL AVERAGE CHANGE			(1.44)	(2.10)	(4.30)

Appendix III

Sparta/Memphis Aquifer 2013

County	Station	Latitude	Longitude	LSA	Date Measured	2013 DTW	2012 DTW	2008 DTW	2003 DTW	Δ12-13	Δ08-13	Δ03-13
Arkansas	02S04W06CDB1	343311.54	912849.29	212	4/16/2013	159.82	160	159	160.87	0.18	(0.82)	1.05
Arkansas	02S04W23DAA1	343044.22	912354.53	208	4/16/2013	144.84	163.5	160.9	149.72	18.66	16.06	4.88
Arkansas	02S05W16CBB1	343143.56	913318.67	216	4/16/2013	173.82	174.28	183.7	178.88	0.46	9.88	5.06
Arkansas	02S05W34ABC1	342925	913147		4/15/2013	179.71						
Arkansas	02S05W35AAB1	342929.98	913035.31	216	4/15/2013	176.39		174.8	174.85		(1.59)	(1.54)
Arkansas	03S03W18CCC2	342553	912251	196	3/27/2013	145.52		138.96			(6.56)	
Arkansas	03S04W02CCB1	342747.58	912458.04	202	4/15/2013	152.46	154.94	155.5	162.24	2.48	3.04	9.78
Arkansas	03S04W26CDA1	342421.03	912438.3	203	4/15/2013	144.56		145.7	137.3		1.14	(7.26)
Arkansas	03S04W33BAA1	342406.95	912639.02	201	4/15/2013	155.84		165.22	159.94		9.38	4.10
Arkansas	03S05W02AAB1	342842.19	913033.71	210	4/15/2013	170.72		173.9	173.43		3.18	2.71
Arkansas	03S05W13BDC1	342631.15	913004.57	210	4/17/2013	168.27	177.1	170.1	178.86	8.83	1.83	10.59
Arkansas	03S05W15CBB1	342633.21	913229.33	206	4/16/2013	178.94	172.59	172.3	171.95	(6.35)	(6.64)	(6.99)
Arkansas	03S05W18CAB1	342629.37	913524.68	196	4/17/2013	165.3		167.7	169.14		2.40	3.84
Arkansas	03S05W28DAB1	342447.16	913240.25	204	4/17/2013	167.21		173.5	172.62		6.29	5.41
Arkansas	03S06W21ACB1	342554.07	913927.23	200	4/15/2013	159.07	161.8	160.8		2.73	1.73	
Arkansas	03S06W30BBD1	342515.54	914216.15	191	4/15/2013	151.64	152.75	160.6	160.74	1.11	8.96	9.10
Arkansas	04S01W04CBD1	342225.42	910808.42	196	4/17/2013	113.17		110.9	113.14		(2.27)	(0.03)
Arkansas	04S01W28BAA1	341926.96	910748.04	190	4/17/2013	105.99		105	106.16		(0.99)	0.17
Arkansas	04S04W11BCC1	342156.96	912501.52	198	4/16/2013	152.03	155.74	155.1	155.5	3.71	3.07	3.47
Arkansas	04S04W19CBB1	342003.73	912928.89	195	4/16/2013	157.54		176.5	162.72		18.96	5.18
Arkansas	04S04W22DAA1	342006.89	912515.15	195	4/16/2013	153.95	162.22	157.2	159.99	8.27	3.25	6.04
Arkansas	04S05W01BAA1	342322.23	912956.46	196	4/16/2013	162.09						
Arkansas	04S05W05ACC1	342302.67	913412.84	186	4/17/2013	156.79		159.5	157.42		2.71	0.63
Arkansas	04S05W15AAA1	342132.16	913133.29	201	4/16/2013	165.29	168.2	167.3	166.7	2.91	2.01	1.41
Arkansas	04S05W31DDA1	341819.25	913448.06	184	4/17/2013	34.26						
Arkansas	04S05W36DCC1	341752	913003.63	196	4/16/2013	161.21	168.87	161.2	163.18	7.66	(0.01)	1.97
Arkansas	05S01W17BAA1	341550.68	910745.34	176	4/17/2013	93.72		91.4	93.49		(2.32)	(0.23)
Arkansas	05S04W26ACA1	341358.31	912434.23	188	4/10/2013	137.79	136.47	139.6	128.95	(1.32)	1.81	(8.84)
Arkansas	05S05W26CDD1	341323.75	913119.96	188	4/10/2013	35.79	35.61	37.5		(0.18)	1.71	
Arkansas	05S05W36DAA1	341245.1	912946.65	180	4/10/2013	143.13	144	144.05	140.16	0.87	0.92	(2.97)
Arkansas	06S02W06ABB1	341227.9	911620.01	181	4/10/2013	118.34		118.4	114.76		0.06	(3.58)
Arkansas	06S02W17ADA1	341022.67	911453.14	188	4/10/2013	113.5		112.95	114.77		(0.55)	1.27
Arkansas	06S02W22CDB1	340904.05	911331.06	186	4/10/2013	112.02		110.7	105.86		(1.32)	(6.16)

Sparta/Memphis Aquifer 2013

County	Station	Latitude	Longitude	LSA	Date Measured	2013 DTW	2012 DTW	2008 DTW	2003 DTW	Δ12-13	Δ08-13	Δ03-13
Arkansas	06S03W27BAA1	340859.22	912008.98	181	4/10/2013	119.1	110.89	120.1	119.62	(8.21)	1.00	0.52
Arkansas	07S02W28ABA1	340339.67	911411.01	181	4/10/2013	106.33		104.2	105.64		(2.13)	(0.69)
Arkansas	07S03W06ABC1	340701.89	912247.68	185	4/10/2013	131.72	136.68	127.1	131.33	4.96	(4.62)	(0.39)
Arkansas	08S02W09BCC1	340031.06	911447.66	174	4/10/2013	100.79	100.2	99.3	100.22	(0.59)	(1.49)	(0.57)
								Declines/ Wells		**5/18**	**13/34**	**12/31**
								Average Change:		**2.57**	**2.00**	**1.22**
Ashley	15S07W32CDD1	332117.77	915101.06	190	3/26/2013	139.27	139.09	137.15	137.84	(0.18)	(2.12)	(1.43)
Ashley	17S09W15ACC1	331333.66	920116.44	100	3/26/2013	24.54	22.95		17.77	(1.59)		(6.77)
								Declines/ Wells		**2/2**	**2/2**	**2/2**
								Average Change:		**(0.89)**	**(2.12)**	**(4.10)**
Bradley	12S09W31CCB1	333711.24	920444.21	231	3/26/2013	174.33	194.65	199.45	183.54	20.32	25.12	9.21
Bradley	13S09W06ACA1	333647.9	920437.48	208	3/26/2013	141.85	161.2	198.25	183.67	19.35	56.40	41.82
Bradley	13S09W06ACB2	333647.13	920416.84	253	3/26/2013	161.72			157.75			(3.97)
Bradley	13S11W17BCD1	333453.65	921607.25	250	3/26/2013	195.14		198.8	192.43		3.66	(2.71)
Bradley	15S11W31DDD1	332142	921621	131	4/1/2013	100.7	101.55			0.85		
Bradley	16S12W21CAA1	331839.32	922052.38	100	3/26/2013	76.66	79.4	78.78	75.29	2.74	2.12	(1.37)
								Declines/ Wells		**0/4**	**0/4**	**3/5**
								Average Change:		**10.82**	**21.83**	**8.60**
Calhoun	13S12W31DAA1	333233	922224	200	3/27/2013	57.5	56.2	57.12		(1.30)	(0.38)	
Calhoun	13S13W32CDA1	333226.81	922741.66	208	3/27/2013	178.15	168.6	192.88	168.68	(9.55)	14.73	(9.47)
Calhoun	14S13W03CAB1	333145.32	922551.43	202	3/25/2013	163.39						
Calhoun	14S13W05BBD1	333206.66	922801.55	189	3/25/2013	149.62		162.85	154.13		13.23	4.51
Calhoun	14S13W12CCB1	333040.05	922403.54	205	3/25/2013	169.24	172.34	181.1	168.45	3.10	11.86	(0.79)
Calhoun	15S13W20BDC1	332410.97	922806.59	109	3/27/2013	26.37	22.9	25.7	34.11	(3.47)	(0.67)	7.74
Calhoun	15S13W32BCA1	332230	922821		3/27/2013	116.77	115.9			(0.87)		
								Declines/ Wells		**4/5**	**3/5**	**2/4**
								Average Change:		**(2.42)**	**7.75**	**0.50**

Sparta/Memphis Aquifer 2013

County	Station	Latitude	Longitude	LSA	Date Measured	2013 DTW	2012 DTW	2008 DTW	2003 DTW	Δ12-13	Δ08-13	Δ03-13
Chicot	13S03W22DAD1	333312.37	912307.62	135	3/27/2013	70.39						
Chicot	15S03W07BCC1	332444.7	912723.3	129	3/27/2013	65.81						
								Declines/ Wells		-	-	-
								Average Change:		-	-	-
Cleveland	09S11W11CDB1	335622.66	921250.52	233	4/9/2013	160.69		162.55			1.86	
Cleveland	10S09W23CDC1	334917.94	920020.5	220	4/9/2013	172.53		177.5	161.88		4.97	(10.65)
Cleveland	10S09W35ACD1	334757.93	915957.13	219	4/9/2013	166.4		191.3	154.2		24.90	(12.20)
Cleveland	10S12W12BDD1	335132.99	921743.38	220	4/9/2013	121.95		125.77	117.29		3.82	(4.66)
Cleveland	11S11W16AAB1	334543.01	921423.47	303	4/9/2013	205.64			205.99			0.35
								Declines/ Wells			**0/4**	**3/4**
								Average Change:			**8.89**	**(6.79)**
Columbia	15S20W20CCB1	332453.37	931215.01	372	3/4/2013	217.08	216.76		217.04	(0.32)		(0.04)
Columbia	16S20W08DCC1	332114.08	931141.34	402	3/4/2013	314.41	317.39	326.5	315.1	2.98	12.09	0.69
Columbia	16S20W18ACD1	332052.93	931237.4	337	3/4/2013	265.02	261.37		264.7	(3.65)		(0.32)
Columbia	16S21W14CBB1	332049.37	931517.28	281	3/4/2013	190.98	192.12	197.7	200.3	1.14	6.72	9.32
Columbia	16S21W20CDC1	331943	931815		4/25/2013	258.05						
Columbia	16S22W22CCD1	331947.61	932224.89	340	3/4/2013	151.97	132.65	137.4	132.68	(19.32)	(14.57)	(19.29)
Columbia	17S19W15ABD1	331537	930328	325	4/25/2013	234.47	268.4	277.8		33.93	43.33	
Columbia	17S19W17ACA1	331538.06	930536.26	303	3/5/2013	263.44	257.83		279.95	(5.61)		16.51
Columbia	17S19W18CBD1	331516.81	930655.59	305	3/5/2013	266.61	261.8	289.6	279.49	(4.81)	22.99	12.88
Columbia	17S19W19BCA1	331432.77	930704.56	301	3/12/2013	270.32			274.59			4.27
Columbia	17S19W30ABB1	331406.12	930650.14	248	4/16/2013	184.14	213.4	218.4	221.9	29.26	34.26	37.76
Columbia	17S20W13BCD1	331532.41	930807.08	340	3/5/2013	308.06		328.2			20.14	
Columbia	17S20W17CDA1	331519.76	931200.69	325.1	3/5/2013	316.26		298.9	303.03		(17.36)	(13.23)
Columbia	17S20W36ABC1	331307.06	930754.88	335	3/12/2013	290.93			297			6.07
Columbia	17S21W01BBC1	331743.07	931423.65	305	4/23/2013	251	250.3	265.4	270.4	(0.70)	14.40	19.40
Columbia	17S21W08DCA1	331613.42	931758.3	300	3/4/2013	207.46			211.61			4.15
Columbia	17S21W11DCC2	331608.55	931448.61	303	4/2/2013	268.93	271.96	292.15	283.03	3.03	23.22	14.10
Columbia	17S21W11DCC3	331609.3	931449.35	298	3/4/2013	291.59						

Sparta/Memphis Aquifer 2013

County	Station	Latitude	Longitude	LSA	Date Measured	2013 DTW	2012 DTW	2008 DTW	2003 DTW	Δ12-13	Δ08-13	Δ03-13
Columbia	17S21W17BAB1	331607.99	931819.6	287	3/4/2013	197.32						
Columbia	17S22W21ABD1	331516.59	932304.21	295	3/4/2013	82.71			81.35			(1.36)
Columbia	17S22W22ABB1	331522.02	932210.07	321	3/4/2013	134	135.59	83.15		1.59	(50.85)	
Columbia	17S22W23BBB1	331520.74	932136.67	318	3/4/2013	148.24	148.97	136.85	114.1	0.73	(11.39)	(34.14)
Columbia	18S20W06DDC1	331142.63	931249.08	300	4/16/2013	270.62	278.7	288		8.08	17.38	
Columbia	18S20W08CBC1	331114.79	931227.04	263	3/12/2013	264.17	266.75	280	270.16	2.58	15.83	5.99
Columbia	18S20W10CAA1	331054.37	931015.76	290	3/13/2013	267.83	262.77	283.25	274.98	(5.06)	15.42	7.15
Columbia	18S21W01ACC1	331223.06	931339.45	295	3/12/2013	281.68		291.85	297.73		10.17	16.05
Columbia	18S22W27DDD1	330834.57	932158.59	312	3/13/2013	132.33	134.02		122.98	1.69		(9.35)
Columbia	18S24W26CC1	330831	932154		4/19/2013	130.79						
Columbia	19S20W08DAB1	330558	931156		3/5/2013	267.24						
Columbia	19S20W09CBD1	330555.38	931128.72	332	4/16/2013	260.22		273.7	266.01		13.48	5.79
Columbia	19S20W34BDD1	330239.09	931030.67	290	3/13/2013	205.94	206	210.62	212.12	0.06	4.68	6.18
Columbia	19S21W16DBB1	330517.2	931724.2	284	3/13/2013	171.22	173.91	174.7	174.42	2.69	3.48	3.20
Columbia	19S23W10ABD1	330643.92	932833.33	242	3/13/2013	44.04	43.99	45.17	45.22	(0.05)	1.13	1.18
Columbia	19S23W11CDA2	330609.39	932744.02	248	3/13/2013	51.64	33.6	53.05	52.56	(18.04)	1.41	0.92
Columbia	19S23W11DDB1	330604.93	932722.12	246	3/13/2013	52.43	52.38	53.34	53.76	(0.05)	0.91	1.33
Columbia	19S23W14BAB1	330554	932752		4/23/2013	44.57	44.45			(0.12)		
Columbia	19S23W14BAB2	330555.24	932752.38	244	3/13/2013	43.53	44.75	47.45	49.99	1.22	3.92	6.46
Columbia	20S22W03DCC1	330138.44	932236.27	214	3/13/2013	51.95		52.27			0.32	
Columbia	20S22W11ACD1	330109.2	932133.2	271	3/13/2013	106.96	107.65	106.95	107.17	0.69	(0.01)	0.21
							Declines/ Wells			**11/25**	**5/26**	**7/28**
							Average Change:			**1.28**	**6.84**	**3.64**
Dallas	07S14W31AAA1	340425.29	923334.44	330	4/30/2013	116.53						
Dallas	07S15W33DAC1	340402	923752		5/1/2013	27.58						
Dallas	07S16W20CAB1	340555.17	924545.07	322	4/30/2013	28.3		32			3.70	
Dallas	08S15W34BDC1	335858.75	923730.11	240	4/30/2013	17.91		23.5			5.59	
Dallas	08S16W18ACC1	340152.47	924639.37	252	5/1/2013	17.62		15.4			(2.22)	
Dallas	08S16W27DDD1	335936.75	924307.17	275	5/1/2013	34.76		34.5			(0.26)	
Dallas	09S13W35CCD1	335309.28	922413.4	200	4/30/2013	72.22		73			0.78	
Dallas	09S14W01BDC1	335753.63	922918.78	265	5/1/2013	41.73						

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County	Station	Latitude	Longitude	LSA	Date Measured	2013 DTW	2012 DTW	2008 DTW	2003 DTW	Δ12-13	Δ08-13	Δ03-13
Dallas	09S16W19CAA1	335605.48	924701.17	260	4/30/2013	7.08		6.3	6.51		(0.78)	(0.57)
Dallas	10S13W34ACA2	334829.46	922457.61	272	5/1/2013	151.41		152.3	150.74		0.89	(0.67)
Dallas	10S14W27CDB1	334907.6	923137.99	270	4/30/2013	26.63		23.6	35.03		(3.03)	8.40
Dallas	10S15W11DBB1	335201	923632	295	5/1/2013	58.79	57.97			(0.82)		
Dallas	10S15W18BCC1	335119.53	924120.08	328	4/30/2013	78.48		78.34	75.39		(0.14)	(3.09)
							Declines/ Wells			1/1	4/9	1/4
							Average Change:			(0.82)	0.50	1.02
Desha	09S02W26AAC1	335346	911520.82	153	4/8/2013	73.66		72.97			(0.69)	
Desha	09S04W28DDD1	335309.6	913006.71	165	4/8/2013	114.56		114.04	112.42		(0.52)	(2.14)
Desha	10S02W26CCC2	334750.23	911623.99	148	4/8/2013	74.4		73.3	72.14		(1.10)	(2.26)
Desha	10S04W11CBC1	335034.41	912905.14	161	4/8/2013	105.59			102.45			(3.14)
Desha	12S03W26CBB1	333748.6	912259.18	143	4/8/2013	81.62		101.7	96.12		20.08	14.50
Desha	12S03W34DAD1	333643.44	912305.04	147	4/8/2013	80.65		83.55	78.45		2.90	(2.20)
							Declines/ Wells				3/5	4/5
							Average Change:				4.13	0.95
Drew	11S04W02ACA2	334631.87	912826.56	153	3/27/2013	95.46	98	98.34	92.38	2.54	2.88	(3.08)
Drew	11S04W25DAA1	334249.46	912706.98	148	3/27/2013	87.05	85.78			(1.27)		
Drew	11S06W11DBC1	334606.63	914122.37	203	3/27/2013	153.95			149.95			(4.00)
Drew	12S06W30BBD1	333807.15	914543.08	271	3/27/2013	210.41		239.1	222.63		28.69	12.22
Drew	12S06W32DAD1	333649.09	914401.96	212	3/28/2013	159.58		171.72	168.02		12.14	8.44
Drew	15S04W12DDA1	332429.38	912723.69	125	3/27/2013	64.4		63.9	62.02		(0.50)	(2.38)
							Declines/ Wells			1/2	1/4	3/5
							Average Change:			0.64	10.80	2.24
Grant	03S13W12AAA1	342845.65	922106.24	361	4/17/2013	130.35		132.4	131.45		2.05	1.10
Grant	03S15W26DAA1	342600.52	923447.01	337	4/17/2013	7		4.5	10.45		(2.50)	3.45
Grant	04S15W02DAC1	342405	923456		6/19/2013	85.9						
Grant	05S13W03CAA1	341843.97	922400.47	260	4/17/2013	85.62		85.7			0.08	

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County	Station	Latitude	Longitude	LSA	Date Measured	2013 DTW	2012 DTW	2008 DTW	2003 DTW	Δ12-13	Δ08-13	Δ03-13
Grant	05S13W03CDA4	341837.64	922401.95	281	4/17/2013	109.94		106.55	111.9		(3.39)	1.96
Grant	05S13W07ADB1	341810	922649.75	270	4/17/2013	79.49		102.9	60.22		23.41	(19.27)
Grant	05S14W06DCC1	341842.5	923326.69	293	4/18/2013	84.42		83.9	87.62		(0.52)	3.20
Grant	05S15W05ABD1	341923.78	923826.87	236	4/17/2013	13.44		11	19.03		(2.44)	5.59
Grant	06S11W05ACD1	341340.82	921413.01	269	5/1/2013	196.49		195			(1.49)	
Grant	06S15W26ACA1	341021.99	923537.59	280	4/29/2013	65.41		64.7	66.34		(0.71)	0.93
Grant	07S12W21BDB1	340558.11	921952.7	223	4/18/2013	4.39		3.14	2.17		(1.25)	(2.22)
							Declines/ Wells				7/10	2/8
							Average Change:				1.32	(0.66)
Hot Springs	05S16W35ACA1	341459.51	924151.12	342	5/23/2013	37.14		32.9	35.67		(4.24)	(1.47)
Jefferson	03S09W23BBD1	342626.95	915712.96	224	4/19/2013	191.4	163.86	171.3		(27.54)	(20.10)	
Jefferson	03S10W14CAD1	342659.22	920330.26	221	4/19/2013	116.5			116.83			0.33
Jefferson	03S11W22ABC1	342650.81	921058.27	310	4/29/2013	172.73	174.18	170.9	175.34	1.45	(1.83)	2.61
Jefferson	04S08W35BBD1	341909.06	915056.13	200	4/11/2013	216.58			211.75			(4.83)
Jefferson	04S09W11BAA1	342309.29	915702.22	210	4/19/2013	143.3	112.3		134.17	(31.00)		(9.13)
Jefferson	05S08W30ADB1	341452.32	915440.2	221	5/10/2013	285.78	282.62	296	295.19	(3.16)	10.22	9.41
Jefferson	05S08W30CBA1	341446.21	915526.54	207.46	4/11/2013	281.47	273.77	290.8	288.87	(7.70)	9.33	7.40
Jefferson	05S09W24DBD1	341529.68	915555.6	208.17	4/11/2013	261.24	261.16		272.52	(0.08)		11.28
Jefferson	05S09W35AAB1	341420.05	915653.1	205	4/11/2013	39.31						
Jefferson	05S10W16BAD1	341700.48	920548.64	277	4/11/2013	38.18						
Jefferson	05S10W16DBD1	341634.93	920534.41	302	4/11/2013	306.95	275.48		279.75	(31.47)		(27.20)
Jefferson	06S08W16CCC1	341143.07	915517.06	202.42	4/1/2013	247.19	245.41	257.8	248.9	(1.78)	10.61	1.71
Jefferson	06S08W25ADC1	341024.86	915116.18	203.48	4/10/2013	219.88	218.72	228.2	217.39	(1.16)	8.32	(2.49)
Jefferson	06S09W17CAD1	341158.7	920206.91	233	4/10/2013	263.57	253		280.07	(10.57)		16.50
Jefferson	06S09W17CCA1	341151.82	920220.85	234.34	4/9/2013	249.28			269.68			20.40
Jefferson	06S10W23ACA2	341123.09	920503.93	235	4/10/2013	217.34	226.45	241.5	227.68	9.11	24.16	10.34

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County	Station	Latitude	Longitude	LSA	Date Measured	2013 DTW	2012 DTW	2008 DTW	2003 DTW	Δ12-13	Δ08-13	Δ03-13
Jefferson	07S07W24BAB1	340632.68	914522.99	188	4/10/2013	168.5	159.23	168.75	161.69	(9.27)	0.25	(6.81)
								Declines/ Wells		10/12	2/8	5/14
								Average Change:		(9.43)	5.12	2.11
Lafayette	16S24W26AAC1	331950.2	933302.96	267	5/22/2013	57.34		56.1			(1.24)	
Lafayette	17S23W19ACC1	331519.6	933127.61	291	5/22/2013	55.29						
Lafayette	17S24W23BBD1	331525.67	933402.79	261	5/22/2013	34.79		32.81			(1.98)	
Lafayette	18S23W29ACC1	330910.83	933039.27	255	5/22/2013	18.38		16.3			(2.08)	
Lafayette	19S23W29BDB1	330351.94	933103.37	250	5/22/2013	41.68		40.57			(1.11)	
Lafayette	20S23W05ADB1	330223.35	933036.08	242	5/22/2013	40.17		37.65			(2.52)	
								Declines/ Wells			5/5	
								Average Change:			(1.79)	
Lee	01N04E09CDD1	344209.69	904119.07	204	4/24/2013	67.75	67.99	64.3		0.24	(3.45)	
Lee	02N01E10CAD1	344743.36	905924.74	201	4/29/2013	59.34		54	51.1		(5.34)	(8.24)
Lee	03N03E28CDB1	345005.93	904748.84	207	4/24/2013	67.27	52.9	52.55	61.11	(14.37)	(14.72)	(6.16)
								Declines/ Wells		1/2	3/3	2/2
								Average Change:		(7.07)	(7.84)	(7.20)
Lincoln	07S07W30CDC1	340443.93	915042.86	208	4/9/2013	173.34			179.23			5.89
Lincoln	08S04W22AAA1	340104.86	912752.79	167	4/9/2013	117.16		117.72	117.93		0.56	0.77
Lincoln	08S05W03BAA2	340309.54	913453.58	180	4/9/2013	133.66		148.47	145.14		14.81	11.48
Lincoln	08S05W35ACC1	335906.6	913337.26	166	4/9/2013	124.81			136.92			12.11
Lincoln	08S08W35DBB1	335858.35	915222.4	250	4/9/2013	209.13			201.56			(7.57)
Lincoln	09S07W07DAD1	335633.89	915128.31	296	4/9/2013	263.49		263.75	268.2		0.26	4.71
								Declines/ Wells			0/3	1/6
								Average Change:			5.21	4.56

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County	Station	Latitude	Longitude	LSA	Date Measured	2013 DTW	2012 DTW	2008 DTW	2003 DTW	Δ12-13	Δ08-13	Δ03-13
Lonoke	01N07W03BCC1	344425.34	914503.28	223	4/22/2013	136.37	133	131.9	127.59	(3.37)	(4.47)	(8.78)
Lonoke	01S08W02DBD1	343854.72	914959.73	210	4/22/2013	109.41	95.65	96.9	96.65	(13.76)	(12.51)	(12.76)
Lonoke	02N07W06ACD1	344939.05	914737.03	241	4/22/2013	127.96	125.35		122.12	(2.61)		(5.84)
Lonoke	02N07W09AAA1	344906.42	914500.3	232	4/22/2013	103.37	103.59	101.4	98.64	0.22	(1.97)	(4.73)
Lonoke	02N07W22DBA1	344651.49	914425.68	227	4/22/2013	137.84	136.09	133.2	126.17	(1.75)	(4.64)	(11.67)
Lonoke	02N07W24DAC1	344650.23	914209.37	231	4/22/2013	153.36	157.5		143.96	4.14		(9.40)
Lonoke	02N07W32DDD1	344453.26	914618.97	226	4/22/2013	143.88	142.01	134.85	127.33	(1.87)	(9.03)	(16.55)
Lonoke	02S07W08DCC1	343235.49	914700.29	202	4/22/2013	130.98						
Lonoke	02S08W16BDA1	343227.68	915232.49	216	4/22/2013	124.53	126.39	130.5	121.07	1.86	5.97	(3.46)
Lonoke	02S09W15BBB2	343246.5	915825	226	4/22/2013	73.1		76.5	72.99		3.40	(0.11)
Lonoke	03N07W23CCC1	345144.19	914349.67	228	4/23/2013	93.23		86.2	86.21		(7.03)	(7.02)
								Declines/ Wells		**5/8**	**6/9**	**10/10**
								Average Change:		**(2.14)**	**(3.79)**	**(8.03)**
Miller	19S27W10BBA1	330719	935344	320	5/22/2013	16.96						
								Declines/ Wells		-	-	-
								Average Change:		-	-	-
Monroe	01N01W15DBC2	344139	910542	185	3/27/2013	65.64	63.36			(2.28)		
Monroe	03N02W26DAB1	345042.21	911025.59	192	4/23/2013	51.18	53.7	49.7	45.87	2.52	(1.48)	(5.31)
								Declines/ Wells		**1/2**	**1/1**	**1/1**
								Average Change:		**0.12**	**(1.48)**	**(5.31)**
Ouchita	11S15W27ABD1	334440.87	923725.58	200	4/8/2013	68.02	70.6	70.7	67.03	2.58	2.68	(0.99)
Ouchita	11S17W14CAC1	334631.35	924927.46	146	4/15/2013	19.5	21.2	21.3	19.59	1.70	1.80	0.09
Ouchita	12S15W09BBA1	334223.32	923922.44	213	4/8/2013	48.39	48.38	58.5	68.75	(0.01)	10.11	20.36
Ouchita	12S16W25BDC1	333929.4	924210.82	140	3/19/2013	37.08	48.7			11.62		
Ouchita	12S16W26ABD1	333945.55	924304.12	137	3/19/2013	34.05	23.9		42.32	(10.15)		8.27
Ouchita	12S18W19CDC1	334013.98	925951.31	235	3/21/2013	31.34	32.76	26.9		1.42	(4.44)	

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County	Station	Latitude	Longitude	LSA	Date Measured	2013 DTW	2012 DTW	2008 DTW	2003 DTW	Δ12-13	Δ08-13	Δ03-13
Ouchita	12S19W09BAB1	334251.46	930351.94	290	4/8/2013	12.9	12.84	13.4	10.42	(0.06)	0.50	(2.48)
Ouchita	13S16W28ADD1	333416.22	924450.63	106	4/9/2013	25.7	33.87	25.15	24.35	8.17	(0.55)	(1.35)
Ouchita	13S18W06BBA1	333819	930006	282	4/9/2013	115.29	115.34	114.45		0.05	(0.84)	
Ouchita	13S19W28BCD1	333433.86	930417.81	230	4/9/2013	33.6	38.15	39.6	33.19	4.55	6.00	(0.41)
Ouchita	14S16W32BDB1	332815.62	924639.52	231	3/20/2013	29.07	28.5	26.8	17.2	(0.57)	(2.27)	(11.87)
Ouchita	14S17W02ABB1	333252.75	924926.84	131	4/8/2013	24.8	21.24			(3.56)		
Ouchita	14S17W03CBA1	333234	925055	140	6/19/2013	17.07	17.84	15.48		0.77	(1.59)	
Ouchita	14S17W05CAD1	333238.01	925254.64	157	3/19/2013	38.1	39.05	35.72	36.25	0.95	(2.38)	(1.85)
Ouchita	14S17W19DBB1	333002.2	925345.44	259	3/19/2013	18.66	12.15	10.7	10.6	(6.51)	(7.96)	(8.06)
Ouchita	14S17W32CAD1	332803.41	925251.18	220	4/15/2013	69.2	79.2	80	82.3	10.00	10.80	13.10
Ouchita	14S18W27BDC1	332917.6	925703.97		4/15/2013	43.96	44.01	48.2	41.99	0.05	4.24	(1.97)
Ouchita	14S19W29ABB1	332941.45	930513.43	280	4/9/2013	90.1	89.51	88.7	85.73	(0.59)	(1.40)	(4.37)
Ouchita	15S15W32DBB2	332233.72	924027.13	119	3/20/2013	156.02	156.7	176.5	174.58	0.68	20.48	18.56
Ouchita	15S16W23DAC1	332416.77	924314.16	170	3/20/2013	123.59	126.49	131.6		2.90	8.01	
Ouchita	15S16W30DBD1	332332	924729		4/8/2013	189.43						
Ouchita	15S18W36ADD1	332310.75	925436.06	160	3/20/2013	90.5	90.72	93.6	95.1	0.22	3.10	(4.60)
Ouchita	15S19W10DCC1	332618.38	930318.37	210	3/19/2013	69.6		70.8	70.85		1.20	(1.25)
							Declines/ Wells			7/21	8/19	11/16
							Average Change:			1.15	2.50	1.32
Phillips	01S02E32DDC1	343324.32	905455.41	211	4/23/2013	78.95	78.45	80	80.73	(0.50)	1.05	1.78
Phillips	02S02E01ADC1	343323.48	905056.27	176	4/23/2013	37.17	28.88	36.2		(8.29)	(0.97)	
Phillips	02S04E02DBA1	343242.87	903906.98	250	4/24/2013	109.59	104.17	92.3	113.3	(5.42)	(17.29)	3.71
Phillips	02S05E16BCB1	343108.32	903525.64	190	4/29/2013	32.92		27.9	32.02		(5.02)	(0.90)
Phillips	02S05E29CCC1	342850.81	903635.44	179	4/24/2013	22.31	25.1	20.55		2.79	(1.76)	
Phillips	03S03E30DAA1	342402.88	904914.59	172	4/29/2013	42.82		42.4	44.69		(0.42)	1.87
Phillips	04S02E25CCC1	341824.2	905121.49	166	4/24/2013	33.59		35.4	36.37		1.81	2.78
							Declines/ Wells			3/4	5/7	1/5
							Average Change:			(2.86)	(3.23)	1.85
Prairie	01N05W19CDC1	344113.1	913505.27	212	4/24/2013	143.87	157.27	145.4	141	13.40	1.53	(2.87)

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County	Station	Latitude	Longitude	LSA	Date Measured	2013 DTW	2012 DTW	2008 DTW	2003 DTW	Δ12-13	Δ08-13	Δ03-13
Prairie	01N06W02ABB1	344442.4	913700.96	221	4/24/2013	119.49	119.84	117.55	117.54	0.35	(1.94)	(1.95)
Prairie	01N06W34CBB1	343943.01	913846.17	226	4/24/2013	159.46	164.81	161.45	157.19	5.35	1.99	(2.27)
Prairie	01S05W06BCB1	343903.98	913531.63	220	4/24/2013	155.64	161.25	158.2	153.77	5.61	2.56	(1.87)
Prairie	01S05W20ABB1	343639.91	913351.89	220	4/24/2013	157.69	147.1	162.7	155.61	(10.59)	5.01	(2.08)
Prairie	01S06W01BDD2	343859.48	913612.77	226	4/24/2013	160.8	164.5		168.59	3.70		7.79
Prairie	01S06W11DBD1	343748.99	913654.24	226	4/24/2013	166.55	172.57	169.1	169.4	6.02	2.55	2.85
Prairie	01S06W12BAB2	343826	913613	228	3/20/2013	168.71	177.52	163.3		8.81	(5.41)	
Prairie	02N04W19ACB1	344649.11	912801.56	211	4/25/2013	55.59						
Prairie	02N05W24BCA4	344659	912937		3/13/2013	104.44	103.23			(1.21)		
Prairie	02N06W19AAB1	344718.24	914049.95	236	4/24/2013	155.88	154.41	151.07	142.97	(1.47)	(4.81)	(12.91)
Prairie	02N06W20BCB1	344706.57	914032.97	236	4/24/2013	151.99	150.77	155.4	139.81	(1.22)	3.41	(12.18)
Prairie	02N06W21DAD1	344644.15	913829.47	232	4/24/2013	123.63	126	122.35	121.02	2.37	(1.28)	(2.61)
Prairie	02N06W22BDD1	344653.66	913800.68	233	4/24/2013	121.07	121.94	120.8	127.91	0.87	(0.27)	6.84
								Declines/ Wells		4/13	5/11	8/11
								Average Change:		2.46	0.30	(1.93)
Pulaski	02S11W29AAA1	343115.07	921225.14	245	5/30/2013	31.66			40.23			8.57
St. Francis	03N01W33CDD1	345446.34	910635.08	210	4/23/2013	72.95	71.76			(1.19)		
Union	16S14W15CAB1	331944.03	923218.09	94	3/15/2013	131.77	141.65	157.95	153.21	9.88	26.18	21.44
Union	16S15W20DAA1	331859.92	923957.97	190	3/19/2013	258	249.35	293.9	275.89	(8.65)	35.90	17.89
Union	16S15W31ACC1	331717.09	924128.9	168	3/20/2013	248.75		264.15	301.68		15.40	52.93
Union	16S16W02ABC1	332205.89	924328.6	116	4/2/2013	150.06	152.32	160.58	170.9	2.26	10.52	20.84

Sparta/Memphis Aquifer 2013

County	Station	Latitude	Longitude	LSA	Date Measured	2013 DTW	2012 DTW	2008 DTW	2003 DTW	Δ12-13	Δ08-13	Δ03-13
Union	16S16W03CBC1	332138	924507		3/26/2013	209.55	211.81			2.26		
Union	16S17W36DCC1	331700	924842	180	3/21/2013	222.3						
Union	16S18W34ABC2	331805.99	925708.91	251	3/19/2013	202.58	201.55	229.01	260.35	(1.03)	26.43	57.77
Union	17S13W31BAC1	331200.17	922915.7	216	3/18/2013	270.67	272.93		299.97	2.26		29.30
Union	17S14W15ABA1	331451.3	923159.8	169	3/14/2013	92.97	87.3	86.6	94.65	(5.67)	(6.37)	1.68
Union	17S14W22BAB1	331354.37	923224.17	201	4/1/2013	273.81	278.56	295.01		4.75	21.20	
Union	17S15W06BAA1	331645.6	924132.99	170	3/20/2013	219.71		234.5	258.75		14.79	39.04
Union	17S15W08CDD1	331504.77	924027.41	174.92	3/19/2013	262.84	271	286.58	333.65	8.16	23.74	70.81
Union	17S15W18DBB1	331438.96	924129.21	182.93	4/2/2013	280.57	288.26	292.41	349.34	7.69	11.84	68.77
Union	17S15W28DBA1	331246.08	923909.78	230	4/2/2013	321.32	329.84	340.27	396.69	8.52	18.95	75.37
Union	17S15W28DCC1	331232.92	923923.73	285	3/25/2013	370.9			445.2			74.30
Union	17S15W31DCA1	331145.05	924116.74	272	3/20/2013	374.58		388.4	436.69		13.82	62.11
Union	17S15W31DCA3	331144.43	924116.29		3/26/2013	104.89			169.93			65.04
Union	17S15W31DDA1	331143.75	924104.87	261	4/1/2013	364.75	374.02	372.3	426.27	9.27	7.55	61.52
Union	17S15W36BAB1	331217	923628		3/27/2013	330.15						
Union	17S16W01BAA1	331649.04	924232.96	188.84	3/18/2013	255.6		270.79			15.19	
Union	17S16W02CCC1	331559.23	924403.41	182	3/21/2013	265.03			339.93			74.90
Union	17S16W12CDD1	331508.8	924228.3	221.58	3/20/2013	324		338.68	399.07		14.68	75.07
Union	17S17W25DBA2	331256	924837	250	4/2/2013	315.91	324.56	331.45		8.65	15.54	
Union	17S17W30DCD1	331257.41	925355.54	280	3/21/2013	298.5	307.85	297.65	319.4	9.35	(0.85)	20.90
Union	18S11W09ABC1	331011.92	921443.35	135	3/19/2013	101.85			96.15			(5.70)
Union	18S12W33BBB1	330650.4	922120.16	112	3/18/2013	136.54	141.7	142.74	137.32	5.16	6.20	0.78
Union	18S12W33CBC1	330618.47	922113.46	112	3/4/2013	110.87	110.36			(0.51)		
Union	18S13W16ADD1	330915	922634		3/27/2013	167.4						
Union	18S14W06CCD1	331039.23	923530.87	182	3/27/2013	309.26		320.4			11.14	
Union	18S15W03DAB1	331103.78	923802.12	240	2/6/2013	325.9	329.02	342.03		3.12	16.13	
Union	18S15W33ADA1	330659.32	923858.48	253	3/19/2013	331.35	353.49	368.28	372.64	22.14	36.93	41.29
Union	18S16W10CDD1	331000.38	924445.32	182	3/20/2013	273.42	277.29	320.4	325.82	3.87	46.98	52.40
Union	18S16W11DAC1	331011.23	924316.37	272	3/18/2013	374.2	375.07	377.9		0.87	3.70	
Union	18S16W12ACB1	331028.75	924231.85	302	3/18/2013	401.4	387.28	402.64	453.75	(14.12)	1.24	52.35
Union	18S16W28BBB1	330809.22	924611.13	225	3/14/2013	287.07	291.1	301.2	329.96	4.03	14.13	42.89
Union	18S17W22BDD1	330855.91	925056.48	285	4/2/2013	322.96	326.2	338.25	359.82	3.24	15.29	36.86
Union	18S18W11ACD2	331050.91	925615.1	239	3/19/2013	257.19	261.5	284.28		4.31	27.09	

Sparta/Memphis Aquifer 2013

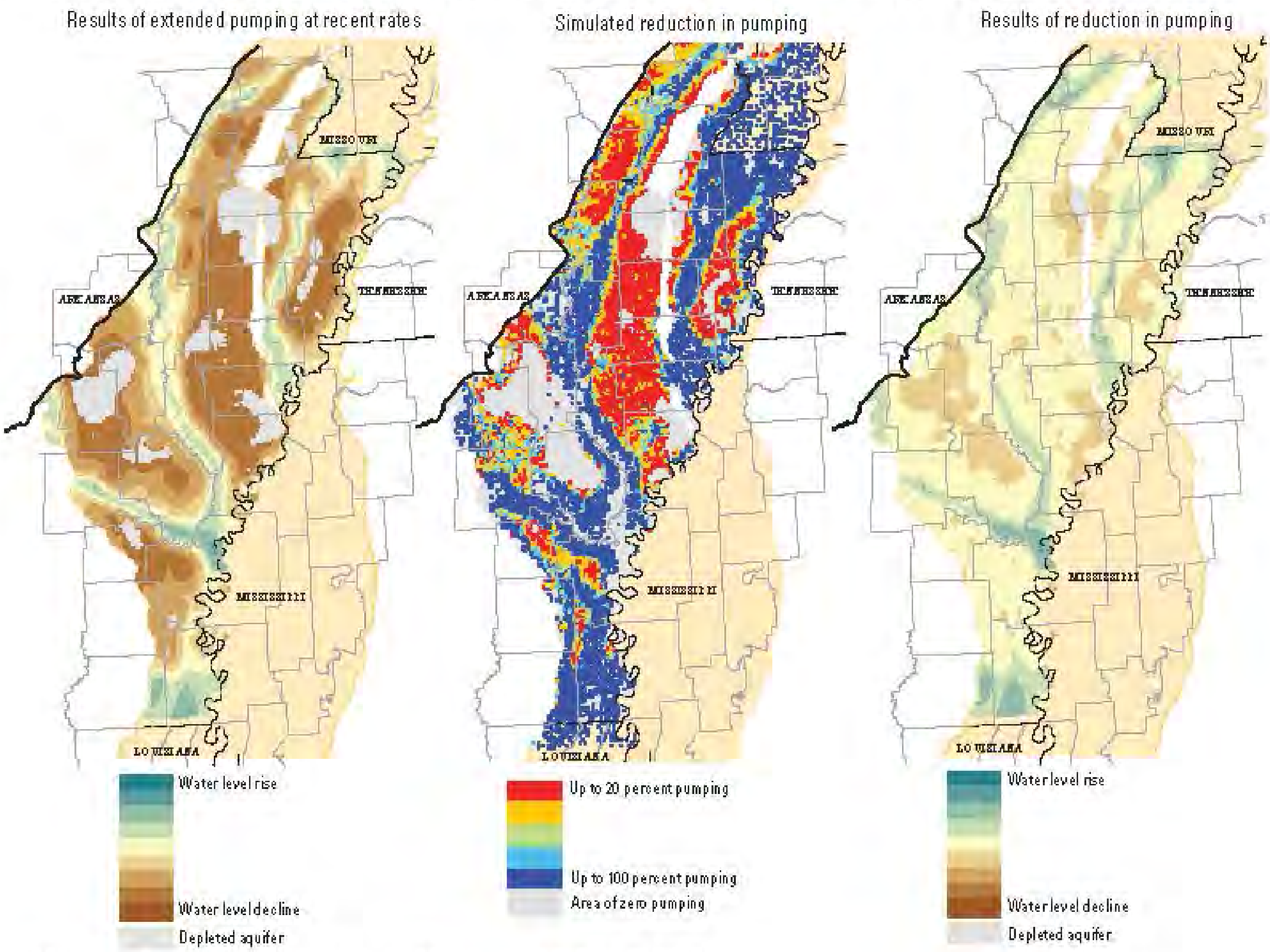
County	Station	Latitude	Longitude	LSA	Date Measured	2013 DTW	2012 DTW	2008 DTW	2003 DTW	Δ12-13	Δ08-13	Δ03-13
Union	19S10W16CBC1	330329.03	920903.96	82	3/19/2013	84.62	85.9	88.7	84.28	1.28	4.08	(0.34)
Union	19S11W23ACA1	330255.38	921228.8	142	3/19/2013	149.11		143.62	151.16		(5.49)	2.05
Union	19S11W25AAA1	330217.84	921113.03	135	3/19/2013	143.78	144.6	149.08	148.02	0.82	5.30	4.24
Union	19S12W13AAA1	330411.26	921716.78	191	3/19/2013	156.54		159.55	154.04		3.01	(2.50)
Union	19S15W01CCA1	330534.81	923645.01	192	3/19/2013	28.07	62.2	73.75	69.3	34.13	45.68	41.23
Union	19S16W35DDC1	330108.86	924325.54	175	4/29/2013	213.59	221.4	235.94	239.08	7.81	22.35	25.49
Union	19S17W16BAA1	330455	925152		3/18/2013	252.6						
Union	19S18W14ADA1	330451.7	925607.9	243	3/14/2013	189.7	190.18	182.22	187.6	0.48	(7.48)	(2.10)
							Declines/ Wells			8/31	4/34	4/32
							Average Change:			4.63	15.02	36.83
							DECLINED WELLS			63/150	77/203	82/105
							TOTAL % WELL DECLINES			42.0	37.9	78.1
							TOTAL AVERAGE CHANGE (ft)			0.95	5.01	6.75

Appendix IV

![USGS science for a changing world]

Prepared in cooperation with the Arkansas Natural Resources Commission

Enhancements to the Mississippi Embayment Regional Aquifer Study (MERAS) Groundwater-Flow Model and Simulations of Sustainable Water-Level Scenarios



Scientific Investigations Report 2013–5161

U.S. Department of the Interior
U.S. Geological Survey

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U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2013

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Contents

Figures

Tables

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1929 (NAD 29).

Altitude, as used in this report, refers to distance above the vertical datum.

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Enhancements to the Mississippi Embayment Regional Aquifer Study (MERAS) Groundwater-Flow Model and Simulations of Sustainable Water-Level Scenarios

By Brian R. Clark[1], Drew A. Westerman[2], and D. Todd Fugitt[3]

Abstract

Arkansas continues to be one of the largest users of groundwater in the Nation. As such, long-term planning and management are essential to ensure continued availability of groundwater and surface water for years to come. The Mississippi Embayment Regional Aquifer Study (MERAS) model was developed previously as a tool to evaluate groundwater availability within the Mississippi embayment, which encompasses much of eastern Arkansas where the majority of groundwater is used. The Arkansas Water Plan is being updated for the first time since 1990 and serves as the State's primary, comprehensive water-resources planning and guidance document. The MERAS model was selected as the best available tool for evaluation of specific water-use pumping scenarios that are currently being considered by the State of Arkansas. The model, developed as part of the U.S. Geological Survey Groundwater Resources Program's assessment of the Nation's groundwater availability, is proving to be invaluable to the State as it works toward development of a sustained yield pumping strategy. One aspect of this investigation was to evaluate multiple methods to improve the match of observed to simulated groundwater levels within the Mississippi River Valley alluvial and middle Claiborne (Sparta) aquifers in the MERAS model. Five primary methods were evaluated: (1) explicit simulation of evapotranspiration (ET), (2) upgrade of the Multi-Node Well (MNW2) Package, (3) geometry improvement within the Streamflow Routing (SFR) Package, (4) parameter estimation of select aquifer properties with pilot points, and (5) modification of water-use estimates. For the planning purposes of the Arkansas Water Plan, three scenarios were developed to evaluate potential future conditions: (1) simulation of previously optimized pumping values within the Mississippi River Valley alluvial and the middle Claiborne aquifers, (2) simulated prolonged effects of pumping at average recent (2000–5) rates, and (3) simulation of drawdown constraints on most pumping wells.

The explicit simulation of ET indicated little, if any, improvement of model fit at the expense of much longer simulation time and was not included in further simulations. Numerous attempts to fully utilize the MNW2 Package were unsuccessful in achieving model stability, though modifications made to the water-use dataset remained intact. Final improvements in the residual statistics may be attributed to a single method, or a cumulative effect of all other methods (geometry improvement with the SFR Package, parameter estimation with pilot points, and modification of water-use estimates) attempted. The root mean squared error (RMSE) for all observations in the model is 22.65 feet (ft) over a range in observed hydraulic head of 741.66 ft. The RMSE for water-level observations in the Mississippi River Valley alluvial aquifer is 14.14 ft (an improvement of almost 3 ft) over a range in observed hydraulic head of 297.25 ft. The RMSE for the Sparta aquifer is 32.02 ft (an improvement of approximately 3 ft) over a range in observed hydraulic head of 634.94 ft.

Three scenarios were developed to utilize a steady-state version of the MERAS model. Scenario 1 was developed to use pumping values resulting from the optimization of baseline rates (typically 1997 pumping rates) from previous optimization modeling of the alluvial aquifer and the Sparta aquifer. Scenario 2 was developed to evaluate the prolonged effects of pumping from the alluvial aquifer at recent pumping rates. Scenario 3A was designed to evaluate withdrawal limits from the alluvial aquifer by utilizing drawdown constraints equal to an altitude of approximately 50 percent of the predevelopment saturated thickness of the alluvial aquifer or 30 ft above the bottom of the alluvial aquifer, whichever was greater. The results of scenario 1 indicate large water-level declines throughout the area of the alluvial aquifer, regardless of the substitution of the optimized pumping values from earlier model simulations. The results of scenario 2 also indicate large areas of water-level decline, as compared to half of the saturated thickness, throughout the alluvial aquifer. The results of scenario 3A reveal some effects from the inclusion of multiple aquifers in a single simulation. The

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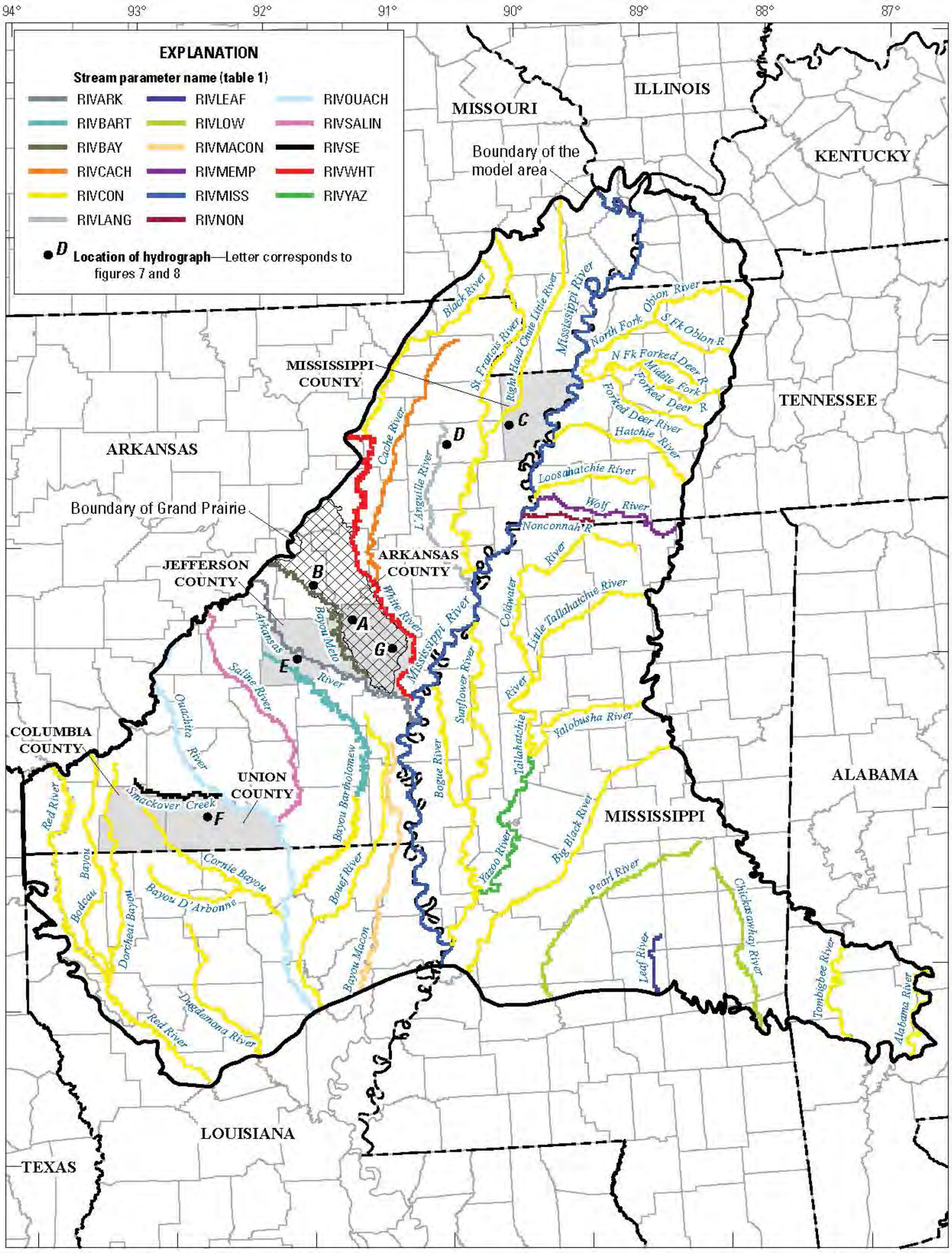
initial configuration of scenario 3A resulted in water levels well below the defined drawdown constraint, and some areas of depleted aquifer (water levels that are near or below the bottom of the aquifer) in east-central Arkansas. A fourth simulation (scenario 3B) was configured to apply the same drawdown constraints from the alluvial aquifer wells to the Sparta aquifer wells in the depleted area. These drawdown constraints reduce leakage from the alluvial aquifer to the underlying Sparta aquifer. This configuration did not produce depleted areas within the alluvial aquifer. Scenarios 3A and 3B indicate that even when pumping is limited in the alluvial aquifer, water levels in the alluvial aquifer may continue to decline in some areas because of pumping in the underlying Sparta aquifer.

Introduction

Arkansas continues to be one of the largest users of groundwater in the Nation (Maupin and Barber, 2005). As such, long-term planning and management are essential to ensure continued availability of groundwater and surface water for years to come (Arkansas Natural Resources Commission, 2013a). One tool implemented as part of the planning process is a groundwater-flow model that can be used to represent recent (2007) and past conditions and evaluate changes in potential future conditions. The Mississippi Embayment Regional Aquifer Study (MERAS) model (fig. 1) of Clark and Hart (2009) and modified in Clark and others (2011) (model versions 1.0 and 1.1, respectively) was developed as a tool to evaluate groundwater availability within the Mississippi embayment, which encompasses much of eastern Arkansas where the majority of groundwater is used. The Arkansas Water Plan is being updated for the first time since 1990 and serves as the State's primary, comprehensive water-resources planning and guidance document (Arkansas Natural Resources Commission, 2013a). The MERAS model has been selected as the best available tool for evaluation of specific water-use pumping scenarios that are currently being considered by the State of Arkansas (Arkansas Natural Resources Commission, written commun., 2013). The model, developed as part of the U.S. Geological Survey (USGS) Groundwater Resources Program's assessment of the Nation's groundwater availability, is proving to be invaluable to the State in the development of a sustained yield pumping strategy. In an effort to continually improve the MERAS model calibration and, thus, the effectiveness of evaluating groundwater availability, the USGS, in cooperation with the Arkansas Natural Resources Commission (ANRC), evaluated multiple methods to improve the match of observed to simulated groundwater levels (reduction in residual error) within the Mississippi River Valley alluvial and middle Claiborne (Sparta) aquifers in the MERAS model. Because of the needs of the ANRC in preparation of the Arkansas Water Plan, the focus of reduction in residual error was primarily in Arkansas. Five methods for reducing the residual error were evaluated: (1) explicit simulation of evapotranspiration (ET) (net recharge was used in previous model versions), (2) upgrade of the Multi-Node Well (MNW) Package, (3) geometry improvement within the Streamflow Routing (SFR) Package, (4) parameter estimation with pilot points, and (5) modification of water-use estimates.

For the analysis contained in this report, the MERAS groundwater-flow model (Clark and others 2011) (hereafter referred to as model version 1.1), which was modified from model version 1.0 (Clark and Hart, 2009) by decreasing the net recharge early in the simulation (predevelopment to the 1960s), was used as a starting point to introduce the enhancements. The MERAS model produced as a result of the enhancements is considered version 2.0 because of the modifications to the MNW Package and the introduction of pilot points. The purpose of this report is to document the multiple methods used to reduce model error, introduce the upgrade of the MNW2 Package and implementation of pilot points to create the MERAS model version 2.0, and provide the resulting calibration. Additionally, the report documents results of scenarios of prolonged pumping using (1) previously optimized pumping, (2) recent average pumping with reductions for surface-water diversions, and (3) drawdown constraints at 50 percent of the Mississippi River Valley alluvial aquifer predevelopment saturated thickness, or 30 ft above the bottom of the alluvial aquifer, whichever was greater. The scenarios are focused on the effects on water-level decline in the Mississippi River Valley alluvial aquifer and the middle Claiborne (Sparta) aquifer within the State boundary of Arkansas.

The MERAS model area is approximately 78,000 square miles (mi^2) and includes eight States with approximately 6,900 miles of simulated streams, 70,000 well locations, and 10 primary hydrogeologic units (Clark and Hart, 2009). The calibration period extends from January 1, 1870, to April 1, 2007, for a total of 137 years and 69 stress periods. The first stress period is simulated as steady state to represent predevelopment conditions. The MERAS model is the only groundwater-flow model currently available to simulate fresh groundwater in all adjacent States that are part of the Mississippi embayment. Therefore, the MERAS model provides a unique tool that is useful for interstate sustainability issues while focusing on a particular State, which is Arkansas in this investigation.



Base from U.S. Geological Survey digital data, variously dated, various scales
Albers Equal-Area Conic projection
Standard parallels 29°30′N and 45°30′N, central meridian -96°W

Figure 1. Location of the Mississippi Embayment Regional Aquifer Study model area, with the primary focus of improvement within the State boundary of Arkansas.

Methods

The explicit simulation of evapotranspiration (ET) required estimates of ET rates for the calibration period from 1870 to 2007. Conceptually, by explicitly simulating ET, the model may more closely approximate the true physical processes at work in the groundwater system and, thus, improve the model calibration, particularly in the early time period of the simulation. ET rates for the simulation period from 1870 to 2007 were estimated from temperature based Potential ET (PET) methods (Hamon, 1961) and adjusted to represent ET at the water table. Grids of maximum and minimum temperature were downloaded from the Parameter-elevation Regression on Independent Slopes Model (PRISM) for the period from 1895 to 2007 (Daly and others, 2000; PRISM Climate Group, 2011). An average of the earliest available temperature grids (1895–97) was used to estimate PET rates for the simulation period from 1870 to 1894. PET rates were calculated using the Hamon method (Hamon, 1961), a method recommended by Lu and others (2005) for regional applications in the Southeastern United States. Grids of PET values were developed for each stress period of the MERAS model version 2.0 and further adjusted through multipliers similar to those used in the estimation of recharge in the MERAS model version 1.0 to achieve representative values of ET at the water table using the ET Package of MODFLOW–2005 (Harbaugh, 2005).

Recent and ongoing advancements in water-resource models allow for explicit simulation of water-management concerns such as multiscreened wells. The MERAS model version 1.1 incorporates the Multi-Node Well 1 (MNW1) Package (Halford and Hanson, 2002) to represent wells completed in multiple aquifers. Recent modifications to the MNW Package (referred to as MNW2) (Konikow and others, 2009) include new output options to more easily evaluate the flow of water through MNWs and, thus, evaluate the effect on the groundwater system. The MNW dataset used in the MERAS model versions 1.0 and 1.1 contained well fields in which each well within the same well field was given the same identifier, which is not compatible with the MNW2 Package. The duplicate well identifiers were replaced with unique identifiers in MERAS model version 2.0 or, in some cases, actual duplicate withdrawals were removed. The MERAS model (all versions) discretized selected hydrogeologic units (such as the middle Claiborne [Sparta] aquifer and the lower Wilcox aquifer [Clark and others, 2011, table 1]) into multiple model layers. Because these units span multiple layers, and the location of well screens in these units was not well known, many of the wells were input into the model as MNWs rather than input as a withdrawal from a single layer (representing a discrete zone within a single hydrogeologic unit). While this method of input accounts for the uncertainty in well screen placement, it adds complexity to the simulation that may not be warranted. These MNWs were replaced by withdrawals from a single layer (the lowermost layer representing each hydrogeologic unit) and simulated as a single-node well in MNW2 in model version 2.0. In the MERAS model version 1.1 in the Grand Prairie area (fig. 1), wells designated with the middle Claiborne aquifer (hereafter referred to as the Sparta aquifer) as the primary aquifer were simulated as extending from the Mississippi River Valley alluvial aquifer (hereafter referred to as the alluvial aquifer) to the lower part of the Sparta aquifer with the MNW Package. However, in the MERAS model version 2.0, these wells were specified only in the Sparta aquifer (layer 7) and were simulated using a single node in MNW2.

The SFR Package also was designated for improvement, particularly the geometry of selected streams simulated by the package (Niswonger and Prudic, 2005). As noted in Clark and Hart (2009), stream widths in the MERAS model version 1.0 were determined from 1:24,000 topographic maps at the midpoint of the stream length simulated in the model area. For the MERAS model version 2.0, the USGS obtained measured cross-section data from the U.S. Army Corps of Engineers on the Arkansas and Mississippi Rivers (fig. 1). From these cross-section data, more accurate estimates of mean stream width and depth were calculated. Additional river parameters representing Bayou Bartholomew, Bayou Macon, Bayou Meto, Leaf River, Nonconnah River, and Yazoo River (fig. 1) also were created to represent potential differences in streambed conductance. Many streambed conductances were modified from the original calibrated values to reflect changes in parameterization and geometry (table 1).

For the MERAS model version 2.0, the benefits of pilot points were evaluated (Doherty, 2003), particularly in the storage and hydraulic conductivity properties of the shallow alluvial aquifer and the deeper confined system of the Sparta aquifer where small changes in storage and hydraulic conductivity can produce large changes in simulated groundwater levels. The MERAS model versions 1.0 and 1.1 used discrete zones to represent aquifer properties and stresses (such as hydraulic conductivity, storage, vertical anisotropy, and recharge), whereas version 2.0 used pilot points to allow for greater flexibility in the spatial assignment of aquifer properties. Essentially, each point at a specified location is assigned a value of a hydraulic property, which can change throughout the calibration process. A hydraulic property value for each model cell is interpolated based on the values of surrounding pilot points, which can serve to spatially vary the properties in a gradational manner, rather than discrete zones of hydraulic properties. More information on pilot points and the geostatistical methods are available in Doherty (2011). Pilot points were distributed uniformly across the alluvial and Sparta aquifers at a spacing of approximately 5 miles (figs. 2 and 3), resulting in a total of 2,056 pilot points for the alluvial and other surficial aquifers (which included alluvial and terrace deposits beyond the Mississippi River Valley alluvial aquifer) and 2,271 pilot points for the Sparta aquifer. Additional pilot points were generated for

Table 1. Streambed conductance parameter values.

[All units are in feet per day; MERAS, Mississippi Embayment Regional Aquifer Study]

River name	MERAS model version 1.1 parameter name	MERAS model version 2.0 parameter name	MERAS model version 1.1 parameter value	MERAS model version 2.0 parameter value
Selected rivers	RIVCON	RIVCON	1.458×10^{-1}	2.458×10^{-1}
Arkansas River	RIVARK	RIVARK	9.0×10^{-2}	1.09
Mississippi River	RIVMISS	RIVMISS	15.4	1.0×10^{-2}
Ouachita River	RIVOUACH	RIVOUACH	16.1	16.1
White River	RIVWHT	RIVWHT	13.8	1.80
L'Anguille River	RIVLANG	RIVLANG	9.9×10^{-1}	1.0×10^{-2}
Saline River	RIVSALIN	RIVSALIN	1.03	0.10
Cache River	RIVCACH	RIVCACH	1.14	1.14
Selected rivers	RIVLOW	RIVLOW	1.099×10^{-2}	1.099×10^{-2}
Wolf River	RIVMEMP	RIVMEMP	1.00	0.10
Bayou Meto	RIVLOW	RIVBAY	1.099×10^{-2}	[1]0.001-0.1
Nonconnah River	RIVMEMP	RIVNON	1.00	0.10
Bayou Macon	RIVCON	RIVMACON	1.458×10^{-1}	1.458×10^{-1}
Bayou Bartholomew	RIVCON	RIVBART	1.458×10^{-1}	4.0×10^{-2}
Leaf River	RIVCON	RIVLEAF	1.458×10^{-1}	1.0×10^{-2}
Yazoo River	RIVCON	RIVYAZ	1.458×10^{-1}	1.2×10^{-1}
Smackover Creek	RIVCON	RIVSE	1.458×10^{-1}	2.0×10^{-1}

[1]Value linearly interpolated from upstream to downstream.

the Vicksburg-Jackson confining unit (fig. 4) and recharge multiplier values (fig. 5). Initial storage values for each pilot point were generated by interpolating a continuous surface between estimated storage values from aquifer tests. Initial values of hydraulic conductivity and recharge multiplier values were duplicated from the zonal values used in the MERAS model version 1.0. The value of each pilot point was then manually and automatically adjusted using a program (PEST; Doherty, 2008) to estimate optimal parameter values through a series of model simulations. After each model simulation, simulated hydraulic-head values were compared automatically to measured hydraulic-head values. The simulations continued until a best fit between simulated hydraulic head and measured hydraulic head was attained. The calibration approach used in the simulation was similar to that used by Clark and Hart (2009), which took advantage of Tikhonov regularization (Tikhonov, 1963; Doherty, 2003; Fienen and others, 2009) and hybrid singular value decomposition (Tonkin and Doherty, 2005; Hunt and others, 2007), also referred to as SVD-Assist in Doherty (2008). These methods can serve to constrain the parameter values so that large discrepancies in hydraulic properties are minimized, and parameters are combined in a way to make automated parameter estimation feasible when the number of pilot points (thus parameters) can easily number in the thousands.

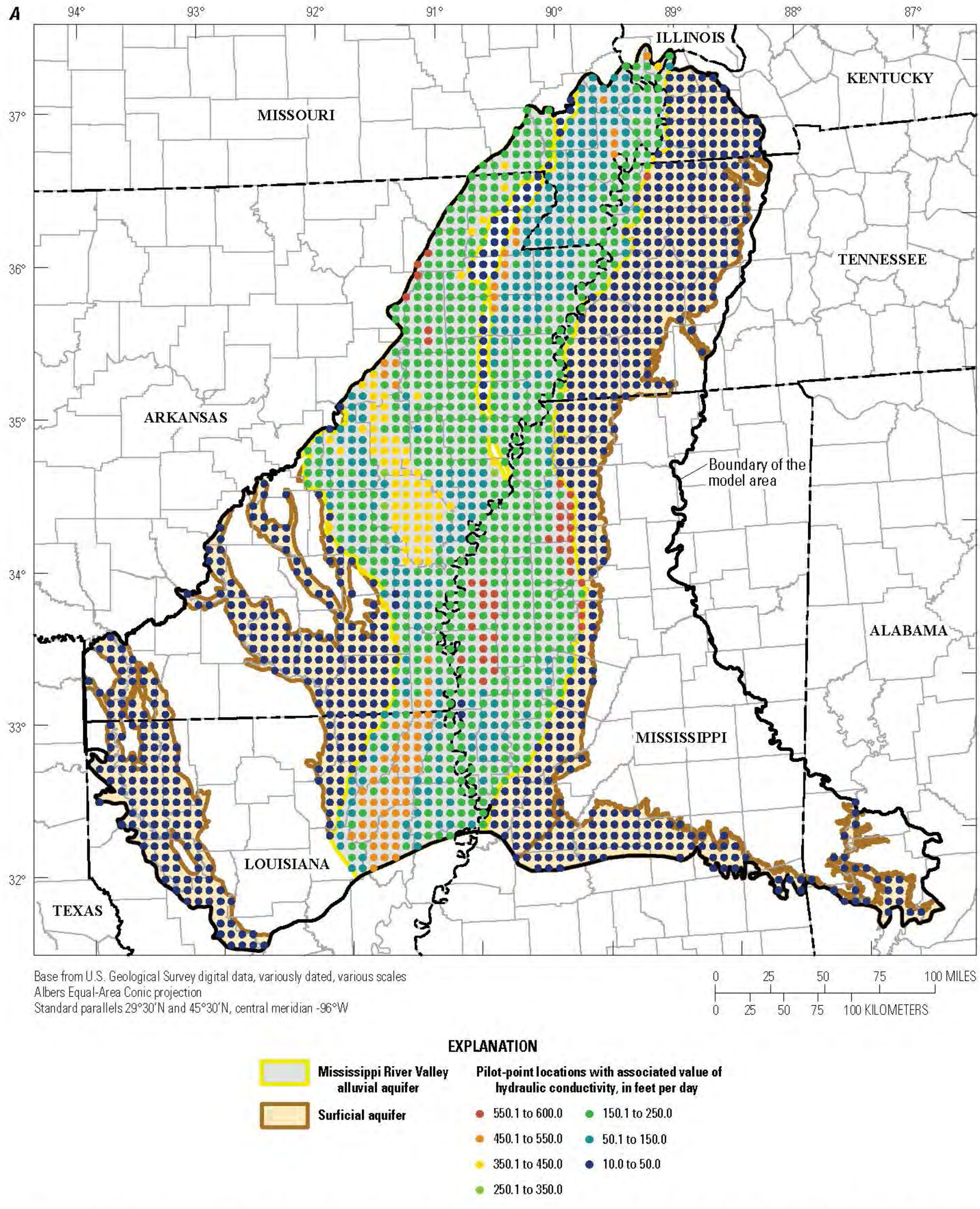


Figure 2. Pilot-point locations and values of (*A*) hydraulic conductivity and (*B*) specific storage used to represent the alluvial (and other surficial) aquifer.

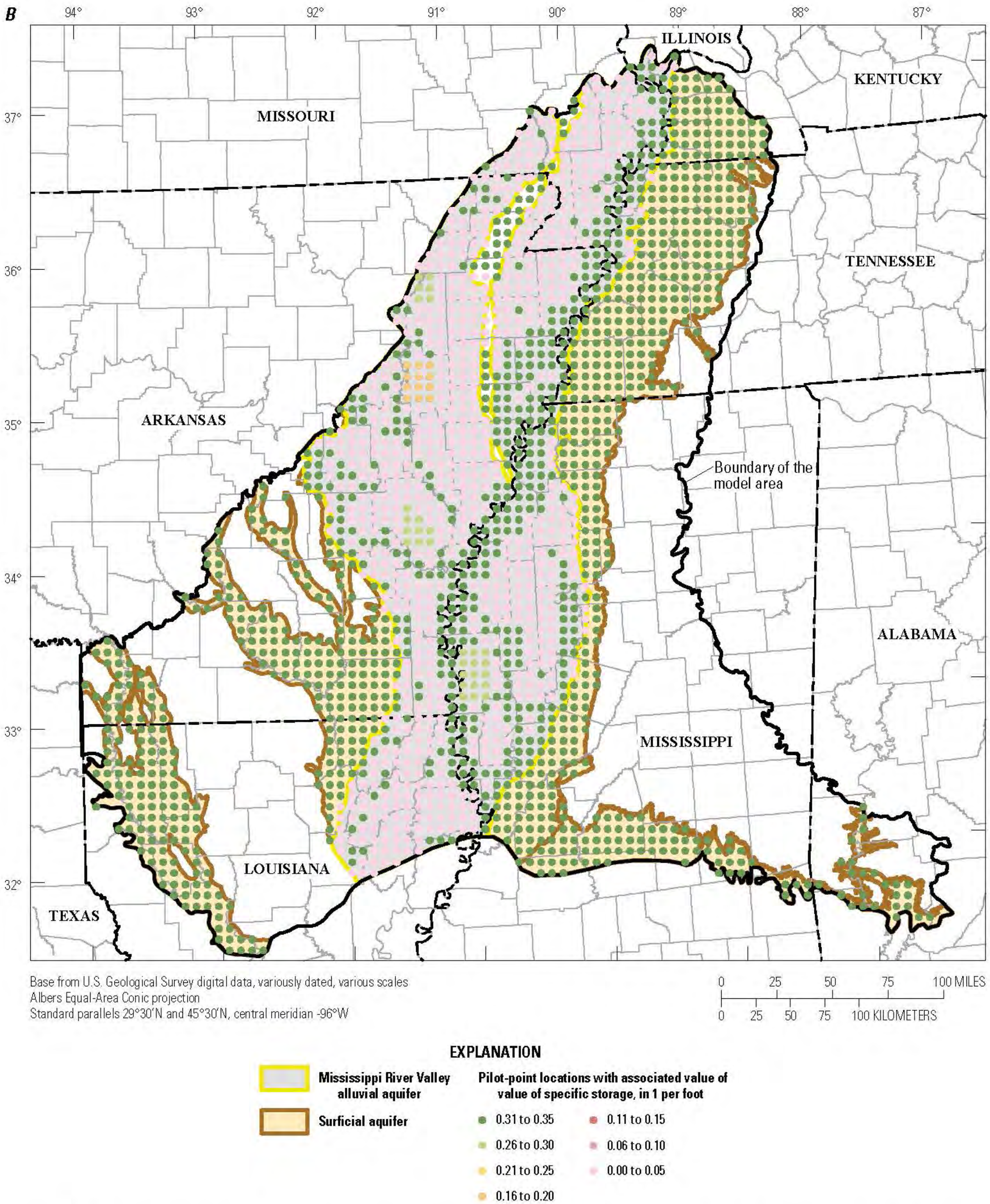


Figure 2. Pilot-point locations and values of (*A*) hydraulic conductivity and (*B*) specific storage used to represent the alluvial (and other surficial) aquifer.—Continued

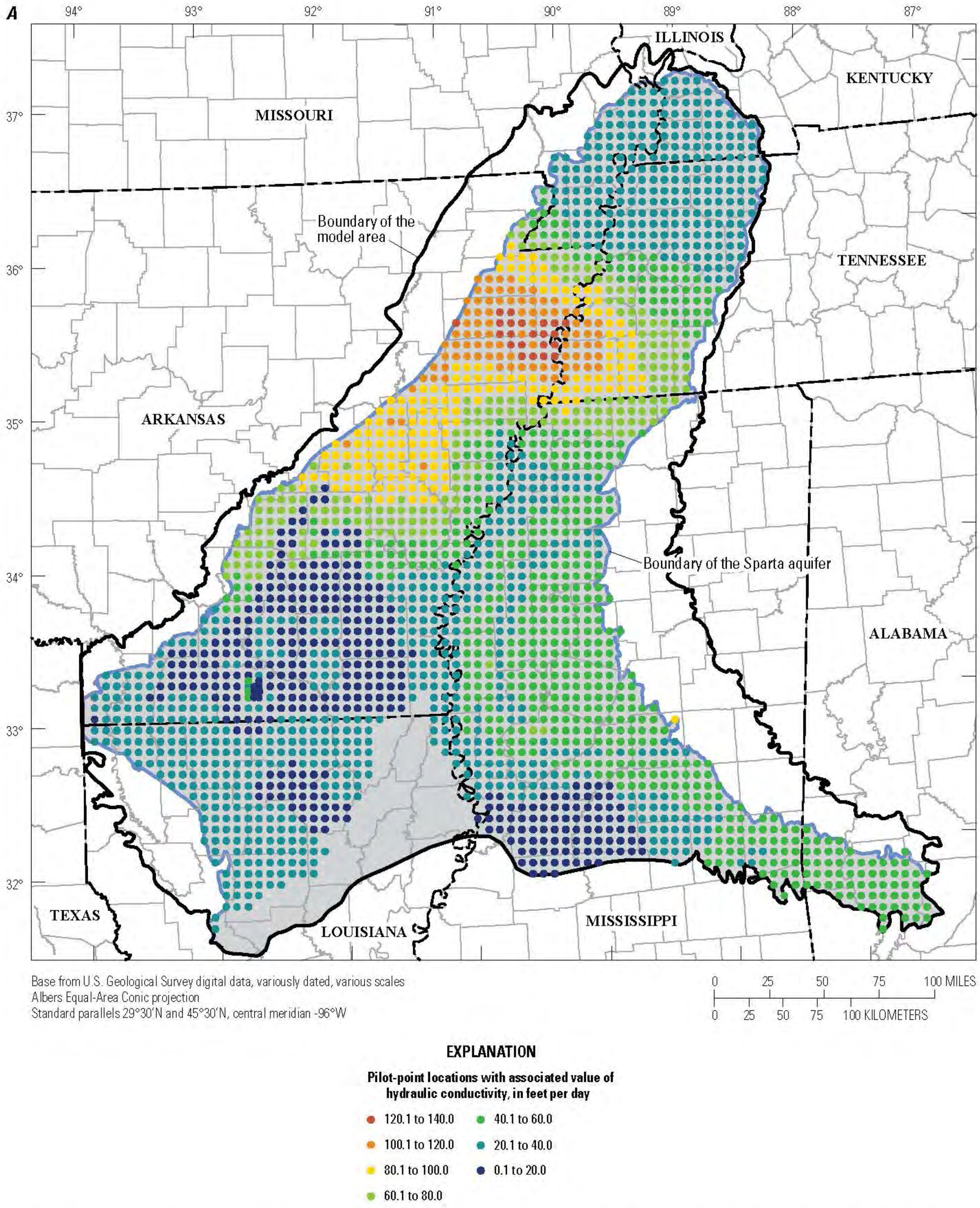


Figure 3. Pilot-point locations and values of (*A*) hydraulic conductivity and (*B*) specific storage used to represent the Sparta aquifer.

B

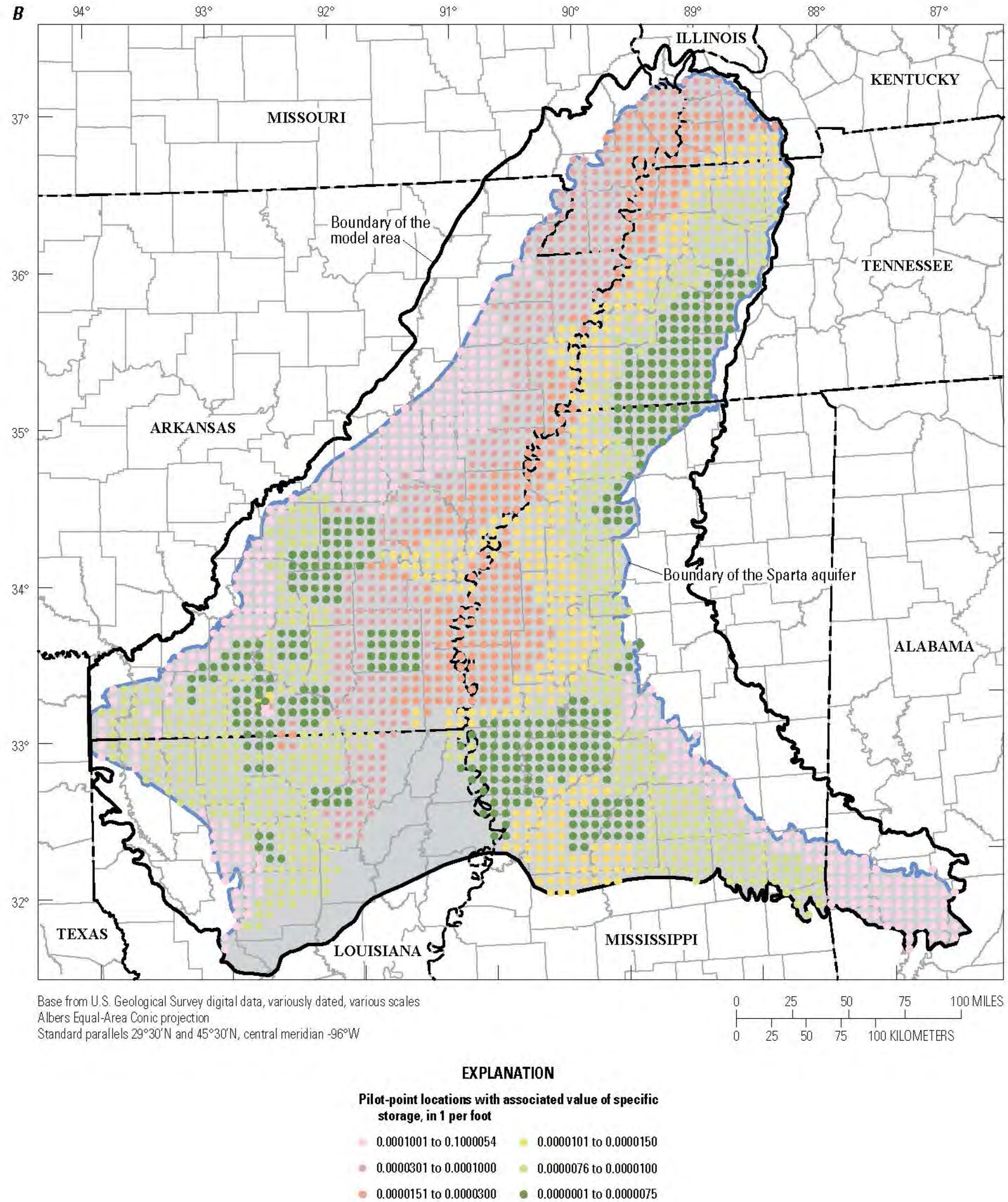


Figure 3. Pilot-point locations and values of (*A*) hydraulic conductivity and (*B*) specific storage used to represent the Sparta aquifer.—Continued

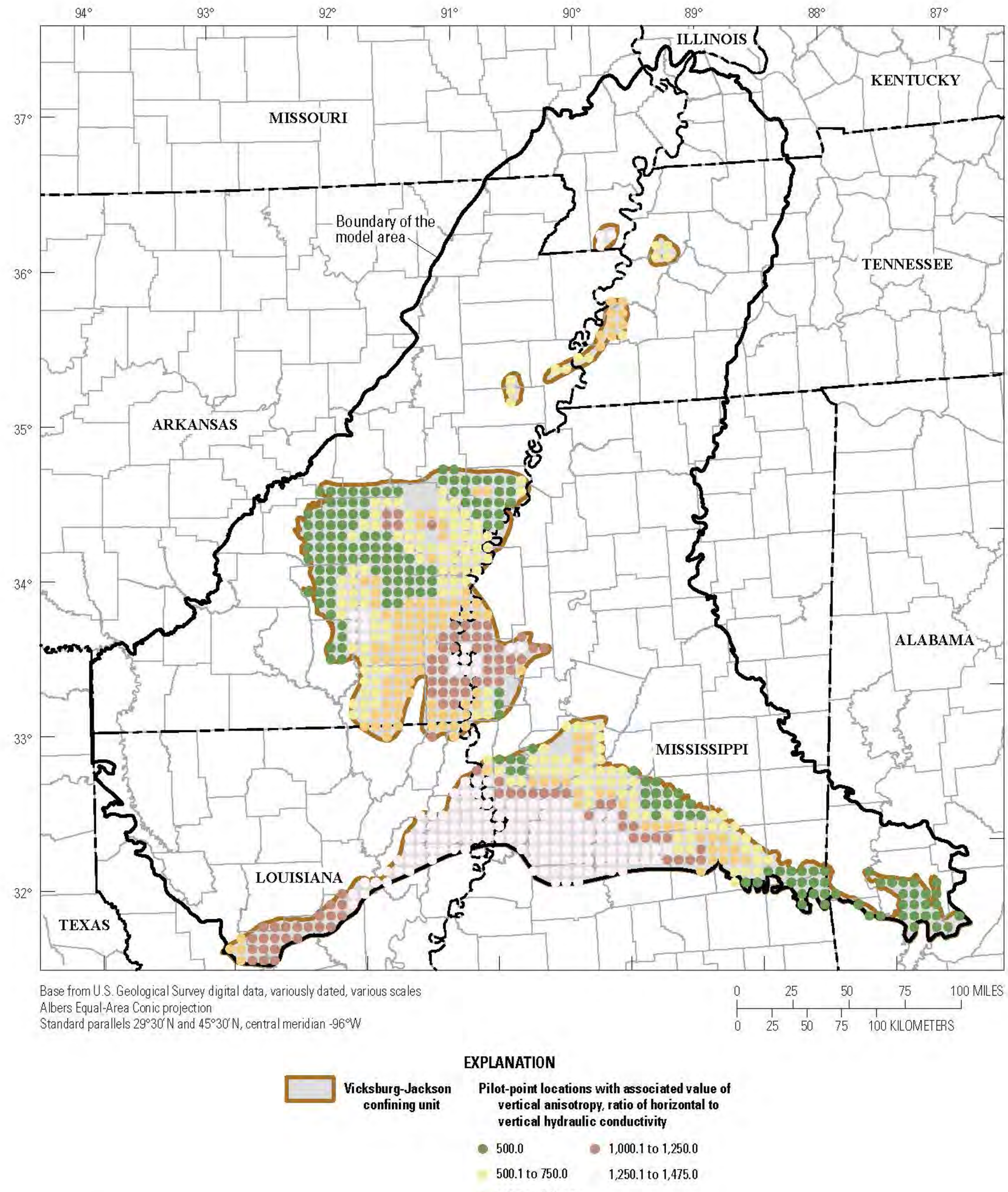


Figure 4. Pilot-point locations and values of vertical anisotropy used to represent the Vicksburg-Jackson confining unit.

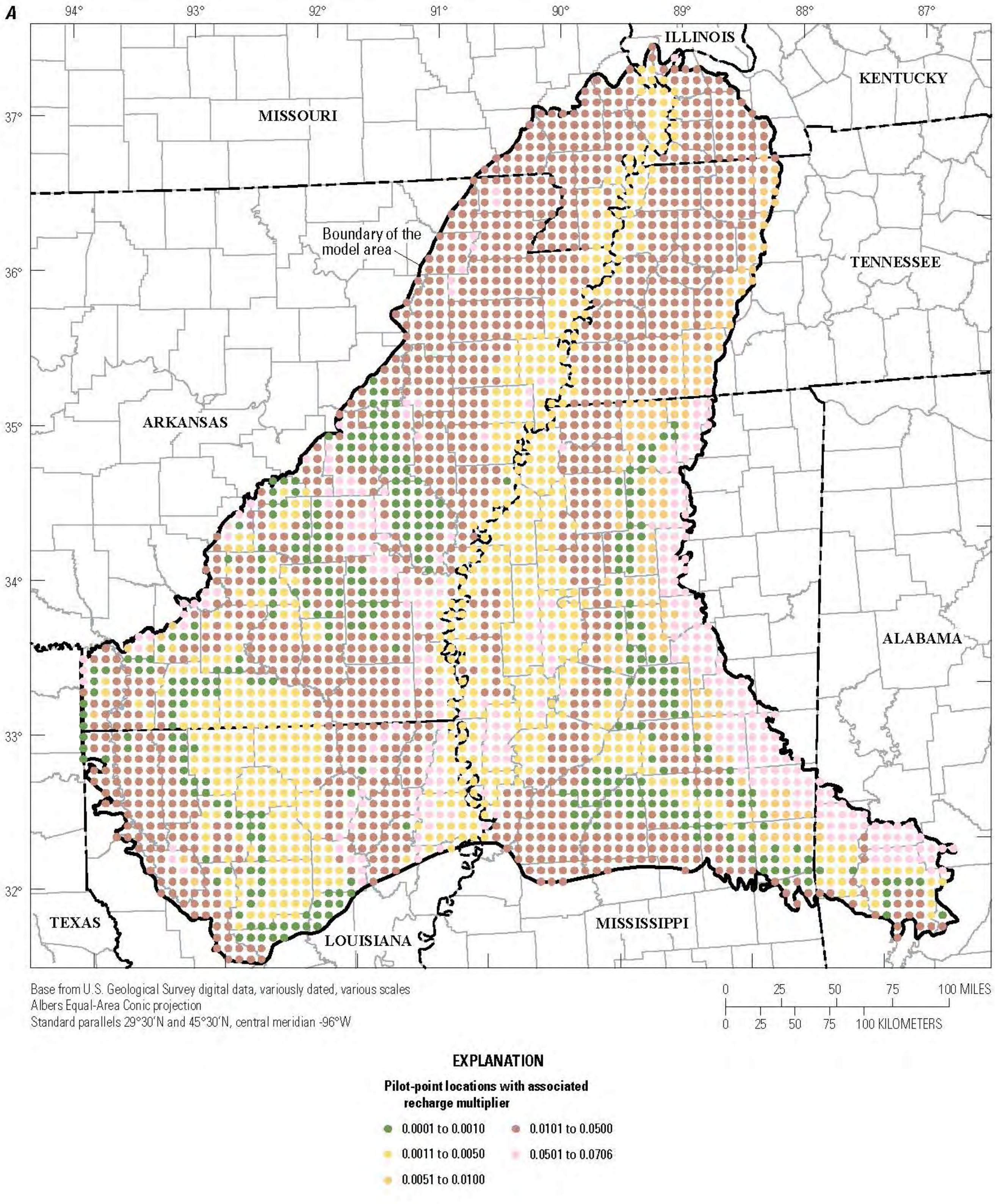


Figure 5. Pilot-point locations and values of recharge multipliers.

During a review of estimated water-use values used in the previous MERAS models, some published values in the 5-year water-use reports (Holland, 1987; Holland, 1993; Lovelace and Johnson, 1996; Lurry, 1987; Walter, 1982) were found to have corrected values estimated after the initial publication date. Additionally, simulated hydraulic head values in select counties such as Columbia, Jefferson, and Union County, Ark. (fig. 1), indicated potential discrepancies with the estimated water-use values from the Sparta aquifer. Upon further comparison with the time-series data, modifications were made to values representing pumping from the Sparta aquifer for select years. As an example, published water-use estimates for Jefferson County, Ark. (Holland, 1987), used in the MERAS model version 1.1 show a general increase in water use from 1965 to 1980, followed by a dramatic decrease (from 71.1 Mgal/day to 42.4 Mgal/day from 1980 to 1985), then another increase (1990 to 1995), followed by another decrease (1995 to 2000) (table 2). Measured water levels in Jefferson County, Ark., used in the MERAS models show an overall steady decline from the 1960s through the early 2000s (Schrader, 2009, fig. 4, p. 16). An increase in water level of approximately 25 ft occurs between about 1982 and 1986, with most of the increase occurring from about 1983 to 1986, which may indicate a decrease in water use for those years. However, because stress periods in the MERAS models represent multiple years in many instances, a large reduction in water use for a single year may not adequately represent average pumping conditions over longer stress periods in the model. Corrections to the 5-year reported values also affected the trend analysis described in Clark and Hart (2009) by modifying the best fit lines based on the updated 5-year values. As a result, corrected values for the 5-year data and trend-estimated data were updated in the water-use data simulated by the MERAS model version 2.0 and incorporated using the methods described in Clark and Hart (2009). While the modifications to water use in the model typically resulted in a positive effect on simulated heads, the cumulative change in water use in the model was not substantial compared to the MERAS model version 1.1.

Table 2. Example comparison of estimated 5-year water-use values in Jefferson County, Arkansas.

[All values are in million gallons per day]

Year	Model version 1.1[1]	Model version 2.0
1960	52.4	52.4
1965	44.4	44.4
1970	59.3	59.3
1975	53.8	53.8
1980	71.1	71.1
1985	42.4	65.0
1990	78.5	63.8
1995	53.9	53.9
2000	50.2	50.2
2005	50.4	50.4

[1]Represents original published values from 5-year water-use reports (Halberg, 1972, 1977; Halberg and Stephens, 1966; Holland, 1987, 1993, 1999, 2004, 2007; Holland and Ludwig, 1981; Stephens and Halberg, 1961).

Evaluation of Model Enhancements

The evaluation of the goodness of model fit is described below through a comparative analysis of root mean square errors (RMSEs) documented in Clark and others (2011) of MERAS model version 1.1. Five primary methods were evaluated to improve the MERAS model, which include (1) explicit simulation of ET, (2) upgrade of the MNW Package, (3) geometry improvement within the SFR Package, (4) parameter estimation with pilot points, and (5) modification of water-use estimation. Any improvement in the simulated hydraulic head value may be attributed to a single method, or a cumulative effect of all methods, with the exception of the explicit simulation of ET. The explicit simulation of ET indicated little, if any, improvement of model fit at the expense of much longer simulation time and was not included in further simulations. Numerous attempts to fully use the MNW2 package were unsuccessful in achieving model stability; therefore, while the MERAS model version 2.0 continues to implement MNW1, all modifications to the pumping dataset were retained, such as removal of duplicate well identifiers and the simplification of withdrawals from a single layer as described in the “Methods” section.

Comparison of Simulated and Observed Values

For comparative purposes to MERAS model version 1.1, the RMSE for observed groundwater levels compared to simulated groundwater levels was computed for each year. The RMSE for all observations in model version 2.0 is 22.65 ft over a range in observed hydraulic head of 741.66 ft over the entire model area, where the range equals the difference between the highest and lowest observed hydraulic head. The RMSE for alluvial observations in model version 2.0 is 14.14 ft (an improvement of almost 3 ft) over a range in observed hydraulic head of 297.25 ft over the entire model area. Likewise, the RMSE for the Sparta aquifer is 32.02 ft (an improvement of approximately 3 ft) over a range in observed hydraulic head of 634.94 ft. RMSE values between the MERAS model version 1.1 and 2.0 are compared in figure 6. The RMSE values derived from MERAS model version 2.0 are similar to or less than RMSE values from the previous MERAS model version for the alluvial aquifer for all time periods (fig. 6). Some of the largest improvements in RMSE values are from the late 1940s and early 1950s. Simulated streamflow is generally similar to the MERAS model version 1.1 and is not shown.

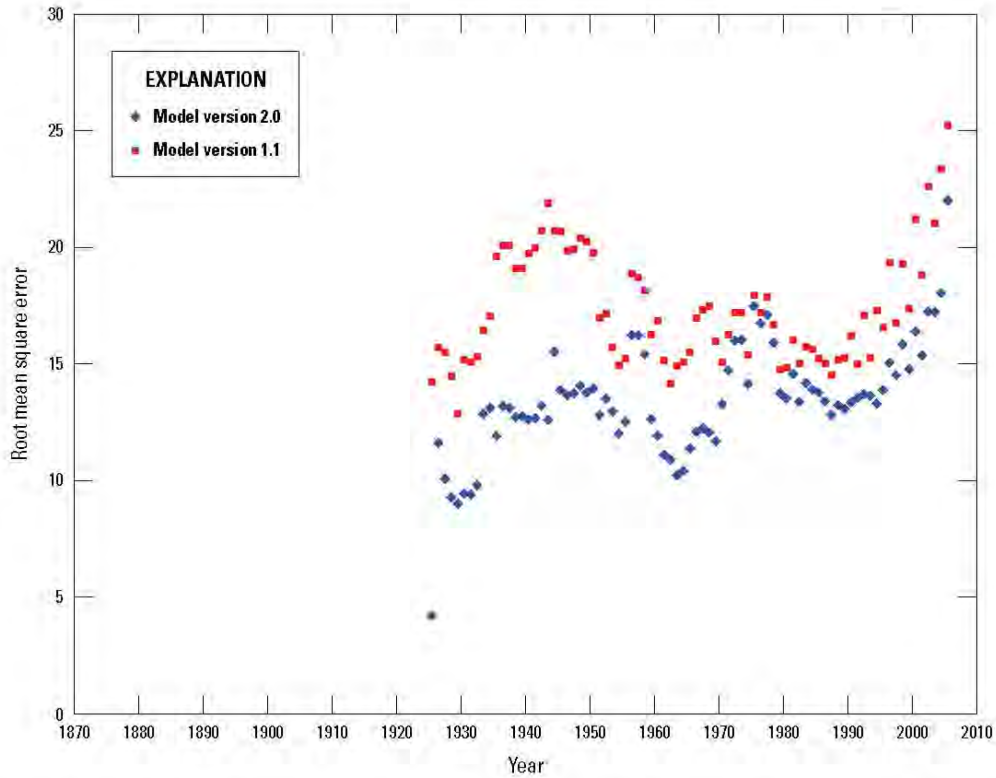


Figure 6. Comparison of root mean square error of the Mississippi River Valley alluvial aquifer between the Mississippi Embayment Regional Aquifer Study (MERAS) model versions 1.1 and 2.0.

Simulated and Observed Hydrographs

Simulated and observed hydrographs of hydraulic head were included in the same manner as presented in Clark and Hart (2009) for wells within Arkansas (fig. 7; locations of wells are included on fig. 1). The location and fit of simulated to observed data of the selected hydrographs give an indication of any spatial bias that may be present in the simulation, which is similar to that presented in MERAS model 1.0 (Clark and Hart, 2009). Simulated hydrographs generally are similar to those of MERAS model versions 1.0 and 1.1; though there are subtle improvements in the match to observed hydrographs in Arkansas, Union, and Mississippi Counties in Arkansas (fig. 1). The MERAS model version 1.0 simulated a water-level decline in the last 10 to 20 years of the simulation period for Mississippi County, whereas MERAS model version 2.0 simulated less decline as indicated by the observed values. The hydrograph in Arkansas County continues to show substantial declines in the simulated hydraulic head. While much effort was applied to improve the model fit in this area, which might require large changes to parameter values, no justifiable reason was found to make these changes based on available aquifer test data. Error in reported water-use amounts is another possible explanation (for the current lack of fit) and is discussed further in the following section “Effects of Water Use Estimation Error.” The observed hydrograph in Arkansas County also may indicate the influence of a boundary condition such as a small stream or lake, which is difficult to adequately represent in large, regional flow models. Another hydrograph difference can be found in Lonoke County, Ark., where the simulated hydraulic head varies by more than 20 ft in the last 20 years of the model simulation. This variability is caused by the irrigation and nonirrigation stress periods used in the later part of the simulation. In light of these differences between simulated and observed values, all hydrographs show good general agreement in the direction and changes in water level. The hydrograph in Mississippi County indicates very little deviation from historical water levels, and the simulation matches this well. Additionally, the hydrograph from Union County, Ark., indicates large water-level declines followed by recovery, which the simulation mimics in a subdued form.

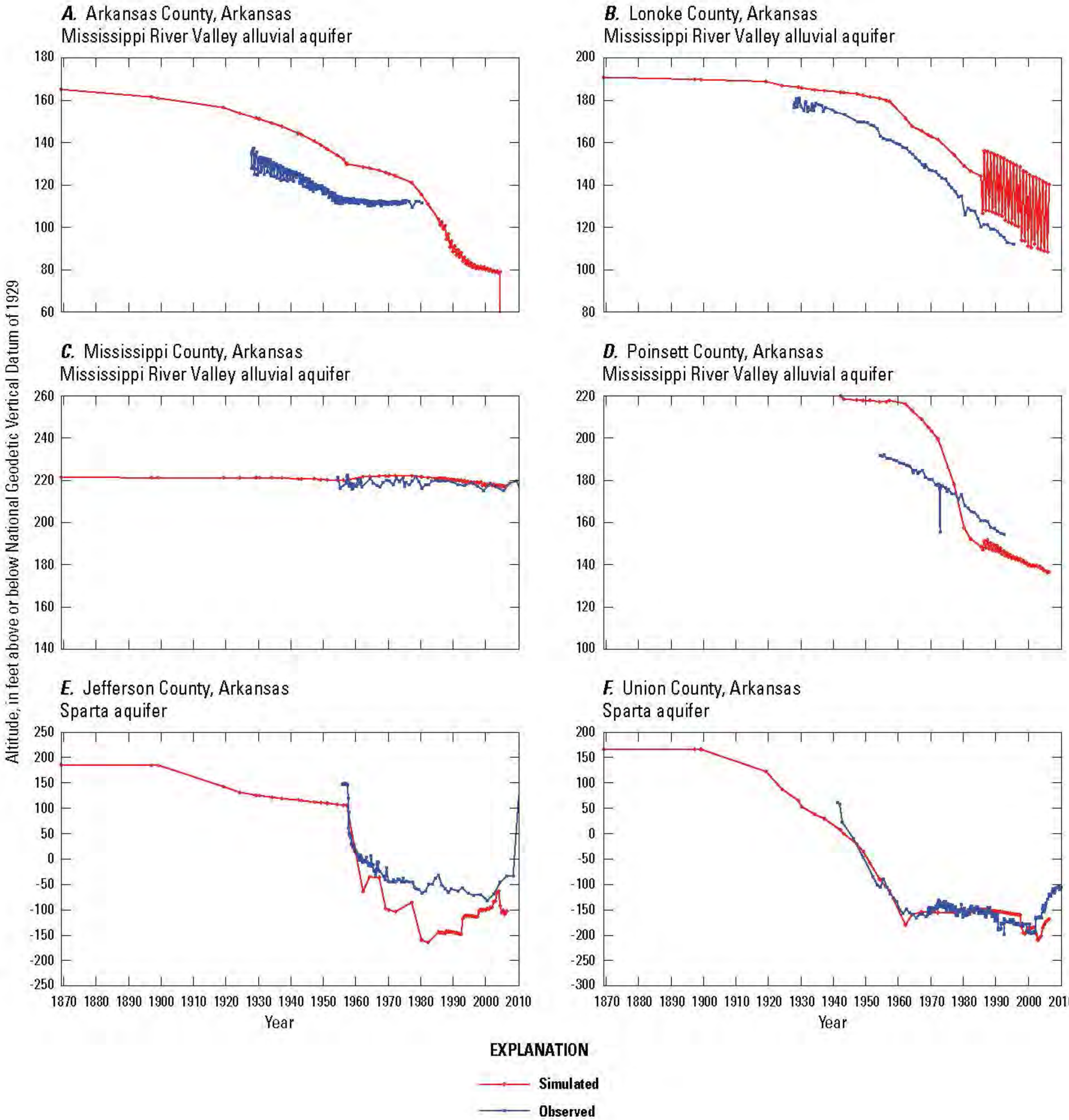


Figure 7. Simulated and observed hydrographs of hydraulic head in selected wells. Letters correspond to figure 1.

Effects of Water-Use Estimation Error

Water-use information in Arkansas is reported yearly by many industrial, municipal, and agricultural entities using the groundwater or surface-water sources (Arkansas Natural Resources Commission, 2013c). In some instances, the reported irrigation amount may represent a rough estimate of the actual amount of water used because of estimating flow from unmetered wells or approximating the depth of water applied over a given extent of crop. To explore the effect of these reported values on simulated heads, water use for all alluvial aquifer wells was reduced by 50 percent for each year after 1982. For some observation wells in the alluvial aquifer, this reduction in pumping resulted in groundwater-level increases of about 20 ft. More drastic differences of 40 ft or more were simulated in some areas of historical groundwater decline, such as a hydrograph from east-central Arkansas County, Ark. (fig. 8). Overall, the new RMSE value was 13.76 ft after the 50-percent reduction in pumping for the alluvial aquifer (compared to a RMSE of 14.14 ft using total reported pumping). Though this improvement is small, it represents the sum total of all alluvial aquifer observations. Many of those observations may not have been affected by the reduction of water use, but the larger improvements in local areas are still reflected (fig. 8).

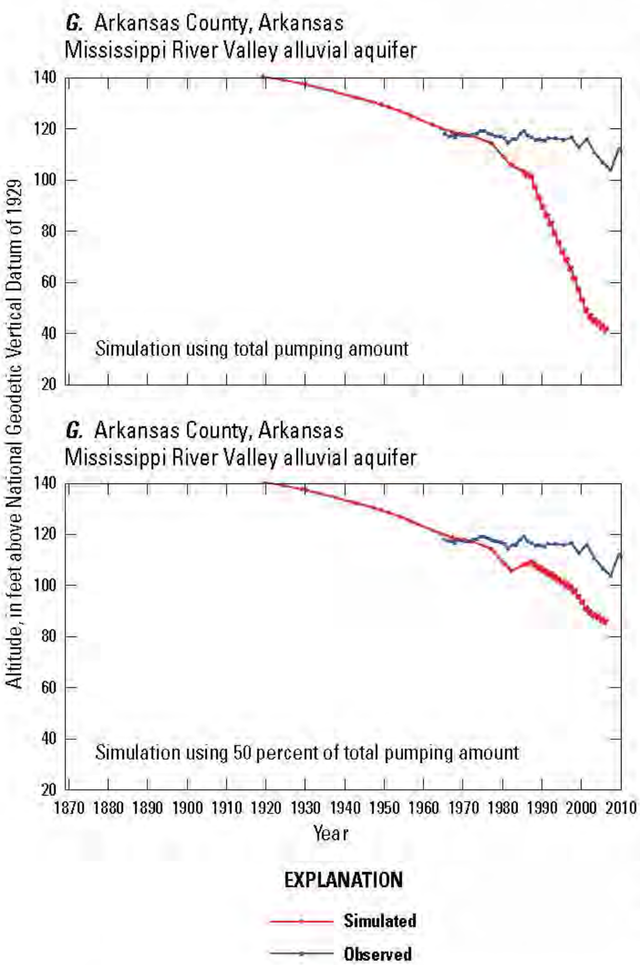


Figure 8. Comparison of hydrographs for simulations using total pumping and a 50-percent reduction in pumping.

Scenario Development

MERAS model version 2.0 may be used to simulate water-level altitudes associated with prolonged pumping to evaluate sustainability of current and projected water-use demands. The following scenarios utilized a steady-state version of the MERAS model that includes average input conditions of streamflow, precipitation (which is converted to net recharge), and the appropriate average pumping condition for the scenario under evaluation. Because of numerical instability within the steady-state scenarios, layer 1 (representing part of the alluvial aquifer) required conversion from a convertible layer to a confined layer in the model configuration. This layer conversion may affect the calculation of transmissivity for part of the alluvial aquifer and is addressed further in “Model Limitations.” For each scenario, the leakage of water from selected reaches of the White, Cache, and Arkansas Rivers (fig. 1) into the alluvial aquifer was extracted from the MERAS model for comparison with regard to effects of groundwater pumping on streamflow. For simplicity, each scenario is summarized as

- 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 ft 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 (fig. 1) set to reduce leakage from the overlying and hydraulically connected alluvial aquifer.

Scenario 1 was developed to use pumping values resulting from the optimization of 100 percent of baseline rates (typically 1997 pumping rates) from previous optimization modeling of the alluvial aquifer (Czarnecki and others, 2003a,b) and the Sparta aquifer (McKee and others, 2004). Each of the previous optimization models used individual models of the alluvial and Sparta aquifers and three modeling packages, MODFLOW-96, MODMAN, and MINOS (Harbaugh and McDonald, 1996; Greenwald, 1998; Murtaugh and Sanders, 1998). The models also determined the maximum total of surface-water and groundwater pumping from the system while maintaining desirable water levels in the aquifer and in streamflows. In each model, 100 percent of the baseline rates indicated that the optimized result placed an upper limit equal to the baseline pumping rate on the amount each well would be allowed to pump. Optimized pumping totals from the previous optimization models for each county within Arkansas were distributed to alluvial and Sparta aquifer wells in the MERAS model version 2.0. In this way, scenario 1 was used to compare the simulation of water levels and streamflow of the MERAS model version 2.0 to previous models used to estimate sustainable yield with regard to the alluvial aquifer and the Sparta aquifer. Pumping values for counties within the MERAS model version 2.0 that were not included in previous optimization work were assigned average pumping rates from recent years 2000 to 2005.

Scenario 2 was developed to evaluate the prolonged effects of pumping from the alluvial aquifer at recent pumping rates with reductions for surface-water diversions. The average pumping for each model cell of all wells in the model, including the alluvial aquifer, from 2000 to 2005 was calculated to represent recent pumping amounts. Because the MERAS model version 2.0 incorporates the MODFLOW MNW1 Package (Halford and Hanson, 2002) to simulate pumping wells, the ability to limit pumping based on a drawdown constraint is included in the model simulations. Using drawdown constraints, pumping is reduced (possibly to the point of zero pumping) when the water level near a well reaches a specified altitude within the well bore. MERAS model versions 1.1 and 2.0 used approximately 2 percent of the aquifer thickness to specify the altitude of drawdown constraints on most pumping wells. In scenario 2, drawdown constraints were assigned as the bottom of the alluvial aquifer for all areas used in previous optimization simulations. Additionally, scenario 2 included reductions of groundwater pumping because of surface-water diversion from the Bayou Meto project area (Bayou Meto Water Management District, 2013) and the Grand Prairie Area Demonstration Project (which is within the Grand Prairie area) (U.S. Army Corps of Engineers, 1999). Surface-water diversion for the Bayou Meto project area is expected to meet approximately 73 percent of the total demand. As such, pumping from all alluvial aquifer wells within the Bayou Meto project area was reduced by 73 percent from the average, recent rate. Surface-water diversion for the Grand Prairie Demonstration Project is planned to approximately equal the total amount of pumping in the project area; therefore, pumping from all alluvial aquifer wells within the project area was reduced to zero.

Scenario 3A was designed to evaluate withdrawal limits from the alluvial aquifer by utilizing drawdown constraints imposed in the MNW1 Package equal to an altitude of approximately 50 percent of the predevelopment saturated thickness of the alluvial aquifer (one of the current water-level criteria for an unconfined aquifer as a Critical Groundwater Area (Arkansas Natural Resources Commission, 2012) or 30 ft above the bottom of the alluvial aquifer, whichever was greater.

By using drawdown constraint altitudes representing approximately 50 percent of the predevelopment saturated thickness, scenario 3A would be similar to other simulations that estimate sustainable yield from groundwater. However, the drawdown constraints imposed in MNW1 do not limit pumping based on additional constraints on streamflow reduction, and MNW1 does not provide an optimal pumping solution as with the capabilities of a complete optimization model such as the Groundwater Management Process of MODFLOW–2005 (Ahlfeld and others, 2011). Additionally, because drawdown constraints are assigned within the well bore, simulated water levels may vary significantly between the well bore and the adjoining aquifer. Therefore, while scenario 3A provides comparative conditions to evaluate sustainable yield based on current pumping rates, the limitations of optimal pumping, drawdown constraints, and conjunctive use from streams apply.

Scenario 3B was designed to include the drawdown constraints in scenario 3A and apply these constraints from the alluvial aquifer wells (at an altitude of approximately 50 percent of the predevelopment saturated thickness of the alluvial aquifer) to the Sparta aquifer wells in the Grand Prairie area. The constraints on the Sparta aquifer wells were set to reduce leakage from the overlying and hydraulically connected alluvial aquifer. The limitations described for scenario 3A also apply to scenario 3B.

Simulations of Sustainable Water-Level Scenarios

Steady-state simulations using the MERAS model version 2.0 provide insight to the aquifer system response using previously optimized pumping (scenario 1), effects of prolonged recent pumping (scenario 2), and effects from reduced pumping based on drawdown constraints (scenario 3A). While the results of the four scenarios (1–3B) described above are useful in gaining understanding of the groundwater system as a whole, caution should be used in interpreting the results, and especially before making comparisons to results from an optimization-simulation model, such as with the Groundwater Management Process (Ahlfeld and others, 2011) or other similar tools. In general, results of the four scenarios reflect the different pumping intensities and the importance of simulating the multiple aquifers of the system in a single model.

The results of scenario 1 indicate large drawdowns throughout the area of the alluvial aquifer, regardless of the substitution of the optimized pumping values from earlier model simulations (fig. 9a). The simulation of scenario 1 may substantiate the need to simulate the aquifers in the Mississippi embayment as a holistic analysis of the groundwater-flow system. Notice that one area of the alluvial aquifer depletion (water levels that are near or below the bottom of the aquifer) lies on either side of Crowleys Ridge (fig. 9a) and corresponds to an area of water-level decline in the Sparta aquifer (fig. 9b). Positive values represent water levels below the top of the aquifer. This area of the Sparta aquifer (near Crowleys Ridge) was beyond the boundary of the previous optimization simulations, which simulated each aquifer (or part of the aquifer) independently so that pumping from the Sparta aquifer did not interfere with pumping from the alluvial aquifer. Because of this, it is possible that more pumping was allowed from each aquifer during the optimization process than might be expected if the system was simulated as a whole. There may be other explanations for the apparent depletion as well, such as the model construction (hydrogeologic framework), boundary conditions, and aquifer property value differences in the earlier models compared to the MERAS model. However, the simulation of pumping from multiple aquifers appeared to play a partial role and is explored further in scenario 3B. The simulated water level of the Sparta aquifer seems more comparable to the previous optimized version of the aquifer in which most water levels over the area are between 100 and 500 ft above the top of the Sparta aquifer (fig. 9b). Most other water levels that fall below the top of the Sparta aquifer are within the outcrop-subcrop zone, or a relatively small area within Union County, Ark., which was also present in the previous optimization work.

The results of scenario 2 also indicate large areas of water-level decline below half of the saturated thickness throughout the alluvial aquifer (fig. 10). This result is not vastly different, with respect to water levels well below the 50-percent constraint, from a similar simulation using 1997 pumping rates in a steady-state simulation (see fig. 11a of Czarnecki and others, 2003a), which indicates large areas of depleted aquifer (water levels that are near or below the bottom of the aquifer) in parts of the Grand Prairie and Cache Critical Groundwater Area (fig. 10) (Arkansas Natural Resources Commission, 2013b). Within the Grand Prairie project area, water levels are typically below half of the alluvial aquifer saturated thickness, though simulations show that without the reduction in pumping, much of the area is completely depleted. The simulation indicates aquifer depletion in the northern part of the Bayou Meto project area, even with a 73-percent reduction in pumping from the alluvial aquifer. This, as with scenario 1, may be caused by pumping from multiple aquifers (as explored further in scenarios 3A and 3B). The simulation of declines on the east side of Crowleys Ridge may reflect an extension of the measured declines noted in some wells in the area since the 1970s (Schrader, 2010, fig. 4g), and because the MERAS model contains an additional 10 years of information beyond the 1997 base pumping information used in Czarnecki and others (2003a).

Because the simulation of scenario 2 included drawdown constraints set at the bottom of the alluvial aquifer within MWN1, the potential exists for a difference in the amount of pumping specified for the scenario (desired pumping) and the amount of pumping allowed to occur in the simulation. Essentially, as water levels decline during the simulation, pumping from wells decreases through loss of pump performance. This results in large areas within the alluvial aquifer that provide less than 20 percent of the desired pumping amount (fig. 11). (Note that desired pumping includes reductions resulting from surface-water diversions.) In some areas, water levels continued to decline to the point that the aquifer was depleted, thus pumping wells were removed in those areas from the simulation (fig. 11). As may be expected, 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 though still less than the desired average amount (fig. 12).

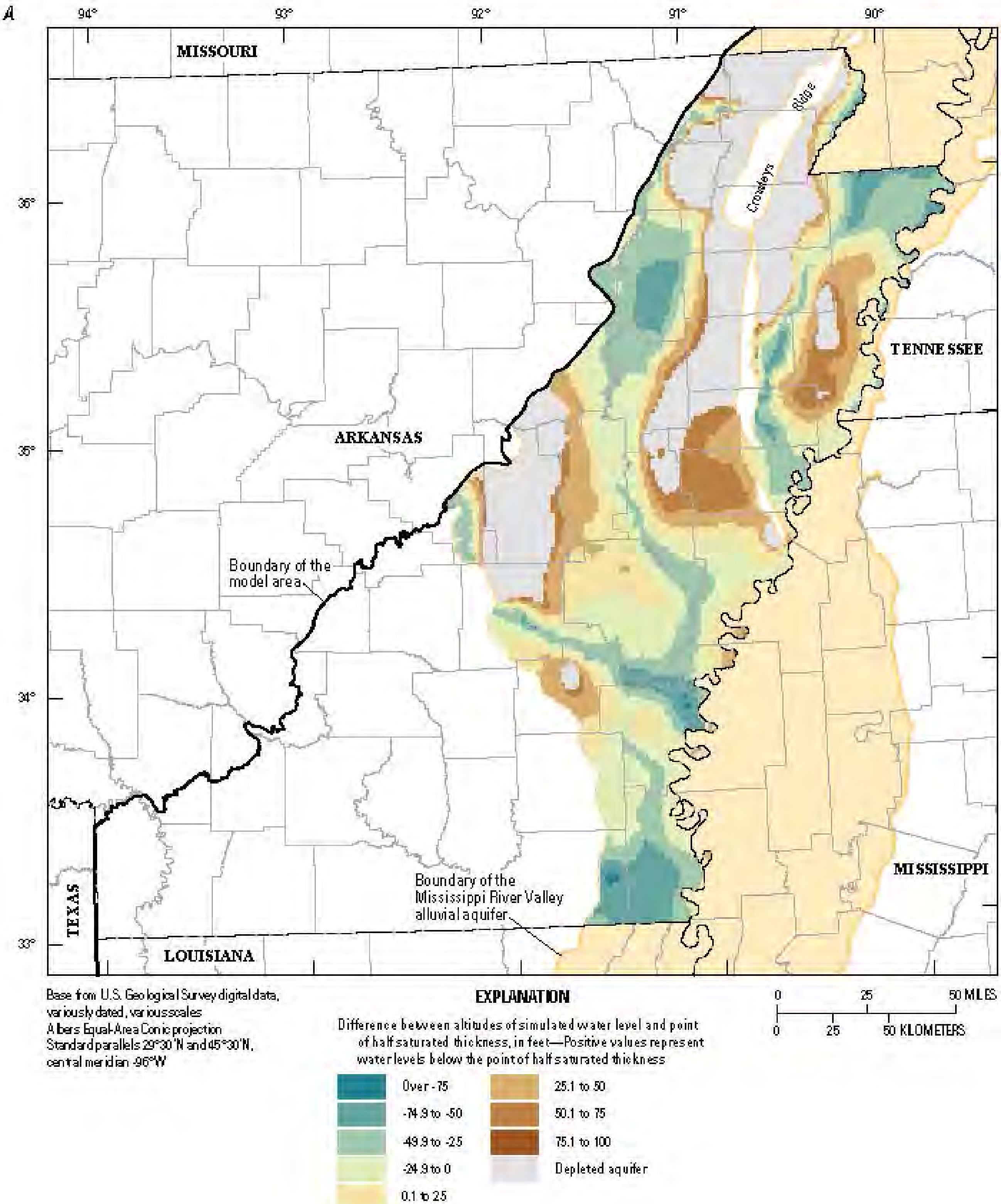


Figure 9. Difference between simulated hydraulic head and the desired drawdown constraint of the (*A*) alluvial aquifer and (*B*) Sparta aquifer for scenario 1.

B

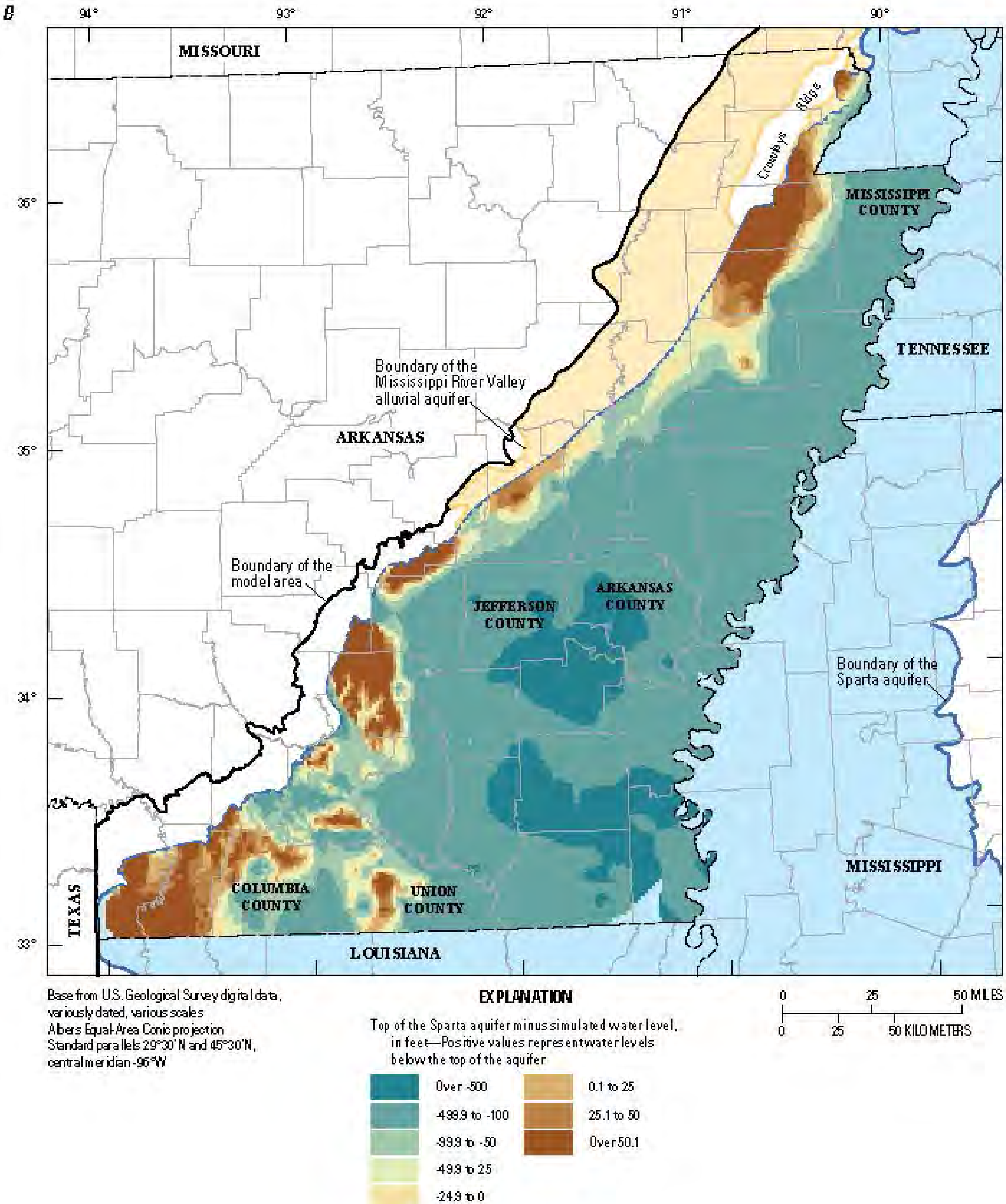


Figure 9. Difference between simulated hydraulic head and the desired drawdown constraint of the (*A*) alluvial aquifer and (*B*) Sparta aquifer for scenario 1.—Continued

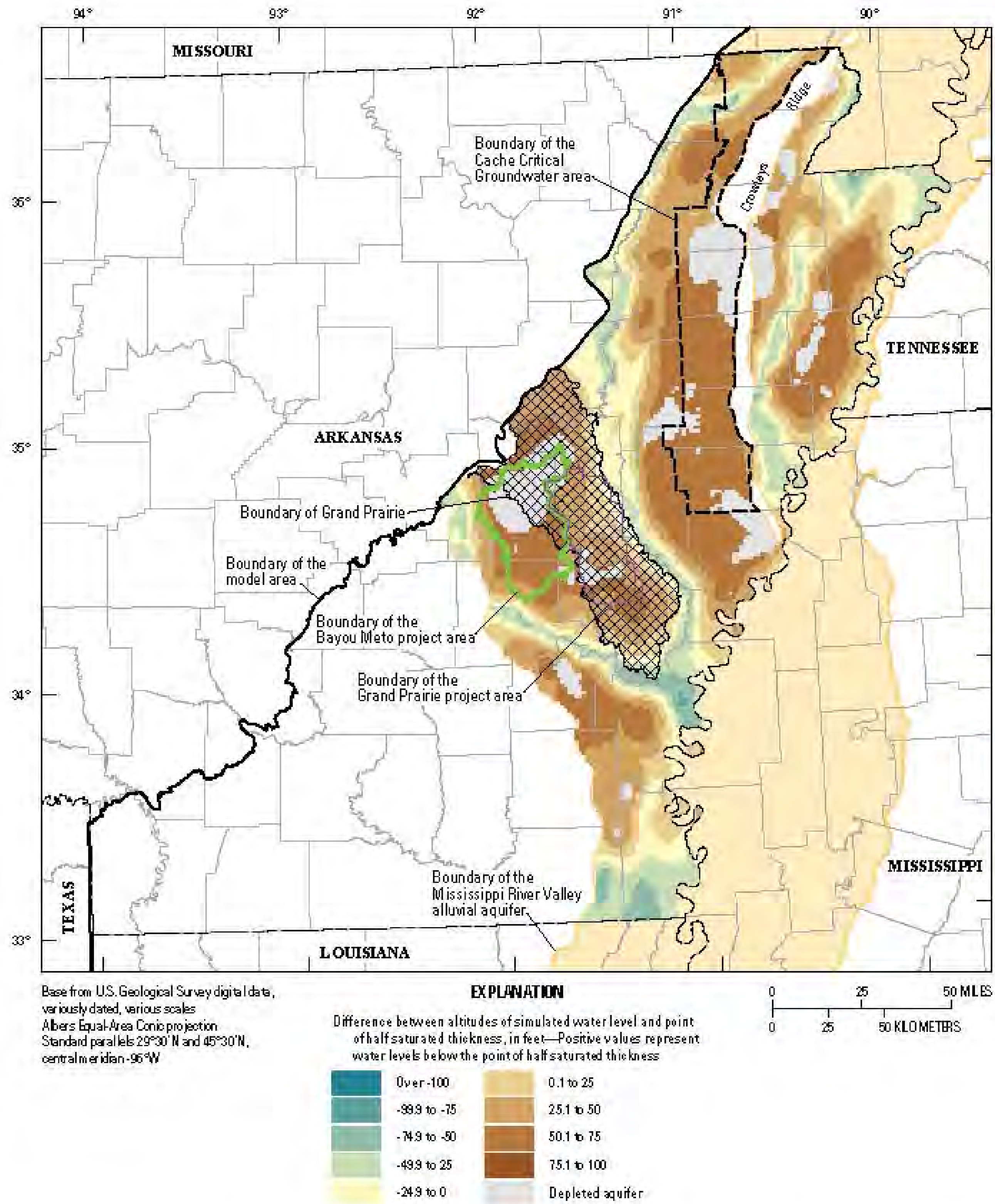


Figure 10. Difference between simulated hydraulic head and half of the saturated thickness of the alluvial aquifer for scenario 2.

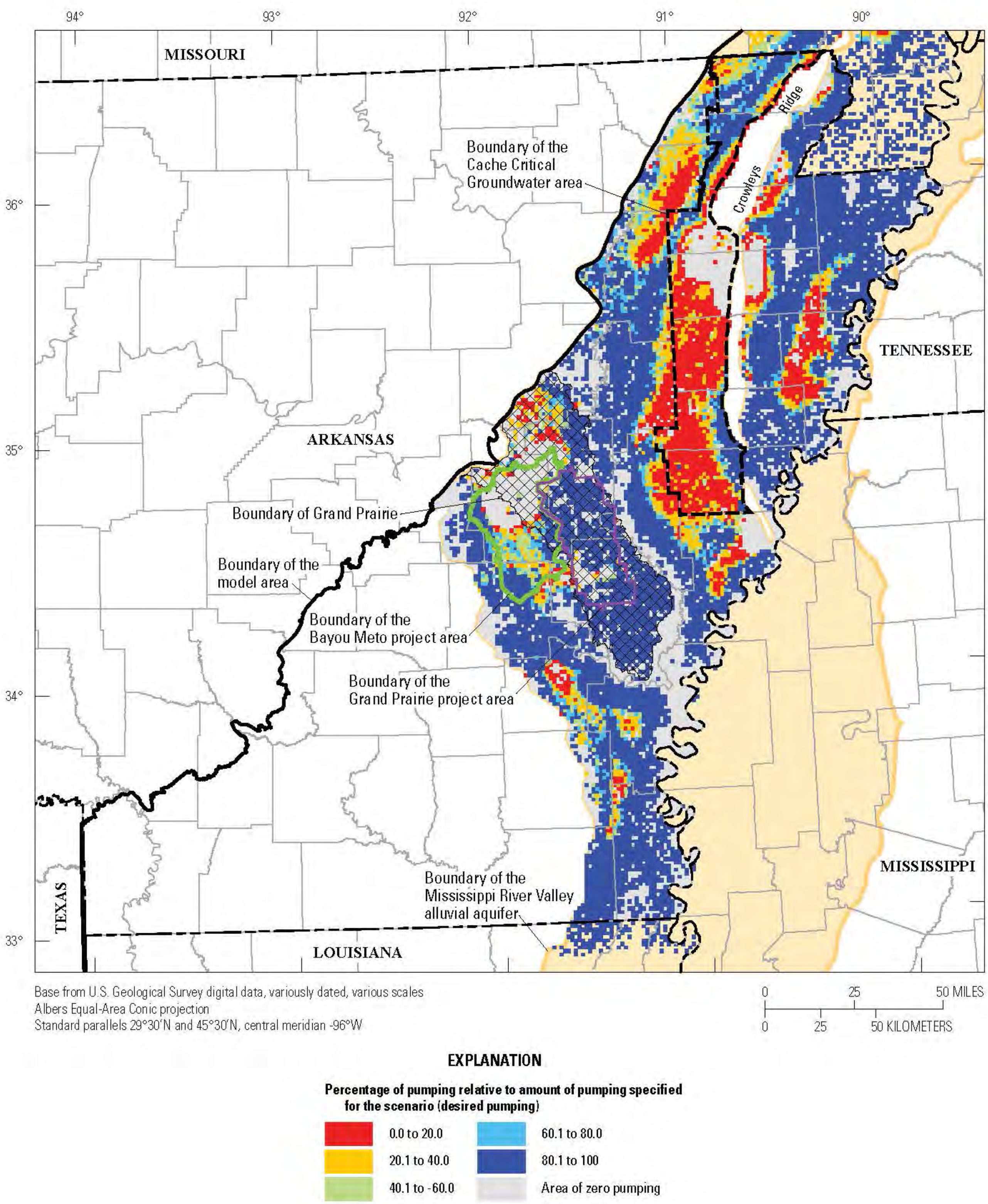


Figure 11. Percentage of desired pumping for scenario 2.

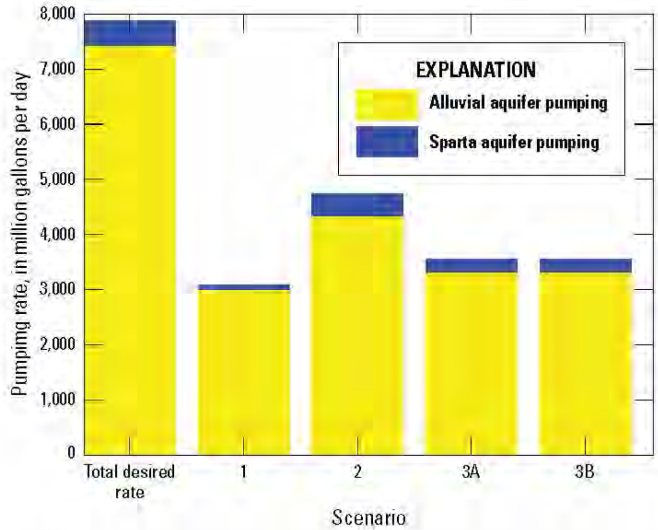


Figure 12. Comparison of pumping rates in the alluvial and Sparta aquifers within the previously optimized areas among each scenario.

The results of scenario 3A reveal some effects from the inclusion of multiple aquifers in a single simulation (fig. 13). Initially, scenario 3A included drawdown constraints on alluvial aquifer wells based on approximately 50 percent of the predevelopment saturated thickness of the alluvial aquifer or 30 ft above the bottom of the alluvial aquifer, whichever was greater. This configuration resulted in water levels well below the defined drawdown constraint and some areas of depleted aquifer in the Bayou Meto project area (fig. 13a). This scenario reflects the areas where the Sparta aquifer subcrops beneath the alluvial aquifer. In this scenario (3A), the drawdown constraints are at an altitude equal to the potentiometric surface of the alluvial aquifer at 50 percent saturated thickness. If water levels in the Sparta aquifer are allowed below this altitude, leakage from the Sparta aquifer to the alluvial aquifer may occur, further dewatering the aquifer. Because of this effect, the water level of the Sparta aquifer must be maintained at a level equal to or greater than the altitude of 50 percent of the predevelopment saturated thickness of the alluvial aquifer. A fourth simulation (scenario 3B) was configured to include the drawdown constraints in scenario 3A and apply these constraints from the alluvial aquifer wells (at an altitude of approximately 50 percent of the predevelopment saturated thickness of the alluvial aquifer) to the Sparta aquifer wells in the Grand Prairie area. These drawdown constraints reduce leakage from the alluvial aquifer to the underlying Sparta aquifer. This configuration did not produce depleted areas within the alluvial aquifer in the Grand Prairie area (fig. 13b). These simulations indicate that even if pumping were limited in the alluvial aquifer, water levels in the alluvial aquifer may continue to decline because of pumping in the underlying Sparta aquifer.

Similar to scenario 2, the drawdown constraints of MNW1 specified in scenario 3B set at half of the saturated thickness of the alluvial aquifer or 30 ft above the bottom of the alluvial aquifer, whichever was greater, allow for a difference in the amount of desired pumping (includes reductions in surface-water diversion areas) and the amount allowed by the drawdown constraints (fig. 14). These results share many similarities to Czarnecki and others (2003a, fig. 8) that simulated large areas of the Grand Prairie and Cache Critical Groundwater areas as unable to sustain pumping under the imposed drawdown constraints. The MERAS model version 2.0 reduces pumping in a manner similar to the previous optimization models, as well as additional areas in the northwestern part of the alluvial aquifer, and also in an area east of Crowleys Ridge (fig. 14). The area of reduced pumping in the northwestern part of the alluvial aquifer may be the result of less accurate thicknesses of the alluvial aquifer or the absence of flow from underlying units, such as the McNairy-Nacatoch aquifer system (Renken, 1998) that was not represented in any of the MERAS models. As with the results of scenario 2, the area of reduced pumping east of Crowleys Ridge may be the result of additional pumping information that was not contained in the earlier optimization work. Though there are additional areas of reduced pumping in the northwestern part of the alluvial aquifer and east of Crowleys Ridge, the total amount of pumping from the alluvial aquifer (within the previously optimized area) is greater than the pumping specified in scenario 1, which corresponds to previously optimized values (fig. 12). The greater amount of pumping allowed by scenarios 3A and 3B is likely because of the ability of some wells to pump at the higher average pumping amount, compared to the 1997 pumping rate used as the baseline rate in previous optimizations. Scenario 3B illustrates an estimate of sustained pumping that could be maintained indefinitely because unmet demands on pumping could be obtained through an alternative surface-water supply.

Streamflow leakage from selected reaches of the White and Arkansas Rivers for each scenario indicates the largest amount of leakage to groundwater in scenario 2, which may be expected because of the lack of drawdown constraints. Simulated leakage from the White River (net leakage from the confluence of the Cache River to the Mississippi River) was 290 cubic feet per second (ft^3/s) in scenario 1, increased to 500 ft^3/s in scenario 2, and declined again to 297 and 285 ft^3/s for scenarios 3A and 3B, respectively. Simulated leakage from the White River near the end of the calibration period (2006) was approximately 92 ft^3/s. Simulated leakage from the Arkansas River (net leakage from the boundary of the model to the confluence of Bayou Meto) was 476 ft^3/s in scenario 1, increased to 523 ft^3/s in scenario 2, and declined again to 348 and 328 ft^3/s for scenarios 3A and 3B, respectively. Simulated leakage from the Arkansas River near the end of the calibration period (2006) was approximately 178 ft^3/s. Simulated leakage from the Cache River did not show appreciable changes in leakage among any scenario, remaining at approximately 5 ft^3/s. Simulated leakage from the Cache River near the end of the calibration period (2006) was approximately 3 ft^3/s.

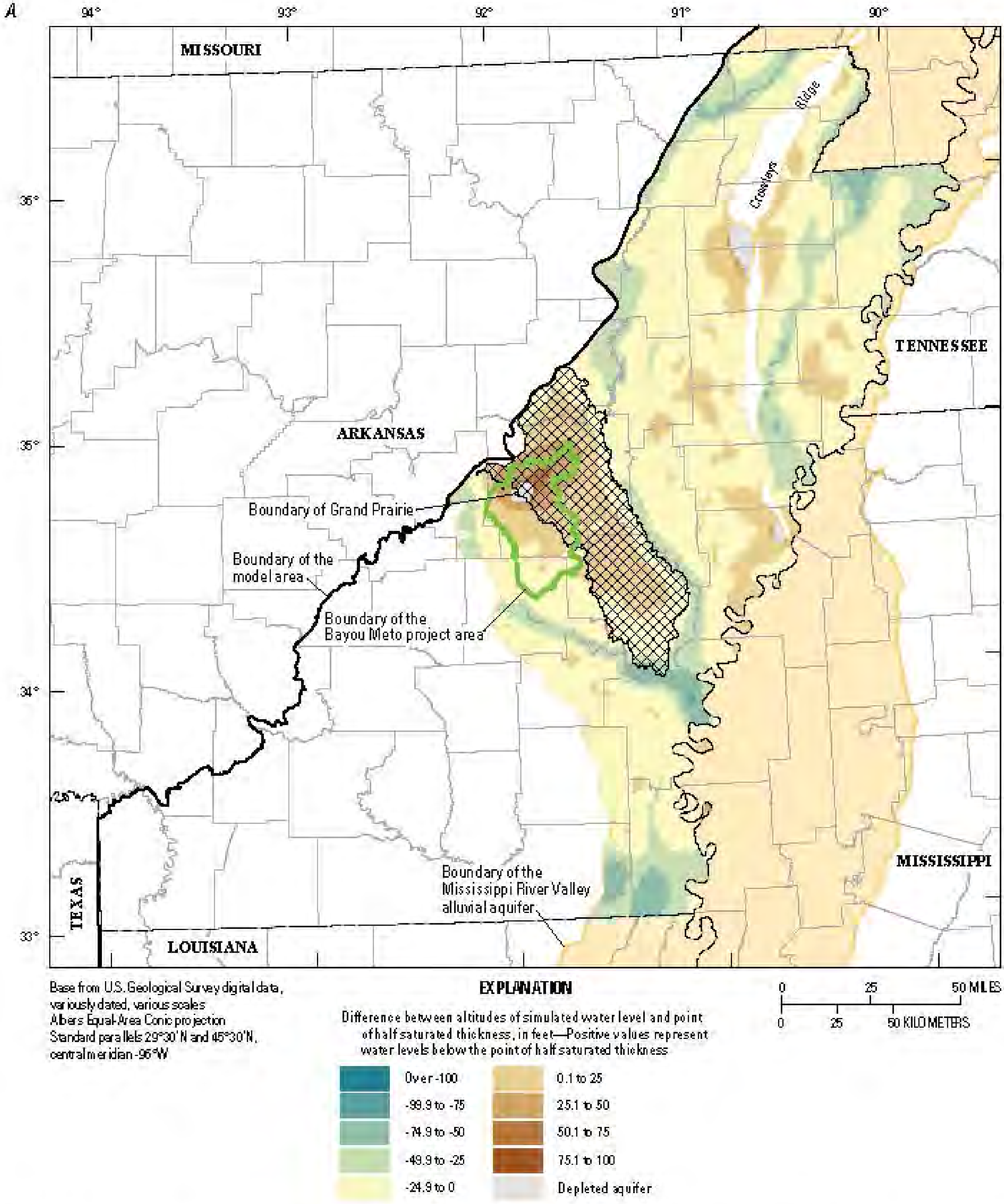


Figure 13. Difference between altitudes of water level and half of the saturated thickness of the (*A*) alluvial aquifer without drawdown constraints on Sparta aquifer wells and (*B*) alluvial aquifer with drawdown constraints on Sparta aquifer wells within the Grand Prairie.

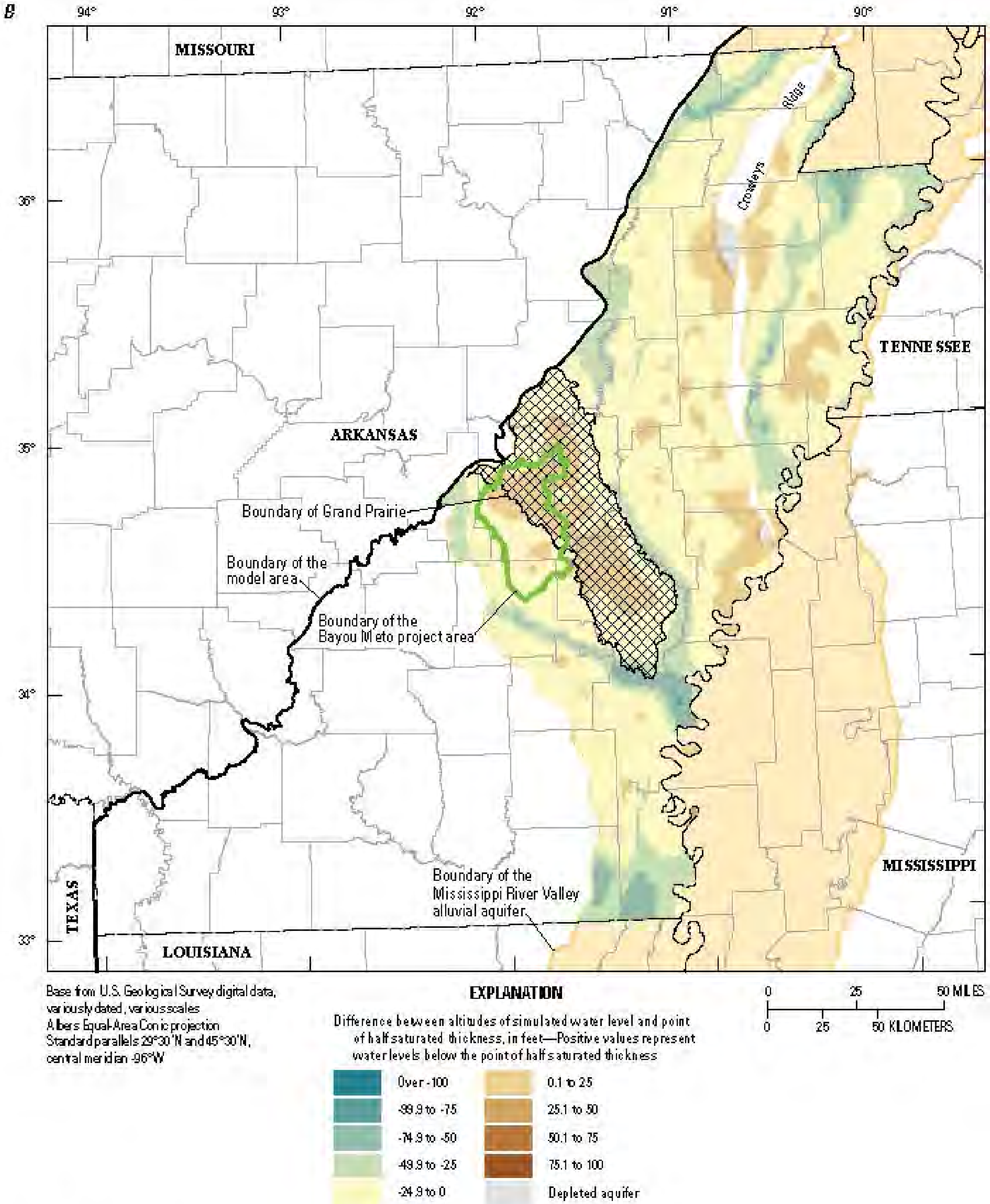


Figure 13. Difference between altitudes of water level and half of the saturated thickness of the (*A*) alluvial aquifer without drawdown constraints on Sparta aquifer wells and (*B*) alluvial aquifer with drawdown constraints on Sparta aquifer wells within the Grand Prairie.—Continued

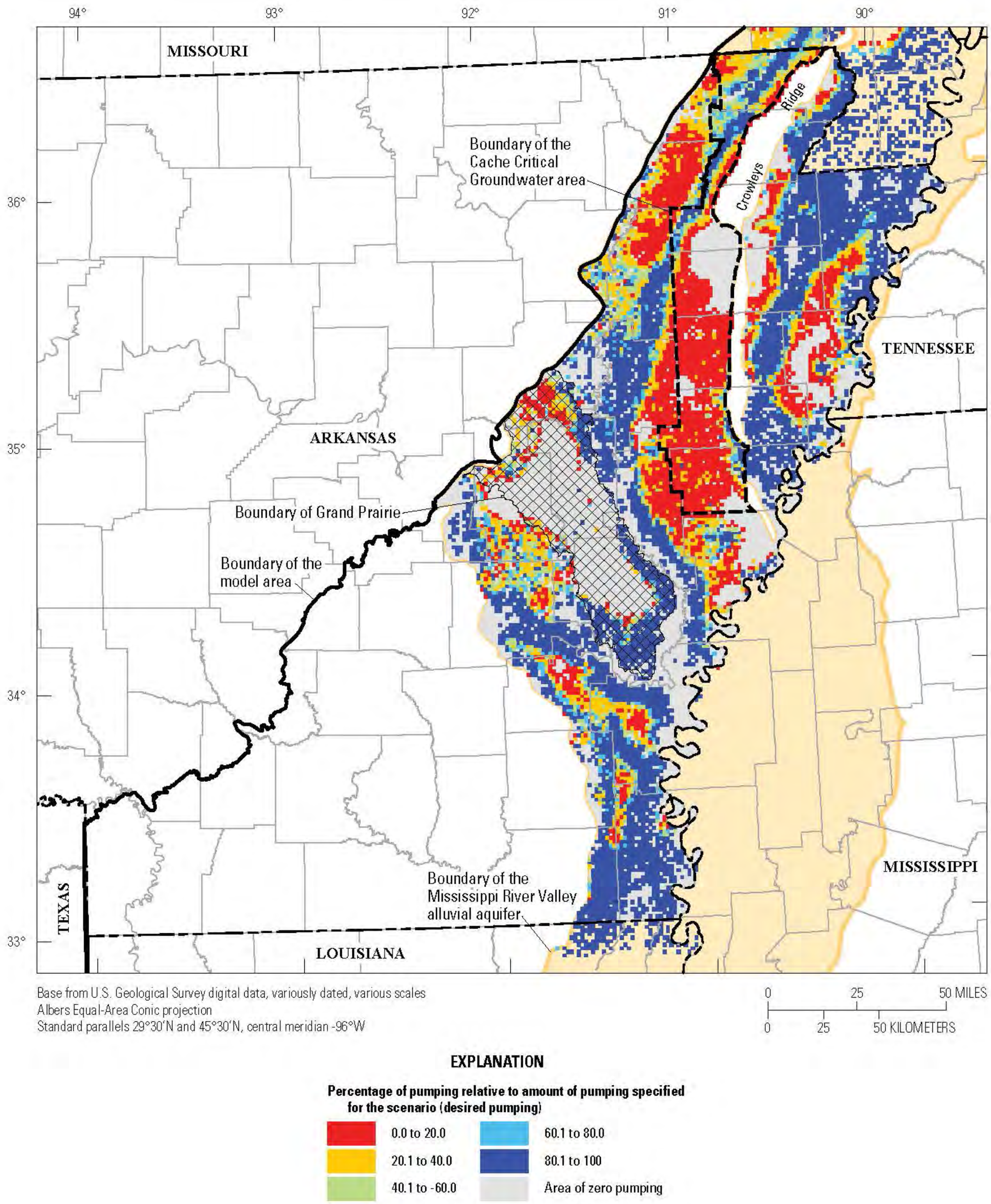


Figure 14. Percentage of desired pumping for scenario 3B.

Model Limitations

An understanding of model limitations is essential to effectively use simulation results. Limitations of analysis using the MERAS model are documented in Clark and Hart (2009). A summary of limitations that should be considered when interpreting model results are restated here. Because the model is a simplification of a complex system (for example, local variations in hydraulic conductivity and specific storage are not reflected in the model), some error in simulated water-level altitude is expected. Additionally, results from the scenarios produced using the MERAS model were based on steady-state conditions. Assumptions made for the development of the steady-state model include the continuation of average pumping and average precipitation for long periods of time. Many factors may influence the steady-state assumptions such as climate change, changes in agricultural practices, and growth or decline of population or industry. Thus, the steady-state scenarios are meant to be used as a guide for potential water-level changes if recent average conditions were to continue indefinitely. The additional assumption of confined layers affects the calculation of transmissivity and storage. By doing so, in areas where the water level declines below the confined layer, the transmissivity is not reduced according to the actual saturated thickness. This condition may result in more groundwater flow than is intended.

The goal of the MERAS model was to develop a model capable of suitable accuracy at regional scales. The intent was not to reproduce individual local-scale details, which are typically not possible given the uniform cell size of 1 mi^2. Although the MERAS model may not represent each local scale detail, it is relevant for a better understanding of the regional flow system.

Summary

Arkansas continues to be one of the largest users of groundwater in the Nation. As such, long-term planning and management are essential to ensure continued availability of groundwater and surface water for years to come. The Mississippi Embayment Regional Aquifer Study (MERAS) model was developed as a tool to evaluate groundwater availability within the Mississippi embayment, which encompasses much of eastern Arkansas where the majority of groundwater is used. The Arkansas Water Plan is being updated for the first time since 1990 and serves as the State's primary, comprehensive water-resources planning and guidance document. The MERAS model was selected as the best available tool for evaluation of specific water-use pumping scenarios that are currently being considered by the State of Arkansas. The model, developed as part of the U.S. Geological Survey Groundwater Resources Program's assessment of the Nation's groundwater availability, is proving to be invaluable to the State in development of a sustained yield pumping strategy. In an effort to continually improve the MERAS model calibration, and thus the effectiveness of evaluating groundwater availability, the U.S. Geological Survey, in cooperation with the Arkansas Natural Resources Commission, evaluated multiple methods to reduce residual error associated with the Mississippi River Valley alluvial and middle Claiborne (Sparta) aquifers in the MERAS model. Five methods for reducing the residual error were evaluated: (1) explicit simulation of evapotranspiration (ET), (2) upgrade of the Multi-Node Well (MNW) Package, (3) geometry improvement within the Streamflow Routing (SFR) Package, (4) parameter estimation with pilot points, and (5) modification of water-use estimation. For planning purposes of the Arkansas Water Plan, three scenarios were developed to evaluate potential future conditions: (1) simulation of previously optimized pumping values with the Mississippi River Valley alluvial and the middle Claiborne (Sparta) aquifers, (2) simulated prolonged effects of pumping at average recent (2000–2005) rates, and (3) simulation of drawdown constraints on most pumping wells.

Evapotranspiration rates for the simulation period from 1870 to 2007 were estimated from temperature based Potential ET (PET) methods and adjusted to represent ET at the water table. Grids of PET values were developed for each stress period of the model and further adjusted through multipliers similar to those used in the estimation of recharge in earlier versions of the MERAS model to achieve representative values of ET at the water table. The MNW dataset used in the earlier versions of the MERAS model contained well fields in which each well within the same well field was given the same identifier. The MNW dataset also contained duplicate well identifiers, which is not compatible with the MNW2 Package. The duplicate well identifiers were replaced with unique identifiers, or in some cases actual duplicate withdrawals were removed. Wells that were originally placed in multiple layers because of screen placement uncertainty were replaced by withdrawals from a single layer (the lowermost layer representing each hydrogeologic unit) and simulated as a single-node well in MNW2. To improve inputs to the SFR Package, the U.S. Geological Survey obtained measured cross-section data from the U.S. Army Corps of Engineers on the Arkansas and Mississippi Rivers. From these cross-section data, more accurate estimates of mean stream width and depth were calculated. Additional river parameters also were created to represent potential differences in streambed conductance. Many streambed conductances were modified from the original calibrated values to reflect changes in parameterization and geometry. Pilot points were distributed uniformly at a spacing of approximately 5 miles for the alluvial and other surficial aquifers (which included alluvial and terrace deposits beyond the Mississippi River Valley alluvial aquifer) and the Sparta aquifer to represent the aquifer properties of hydraulic conductivity and specific storage. Additional pilot points were generated for the Vicksburg-Jackson confining unit (to represent vertical anisotropy) and recharge multiplier values. During a review of estimated water-use values used in the previous MERAS models, some published values in the 5-year water-use reports were found to have corrected values estimated after the initial publication date. Additionally, residuals in select counties such as Columbia, Jefferson, and Union County, Arkansas, indicated potential issues with the estimated water-use values. Upon further comparison with the time-series data, modifications were made to water use values for select years.

The explicit simulation of ET indicated little, if any, improvement of model fit at the expense of much longer simulation time and was not included in further simulations. Numerous attempts to fully utilize the MNW2 Package were unsuccessful in achieving model stability, although modifications made to the water-use dataset remained intact. Final improvements in the residual statistics may be attributed to a single method, or a cumulative effect of all methods attempted. For comparative purposes to the previous MERAS model, the value of root mean square error (RMSE) was computed for each year. The RMSE for all observations in the model is 22.65 feet (ft) over a range in observed hydraulic head of 741.66 ft. The RMSE for alluvial observations is 14.14 ft (an improvement of almost 3 ft) over a range in observed hydraulic head of 297.25 ft. The RMSE for the Sparta aquifer is 32.02 ft (an improvement of approximately 3 ft) over a range in observed hydraulic head of 634.94 ft.

Four scenarios were developed to utilize a steady-state version of the MERAS model that includes average input conditions of streamflow, precipitation (which is converted to net recharge), and the appropriate average pumping condition for the scenario under evaluation. Scenario 1 was developed to use pumping values resulting from the optimization of 100 percent of baseline rates (typically 1997 pumping rates) from previous optimization modeling of the alluvial aquifer and the Sparta aquifer. Scenario 2 was developed to evaluate the prolonged effects of pumping from the alluvial aquifer at recent pumping rates. Scenarios 3A and 3B were designed to evaluate withdrawal limits from the alluvial aquifer by utilizing drawdown constraints equal to an altitude of approximately 50 percent of the predevelopment saturated thickness of the alluvial aquifer or 30 ft above the bottom of the alluvial aquifer, whichever was greater. The results of scenario 1 indicate large drawdowns throughout the area of the alluvial aquifer, regardless of the substitution of the optimized pumping values from earlier model simulations. In previous optimization simulations, each aquifer, or part of the aquifer, was simulated independently so that pumping from the Sparta aquifer did not interfere with pumping from the alluvial aquifer. Because of this, it is possible that more pumping was allowed from each aquifer than might be expected if the system was simulated as a whole. The results of scenario 2 also indicate large areas of water-level decline below half of the saturated thickness, throughout the alluvial aquifer. The simulation of declines in some areas may indicate the continued declines noted in some wells in the area since the 1970s, and occur partially because the MERAS model contains an additional 10 years of information beyond the 1997 base pumping information used in previous modeling efforts. The results of scenario 3A reveal some effects from the inclusion of multiple aquifers in a single simulation. The initial configuration of scenario 3A resulted in water levels well below the defined drawdown constraint and some areas of depleted aquifer in east-central Arkansas. A fourth simulation (scenario 3B) was configured to apply the same drawdown constraints from the alluvial aquifer wells to the Sparta aquifer wells in the depleted area. These drawdown constraints reduce leakage from the alluvial aquifer to the underlying Sparta aquifer. This configuration did not produce depleted areas within the alluvial aquifer in the Grand Prairie area. Scenario 3A and 3B simulations indicate that even with pumping limited in the alluvial aquifer, water levels in some areas may continue to decline because of pumping in the underlying Sparta aquifer.

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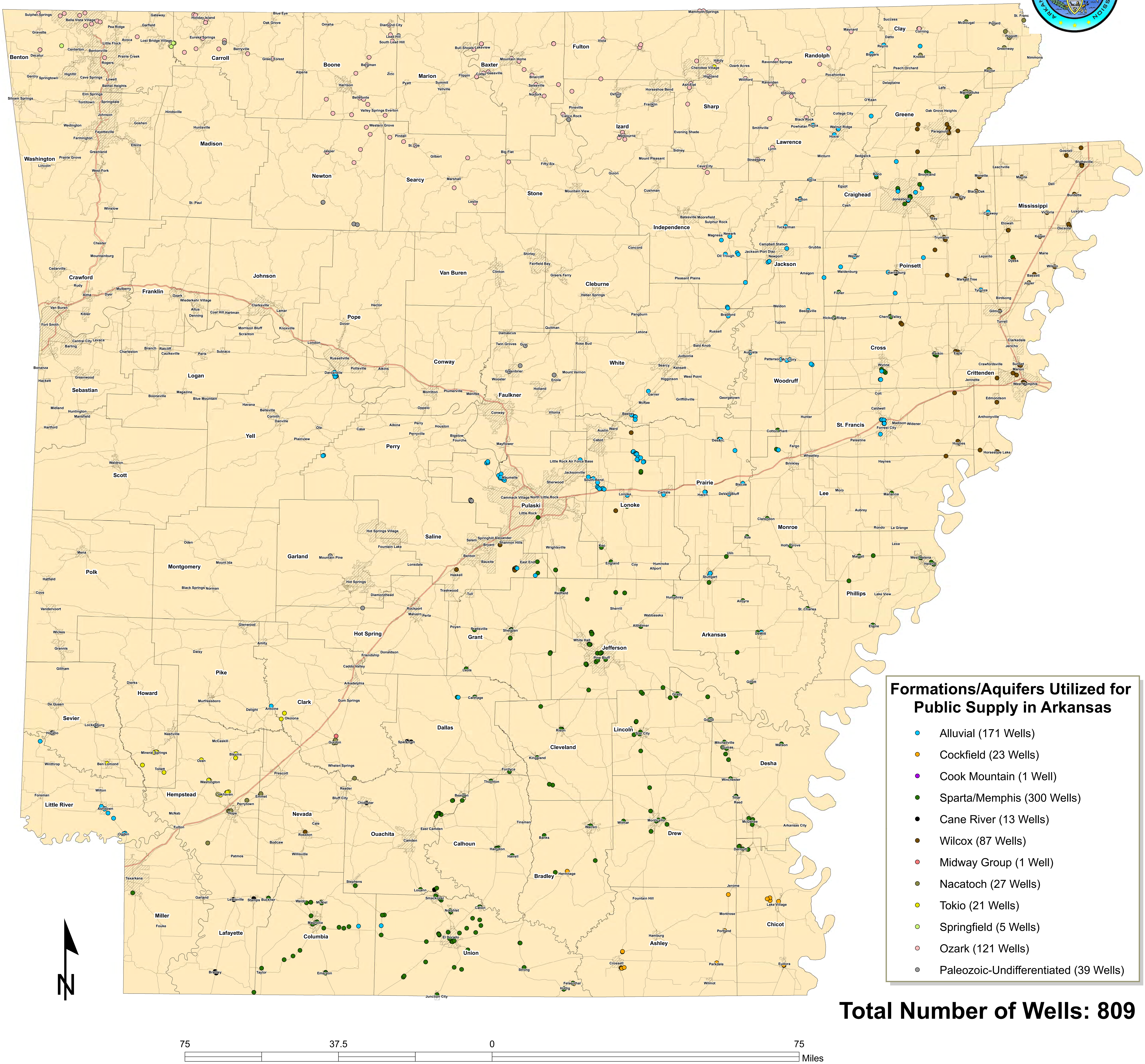
Public Groundwater Sources in Arkansas



Total Number of Wells: 809