Water Resource Inventory and Assessment (WRIA):
Dale Bumpers White River National Wildlife Refuge
Arkansas, Desha, Monroe, and Phillips Counties, Arkansas

U.S. Department of the Interior
Fish and Wildlife Service
Southeast Region
Atlanta, Georgia
April 2015

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April 2015
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Please cite this publication as:
Holt, R.L. and K.J. Hunt. 2015. Water Resource Inventory and Assessment (WRIA): Dale Bumpers White River National Wildlife Refuge, Arkansas, Desha, Monroe and Phillips counties, Arkansas. U.S. Fish and Wildlife Service, Southeast Region. Atlanta, Georgia. 150 pp. + appendices.

COVER PHOTO: Dale Bumpers White River National Wildlife Refuge. Photo credit: Matt Savage, USFWS Forestry Technician

Acknowledgments

This work was completed through contract PO# F11PD00794 and PO# F14PB00569 between the U.S. Fish and Wildlife Service and Atkins North America, Inc. Information for this report was compiled through coordination with multiple state and federal partners and non-governmental agencies. Significant input and reviews for this process was provided by staff at Dale Bumpers White River National Wildlife Refuge and specifically included assistance from Jeff Denman, Jay Hitchcock, Ron Hollis, and John Stark. Additional review and editorial comments were provided by John Faustini (USFWS), Jim Petersen (USGS), Jason Phillips (USFWS), and Keith Whalen (USFS). The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

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1 Executive Summary

This Water Resource Inventory and Assessment (WRIA) for Dale Bumpers White River National Wildlife Refuge (DBWRNWR or the refuge) summarizes available and relevant information for refuge water resources, including aquatic resource needs and issues of concern, both immediate and long-term. A primary purpose of the document is to provide recommendations to address any perceived water resource-related threats, needs or concerns on the refuge. Topics addressed within the WRIA report include the refuge's natural setting (topography, climate, geology, soils, hydrology), effects of development within the associated watershed(s), potential effects from climate change, assessment and evaluation of refuge infrastructure in relation to water resources, historic and current water monitoring activities on and near the refuge, water quality and quantity information, and state water use regulatory guidelines. All of this information was compiled from publicly available reports (e.g., published and unpublished research reports), databases (e.g., websites maintained by government agencies, academic institutions, and non-governmental organizations), and geospatial datasets from federal, state, and local agencies.

The primary drivers of the threats, needs, and issues of concern identified in this assessment are the anthropogenic and environmental stressors occurring within the White River Basin (including the White and Cache Rivers) and, to some degree, influences from the Arkansas and Mississippi Rivers, which are located at the extreme southern portion of the refuge. These areas together comprise the Region of Hydrologic Influence (RHI) for DBWRNWR. For the purposes of this assessment, the RHI was defined as the Upper and Lower White Basins [six digit hydrologic unit code (HUC-6): 110100 and 080203, respectively], which encompass lands and waters upstream of the refuge, and the Lower Arkansas [080204] and Lower Mississippi-Helena [080201] Basins, located immediately downstream of the refuge. The Lower Arkansas and Lower Mississippi-Helena were included because of backwater effects and inundation that occurs on the refuge in association with high water events within these basins.

1.1 Findings

- The RHI, defined as the area potentially influencing the hydrology and water quality on the refuge, encompasses an area of 19,228,966 acres or 30,045 square miles (mi^2)[1].

- The entire White River Basin (upper and lower) extends for a total of 27,765 mi^2, with 10,622 mi^2 in southern Missouri and 17,143 mi^2 in Arkansas.

- Major tributaries to the White River include the James River, North Fork River, Buffalo River, Black River, Village Creek, Little Red River, Bayou Des Arc, Wattensaw Bayou, Cache River, Big Creek and Bayou LaGrue.

- The White River mainstem flows 720 miles from its origin in the Boston Mountains of the Interior Highlands (elevation 785 meters (m) [2,575 feet] above mean sea level [MSL]) to its confluence with the Mississippi River (Brown et al. 2005) at a bed elevation of about 125 feet MSL. When considering the entire length of the river, the average slope is 0.064%, which is equivalent to 3.4 feet in elevation loss per river mile; however, there is a marked difference in the relief of the coastal

[1] For the purposes of this report, all units are expressed in English measures, unless citing information from a primary source where the native data are presented in metric units. In those cases, the English unit conversions are also provided.

plain (Lower White) section of the basin compared to the Interior Highlands (Upper White) portion. The elevation at the northern boundary of the Lower White River Basin, 185 miles above the mouth of the White River, is approximately 300 feet mean sea level (MSL), resulting in an average basin slope of 0.018%, or 0.95 feet per mile (see “Geology and Topography” in USFWS [2012]).

- The Mississippi River significantly affects the hydrology of the lower White River, both in terms of discharge and stage. The Mississippi River’s mean annual flow at the confluence is 480,000 cubic feet per second (cfs), more than 15 times greater than that of the White River (30,787 cfs). Water backs up from the Mississippi River and slows, or even stops, the flow of water moving down the White River. As this slowing or stoppage occurs, the stage of the White River rises to match that of the Mississippi River. The Mississippi River’s stage can fluctuate by as much as 57 feet at the confluence with the White River and influences water levels and inundation from the White River for a considerable distance upstream.

- Discharges for the lower White River, based on the USGS gage at Clarendon, AR (Site# 07077800), have a period of record for 53 years (1928 – 1981). The average annual discharge over that period of record is 29,617 cfs. The average monthly discharge is highest between January and June and lowest between July and December. The average monthly discharge peaks in April whereas the month with the lowest average discharge is October.

- Recently (in 2008 and 2011), substantial floods occurred on the White River. The White River stage at Clarendon reached 33.73 feet NGVD29 in April 2008, which was the highest stage since the flood of 1973. Three years later (May 2011), the White River stage at Clarendon peaked at 37.47 feet NGVD29, the highest recorded stage height since the 1927 flood.

- Within the RHI, there are a total of 71,689 miles of streams (18,923 miles of named streams and 52,766 miles of unnamed streams). On the Refuge, there are 42 named creeks and rivers totaling over 263 miles. In addition to these named streams, there are over 602 miles of unnamed streams within this area.

- The White River flows through the refuge within the acquisition boundary for 94.5 miles.

- The White River RHI contains a total of 399 dams. A majority of these dams were built primarily for recreation, but many also perform flood protection and irrigation functions which alter hydrology on a more local scale.

- The majority of the dams in the RHI store less than 200 acre-feet of water and the vast majority are privately owned. However, there are seven large dams (four on the main stem White River and three on major tributaries) that aid in navigation and/or serve as hydropower generators.

- More than 96% of the Refuge lands and more than 94% of the lands within the acquisition boundary are classified as wetlands according to the National Wetland Inventory (NWI). The wetlands are primarily palustrine with large freshwater forested/shrub areas.

- The U.S. Geological Survey (USGS) has collected water quality data at 292 active and historic surface water sites within the RHI. Ten of these sites are within ten miles of the acquisition boundary for

Dale Bumpers White River NWR. Site number 07077000 (White River at DeValls Bluff, AR) is the closest active monitoring site to the refuge, with a period of record beginning in 1945.

- USGS lists 33,874 wells within the RHI that have been sampled (or could potentially be sampled) for groundwater levels. There are 19,817 monitored groundwater wells located within the lower White River Basin. Of these, 4,142 are within ten miles of DBWRNWR; however, only 34 are located on the refuge. Ten of these wells have had groundwater level measurements conducted by USGS.

- Within the RHI, USGS has measured groundwater quality at 812 locations, including five sites (wells) located on the refuge.

- The uppermost unit of MEAS (Mississippi Embayment Aquifer System) underlying the refuge is the Mississippi River Valley alluvial aquifer. This aquifer produced about 94% of the groundwater withdrawn in Arkansas in 2010, and is primarily used for irrigation. Groundwater wells drawing from the alluvial aquifer can yield from 50 to more than 500 gallons per minute.

- The Mississippi Embayment Regional Aquifer Study (MERAS) estimates that groundwater withdrawals have increased 132% in the agricultural areas of Arkansas from 1985 to 2000. Total net volumetric depletion for the entire Mississippi Embayment aquifer system between 1900 and 2008 is estimated at 182 km^3 (43.6 m^3). The most dramatic depletion rates are estimated to have occurred between 1991 and 2000 (5.9 km^3/yr) and between 2001 and 2008 (8.1 km^3/yr).

- A digital groundwater flow model for the Sparta Aquifer projected that maintaining 1995 pumping rates would result in relatively minor (less than 10 feet) water level declines in the Grand Prairie area. However, the same model, using the 1980 through 1995 rate of change in pumping activity and as projected through 2027, predicted water level declines of 100 to over 200 feet in the Grand Prairie area.

- According to the most recent information available (from 2005), agricultural irrigation accounted for 90% of water use in Arkansas.

- A Contaminant Assessment Process (CAP) was conducted for the refuge in 2003 and 2004. Mean DDT (dichlorodiphenyltrichloroethane) concentrations in benthic fish tissues collected from DBWRNWR waters exceeded the Predator Protection Level (PPL) of 1,000 ng/g while DDT concentrations in predatory fish tissues were below this level. Mean concentrations of toxaphene in both benthic and predatory fish tissues exceeded the lowest biological effects value (400 ng/g), while the maximum concentration in benthic fishes also exceeded the PPL.

- DBWRNWR had a high number of current use pesticides (CUP) detections from both off and on-refuge sampling sites. Levels of trifluralin that were detected on-refuge exceeded either the lowest LC50 data (11 µg/L) or aquatic life criteria value (0.2 µg/L) for the White River. Azinphos-methyl, metribuzin, trifluralin, chlorpyrifos, metolachlor, atrazine, diazinon, and phorate all exceeded aquatic life criteria values at nearby off-refuge sites.

- Impaired waters (waters identified in 303d list), and additional waterbodies with total maximum daily loads (TMDLs) determined, were identified within or near the refuge acquisition boundary. In 2008, three waterbodies on or in proximity to the refuge did not meet their designated uses. Boat

Gunwale Slash and Prairie Cypress Creek did not meet the aquatic life use because of inadequate dissolved oxygen concentrations, and agriculture was identified as the primary source of the problem; this condition occurs during the season when flows are diminished and water temperatures are elevated. Big Creek did not meet its agriculture and industrial use designation because of chloride and total dissolved solids concentrations. Agriculture was identified as both the primary and secondary source of the problems.

- Within the RHI there are a total of 505 National Pollutant Discharge Elimination System (NPDES) permitted facilities. This includes two major facilities that discharge into the White River within the refuge acquisition boundary: the City of Clarendon and the City of St. Charles.

- Currently there are no known groundwater quality problems on the refuge; however, saltwater intrusion into the alluvial aquifer as a result of heavy drawdown of water, irrigation practices and area hydrogeology has been detected in the southeast part of the state.

- Excessive sedimentation is of primary concern on the refuge; however, the majority of sources of erosion and sediment transport occur outside the refuge boundaries.

- The ordinary high water mark (OHWM) is defined in the Arkansas code as "the line delimiting the bed of a stream from its bank, that line at which the presence of water is continued for such length of time as to mark upon the soil and vegetation a distinct character"(Ark. Code Ann. § 15-22-202). If the water is non-navigable, the riparian owner has rights to the center of the stream. For navigable waters, the public has the right to use the water and beds "for the purposes of bathing, hunting, fishing, and the landing of boats" in addition to navigation and commerce (Craig 2007- Anderson v. Reames, 161 S.W.2d 957, 960-61 (Ark. 1942)).

1.2 Key Water Resources Issues of Concern

Of primary concerns to the refuge are the timing, duration, quantity and quality of surface water flows. Additionally, the size and complexity of the RHI and the refuge's location within the RHI, lends to a multitude of perceived threats and issues of concern that can directly or indirectly impact the water resources. Most of the specific threats and issues of concern are related to anthropogenic changes within the basin and are most associated with water quantity and water quality issues. Anthropogenic changes within the RHI, such as the construction of dams and levees, groundwater withdrawals for irrigation, and conversion of bottomland hardwoods to agricultural fields, greatly influence the hydrology within the basin and, ultimately, on the refuge.

During a *Needs Assessment* review by the Inventory and Monitoring Program, refuge staff identified the top issues or concerns regarding threats to the refuge's water quantity supply as: 1) altered river flows from flood control and navigation or irrigation projects, and 2) unseasonal flooding from irrigation run-off (altered hydroperiod). When specifically asked to identify the top issues or concerns regarding threats to the refuge's water quality, the following were identified: 1) agricultural run-off, 2) sedimentation/silt, and 3) head cutting (increased erosion rates). Later in this document (Section 6.1), the perceived threats or issues of concern are identified in detail and divided into two temporal categories: 1) urgent/immediate issues (those for which impacts have already manifested) and, 2) long term issues (currently not an immediate threat but if current practices continue, then impacts are likely).

1.3 Recommendations

A brief overview of the needs and recommendations for Dale Bumpers White River NWR are summarized below. A more in-depth discussion of needs and recommendations is provided in Section 6.2 of the Assessment.

Several of the identified needs and recommendations coincide with those found within other refuge planning documents, more specifically, the Comprehensive Conservation Plan (CCP). Where appropriate, the CCP objectives and strategies referencing the aquatic resources and hydrology (e.g., CCP Objectives 2-4, 2-5, 2-6, and 2-7) should be prioritized based on information contained within this WRIA and as practical for refuge implementation/operations.

One of the primary needs and recommendations is to establish, or build upon, partnerships with other local, state, and federal agencies. These collaborative efforts will assist in addressing other needs and recommendations. For example, the acquisition of a complete LIDAR (Light Detection and Ranging) dataset for the entire refuge is an immediate need. By acquiring the LIDAR, the development of an inundation model, which is also a need and recommendation, can be completed. The inundation model would allow refuge staff to gain a better understanding of the hydrological processes occurring on the refuge.

2 Introduction

This Water Resource Inventory and Assessment (WRIA) Summary Report for Dale Bumpers White River National Wildlife Refuge (DBWRNWR or refuge) inventories relevant hydrologic information, provides an assessment of water resource needs and issues of concern, and makes recommendations to address those needs and concerns. The information compiled as part of the WRIA process will ultimately be housed in an online WRIA database currently under development by the U.S. Fish and Wildlife Service (Service or USFWS) Natural Resources Program Center (NRPC). Together, the WRIA Summary Report and the accompanying information in the online WRIA database are intended to be a reference to help guide on-going and adaptive water resource management. This WRIA Summary Report was developed with input by refuge staff as well as internal and external partners with extensive knowledge about the White River Basin. The document incorporates existing hydrologic information compiled between April 2012 and December 2014.

The WRIA database and summary reports provide a reconnaissance-level inventory and assessment of water resources on and adjacent to National Wildlife Refuges and National Fish Hatcheries nationwide. Achieving a greater understanding of existing refuge water resources will help identify potential concerns or threats to those resources and will provide a basis for wildlife habitat management and operational recommendations to refuge managers, wildlife biologists, field staff, Regional Office personnel, and Department of Interior managers. A national team composed of Service water resource staff, environmental contaminants biologists, and other Service employees developed the standardized content of the national interactive online WRIA database and summary reports.

The long term goal of the National Wildlife Refuge System (NWRS) WRIA effort is to provide up-to-date, accurate data on NWRS water quantity and quality in order to acquire, manage, and protect adequate supplies of clean and fresh water. An accurate water resources inventory is essential to prioritize issues and tasks and to take prescriptive actions that are consistent with the established purposes of the refuge. Reconnaissance-level water resource assessments evaluate water rights, water quantity, known water quality issues, water management, potential water acquisitions, threats to water supplies, and other water resource issues for each field station.

WRIAs are recognized as an important part of the NWRS Inventory and Monitoring (I&M) initiative and are prioritized in the National I&M Operational Blueprint as Task 2a (USFWS 2010a). In addition, this WRIA work supports the Water Resources Inventory and Monitoring (WRIM) Operational Goal, as well as Objective WRIM 1.0, and Task WRIM 1.4 within the National I&M Seven Year Plan (USFWS 2013a). The seven-year plan outlines a strategic, focused, measureable and prioritized plan directly tied to the I&M Operational Blueprint. Hydrologic and water resource information compiled during the WRIA process can facilitate the development of other key documents for each refuge including Hydrogeomorphic Analyses (HGMs), Comprehensive Conservation Plans (CCPs), Habitat Management Plans (HMPs) and Inventory and Monitoring Plans (IMPs). A CCP for the refuge was completed in 2012 (USFWS 2012) and the refuge's HGM was initiated the same year. An HMP is currently scheduled for development in 2015.

Preliminary water resource assessments conducted within Region 4 by the Service beginning in 2007, as well as hydrologic and climate change vulnerability assessments conducted by the USFWS and USGS in 2009, identified DBWRNWR as one of six top-priority sites within Region 4 recommended for detailed hydrologic characterization. A hydrologic and landscape database was published for White River and Cache River NWRs in 2012 (Buell et al. 2012). Key water quantity threats outlined for the refuge in this and the 2009 USFWS assessment included the effects of hydropower regulation; channelization and ditching; agricultural, municipal, and industrial water use, both surface water and groundwater withdrawal; dredging for navigation-channel maintenance; changes in land cover and land use; water quality effects of various land uses; climate variability; and impacts of beavers on wetlands. Water quality issues included land application of fertilizers and pesticides; erosion and deposition of sediment; and municipal and industrial discharge (USFWS 2009a; Buell et al. 2012). Following this work, the WRIA process was initiated in 2012 and a formal kick-off meeting and refuge visit were held on May 22, 2013.

3 Facility Information

Dale Bumpers White River NWR is located in southeastern Arkansas, in Desha, Monroe, Arkansas and Phillips Counties near the town of St. Charles, approximately 100 miles southeast of Little Rock and 115 miles southwest of Memphis, TN. Additionally, it is located within the defined boundaries of the Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative (GCPO LCC) (Figure 1). The refuge was established September 5, 1935 by Executive Order 7173 to protect and conserve migratory birds and other wildlife resources in accordance with other applicable laws (e.g., Migratory Bird Conservation Act, Fish and Wildlife Coordination Act and Refuge Recreation Act [16 U.S.C. 460k-460k-4], as amended).

The original fee title acquisition area consisted of 112,771 acres, the vast majority of which were located south of State Highway 1 (the Southern Unit) (Figure 2). Many parcels were purchased with a timber reservation, and selective cutting occurred in the 1940s. In 1992, the Arkansas-Idaho Land Exchange Act added 40,749 acres, transferred from the Potlatch Corporation, to the approximately 9,000 acres of refuge land north of State Highway 1. This highway now serves as the dividing line between the Northern and Southern Units of the refuge. Most management activities continue to occur in the Southern Unit (USFWS 2012) (Figure 3).

DBWRNWR currently covers 160,756 acres within a 172,457-acre approved acquisition boundary. The current acquisition boundary of the refuge is located along 92 miles of the White River, from Clarendon to Benzal Bridge (DBWRNWR staff, written communication). The USFWS has proposed to expand the current acquisition boundary to include an additional 125,349 acres surrounding and south of the DBWRNWR, an area that includes the White River-Mississippi River confluence. The expansion would incorporate the floodplain for nine additional river miles (RM) of the White River, approximately 26 river miles of the Arkansas River and 34 river miles of the Mississippi River (USFWS 2013b). Throughout this WRIA the current acquisition boundary (172,457 acres) is referenced. If the refuge acquisition boundary is expanded in the future, this WRIA would need to be revised to incorporate the hydrologic features of the additional area.

The refuge is located in the lower White River Watershed, near the White River's confluence with the Mississippi River. The White River Basin extends for a total of 27,765 square miles (sq. mi. or mi^2), with 10,622 mi^2 in southern Missouri and 17,143 mi^2 in Arkansas. The White River flows for approximately 722 miles from the Boston Mountains in northwestern Arkansas to its confluence with the Mississippi River in Desha County, Arkansas (Arkansas Studies Institute 2013). Since 1989 DBWRNWR, Cache River NWR and three state wildlife management areas, collectively referred to as the "Cache/Lower White Rivers Joint Venture Area," have been designated "Wetlands of International Importance" under the Ramsar Convention. The total area encompassed by this designation is currently 201,178 acres (314.3 mi^2). The refuge and nearby natural areas also include some of the few remaining old-growth bottomland hardwood (BLH) forests in the South. Lastly, the area is designated a Globally Important Bird Area by the American Bird Conservancy and an Arkansas Important Bird Area by Audubon Arkansas (USFWS 2012).

Key terrestrial habitats present on the refuge include second and third growth, selectively logged bottomland hardwood and swamp forest (USFWS 2012), some of the last remaining in the Mississippi River Valley (Lopez et al. 2003). There are more than 70 distinct plant communities located within the refuge, including pre-Columbian cypress and tupelo swamps (USFWS 2012). Four species classified as Federally endangered are associated with the refuge: the ivory-billed woodpecker (*Campephilus principalis*), interior least tern (*Sterna antillarum athalassos*), pink mucket mussel (*Lampsilis orbiculata*) and fat pocketbook mussel (*Potamilus capax*). Additionally, the rabbitsfoot mussel (*Quadrula cylindrica cylindrica*) is a threatened species that are associated with the refuge and adjacent waters. There are also 26 known species of concern (primarily mollusks and fish) and two Special Element – Natural Communities (Mississippi

River Low Floodplain and Willow oak forest) on the refuge (USFWS 2012). The White River also supports important riverine fish species, including shovelnose sturgeon (*Scaphirhynchus platorynchos*) and paddlefish (*Polyodon spathula*), as well as diverse and productive aquatic plant communities within the bottomland hardwood swamps. The Lower White River Region also provides suitable habitat for the largest winter concentration of mallard ducks (*Anas platyrhynchos*) in North America (Lopez et al. 2003).

Several aquatic species that occur within the White River drainage and on refuge lands may be Federally-listed in the future. In 2010 the Center for Biological Diversity petitioned the Service to list 404 predominantly southeastern aquatic species currently under consideration by the USFWS, many of which are known to occur in the White River drainage (CBD 2010). More detailed information about the biological assemblages found within the White River Basin is summarized in Section 5.3.1.3 of this report.

Map Date: 7/31/2014 File: Fig1_R4_Overview.mxd Data Source: USFWS LCC Boundaries; Natural Earth 10m River and Lake Centerlines; ESRI Map Service.

Figure 1. Location of Dale Bumpers White River National Wildlife Refuge in relation to US Fish and Wildlife Service Region 4 Landscape Conservation Cooperative Boundaries.

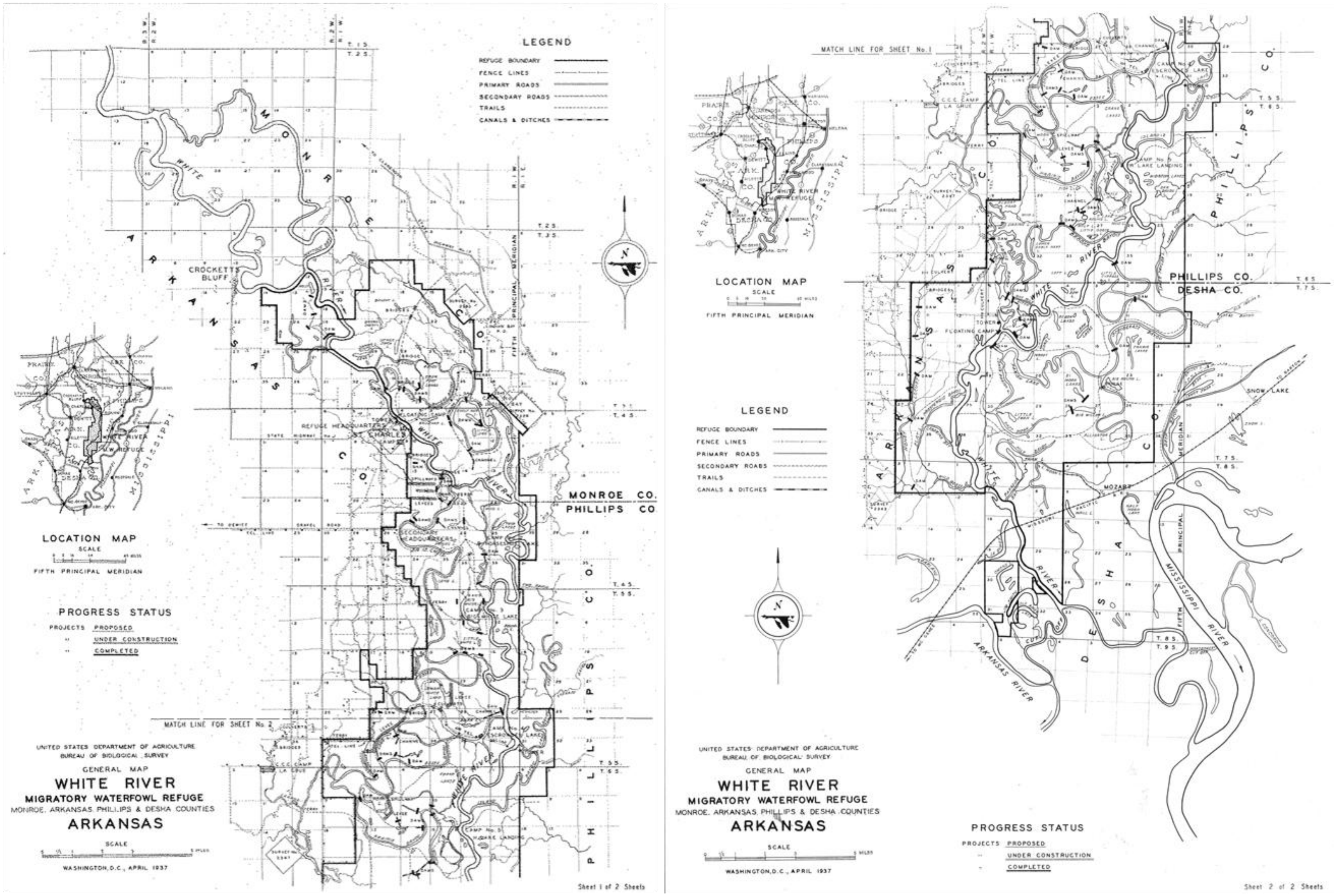
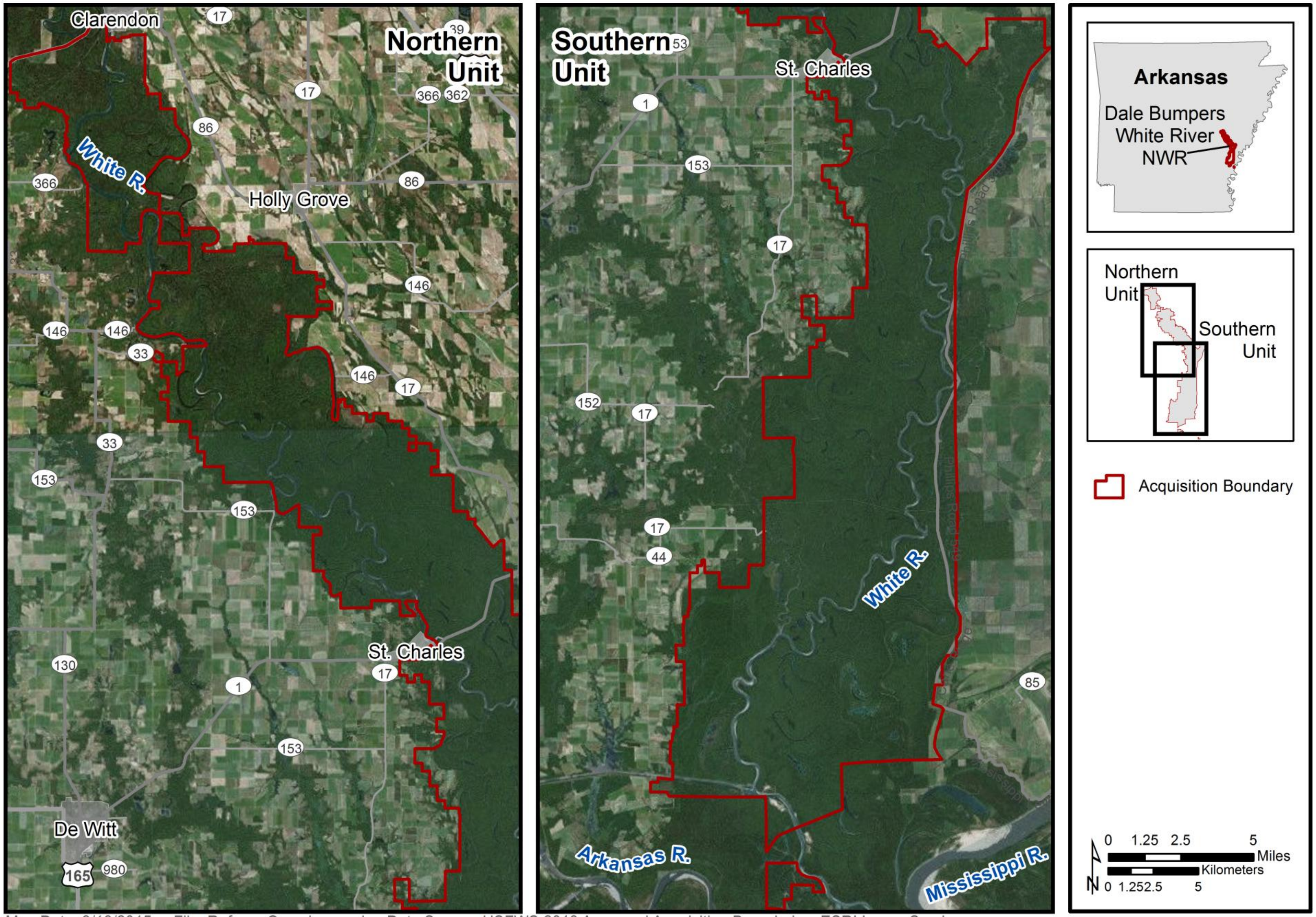


Figure 2. Extent of Dale Bumpers White River National Wildlife Refuge in 1937.



Map Date: 3/18/2015 File: Refuge_Overview.mxd Data Source: USFWS 2013 Approved Acquisition Boundaries, ESRI Image Service.

Figure 3. Dale Bumpers White River National Wildlife Refuge overview.

As of March 2015 the refuge has 10 full-time staff, supplemented by seasonal forest technicians and student trainee positions. All staff are located at the refuge headquarters and visitor center in St. Charles, AR. Fully-functioning management units on the refuge consist of a Farm Unit, moist soil impoundments and green tree reservoirs (GTR). The approximately 300-acre Farm Unit is composed of open agricultural fields that provide supplemental food for migratory waterfowl and habitat for grassland species. Additionally waterfowl management occurs in moist soil impoundments and GTR. The refuge currently has the capability of providing habitat for wintering waterfowl at 31 impoundments and/or fields, each with varying degrees of water level manipulation; only 11 locations consisting of small ponds, moist soil impoundments and flooded fields on the Farm Unit have complete water management capability according to Lower Mississippi Valley Joint Venture (LMVJV) standards. Other water control structures are not capable of providing complete water management capability due to the fact that they are likely to be overbank flooded by the White River. Refuge staff also manage forest resources according to the 2007 Forested Habitat Management Plan, which includes periodic thinning and prescribed burning to enhance wildlife habitat and achieve resource management objectives (USFWS 2012).

The refuge maintains 98 miles of listed roads (gravel and asphalt) and 477 miles of forest management roads (dirt), 357 miles of which are used for wildlife-dependent recreation (i.e., hunting, fishing,). There are also ATV and hiking trails that can be used for wildlife dependent recreation. In 2013, the refuge completed a 1.25-mile hiking trail called the Bottomland Hardwood Trail. A 1-mile handicap accessible trail, called the Upland Trail, is located across from the visitor center. Other public use areas on the refuge include 24 campgrounds and 18 improved boat ramps, most of which are located in proximity to the campgrounds. The majority of the campgrounds and boat ramps are located in the Southern Unit of the refuge. There are also over 100 small, unimproved (primitive) boat ramps only accessible by ATV (USFWS 2012).

According to the CCP, the primary threats to biological diversity in the Lower Mississippi Valley refuges include: habitat loss (e.g., loss of 20 million acres of bottomland hardwood forests); habitat fragmentation (e.g., loss of connectivity between bottomland hardwood forest sites); agricultural and timber harvesting practices; navigation and water diversion projects; and the cumulative impacts of both land and water resource development activities (USFWS 2012). Other, more specific threats to the refuge include agricultural effects on the hydrologic regime; reservoir operation; diversion of White River discharge to agricultural aqueducts upstream of the refuge as a means of reducing reliance on groundwater withdrawals from the Mississippi River Valley alluvial aquifer; dredging and channel maintenance for navigation; plans to prevent the Arkansas and White Rivers from merging downstream of the refuge (i.e., levee construction at the Melinda structure as a part of the McClellan-Kerr Arkansas River Navigation System); backwater flooding in the lower section of the refuge (Buell et al. 2012); and operation of the Graham Burke Pumping Station.

4 Natural Setting

4.1 Region of Hydrologic Influence (RHI)

This assessment focuses on water resources within the geographic extent of the refuge acquisition boundary, and more broadly on water resources within a Region of Hydrologic Influence (RHI) containing the refuge. The RHI describes the portion of the watershed upstream of the refuge that affects the condition of water resources on the refuge. This construct anchors the refuge in the greater watershed and provides a reference for discussing the refuge within a watershed context. Because water travels down gradient, it is the activities occurring upstream of the refuge that will tend to most directly affect water quantity (e.g., diversions, withdrawals, land cover changes) or water quality (e.g., pollution from agricultural, urban, or industrial land uses) on the refuge. However, the low gradient of the Mississippi Alluvial Valley (MAV), in concert with numerous anthropogenic changes to the system and active management, has resulted in conditions where downstream areas with little direct hydrologic connection affect conditions upstream at the refuge. Accordingly, the RHI primarily focuses on upstream basin conditions, with the addition of downstream areas containing features and management practices directly relevant to hydrologic conditions within DBWRNWR.

Geographic delineations for the RHI are drawn from the National Watershed Boundary Dataset (WBD), a hierarchical framework that divides the landscape into progressively smaller hydrologic units (HUs). At the coarsest scale, the HUs are called hydrologic regions and assigned unique 2-digit codes. At progressively finer scales, 4-, 6-, 8-, 10-, and 12-digit HUs are called subregions, basins, subbasins, watersheds, and subwatersheds, respectively (Laitta et al. 2004).

For the purposes of this assessment, the RHI was defined as the Upper and Lower White Basins (110100 and 080203), which encompass lands and waters upstream of the refuge, together with the Lower Arkansas (080204) and Lower Mississippi-Helena (080201) Basins that adjoin the Lower White Basin. Although these basins are not part of the upstream contributing watershed area for the refuge, anthropogenic changes in these HUs—such as the construction of major dams and levees, groundwater withdrawals for agriculture, and conversion of BLH to actively managed agricultural lands—influence the hydrology on the refuge. An account of such changes is necessary for discussing refuge water resource conditions (Figure 4). Table 1 details the subbasin (HU-8) units within the RHI. The RHI includes a total drainage area of 30,045 mi^2 (19,228,966 acres).

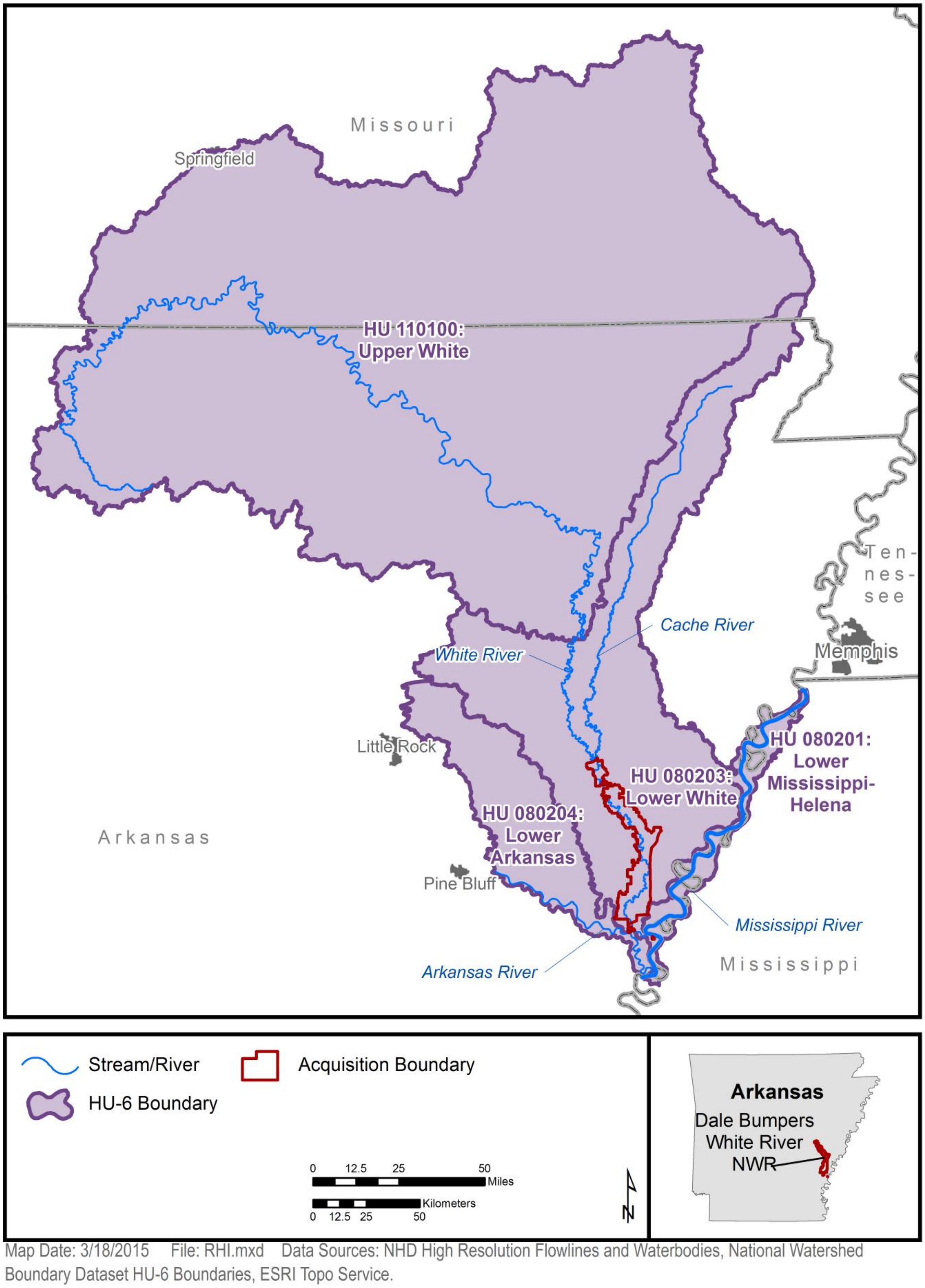


Figure 4. Region of Hydrologic Influence (RHI) for Dale Bumpers White River National Wildlife Refuge.

Table 1. National Watershed Boundary Dataset (WBD) units within the Region of Hydrologic Influence (RHI).

Basin	Subbasin	Name	States	Acres
Lower Mississippi-Helena (080201)	08020100	Lower Mississippi-Helena	AR	380511
Lower White (080203)	08020301	Lower White-Bayou Des Arc	AR	726669
	08020302	Cache	AR	1284840
	08020303	Lower White	AR	870808
	08020304	Big	AR	606272
Lower Arkansas (080204)	08020401	Lower Arkansas	AR	423305
	08020402	Bayou Meto	AR	641115
Upper White (110100)	11010001	Beaver Reservoir	AR, MO	1633850
	11010002	James	MO	931543
	11010003	Bull Shoals Lake	AR, MO	1666870
	11010004	Middle White	AR	943986
	11010005	Buffalo	AR	856964
	11010006	North Fork White	AR, MO	1171330
	11010007	Upper Black	AR, MO	1231990
	11010008	Current	MO, AR	1675730
	11010009	Lower Black	AR	523919
	11010010	Spring	AR	777317
	11010011	Eleven Point	AR, MO	769440
	11010012	Strawberry	AR	486616
	11010013	Upper White-Village	AR	473611
	11010014	Little Red	AR	1152280

4.2 Topography and Landforms

The landforms of the Upper and Lower White River Basins are markedly different. The Upper White River Basin, which encompasses nearly three-quarters of the RHI and includes the headwaters of the White River, falls within the Ozark Plateaus province of the Interior Highlands (Figure 5). The Ozark Plateaus are made of generally flat-lying strata that have been deeply dissected by numerous streams (McFarland 2004). This area is noted for having the greatest relief between the Appalachians and the Rocky Mountains. Most of the Upper White River Basin drains a section of the Ozark Plateaus known as the Springfield-Salem Plateaus. This area has been deeply dissected by streams and is characterized by rolling terrain and extensive karst features such as caves, springs, and disappearing streams. Rivers within the Ozark Plateau can be incised as much as several hundred feet below the surface, creating rugged bluffs. Floodplains are generally much narrower than those associated with streams in the adjoining Coastal Plain, and surface water discharge is augmented by spring flow.

The Lower White River basin includes DBWRNWR. The basin drains the relatively flatter areas of the Coastal Plain province to the south and east of the Ozarks. Elevations along the White River in this basin range from 300 ft above mean sea level (MSL) near the confluence with the Little Red River, to 125 ft above MSL at the mouth of the White River (USFWS 2012). There are elevations in the northernmost portion of the Lower White River Basin along the Cache River that exceed 500 ft above MSL; these occur along Crowley's Ridge. The surface of the basin generally slopes gently southward. Major drainage systems in this part of the Coastal Plain include the Mississippi, St. Francis, White, Arkansas, Yazoo, Ouachita, and Boeuf Rivers. The Ozark Escarpment, which acts as the fall line between the Coastal Plain and the Interior Highlands, trends from northeast to southwest, and occurs along the White River near Batesville, Arkansas.

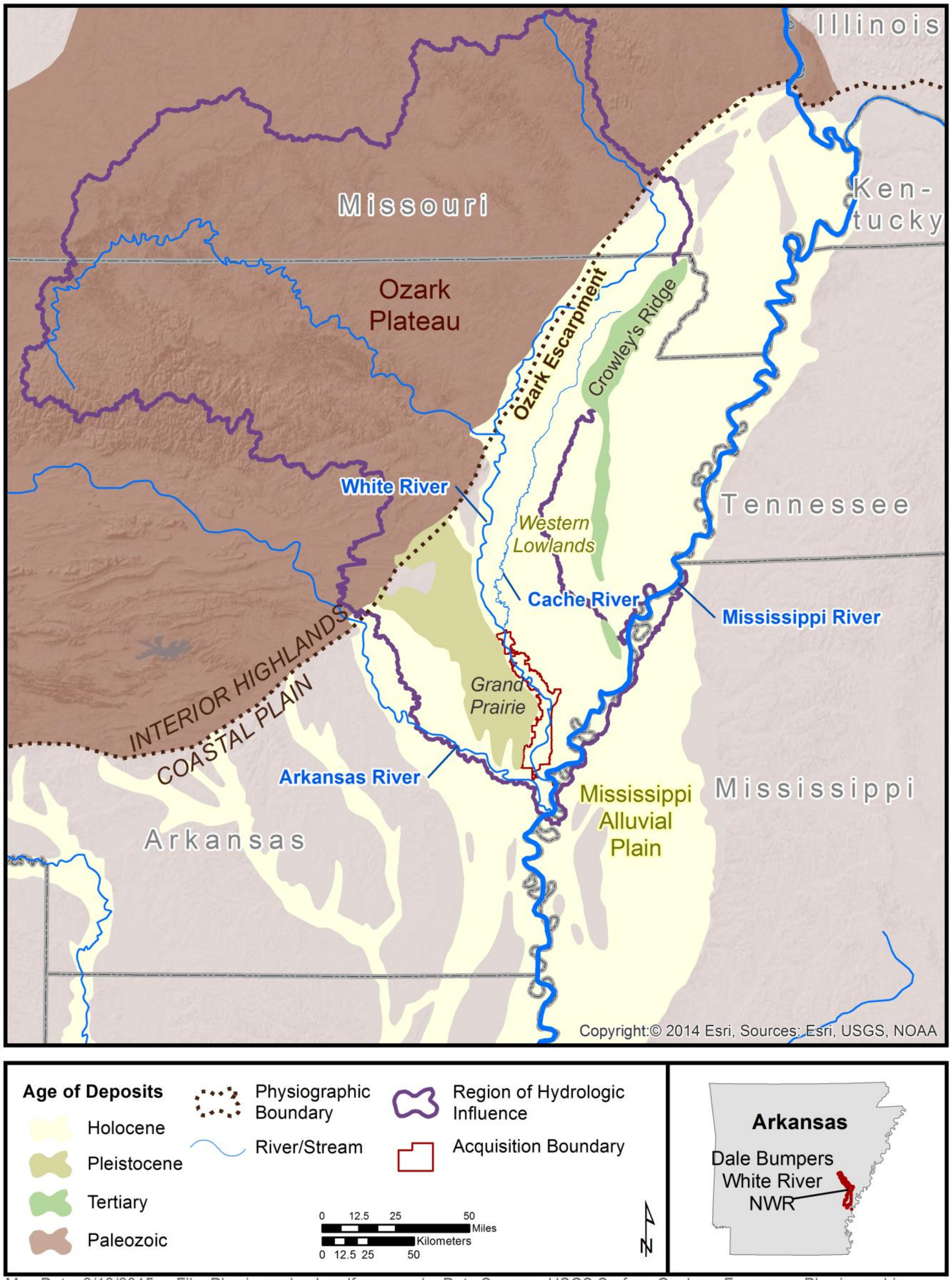
In physiographic terms, DBWRNWR is located in the broad, flat Mississippi Alluvial Plain, a section of the Coastal Plain. This area is often alternatively referred to as the Mississippi Alluvial Valley (MAV), the Mississippi River Delta, and the Mississippi Embayment. All names generally refer to the low-lying area presently dominated by fluvial sediments of the Mississippi River. Saucier (1994) uses the terms "alluvial plain" to refer to Holocene deposits and landforms, and "alluvial valley" to include landforms and deposits that are primarily of Wisconsin and Holocene age. Figure 5 shows the location of the refuge within the MAV, with proximity to important physiographic areas and features.

Throughout the larger MAV, eroded Tertiary remnants subdivide the area into lowlands, which are further subdivided into smaller units by ridges of Wisconsin or Holocene age (Saucier 1994). The most prominent topographic feature in the present-day MAV is Crowley's Ridge, a narrow erosional remnant of Tertiary strata, which runs north to south and bisects the northern portion of the alluvial plain (Figure 5). Crowley's Ridge is thought to be the remains of uplands that once separated the Mississippi River system to the west from the Ohio River system to the east. The ridge is similar in age and geology to the uplands bounding the MAV to the east (Saucier 1994). The southern half of the ridge is approximately 3 miles wide and rises 100 to 150 feet above the surrounding plain. The northern half of the ridge, which begins around Jonesboro, AR and extends north-northeast to the Missouri border, ranges from 10 to 12 miles wide, at an average elevation of 250 feet above the alluvial plain. Crowley's Ridge divides the Cache River and Lower White River Basins to the west from the St. Francis River Basin to the east.

A less prominent interfluve within the Lower White River Basin is the Grand Prairie, which separates the Arkansas River Basin from the Lower White River Basin (Figure 5). The Grand Prairie is a low terrace dating to the Sangamon Stage, an interglacial period approximately 125,000 years before present (B.P.). The terrace has a relatively constant width of around 25 miles. Elevation ranges from 20 to 40 feet higher than the adjacent White River lowlands (Saucier 1994).

Between Crowley's Ridge and the Grand Prairie is an area called the Western Lowlands, which roughly corresponds to the Lower White River Basin and the lower portion of the Upper White River Basin up to the Ozark Escarpment. This area of lowlands features local drainages that have formed narrow valleys and floodplains within early Wisconsin-age glacial outwash (Saucier 1994).

Within the present-day MAV, the topography is relatively flat and characterized by braided-stream terraces, meander belts and backswamps (USFWS 2012). Section 4.5 will address the dominant surface processes and landforms that characterize the present-day DBWRNWR.



Map Date: 3/18/2015 File: Physiography_Landforms.mxd Data Sources: USGS Surface Geology, Fenneman Physiographic Boundaries, Natural Earth 10m River Centerlines, ESRI Topo Service

Figure 5. Physiographic divisions and major landforms in the vicinity of Dale Bumpers White River National Wildlife Refuge.

4.3 Geology and Hydrogeology

The MAV and the refuge are underlain by the Mississippi Embayment geologic structure, an area of lowlands formed by a plunging syncline that extends from central Louisiana into southern Missouri and Illinois between the Appalachians to the east and the Ozark-Ouachita highlands to the north and west (Saucier 1994; Figure 6). Below the White River system is Paleozoic bedrock located 1,000 to 4,000 feet below sea level (USFWS 2012).The northernmost reaches of the embayment were flooded by waters from the Gulf of Mexico during the Cretaceous Period, more than 65 million years B.P.

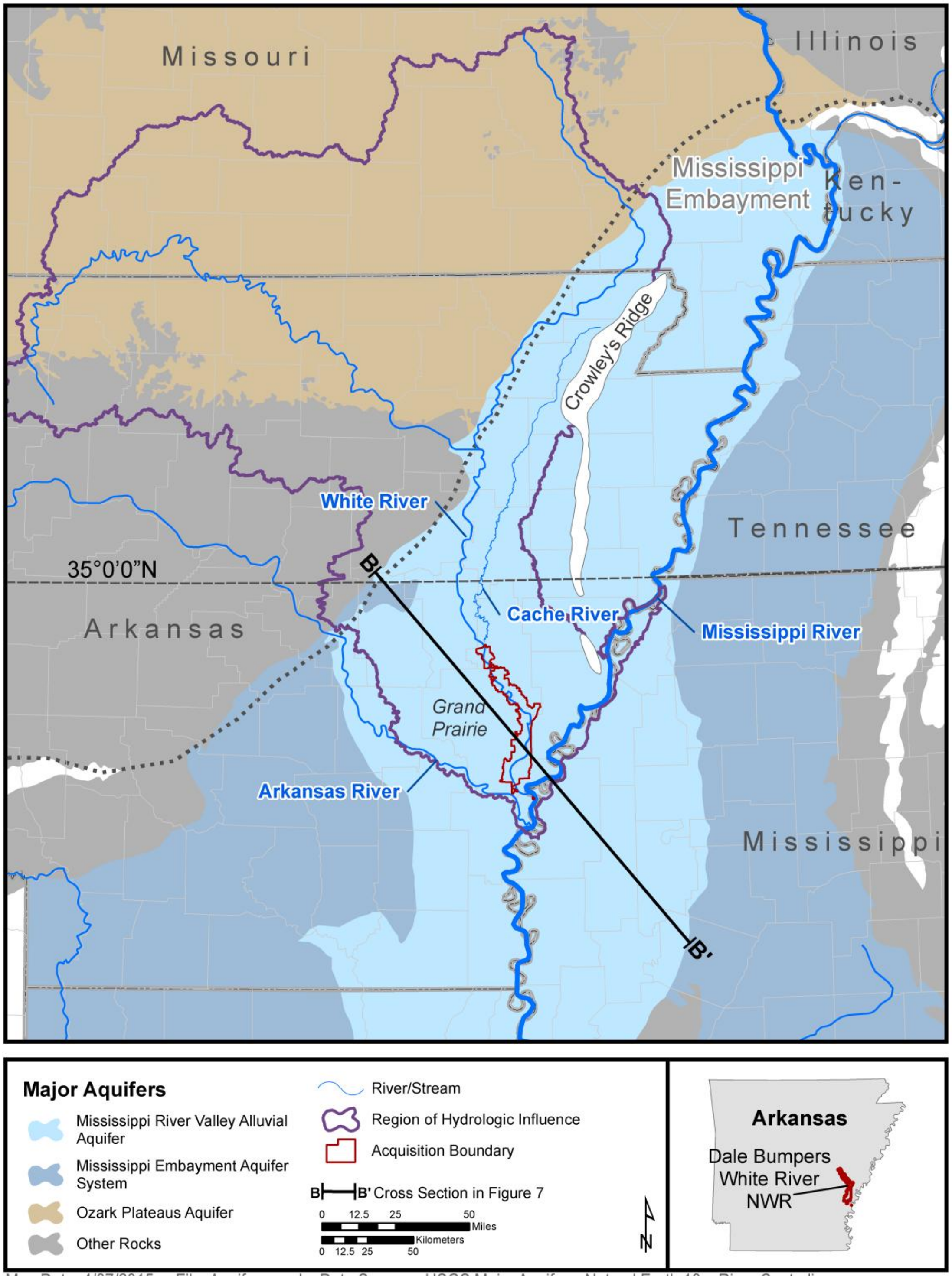
With the advent of continental glaciations during the Pleistocene, sea levels receded and the coastal shoreline retreated southward. The low area formed by the Embayment gradually filled with sediment. Layers of sand and gravel were deposited by the deltas of the ancestral Mississippi and other rivers. Clays, mud, marl, and shale were deposited during periodic marine invasions (Saucier 1994). At the conclusion of the Pleistocene epoch and the most recent (Wisconsin) glacial retreat, sea levels rose again. During glacial retreat, the MAV acted as the conduit for glacial meltwater and sediments. Deposits from this time occur in the form of braided stream terraces known as valley trains, as well as unconsolidated alluvium. Additional deposits of loess (wind-blown silt) also date to earlier periods of the Pleistocene (Saucier 1994).

At the beginning of the Holocene epoch, approximately 12,000 years B.P., water and sediment supplies from glacial outwash decreased, the ancestral Mississippi River system transitioned from a braided outwash complex to an aggrading, meandering low-gradient channel. Cyclic changes in base level caused the channel to entrench into the valley fill, creating erosional terraces within the MAV. The Holocene alluvial plain, the area in which the refuge is located, is dominated by the meander belts of the Mississippi and Arkansas Rivers. Each is a low, broad ridge that is a mile to several miles wide, and 5 to 10 feet higher than the adjacent floodplain areas (Saucier 1994).

The Ozark Plateaus aquifer system underlies the Upper White River system (Figure 6). It is a carbonate-rock and sandstone aquifer system that extends across most of northern Arkansas and includes (from shallowest to deepest) the Springfield Plateau, Ozark and St. Francis aquifers. The Ozark aquifer is the principal source of groundwater for agricultural and domestic uses in northern Arkansas; wells in the most productive sandstone strata commonly yield 100-300 gallons per minute. In the northeastern part of Arkansas the Ozark aquifer extends beneath the Mississippi River Valley alluvial aquifer (Renken 1998).

The Mississippi Embayment Aquifer System (MEAS) underlies the Mississippi Alluvial Plain section of the Coastal Plain province in Arkansas. It is composed of six aquifers in poorly to unconsolidated bedded sand, silt and clay (Renken 1998). In Arkansas, the extent of MEAS ranges from the upper northeast corner of the state to the lower southwest corner, roughly corresponding with the Coastal Plain boundary (Figure 6).

The uppermost unit of MEAS in the vicinity of the refuge and along the core of the Mississippi Embayment is the Mississippi River Valley alluvial aquifer, commonly referred to as the alluvial aquifer. The alluvial aquifer produced 94% of the groundwater withdrawn in Arkansas in 2010 (Kresse et al. 2014), and is primarily used for irrigation. Groundwater wells drawing from the alluvial aquifer can yield from 50 to more than 500 gallons per minute (Pugh 2008).



Map Date: 4/07/2015 File: Aquifers.mxd Data Sources: USGS Major Aquifers, Natural Earth 10m River Centerlines, ESRI Topo Service

Figure 6. Extent of major aquifers within the Region of Hydrologic Influence. See Figure 7 for B – B′ cross section detail. South of 35N, the Sparta aquifer is separated from deeper aquifers by a confining unit. North of latitude 35N the connected aquifers of the Middle and Lower Claiborne units are collectively referred to as the Memphis aquifer.

The alluvial aquifer is composed of unconsolidated Quaternary (Holocene and Pleistocene) alluvium overlying and laterally adjacent to the aquifers and confining units of the Mississippi Embayment (Figure 7). It contains two distinct lithologies: a clay and silt cap that varies in thickness and extent overlying coarse sand and gravel, which are often well-sorted and generally become finer in texture with proximity to the surface (Renken 1998). The hydraulic conductivity is greater at the bottom of the aquifer and decreases upward as the sediment size decreases (Mahon and Poynter 1993).

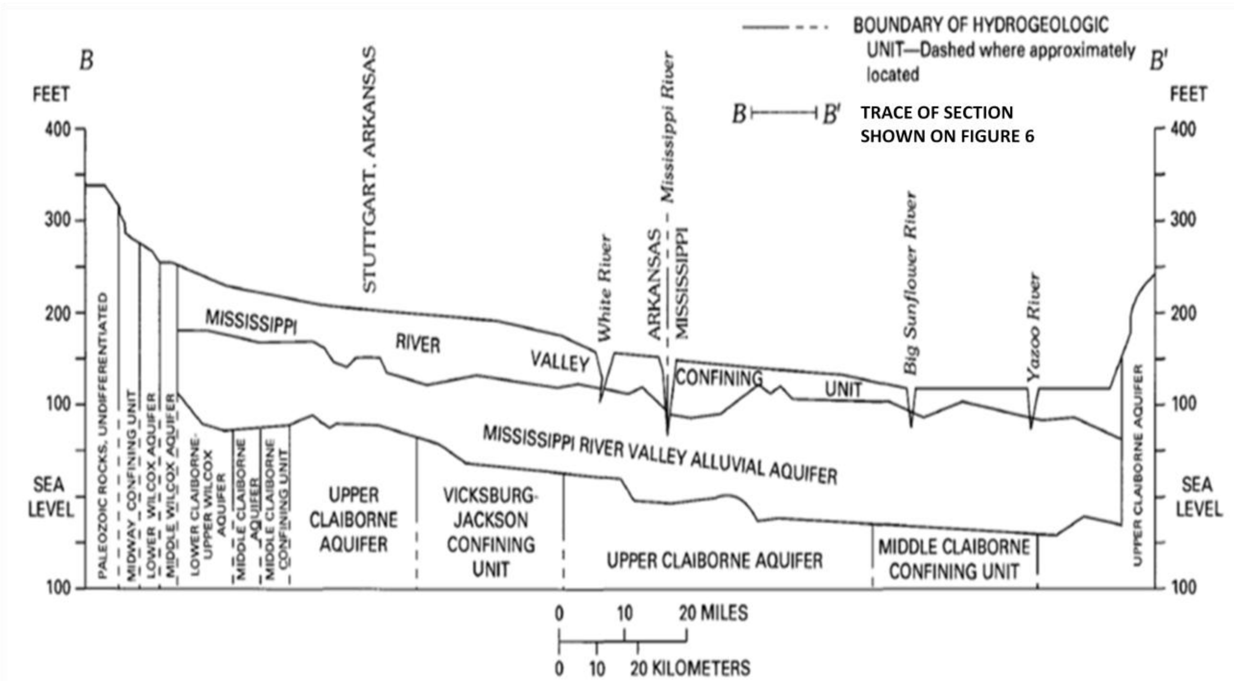


Figure 7. Aquifers in cross section (as shown on Figure 6). Modified from Ackerman (1989).

The alluvial aquifer underlies about 32,000 mi^2 and generally ranges from 50 to 125 miles in east to west extent and about 250 miles north to south, adjacent to the Mississippi River (Holland 2007). The thickness of the alluvial aquifer ranges from 60 to 140 feet, with an average of 100 feet. These estimates of measure include the clay/silt cap, which has an average thickness of 30 feet (Ackerman 1996), but which can exceed 60 feet in thickness throughout the Grand Prairie area (Renken 1998). The clay/silt cap acts as a confining unit throughout much of the aquifer. Saturated thickness is usually equal to the thickness of the aquifer, except for areas where groundwater pumping has caused cones of depression to develop.

Recharge for the alluvial aquifer comes from direct precipitation (in places where confining unit is absent), runoff from adjacent slopes, upward flow from underlying aquifers, and infiltration from streams during periods when water levels in surface features are higher than water levels in the aquifer. Within the Lower White River Basin, the presence of clay soils at the surface prevents widespread recharge of the alluvial aquifer from surface waters (USFWS 2012). However, recharge from induced stream infiltration may take place where well withdrawals have lowered the adjacent water table below the stream level. Alternately, during dry periods, water may discharge from the alluvial deposits or adjoining aquifers into the streams, which contributes to baseflow (Renken 1998).

Groundwater enters the alluvial aquifer from the north and west and flows in a south and east direction toward major rivers. The groundwater flow paths within the alluvial aquifer may extend from tens to hundreds of miles before intersecting major rivers such as the Mississippi, Arkansas or White Rivers. In areas of high groundwater withdrawal, groundwater flows towards cones of depression that are formed as a result of groundwater pumping.

The fine-textured loess of Crowley's Ridge acts as a major hydrologic interruption within the alluvial aquifer, bisecting the northern portion of the unit. Both the White and Arkansas Rivers penetrate the alluvial aquifer and also act as local hydrologic boundaries (Ackerman 1996).

Below the alluvial aquifer are deeper aquifers within geologic units ranging in age from late Cretaceous to middle Eocene (approximately 70 – 40 million years B.P.) (Table 2). These units consist of alternating beds of sand and clay with some interbedded silt, lignite, and limestone (Grubb 1984), and range from 60 to 600 feet in thickness. The Vicksburg-Jackson confining unit, which separates the alluvial aquifer from the lower strata, is present in parts of southeastern Arkansas but absent in the northeast. Thus, in northeastern Arkansas, the southward-dipping lower strata of the MEAS are hydraulically connected to the alluvial aquifer; however, the distinct differences in texture and permeability between the units can cause them to act as lower confining units (Renken 1998).

In the Lower White River Basin, the most important of these deeper aquifers lie in the Sparta and Memphis Sands of the Middle and Lower Claiborne aquifers. The Sparta aquifer consists of fine- to medium-grained sand near the top, grading to coarse-grained sand at the bottom with some interbedded clay. Maximum thickness of this unit is around 900 feet (Pugh 2008). The Sparta aquifer is primarily found in portions of southeastern Arkansas, where it is hydraulically isolated from deeper aquifers by the Lower Claiborne confining unit. North of latitude 35N (as shown on Figure 6) this confining unit is absent, and the connected aquifers of the Middle and Lower Claiborne units are collectively referred to as the Memphis aquifer (Ackerman 1996; Pugh 2008).

Both the Sparta and Memphis aquifers are primarily used for industrial and public water consumption. Water quality in these aquifers makes them more suitable for public consumption wells than the alluvial aquifer (EPA 2009). The Sparta aquifer commonly yields 1,000 gallons per minute (Pugh 2008). Yields of as much as 2000 gallons per minute may occur in the Memphis aquifer in areas of eastern Arkansas (Renken 1998). Wells in the Middle Claiborne aquifers in Arkansas are reported to yield from 300 to 1000 gallons per minute.

Recharge within the Claiborne aquifers is primarily gravity driven. Water would flow naturally from the northwest to the southeast; however, large groundwater withdrawals in southern Arkansas have caused declines of the potentiometric surface and some changes in direction of regional predevelopment flow. Large withdrawal rates from the middle Claiborne aquifer have also induced downward leakage of water into the middle Claiborne aquifer from the upper Claiborne and the Mississippi River Valley alluvial aquifers (Renken 1998).

Table 2. Hydrogeologic Units in the vicinity of Dale Bumpers White River National Wildlife Refuge. Modified from Ackerman (1996).

<table>
<tr><th>ERA</th><th>SYSTEM</th><th>SERIES</th><th colspan="2">NORTHEASTERN ARKANSAS</th><th colspan="2">SOUTHEASTERN ARKANSAS</th><th colspan="2">HYDROSTRATIGRAPHIC UNITS</th></tr>
<tr><td rowspan="9">CENOZOIC</td><td rowspan="2">QUATERNARY</td><td>HOLOCENE</td><td colspan="2" rowspan="2">Alluvium and terrace deposits</td><td colspan="2" rowspan="2">Alluvium and terrace deposits</td><td rowspan="9">Mississippi Embayment Aquifer System</td><td>Mississippi River confining unit</td></tr>
<tr><td>PLEISTOCENE</td><td>Mississippi River Valley alluvial aquifer</td></tr>
<tr><td rowspan="7">TERTIARY</td><td>OLIGOCENE</td><td colspan="2" rowspan="2">not present</td><td colspan="2">not present</td><td rowspan="2">Vicksburg-Jackson Confining Unit</td></tr>
<tr><td rowspan="6">EOCENE</td><td>Jackson Group</td><td>Undifferentiated</td></tr>
<tr><td rowspan="5">Claiborne Group</td><td>Cockfield Formation</td><td rowspan="5">Claiborne Group</td><td>Cockfield Formation</td><td>Upper Claiborne Aquifer</td></tr>
<tr><td>Cook Mountain Formation</td><td>Cook Mountain Formation</td><td>Middle Claiborne Aquifer</td></tr>
<tr><td rowspan="3">Memphis Sand</td><td>Sparta Sand</td><td>Middle Claiborne Aquifer</td></tr>
<tr><td>Cane River Formation</td><td>Lower Claiborne confining unit</td></tr>
<tr><td>Carrizo Sand</td><td>Lower Claiborne-upper Wilcox aquifer</td></tr>
</table>

4.4 Soils

Soils in the White River Basin strongly influence important hydrologic and geomorphologic processes and ecosystem services such as runoff, erosion, groundwater recharge, and nutrient cycling. The geologic surface deposits acting as parent materials throughout the entire MAV are predominately unconsolidated sediments transported by water and wind. Some soils in the basin are highly susceptible to erosion, especially the loess-derived soils along Crowley's Ridge, while soils within the refuge acquisition boundary are not generally susceptible to erosion because of their geographic setting, slope, and texture. The soil types near DBWRNWR are mostly hydric and alluvial. Table 3 summarizes characteristics of the major soil types found within the refuge acquisition boundary. The distribution of individual soil series is problematic because individual counties were mapped over a one hundred year period and the same soil is called by different names in different counties (e.g., Kobel in Woodruff County is called Sharkey in Monroe County). When examining Table 3, more emphasis should be placed on series with similar characteristics, primarily characteristics that indicate the presence or absence of groundwater near the surface (i.e., hydric soils).

Broadly speaking, the northern portion of the refuge is dominated by Kobel-Commerce-Dubbs association and the southern portion of the refuge is dominated by the Sharkey-Alligator-Tunica association (USDA 2013). Both associations are found in broad, low, level areas in floodplains. Individual soil series occupy different geographic settings or locations (Table 3) within the floodplain, with different textures, and drainage classes that reflect their formation and govern their hydrologic function with respect to runoff, erosion, and groundwater recharge. Soil hydrologic processes include infiltration, storage, redistribution, drainage, evaporation, and transpiration. All soil hydrologic processes occur within soil pore space. Porosity describes the relative volume of void space between soil particles that may be filled with air or water. Soil porosity depends on the texture and structure of soil. Coarse-textured soils tend to have larger pores but less total pore space than fine-textured soils. As a result, coarse-textured soils tend to be more permeable, permitting quicker infiltration with greater potential for groundwater recharge, while fine-textured soils generally have greater moisture holding capacity.

The Sharkey series consists of very deep, poorly and very poorly drained, very slowly permeable soils that formed in clayey alluvium on floodplains and low terraces. Tunica soils are similar to Sharkey but have a loamy horizon within 20 to 36 inches of the soil surface. They are saturated in the surface layer and along cracks and slickenside faces in the subsoil during the wet seasons. Water runs off the surface at a high to very high rate.

The refuge soils have a high clay content causing water to perch and pond at the surface and preventing significant groundwater recharge through infiltration. While recharge is limited, the propensity to surface ponding makes extensive rice cultivation possible (USFWS 2012). The Farm Unit soils are generally rich and fertile, which is the primary reason for historic drainage and land clearing for agriculture. Hydric soils in the refuge, and the wetlands that contain them, can mitigate the effects of nutrient additions for agriculture in the rest of the basin.

The Natural Resources Conservation Service (NRCS) defines a hydric soil as “soil that formed under conditions of saturation, flooding or ponding long enough during the growing season to develop anaerobic conditions in the upper part” (SSURGO undated). The concept of hydric soils includes soils developed under sufficiently wet conditions to support the growth and regeneration of hydrophytic vegetation. Soils that are sufficiently wet because of artificial measures are included in the concept of hydric soils. Also, soils in which the hydrology has been artificially modified are hydric if the soil, in an unaltered state, was hydric. Some series, designated as hydric, have phases that are not hydric depending on water table, flooding, and ponding characteristics. NRCS maintains a national list of hydric soil components (USDA 2013). Within the Soil Survey Geographic (SSURGO) Database, “hydric soils” include all map units in which the majority of soil components meet hydric criteria. “Partially hydric soils” may have some hydric components within a larger matrix of non-hydric components (SSURGO undated). Using these criteria, 52% of soils within the acquisition boundary of DBWRNWR are classified as hydric, and 39% of soils are partially hydric. Less than 2% of soils can be classified as not hydric (SSURGO undated), with the remainder mapped as water.

Table 3. Soil series found within the acquisition boundary of DBWRNWR. [Source: SSURGO undated].

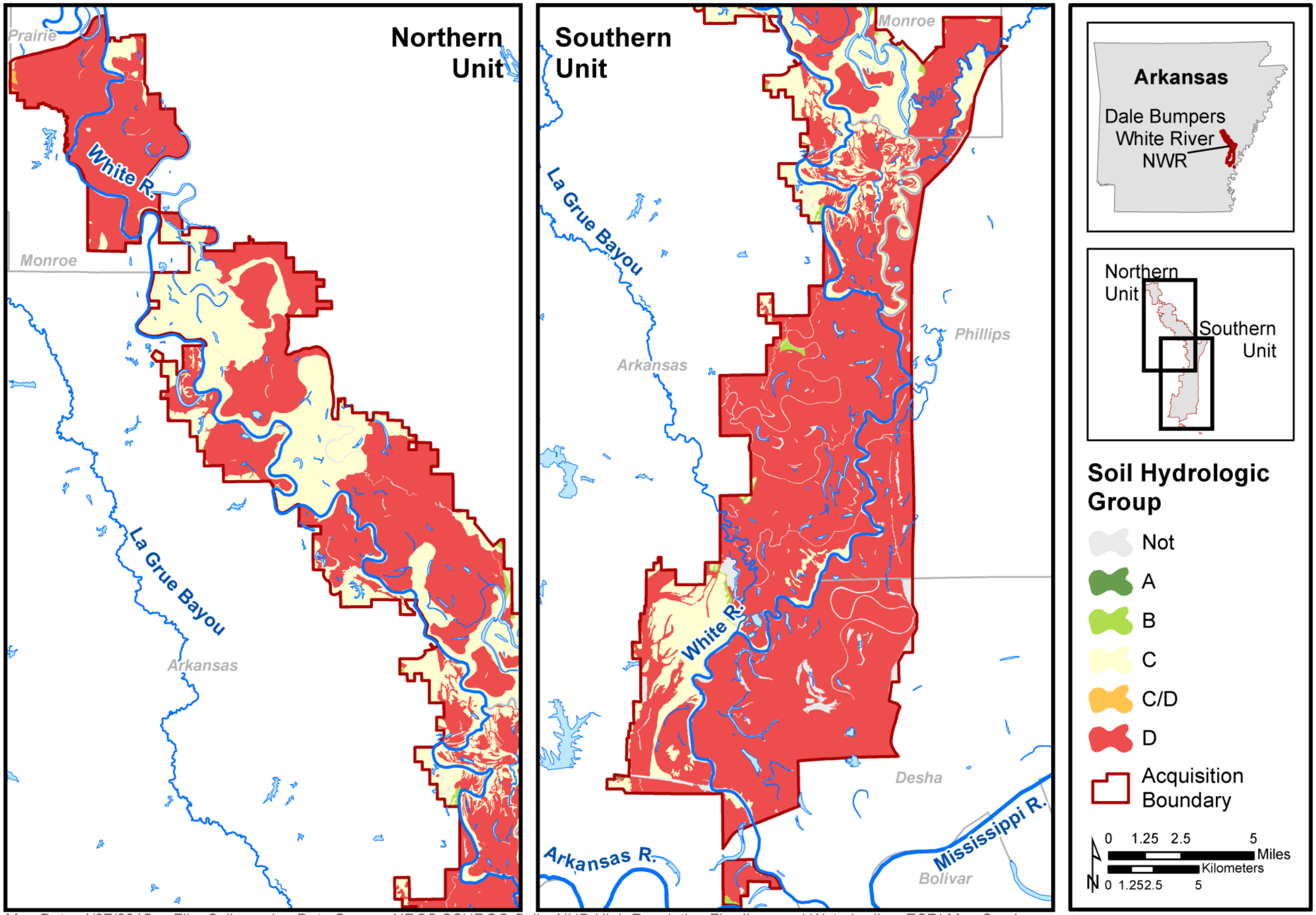
Series Name	Acres within Acquisition Boundary	Slope	Drainage	Hydric	Hydrologic Soil Group	Surface Texture	Subsurface texture	Location	Parent Material
Amagon	375	level to very gently sloping	poorly drained	Y	C	silt loam	silty clay loam	low terraces; depressions, natural levees	stratified silty alluvium
Bosket	79	level to undulating	well drained	N	B	fine sandy loam	fine sandy loam, sandy clay loam, loamy fine sand	natural levees along creeks and abandoned river channels	stratified beds of predominantly loamy sediment
Calhoun	58	level to very gently sloping	poorly drained	Y	C	silt loam	silty clay loam	low ridges	loess
Commerce	21447	level to gently undulating	somewhat poorly drained	Y	C	silt loam	silt loam to silty clay loam	natural levees	beds of stratified loamy alluvium
Crevasse	4	level to gentle	excessively drained	Y	A	loamy sand	sand	river valley, natural levee	sandy alluvium
Desha	482	level to gently sloping	somewhat poorly drained	Y	D	silty clay	clay	River valley, floodplain	clayey alluvium
Dewitt	138	level	poorly drained	Y	C	silt loam	silty clay loam	upland, stream terrace	loamy alluvium
Dubbs	583	level to gently sloping	well drained	N	B	loam, silt loam, and silty clay loam	fine sandy loam	river valley, natural levee	loamy alluvium
Dundee	5265	level to gently sloping	somewhat poorly drained	N	C	silt loam, silty clay loam, and loam	sandy loam	river valley, natural levee	loamy alluvium
Ethel	143	level to gently sloping	poorly drained	Y	C	silt loam	silty clay loam	upland, stream terrace	silty alluvium
Fluvaquents, frequently flooded	1535	n/a	n/a	Y	D	n/a	n/a	borrow pits on the river side of levees	stratified sediments deopsited during floods
Foley-Calhoun-Bonn complex	2077	level	poorly drained	Y	D	silt loam	silt loam to silty clay loam	broad flats in areas of wind-deposited sediments	loess
Forestdale	2223	level to gently sloping	poorly drained	Y	D	silty clay loam	silty clay to silty clay loam	river valley, stream terrace	clayey alluvium
Gore	278	gently sloping	moderately well drained	N	D	silt loam	silty clay, clay	higher escarpments above floodplains of existing streams	clayey sediments deposited in abandoned slack water areas of floodplains of extinct drainage systems
Grenada	88	level to gently sloping	moderately well drained	N	C	silt loam	silt loam to silty clay loam, fragipan	tops and side slopes of low ridges	loess
Immanuel	3837	gently to moderately sloping	moderately well drained	N	C	silt loam	silt loam to silty clay loam	upland, terrace	loess influenced alluvium
Keo	61	level to very gently sloping	well drained	N	B	loam, very fine sandy loam, and silt loam	loam to silty clay loam	river valley, natural levee	loamy alluvium

Series Name	Acres within Acquisition Boundary	Slope	Drainage	Hydric	Hydrologic Soil Group	Surface Texture	Subsurface texture	Location	Parent Material
Kobel	39168	level	poorly drained	Y	D	silty clay loam	clay, silty clay loam, and clay loam	floodplains and back swamps	clayey alluvium
Levee	121	n/a	n/a	n/a		n/a	n/a	n/a	highly variable
Memphis	21	level	well drained	N	B	silt loam	silty clay loam	n/a	loess
Mhoon	591	level	poorly drained	Y	D	silt loam	silt loam, silty clay loam	floodplains	stratified beds of loamy sediments
Muskogee	64	gently sloping	moderately well drained	N	C	silt loam	silty clay loam to silty clay	upland, terrace	silty over clayey alluvium
Newellton	96	level to gently undulating	somewhat poorly drained	Y	D	clay	silty clay, silt loam, fine sandy loam	slack water areas	clayey sediments
Oaklimeter	148	level to gently sloping	moderately well drained	Y	C	silt loam	silt loam	upland, flood plain	silty alluvium
Overcup	2030	level to very gently sloping	poorly drained	Y	D	silt loam	clay, silty clay, and silty clay loam	river valley, stream terrace	clayey alluvium
Perry	2550	level to very gently sloping	poorly drained	Y	D	clay	clay	river valley, backswamp	clayey alluvium
Pits, borrow	290	n/a	n/a	n/a		n/a	n/a	n/a	n/a
Portland	127	level to very gently sloping	somewhat poorly drained	Y	D	clay	silty clay	river valley, backswamp	clayey alluvium
Riverwash	5	n/a	n/a	n/a	A	sandy	n/a	channel	unstable sediments; frequently flooded and re-worked
Sharkey	66096	level	poorly drained	Y	D	clay	clay	broad flats	thick beds of fine-textured slackwater deposits
Sharkey-Commerce-Coushatta association	67	level	poorly drained	Y	D	clay, silt loam, silty clay loam	clay, silt loam, silty clay loam	Areas along the Mississippi and Arkansas Rivers not protected by levees	n/a
Stuttgart	149	level to gently sloping	somewhat poorly drained	N	D	silt loam	silty clay, silty clay loam, silt loam	upland, stream terrace	silty and clayey alluvium
Tichnor	409	level to very gently sloping	poorly drained	Y	C	silt loam	silty clay loam to silt loam	upland, flood plain	loamy alluvium
Tunica	1928	level to very gently sloping	poorly drained	Y	D	clay	silty clay, silty clay loam, silt loam; loamy sand	slackwater areas	thin beds of clayey sediments underlain by loamy sediments
Udipsamments	34	level to gently sloping	excessively drained	N	A	loamy fine sand	stratified loamy fine sand, fine sand, and sand	river valley, floodplain	sandy sediments dredged from navigation channels and deposited on banks
Water	12974	n/a	n/a	n/a		n/a	n/a	n/a	n/a
Yancopin	6755	level to gently sloping	somewhat poorly drained	Y	C	silty clay loam to silt loam	sandy loam	river valley, floodplain	n/a
Yorktown	145	level to very gently sloping	very poorly drained	Y	D	silty clay	clay	river valley, oxbow	clayey alluvium

NRCS also assigns a hydrologic soil group to each map unit as an indicator of the runoff (and conversely, recharge) potential for the soil unit when thoroughly wet. Hydrologic soil group is different from the concept of hydric soil discussed earlier, though related. There are four groups, ranging from A (high infiltration/low runoff) to D (very slow infiltration/high runoff). If a soil is assigned to a dual hydrologic soil group, the first letter is for drained areas and the second letter is for undrained areas. The majority of soils within the acquisition boundary of the refuge (91%) fall into hydrologic soil groups C and D (Table 4, Figure 8). These groups are characterized by slow infiltration and high runoff potential (Table 4), which again is the consequence of high clay content. The vast majority of all hydric soils at the refuge are in hydrologic soil group D. The majority of partially hydric soils are in group C, but a substantial portion (44%) is in group D.

Table 4. Acres of refuge soils by hydrologic soil group.
[Source: USDA 2013].

Hydrologic soil group	**Acres within acquisition boundary**	**Percent of total area**
None assigned	13385	8
A	43	Less than 1
B	744	Less than 1
C	38448	22
C/D	92	Less than 1
D	119731	69
Total	***172443***	***100***



Map Date: 4/07/2015 File: Soils.mxd Data Source: NRCS SSURGO Soils, NHD High Resolution Flowlines and Waterbodies, ESRI Map Service.

Figure 8. Hydrologic soil groups within the acquisition boundary of Dale Bumpers White River National Wildlife Refuge. Runoff properties range from group A (high infiltration/low runoff) to group D (very slow infiltration/high runoff).

4.5 Hydrology and Geomorphology

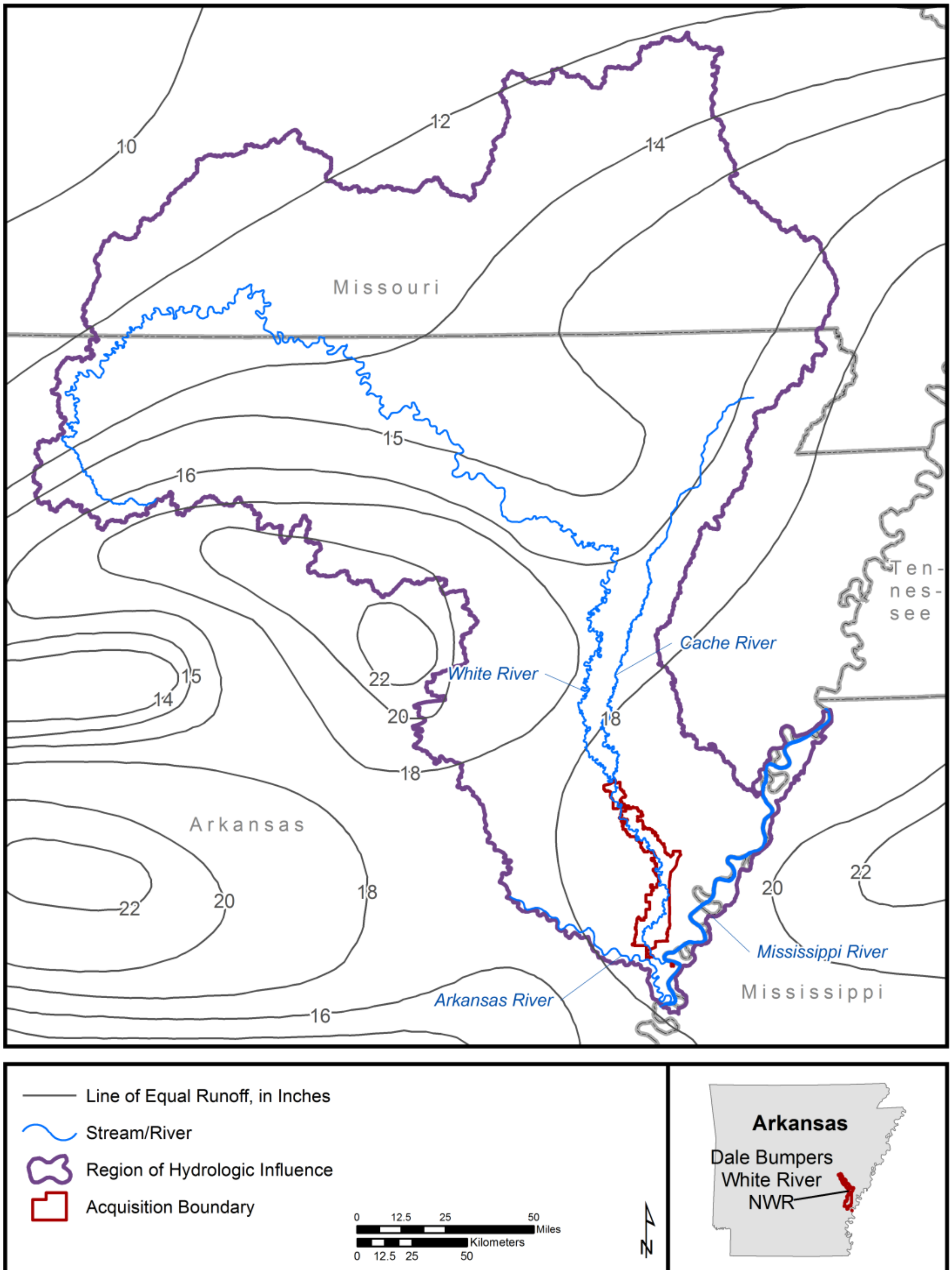
Hydrology and geomorphology are the products of the interwoven relations between climate, geology, topography, and land cover. For example, runoff, a key driver of basin hydrology and geomorphology, results from the interaction of precipitation, topography, soils, land cover, and evapotranspiration. Mean-annual runoff is highest (18 to 20 inches) along the southwestern boundary of the White River Basin and generally increases south-southeastward from about 12 inches near the northern boundary to over 18 inches in the vicinity of the refuge near the basin outlet (Gebert 1987; shown on Figure 9).

The Upper and Lower White River Basins drain 27,765 mi^2 in Arkansas and Missouri. The majority of basin area (23,044 mi^2/83%) lies within the Ozark Plateau; only 17% (4720 mi^2) is within the MAV (Jason Phillips, USFWS, personal communication, May 22, 2013). Major tributaries to the White River include the James River, North Fork River, Buffalo River, Black River, Village Creek, Little Red River, Bayou Des Arc, Wattensaw Bayou, Cache River, Big Creek and Bayou LaGrue.

The White River mainstem flows 720 miles from its origins in the Boston Mountains of the Interior Highlands (elevation 2,575 feet MSL) to its confluence with the Mississippi River, where the bed elevation is 125 feet MSL. When considering the entire length of the river, the average slope is 0.064%, which is equivalent to 3.4 feet in elevation loss per river mile; however, there is a marked difference in the relief of the coastal plain (Lower White) section of the basin as compared to the Interior Highlands (Upper White) portion. The elevation at the northern boundary of the Lower White River Basin, 185 miles above the mouth of the White River, is approximately 300 feet MSL, resulting in an average basin slope of 0.018%, or 0.95 feet per mile (see "Geology and Topography" in USFWS [2012]).

The lower White River system includes numerous channels, sloughs, oxbow lakes and swamps, as well as relatively shallow depressions in the bottomlands that are inundated during fall and winter (Figure 10). These depressions eventually expand and connect to one another, creating larger inundated areas. The lakes, bayous, streams and ephemeral channels are all connected to the White River due to the subtle ridge and swale topography of the floodplain. At higher river stages, but before the flooding occurs, the river channel is able to carry greater quantities of sediment. When the main channel reaches flood stage and overflows its banks, it connects to sloughs and bayous within the floodplain. In these peripheral features, the velocity of the flood waters decreases to a point where sediment transport capacity diminishes and deposition occurs. As flood stage recedes and water elevation decreases, connections are gradually filled (see "Pre-Settlement Conditions" and "Hydrologic Connectivity" in USFWS [2012]). Detailed geologic and geomorphologic quadrangle maps of the area comprising and surrounding the refuge are found in Appendix A.

Settlement of the basin led to substantial hydrologic alterations for flood control, navigation and agricultural production. These modifications are discussed in detail in Section 5.4.4 of this report and "Hydrologic Modifications" in USFWS (2012).



Map Date: 3/18/2015 File: Runoff.mxd Data Sources: USGS Average Annual Runoff in the United States, 1951 - 1980, NHD High Resolution Flowlines and Waterbodies, National Watershed Boundary Dataset HU-6 Boundaries, ESRI Topo Service.

Figure 9. Lines of equal runoff, 1951 - 1980 (in inches) within the Region of Hydrologic Influence RHI).

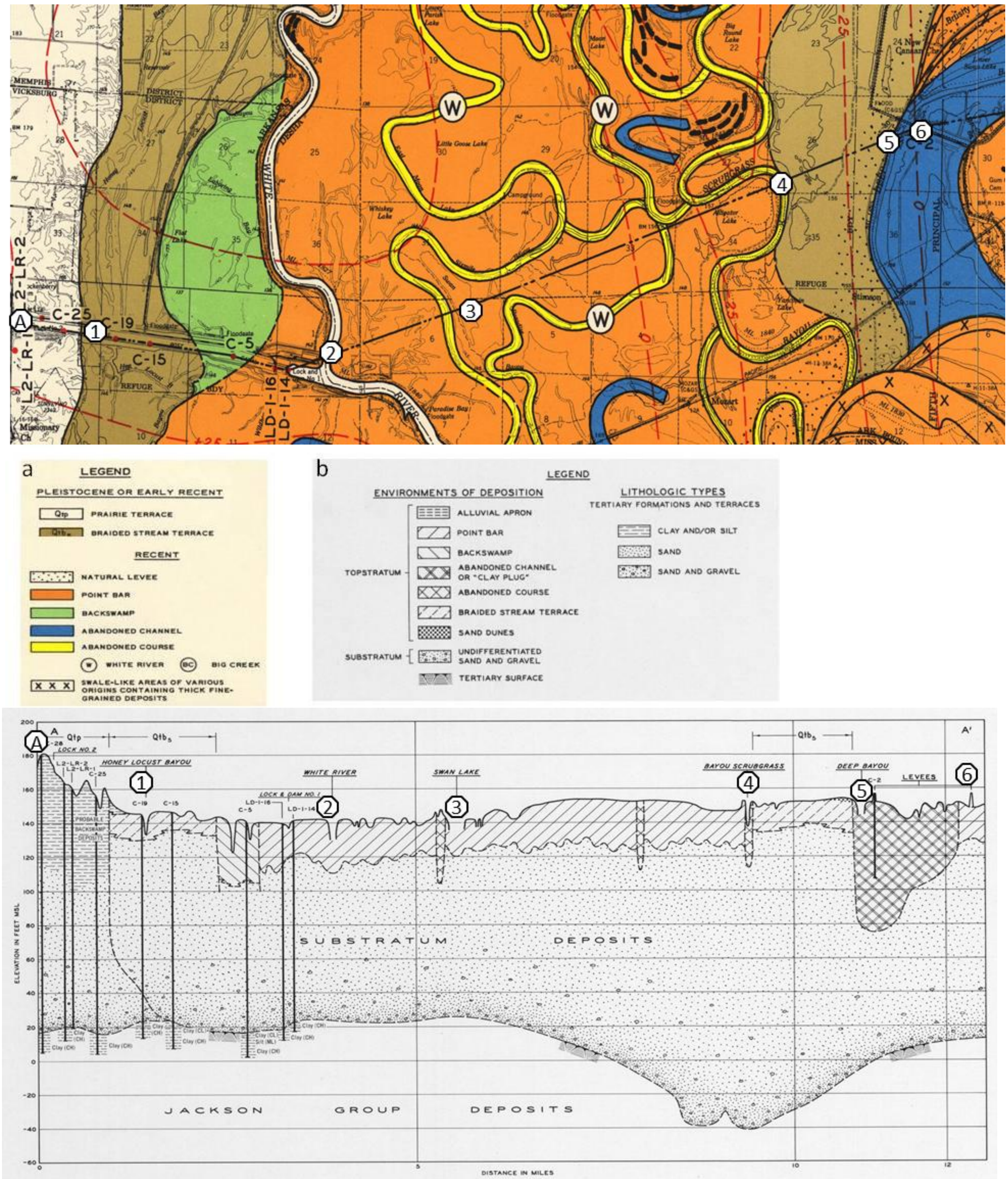


Figure 10. Geomorphic map and cross section in the vicinity of the lower DBWRNWR. Modified from Smith and Saucier (1971): Henrico (a) & (b). Cross section A – A1, located within the lower White River Basin, as an example of floodplain features in an anabranching system floodplain. The numbers in each figure roughly correspond to the following features: 1 – Honey Locust Bayou; 2 – Main Channel of White River; 3 – Abandoned course of White River and Swan Lake; 4 – Bayou Scrubgrass; 5 – Deep Bayou; 6 – Man-made levee. See Appendix A for full geologic plates.

Flooding of the lower White River system is significantly influenced by the White and Mississippi rivers, and to a lesser degree, the Arkansas River. The Mississippi River, which intersects with the White River south of the refuge at Montgomery Point, AR, greatly affects the hydrology of the lower White River, in terms of discharge and stage. The Mississippi River's mean annual flow at the confluence is 480,000 cubic feet per second (cfs), more than 15 times greater than that of the White River (30,787 cfs) (USFWS 2012). Water backs up the White River from the Mississippi River and slows, or even stops, the flow of water moving down the White River. As it does, the stage of the White River rises to match that of the Mississippi River. The Mississippi River's stage can fluctuate by as much as 57 feet at the mouth of the White River, which influences the White River for a considerable distance upstream. Local rainfall patterns also influence flooding in the system. Seasonal rains continue to inundate bottomland depressions, as described above, and when the mainstems of streams rise over their banks, the entire river bottom is connected as one body of water (see "Current Hydrologic Status" in USFWS [2012]).

4.6 Anthropogenic Landscape Changes

Numerous landscape-level activities and actions have directly and indirectly influenced both water quantity and water quality within the White River Basin and are discussed below. A land cover analysis, as well as specific research related to how landscape changes have altered water quantity and water quality, is discussed in Sections 5.4.6 and 5.5.4 of this report.

4.6.1 Land Clearing and Conversion to Agriculture

Overall, the Lower Mississippi Alluvial Valley (LMAV) has undergone the most widespread loss of bottomland hardwood forests in the United States, with as much as 96% caused by conversion to agriculture (MacDonald et al. 1979, DOI 1988, cited in Schoenholtz et al. 2005).

Land clearing for agriculture on a limited scale preceded European settlement. American Indians of the Mississippian period burned and cleared land for agriculture (Gardiner and Oliver 2005). Natural levees, in particular, were extensively used for growing Maize (Hudson 1997, cited in Klimas et al. 2004). American Indian disturbance of the forests of the LMAV rose dramatically and peaked between 3,200 and 1,350 B.P. (Galloway 1994, cited in Gardiner and Oliver 2005).

Early European settlers (late 1600s to 1700s) also cleared lands for small farms along natural levees and point bar deposits, which contained well drained, fertile soils and provided river access (Frederickson 2005, King et al. 2005, cited in LMVJV 2007). Approximately one half of the forests (original acreage estimated at 22 to 24 million acres) in the LMAV were cleared between 1800 and 1935 (Smith et al. 1993; Schoenholtz et al. 2005). Timber harvesting in bald cypress swamps was done by hand from small boats until the late 1800s when the pull-boat system and logging railroads were used for extraction (Schoenholtz et al. 2005). The railroad system made large-scale commercial timber harvest, market hunting and expanded settlement possible (Klimas et al. 2004). From 1880 to 1920, nearly all virgin forests in the Arkansas Delta were cut over (Smith et al. 1984, cited in Klimas et al. 2004).

The construction of the levee system on the Mississippi River and tributaries such as the White River following the "Great Flood" of 1927 (see below) accelerated conversion of bottomland hardwoods to agricultural production. Extensive conversion occurred in the Cache River/Lower White River Basin from the 1940s through the mid-1970s as land protected by the levees was cleared for cultivation. Areas within the Cache/Bayou DeView portion of the basin were cleared to the riverbanks (USFWS 2012). Between 1940 and 1960 land clearing for rice farming expanded in the LMAV, particularly in the Cache River Basin. A total of 22% of the land remaining in forest at the beginning of World War II was cleared by 1960. A spike in soybean prices, combined with improved flood control, drainage and technology that made larger areas suitable for agriculture, caused unprecedented land clearing in the 1960s and 1970s (LMVJV 2007). By the 1980s the forested area of the LMAV had been reduced to 20% of the original total, occurring in small and finely dispersed fragments with larger fragments centralized along the major river systems (Creasman et al. 1992, Haynes 2004, Twedt and Loesch 1999, cited in LMVJV 2007). In Arkansas, losses are more dramatic; approximately 15% of the original 8 million acres remain, with most fragmentation on drier areas (e.g., natural levees) and the largest tracts remaining in lowlands (Rudis 1995, cited in Klimas et al. 2004).

4.6.2 Flood Control

Conversion of cleared lands to agriculture was common because of the high natural fertility of alluvial soils; however, lands flooded periodically and drainage was necessary so local communities cleared, ditched and drained lands (LMVJV 2007). In May of 1927 the Mississippi River flooded, affecting states from Illinois and Kentucky down to Louisiana. This flood, known as the Great Flood, was the largest flood recorded in North America and the fourth largest in the world (O'Connor and Costa 2004). In response to the devastation caused by the flood, the U.S. Congress passed the 1928 Flood Control Act, which put flood control under federal authority. The U.S. Army Corps of Engineers (Corps or USACE) initiated landscape-scale flood control of the Mississippi River and its tributaries with over 3,700 miles of levees constructed (IFMRC 1994, cited in LMVJV 2007). The extensive levee system prevents overland flooding of the Mississippi River onto much of its original floodplain (Gardiner and Oliver 2005). The White River levee system, constructed in 1939, begins approximately 8 miles upstream from the confluence with the Mississippi River and extends upstream for approximately 50 miles. In conjunction with the levee system, a series of dams on the upper White River was constructed for agricultural flood control and water supply starting in 1943 (USFWS 2012). The effects of the flood control system on hydrologic regimes on the White River are described in Sections 5.4.4 and 5.4.6.

4.6.3 Refuge

As discussed in Section 1, the refuge was established in 1935 to protect and conserve migratory birds and other wildlife resources. The Civilian Conservation Corps (CCC) conducted a number of improvement projects on the DBWRNWR and other refuges throughout the country, such as constructing dams, dikes and water control structures, establishing food plots and planting trees and other vegetation. Dale Bumpers White River NWR had three CCC camps and boasts the most complete and intact collection of CCC structures in the NWRS. Buildings such as carpentry shops, storage sheds, refuge housing and a fire tower are concentrated on the Farm Unit and St. Charles Work Center (i.e., St. Charles Compound Area), which is located directly adjacent to the White River north of the St. Charles boat ramp. Prior to acquisition by the USFWS in 1992, most of the lands in the Northern Unit of the refuge were owned by a timber company, the Potlatch Corporation, and selective logging has occurred throughout most of the refuge (USFWS 2012). The refuge now protects the largest area of bottomland hardwood forest in the Delta Region of Arkansas (Klimas et al. 2004).

4.6.4 Recent Land Use Change

In the late 1980s Congress passed Farm Bill legislation that introduced "swampbuster" provisions to slow wetland conversion, which was followed by the Wetland Reserve Program and other private land conservation programs that encouraged restoration of bottomland forests. Collectively these programs intend to replant over 7 million acres of forest on marginal agricultural lands (i.e., afforestation) in the LMAV (King and Keeland 1999, cited in Hanberry et al. 2012) and reforest hundreds of thousands of acres of degraded wetland areas (King et al. 2005, cited in Hanberry et al. 2012). Afforestation (establishing forest cover in areas having nonforest land cover) and reforestation (replanting forest after logging, fire, or storm damage) are management priorities for both DBWRNWR and Cache River NWR (USFWS 2009b, 2012). As of 2005, the estimated coverage of afforested land in the LMAV was approximately 479,000 acres. Deforestation has nearly halted and forest restoration is the dominant land use change in the LMAV, but remnant and ongoing effects of agricultural activities, altered hydrologic regimes and other factors continue to degrade forests (Gardiner and Oliver 2005).

4.7 Climate

4.7.1 Historical Climate

Climatic information presented in this WRIA comes from the U.S. Historical Climatology Network (USHCN) of monitoring sites maintained by the National Weather Service (NWS) (Menne et al. date unknown) and the PRISM (Parameter-elevation Regressions on Independent Slopes Model) climate mapping service, which is the U.S. Department of Agriculture's (USDA) official source of climatological data (PRISM 2010). The period of record for the USHCN data is 1895 – 2012, while the PRISM data represent 1971 – 2000 climatological normals. The closest USHCN station to DBWRNWR is in Rohwer, AR, approximately 15 miles south of the southern end of the refuge; however, an error with the web interface at the time of this writing rendered the data for this station irretrievable. The next closest USHCN station is located in Pine Bluff, AR, approximately 70 miles west of the refuge. For the PRISM location, a central point within the refuge was selected (34.312939, -91.081099) and used to access the PRISM Data Explorer. Figure 11 shows the locations of climate monitoring stations cited within this report.

4.7.1.1 Temperature

The climate of central and eastern Arkansas is mild and moderately humid with average monthly temperatures in the vicinity of the refuge ranging from approximately 43°F (6.1°C) to 82°F (27.8°C) (Figure 12). Mean monthly temperatures exhibit the greatest year-to-year variability in fall through early spring (October through March) and the least variability in the spring and summer (April through August) (Figure 12). The PRISM dataset shows average minimum and maximum temperatures in the vicinity of the refuge ranging from approximately 31°F (-0.6°C) in January to 92°F (33.3°C) in July (Table 5). Analysis of the average daily maximum, mean, and minimum temperature by water year reveals no apparent trends in minimum, mean and maximum annual temperature (Figure 13).

4.7.1.2 Precipitation

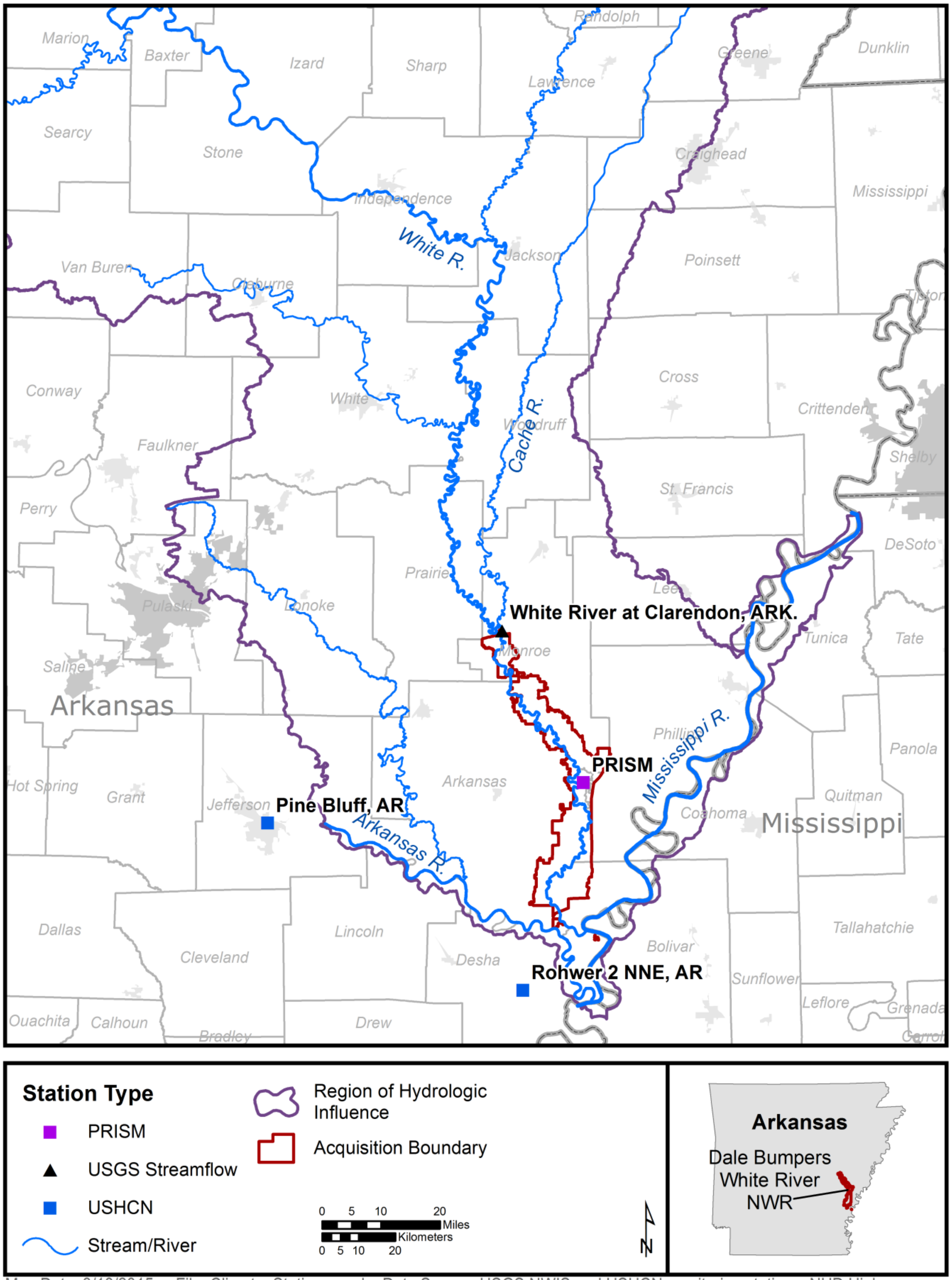
The region receives an average of approximately 50 inches of precipitation annually with mean monthly precipitation (from PRISM dataset) ranging from roughly 3 to 5 inches (7.6 to 12.7 centimeters [cm]) (Table 5, Figure 14). Precipitation is somewhat seasonal with nearly one-third of the annual rainfall occurring from March to May and less than one-fifth of the annual rainfall occurring from July to September (USFWS 2009b). March receives the greatest amount of precipitation at an average of 5.53 inches whereas August receives the least at an average of 2.33 inches (Table 5). Data suggest that from approximately 1901 to 1912 and from 1982 to 1993 the region experienced extended periods of above average precipitation, and from approximately 1962 to 1973 and 1994 to 2000 the region experienced extended periods of below average precipitation (drought periods) (Figure 15). Wet periods in which precipitation exceeded the average by ten inches in two consecutive years or two out of three consecutive years have occurred on seven occasions (1904-06, 1944-45, 1956-57, 1972-73, 1982-84, 1988-90, and 2007-8), while corresponding dry periods in which precipitation was ten or more inches below average have only occurred three times, in 1953-55, 1970-71, and 1975-76 (Figure 15). While short and extended periods at either extreme do occur throughout the period of record, there does not appear to be any obvious increasing or decreasing trends in annual precipitation.

Snowfall has been recorded at the USHCN station in Pine Bluff in December through March, with most occurring in January (Weather Warehouse date unknown).

Table 5. PRISM Monthly Normals (1971-2000) for precipitation and maximum and minimum temperature at DBWRNWR. [Source: PRISM 2010].

Month	Precipitation (In)	Max Temperature (F)	Min Temperature (F)
January	4.22	49.12	30.90
February	4.13	55.42	35.06
March	5.53	64.31	43.32
April	5.44	73.26	51.08
May	5.05	81.10	60.31
June	4.22	88.79	68.20
July	3.71	92.35	71.71
August	2.33	91.49	69.64
September	3.05	85.71	62.80
October	3.80	75.87	51.24
November	5.40	62.78	41.94
December	5.04	52.84	34.29
Total Precipitation	**50.5**		
Mean Temperature		**72.75**	**51.71**

1971-2000 Normals for -91.081099, 34.312939. Downloaded 6/19/13 from http://prismmap.nacse.org/nn/. Copyright 2010. PRISM Climate Group, Oregon State University.



Map Date: 3/18/2015 File: Climate_Stations.mxd Data Source: USGS NWIS and USHCN monitoring stations, NHD High Resolution Flowlines, ESRI Topo Service.

Figure 11. Climate monitoring data locations near Dale Bumpers White River National Wildlife Refuge. Stations are identified by agency-given name.

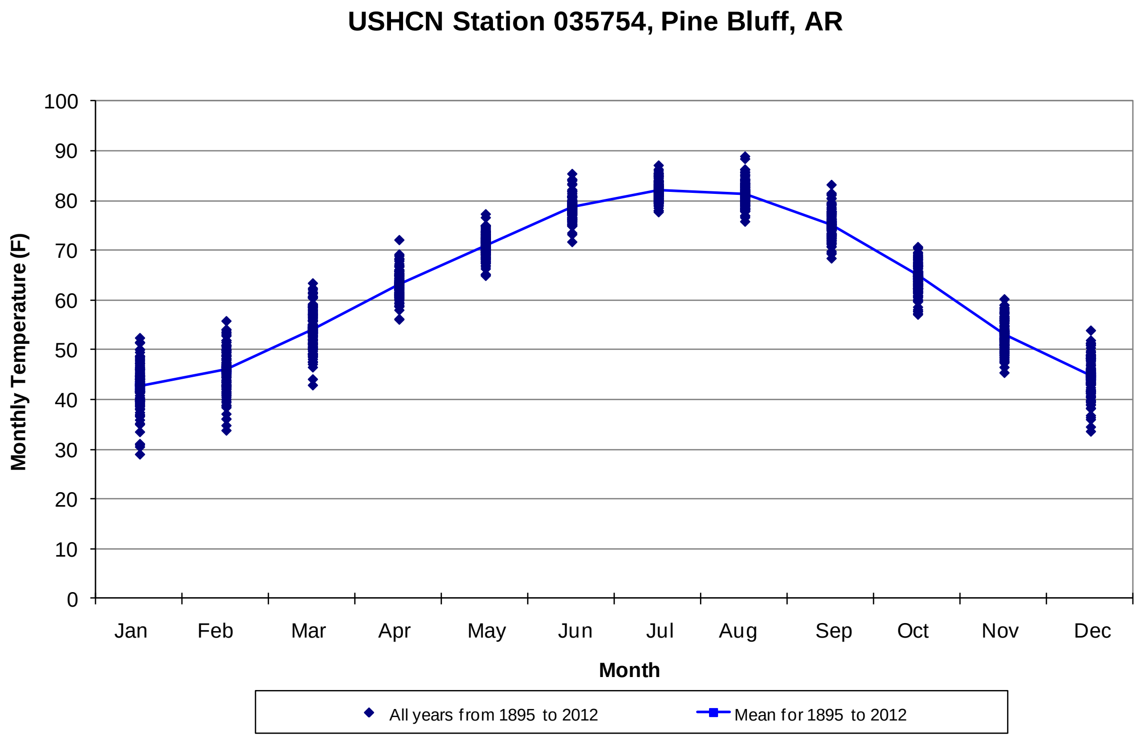


Figure 12. Mean and distribution of monthly temperature for 1895 – 2012 for USHCN Station 035754 at Pine Bluff, AR. [Source: Menne et al. date unknown].

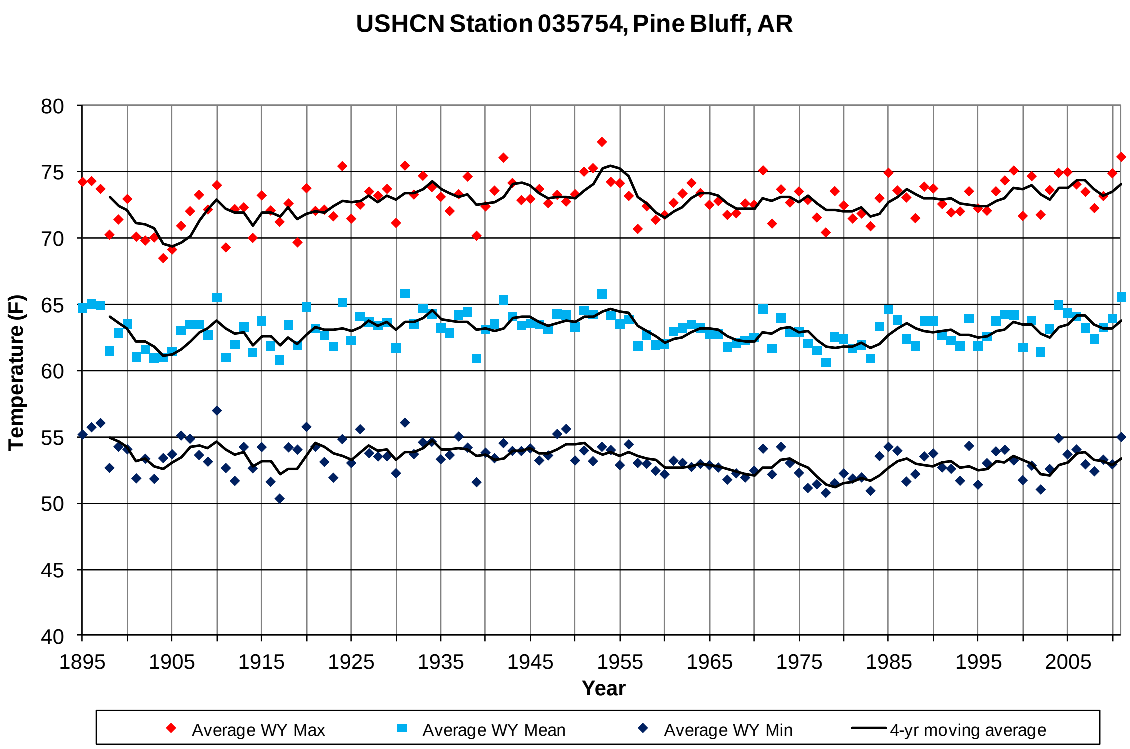


Figure 13. Average daily maximum, mean, and minimum temperature by water year (1895 – 2012) at Pine Bluff, AR (USHCN Station 035754). [Source: Menne et al. date unknown].

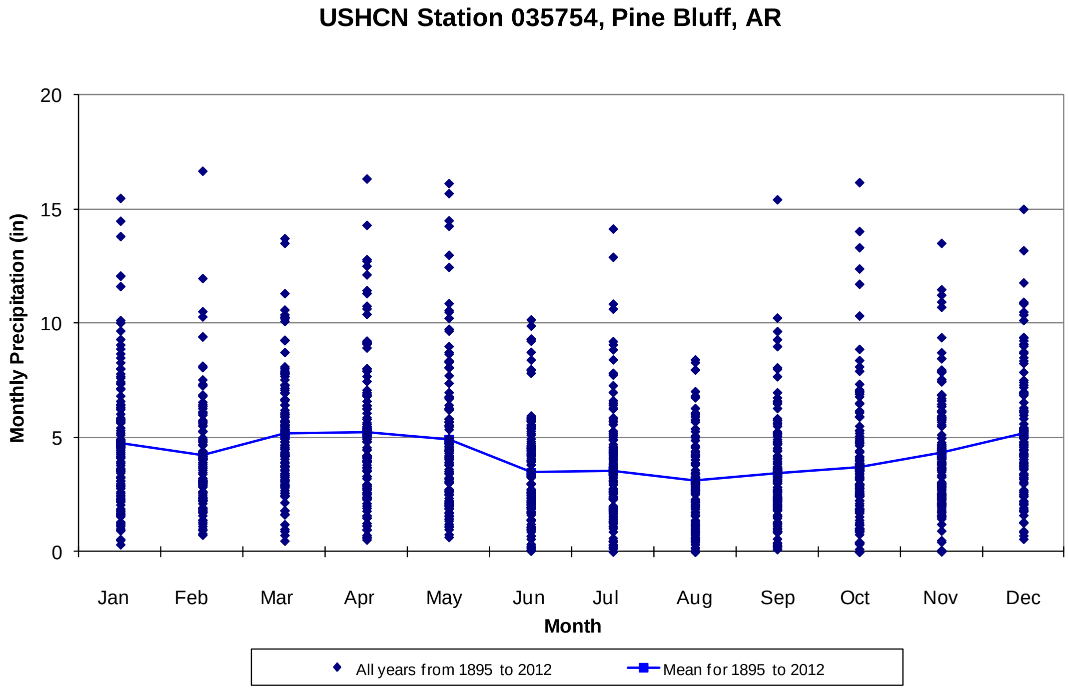


Figure 14. Mean and distribution of monthly precipitation for 1895 – 2012 for USHCN Station 035754 at Pine Bluff, AR. [Source: Menne et al. undated].

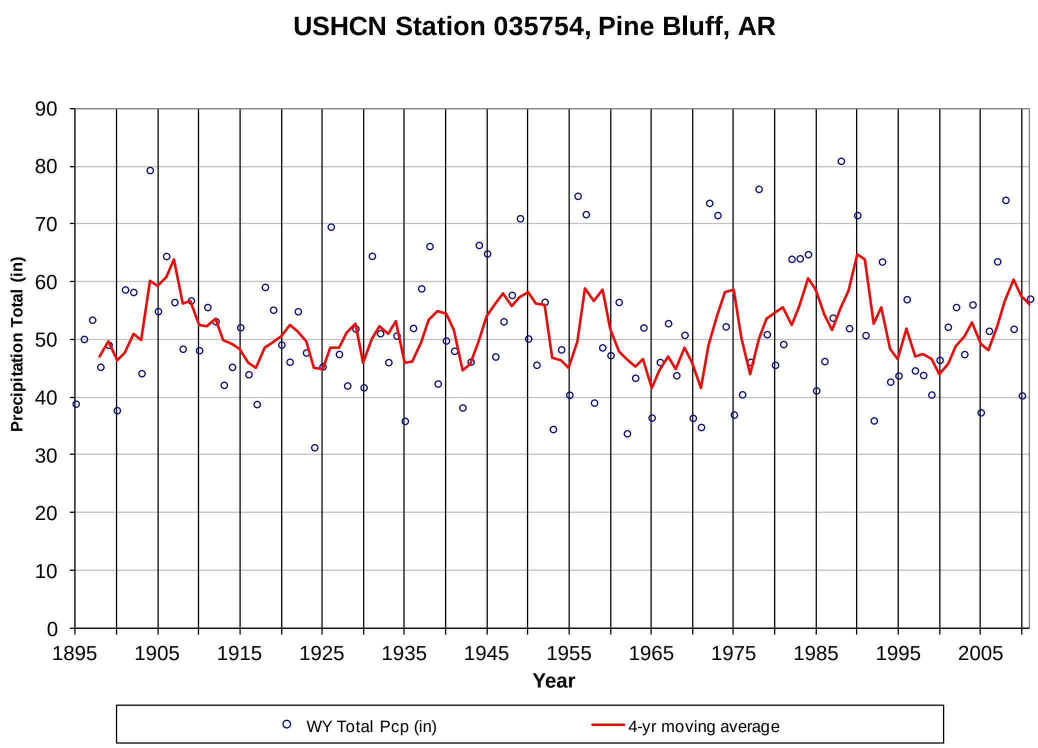


Figure 15. Total annual precipitation by water year (1895 – 2011) at Pine Bluff, AR (USHCN Station 035754). [Source: Menne et al. undated].

4.7.1.3 Streamflow

Within the White River Basin, streamflow is linked to precipitation, as well as upstream surface water flows and groundwater contributions. Information related to water quantity conditions within the White River is presented in the water quantity section later in this document (Section 5.4). General trends for the Lower White River, based on the U.S. Geological Survey (USGS) gage at Clarendon, AR (07077800) are summarized for the period of record (1928 – 1981) in Figure 16 and Figure 17. The average annual discharge over the period of record is 29,617 cfs. The average monthly discharge is highest between January and June and lowest between July and December. The average monthly discharge peaks in April whereas the month with the lowest average discharge is October. Streamflow on the White River at Clarendon is highly variable. Notable departures from the long-term average streamflow include above-average flows in 1949 – 1952 and 1973 - 1975, and below-average flows in 1953 - 1956, 1962 – 1967, and 1970 - 1972 (Figure 17). While short and extended periods of above and below the average discharge did occur throughout the period of record, there are no apparent trends in the average annual discharge. The effects of upstream dam construction and other anthropogenic modifications on streamflow are discussed in section 5.4.

4.7.1.4 Drought Conditions

According to USGS (1991), Arkansas has never had a major drought that significantly lowered water levels in deep regional aquifers. In contrast, shallow aquifers in the western and southeastern (e.g., alluvial aquifer) parts of the state have experienced significant declines during drought periods. State-wide, moderate intensity (recurrence interval of 10 to >25 years) droughts occurred in 1954 – 1956, 1963 – 1967 and 1970 – 1972 (USGS 1991). These periods are reflected in the water year precipitation patterns in Figure 15 and the streamflow patterns in (Figure 17). More recently, Arkansas experienced severe to exceptional (D2 to D4) drought conditions in the summer of 2012, during one of the most severe droughts in U.S. history, with devastating impacts to field crops and cattle production. The entire state was designated as a primary natural disaster area by the USDA (Kemper et al. date unknown). The drought was mitigated by the use of irrigation, which is used for a large percentage of field crops in Arkansas (Kemper et al. date unknown); however, overpumping of groundwater for irrigation during droughts can cause significant water level declines, as occurred during the early 1980s drought in northern Arkansas (USGS 1991). During the summer of 2012 the White River stage at Clarendon dropped to its lowest point in August (8.32 feet NGVD29) (USACE undated-a).

4.7.1.5 Storm Frequency and Intensity

Storm frequencies, intensities and duration greatly influence the hydrology within Arkansas and, more specifically, within the White River basin. Subsequently, these storm related issues lead to seasonal flooding and continuously variable hydrological regimes within the White River and on the refuge. Flooding in Arkansas is generally widespread in winter, where it lasts for several weeks, whereas spring flooding is generally local and of long duration. The timing of spring flooding varies from year to year, but typically occurs between January and July with a small break in March. Tropical storms and remnants from hurricanes occasionally move northward from the Gulf of Mexico, bringing large quantities of precipitation and producing floods. State-wide, a major flood (recurrence interval of 10 to >100 years) occurred in 1927 (Section 5.4.4) (USGS 1991) at which time the White River at Clarendon, AR, reached its highest recorded stage of 43.3 feet NGVD29; flood stage is 26 feet. Other major floods (recurrence interval of 25 to 100 years) occurred in 1973, 1974, 1978 and 1987 in the vicinity of

DBWRNWR (USGS 1991). More recently, substantial floods occurred on the White River in 2008 and 2011. The White River stage at Clarendon reached 33.73 feet NGVD29 in April 2008, which was the highest stage since the flood of 1973, when the flood stage crested at 34.9 feet (USACE undated-a). The St. Charles gage reached 34.57 feet in April 2008 (Ron Hollis, USFWS, written communication, November 27, 2013). In 2011, late spring runoff and record snowmelt from the Upper Mississippi River Valley, combined with heavy precipitation, led to record floods throughout most of Arkansas in April and May. Pine Bluff, AR received 14.21 inches of rainfall in April 2011, 292% of normal April precipitation (Westerman et al. 2013). The White River stage at Clarendon peaked at 37.47 feet NGVD29 in May 2011, the highest recorded stage height since the 1927 flood (USACE undated-a). This corresponds to a recurrence interval greater than 50 years. In the 2011 flood the White River stage at St. Charles reached 39.99 feet in May, which was the third highest on record since the flood of 1927 (Ron Hollis, USFWS, written communication, November 27, 2013).

Arkansas is also characterized by tornado activity. From 1950 – 2012, there were a total of 2,023 tornadoes reported in the state, with 109 tornadoes reported in the counties encompassing DBWRNWR (NOAA undated-a). Peak tornado occurrence in Arkansas from 1950 to 1991 occurred in March through May (NOAA undated-b). On July 30, 2009 an EF-4 tornado destroyed approximately 1,750 acres of BLH forest on the refuge (Ron Hollis, USFWS, written communication, November 27, 2013).

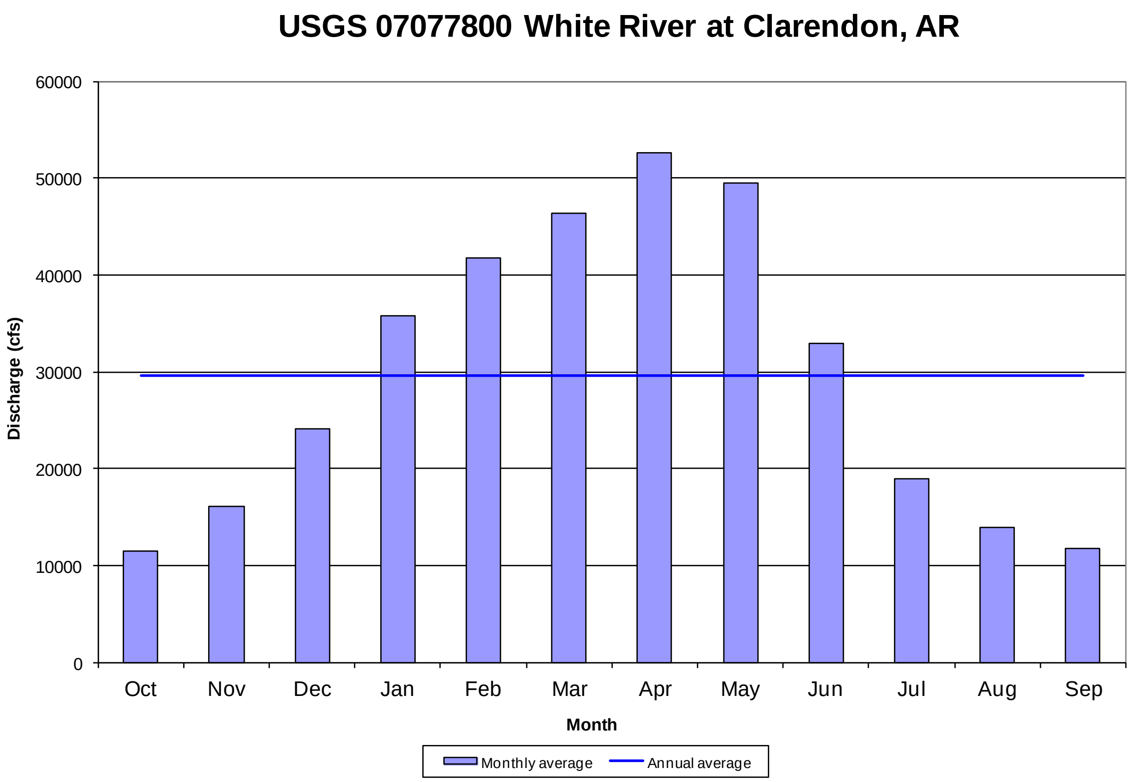


Figure 16. Average monthly discharge from the White River at Clarendon, AR. From data collected between 1929 – 1981 and 1993. [Source: USGS 2013a].

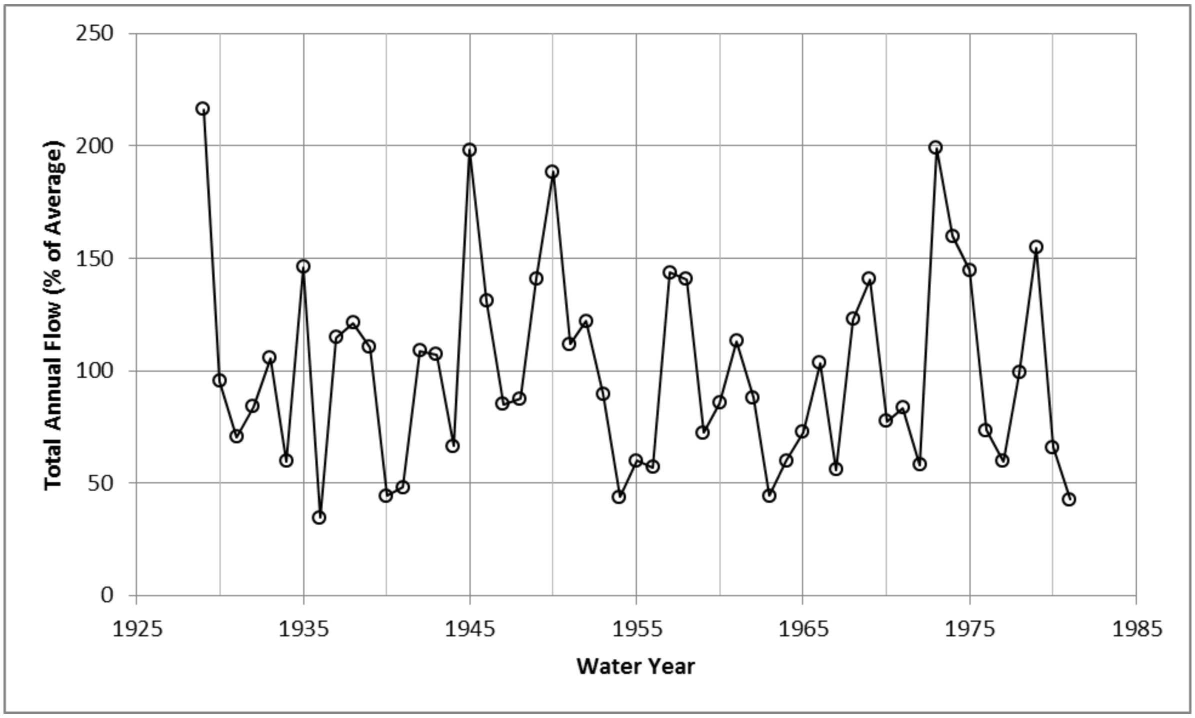


Figure 17. Percent of average annual flow on White River at Clarendon, AR: 1929 - 1981. Average annual flow from the period of record is 29,617 cubic feet per second (cfs). 1 cfs = 448.8 gallons per minute. [Source: USGS 2013a].

4.7.2 Climate Change Projections

The Climate of the Southeast United States: Variability, Change, Impacts, and Vulnerability (Ingram et al. 2013) synthesized a large body of scientific information composed of numerous peer-reviewed scientific assessments. Climate models project continued warming in the southeastern United States, and an increase in the rate of warming through 2100. By the end of the 21st century, the interior of the region is projected to warm by as much as 9°F, with the greatest temperature increases projected to occur in the summer and maximum temperatures exceeding 95°F are expected to increase across the Southeast (Ingram et al. 2013). In eastern Arkansas, the number of days per year with a peak temperature over 90°F is expected to double, from an average of around 60 days to more than 150 days by 2080 (Karl et al. 2009).

Spatial and temporal changes in temperature and rainfall patterns will add substantial complexity to management planning on DBWRNWR. In the eastern United States, documented seasonal warming patterns, extended growing seasons, high spring stream flow, decreases in snow depth, and increased drought frequency are projected to continue (Scott et al. 2008). Although the specific impacts climate change will have on the White River system are not known, these regional changes to the quantity and timing of available water are likely to magnify the influences of other identified threats and challenges currently impacting the system.

4.7.2.1 Temperature

The southeast U.S. has not exhibited an overall warming trend in surface temperature since the beginning of the 20th century (IPCC 2007). Annual and seasonal temperatures across the region exhibited much variability over the first half of the 20th century, although most years were above the long-term average (since 1895) (Ingram et al. 2013). This was followed by a cooling period in the 1960s and 1970s. Since then, temperatures have steadily increased, with the most recent decade (2001 to 2010) being the warmest on record (Ingram et al. 2013, NOAA 2013). Seasonal temperature increases by the middle of the 21st century, relative to a 1971-2000 baseline, are projected to be greatest in the summer and least in the spring. In the vicinity of the refuge, summer temperatures are projected to increase by 5.5 - 6.0°C (9.9 - 10.8°F), fall temperatures by 4.5 - 5.0°C (8.1 - 9.0°F), winter temperatures by 3.5 - 4.0°C (6.3 - 7.2°F), and spring temperatures by 2.5 - 3.0°C (4.5 - 5.4°F) (Figure 2.11 in Ingram et al., 2013). The frequency of maximum temperatures exceeding 95°F has been increasing during the 20th and early 21st centuries in the vicinity of the refuge, and the frequency of these extreme heat days is projected to increase by 25 to 30 days per year by the middle of the 21st century (2041 - 2070) relative to a 1980 - 2000 baseline (Ingram et al. 2013). The frequency of minimum temperatures exceeding 75°F has also generally been increasing across most of the Southeast, although DeGaetano and Allen (2002) have attributed this trend to increasing urbanization.

By the last decade of the 21st century, global average surface temperature is projected to rise by 2.8°C (5.0°F) with a likely range of 1.7 - 4.4°C (3.0 - 7.9°F) under the A1B (moderate) emissions scenario and 3.4°C (6.1°F) and a likely range of 2.0 - 5.4°C (3.6 - 9.7°F) under the A2 (high) emissions scenario relative to a 1980 - 1999 baseline (IPCC 2007). Based on the ensemble average of downscaled projections from 15 climate models obtained via the Climate Wizard website (Girvetz et al. 2009), the increase in estimated annual temperature for the same period for the Lower White River Basin under the A2 scenario is about 2°C (3.6°F), with summer temperatures increasing by 0.3 to 0.7°C (0.5 to 1.3°F) more than winter, spring and fall temperatures (Figure 18a). While individual model predictions vary, they generally show the same seasonal pattern and agree fairly closely on the magnitude of the overall increase in mean temperature, with a range of about 0.9°C (1.6°F) between the 10th and 90th percentile model predictions for mean annual temperature increase and 0.9 to 1.9°C (1.6 to 3.4°F) for seasonal mean temperature increases.

4.7.2.2 Precipitation

Inter-annual variability in precipitation has increased over the last several decades across much of the Southeast, with more exceptionally wet and dry summers observed as compared to the middle part of the 20th century (Groisman and Knight 2008; Wang et al. 2010; NOAA 2013). This precipitation variability is related to the mean positioning of the Bermuda High, a semi-permanent high pressure system typically situated off of the Atlantic Coast (NOAA 2013).

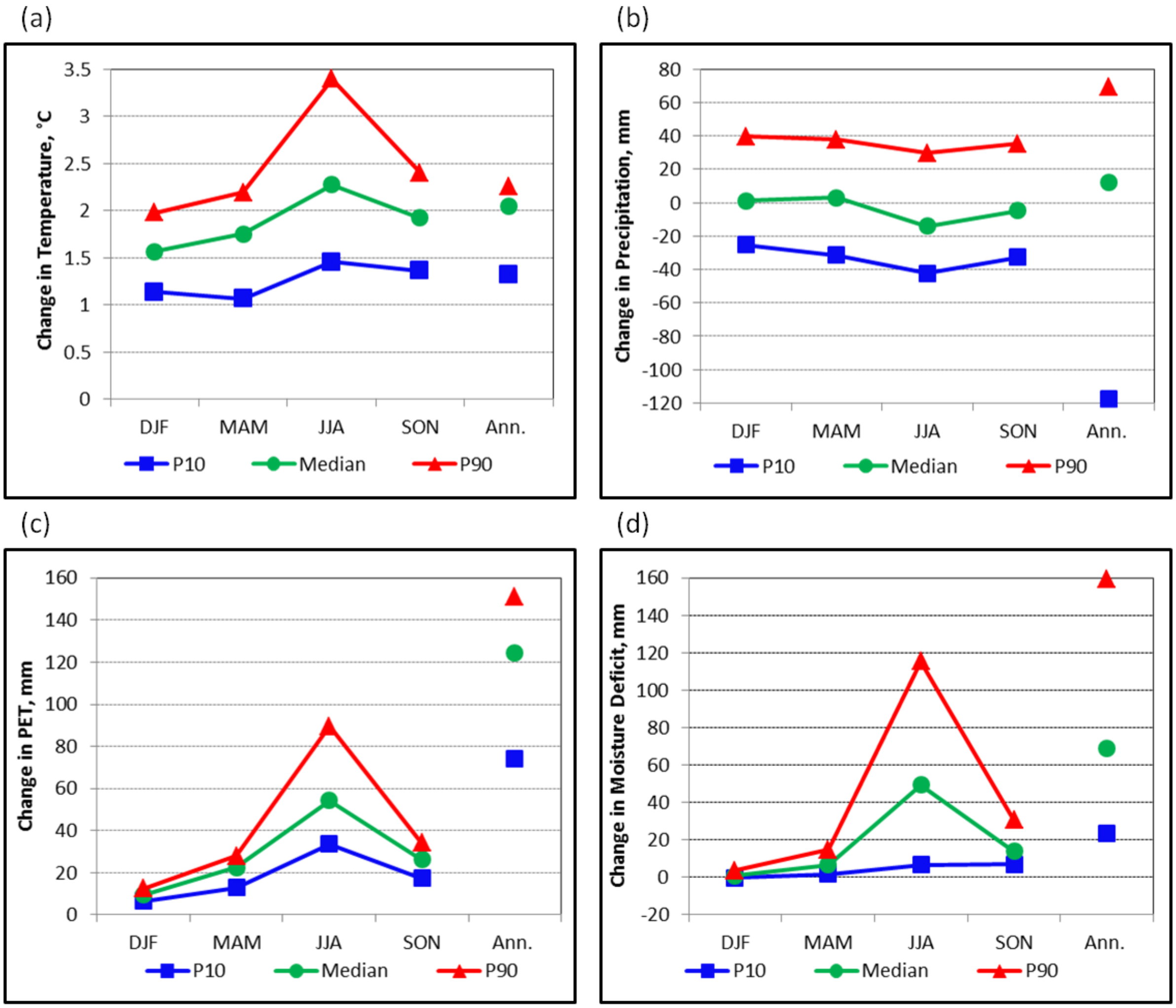


Figure 18. Ensemble downscaled climate model projections for the Lower White River Basin under the A2 (high) emissions scenario. Plots show predicted changes in 30-year mean for selected annual and seasonal climate metrics for the period 2071-2100 vs. 1961-1990: (a) Mean air temperature, (b) total precipitation, (c) potential evapotranspiration (PET), and (d) climatic moisture deficit (a measure of moisture stress; see text for details). In each panel, the green line shows the median value of 15 climate model projections, while the blue and red lines show the 10th and 90th percentile values, respectively. Abbreviations: P10/P90 – 10th and 90th percentile model predictions, respectively; DJF – Dec-Jan-Feb; MAM – Mar-Apr-May; JJA – Jun-Jul-Aug; SON – Sep-Oct-Nov. [Source: Girvetz et al. 2009: Climate Wizard Custom (http://climatewizardcustom.org)].

As summarized by Karl et al. (2009), CCSP (2008), Ingram et al. (2013), and NOAA (2013), changes in annual precipitation for the Southeast do not exhibit any strong trends, although projections for the near-term (present day to 2040) show notable seasonal variations, with a decrease in precipitation during summer months, and an increase in the fall (1-2%). It should be noted that there is considerable disagreement between the various climate models on the magnitude and direction of changes in precipitation, and that none of the CMIP3 (Coupled Model Intercomparison Project phase 3) climate models reproduced the observed 30% increase in decadal mean fall precipitation (relative to a 1901 –

1960 average) in the Southeast (Karl et al. 2009; NOAA 2013: Figure 46). For future time periods (2021 – 2050; 2040 – 2070; 2070 – 2099) for both low (B1) and high (A2) emissions scenarios simulate both increases and decreases in annual mean precipitation. The inter-model range of changes in precipitation (i.e., the difference between the highest and lowest model values) varies from 14% to 34% (NOAA 2013).

The lack of model agreement on precipitation predictions is also demonstrated by the Climate Wizard results for the Lower White River Basin (Figure 18b). The median prediction is for a modest increase of just under 12 millimeters (mm) or 0.5 inch (in) annually, 0.9% of the current normal annual precipitation total (50 in or 1270 mm; Table 5), but the predictions range from a decrease of nearly 120 mm (4.7 in) to an increase of nearly 70 mm (2.8 in) (Figure 18b).

4.7.2.3 Evapotranspiration

Potential evapotranspiration (PET) is predicted to increase by 73 - 151 mm (2.9 - 5.9 in) annually due to increased temperatures, with the bulk of the increase, 34 - 90 mm (1.3 - 3.5 in), occurring in the summer months (Figure 18c), which could lead to increased moisture stress for plants and decreased water availability for management of the refuge's impoundments during the summer and fall. Climatic moisture deficit, a metric quantifying potential moisture stress (calculated as monthly PET minus precipitation, with a value of zero for months where precipitation is greater than PET) is predicted to increase by 23 to 159 mm (0.5 to 6.3 in) annually, with the largest increase, 6 to 115 mm (0.2 to 4.5 in), during the summer months (Figure 18d), but the range of predicted values is large due to the divergent model predictions for precipitation.

4.7.2.4 Storm Severity

The frequency of extreme precipitation events has been increasing across the Southeast, particularly over the past two decades. Increases in extreme precipitation events have been most pronounced in the lower Mississippi River Valley (i.e., the vicinity of the refuge) and along the northern Gulf Coast (Ingram et al. 2013, NOAA 2013). This trend in more intense precipitation events is also seen in other places around the world (IPCC 2007), and may be tied to a warming atmosphere which has a greater capacity to hold water vapor, therefore producing higher rates of precipitation (NOAA 2013). The increase in extreme precipitation, coupled with increased runoff due to the expansion of impervious surfaces and urbanization, has led to an increased risk of flooding in urban areas of the region (Shepherd et al. 2011; NOAA 2013). Across the Southeast, for all regional climate model simulations and emissions scenarios, the average annual number of days with precipitation exceeding 1 inch increases, with the largest increases across the Appalachian Mountains (NOAA 2013).

Increases in storm severity will exacerbate existing problems caused by runoff from nearby agricultural lands. Increased run off leads to unnaturally high peak flows and velocities, decreasing the stability of the sand and gravel substrates that many species of mussels and fishes depend on. Any additional increases in runoff from a climate change-based increase in storm severity would cause additional scouring and river bank deterioration, along with impacts from nonpoint source pollution and sedimentation. However, despite the long-term increase in extreme precipitation events, there has so far been no discernible trend in the magnitude of floods along unregulated ex-urban streams in the region (Ingram et al. 2013).

4.7.2.5 Impacts to Wetlands and Waterfowl Species

Migrations supported by refuges may become asynchronous with changing seasons, native and non-native invasive species will likely extend their range, and vegetation types may shift to plant communities that are inappropriate for refuge trust species (Scott et al. 2008). Changes in the migration patterns of waterfowl could have a significant impact on how refuges manage their woodlands and water resources throughout the year. In an unpublished analysis of waterfowl inventory data, climate data, crop production data and other related factors, Dr. Jim Bednarz and his team found that warmer winters equated to more ducks in northern states (Minnesota, Illinois, Iowa and Ohio) and fewer ducks in southern states, including Arkansas. Warmer winters could create the conditions ducks need (ice-free wetlands and plenty of food) in northern states, such that they would not need to migrate south (Strickland 2011). Additionally, untimely flooding could change flood zones in bottomland forests, affecting tree regeneration and survival, as well as waterfowl populations (Browne and Humburg 2010).

5 Inventory Summary and Discussion

This section briefly summarizes and discusses important aspects of the water resources inventory (both surface water and groundwater) for DBWRNWR, including important physical water resources, water resources related infrastructure and monitoring, water quantity, and water quality conditions. Water resource links, including streamflow and groundwater data and relevant water resource reports for the Lower White subbasin (HUC 08020303) (and the other subbasins in the RHI), are available from the USGS.

5.1 Water Resources

5.1.1 Rivers/Streams/Creeks

An inventory of named streams was compiled from the National Hydrography High-Resolution (1:24000) Dataset (NHD) for the RHI, using the flowline feature dataset. The RHI for the DBWRNWR includes a total of 71,689 miles of streams; these include 18,923 miles of named streams and 52,766 miles of unnamed streams (USGS 2013b). Within a 0.5 mile buffer of the refuge acquisition boundary, there are 42 named streams, totaling 263.2 miles, as well as 602.4 miles of unnamed streams (Table 6, Figure 19a and 19b). The White River flows through the area encompassed within the refuge acquisition boundary for 94.5 miles.

5.1.2 Canals and Drainage Ditches

The NHD includes an additional 78.3 miles of canals and drainage ditches within the RHI for the DBWRNWR, including 11.2 miles within a 0.5 mile buffer of the refuge acquisition boundary (USGS 2013b; Figure 19a and 19b). This includes 1.4 miles of the Arkansas Post Canal (Section 5.4.3), which is classified as a named artificial path in the NHD, rather than a canal. The actual length of the Arkansas Post Canal within the refuge boundaries is more than five miles; however, most of the line segments representing canal boundaries within the NHD are unnamed (Figure 19b).

Table 6. National Hydrography Dataset (NHD) named streams with mileage within 0.5 mile of Dale Bumpers White River National Wildlife Refuge acquisition boundary [Source: USGS 2013b].

Name	Miles within 0.5 mile buffer of acquisition boundary	Name	Miles within 0.5 mile buffer of acquisition boundary
(unnamed)	*602.4*	Little Cypress Bayou	0.3
Arkansas River	1.6	Little Island Bayou	4.2
Bass Creek	6.3	Maddox Bay	11.1
Bee Bayou	1.5	McPete Branch	1.7
Bell Gully	4.2	Menard Bayou	1.3
Big Creek	15.0	Mild Ditch	0.1
Big Cypress Creek	1.8	Mill Bayou	1.1
Boat Gunwale Slash	1.0	Montgomery Cutoff	2.3
Caney Bayou	2.2	Panther Branch	4.9
Cocklebur Slough	0.8	Poplar Creek	3.7
Dawson Slough	2.0	Prairie Cypress Creek	3.5
Deep Bayou	2.9	Roc Roe Bayou	5.7
Dial Creek	3.4	Sandy Bayou	3.1
East Bayou	4.3	Scrubgrass Bayou	7.7
Essex Bayou	18.7	Sixmile Bayou	3.5
Green Bayou	2.9	Tarleton Creek	2.8
Hill Bayou	2.6	Tipsy Branch	0.3
Honey Locust Bayou	6.1	Twin Slough	4.5
Indian Bay	6.8	Walker Cypress Creek	4.6
Indian Bayou	8.5	White River	94.5
Jessie Slough	0.1	Wildhorse Bayou	0.7
La Grue Bayou	9.3	***Total***	***865.6***

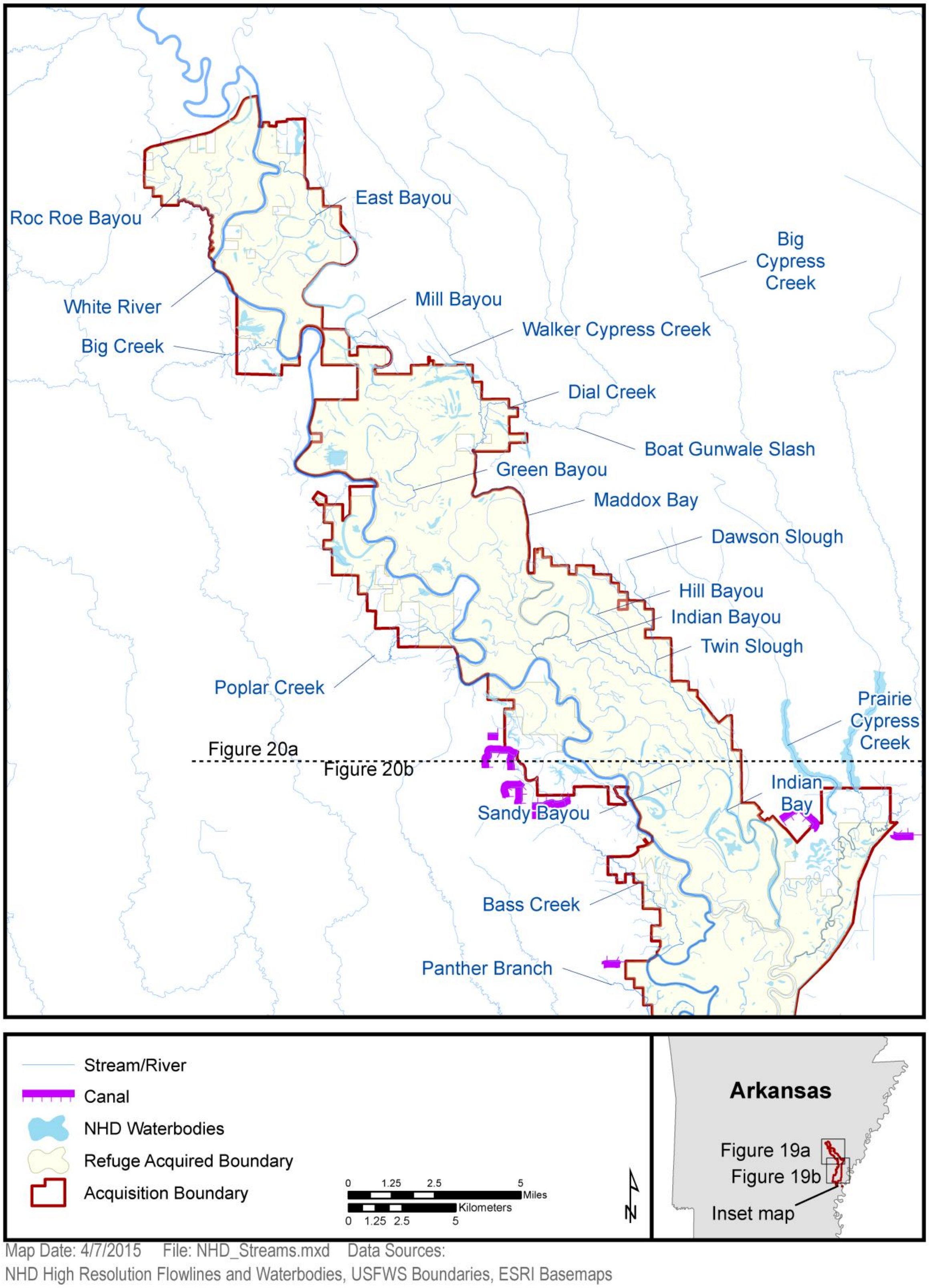
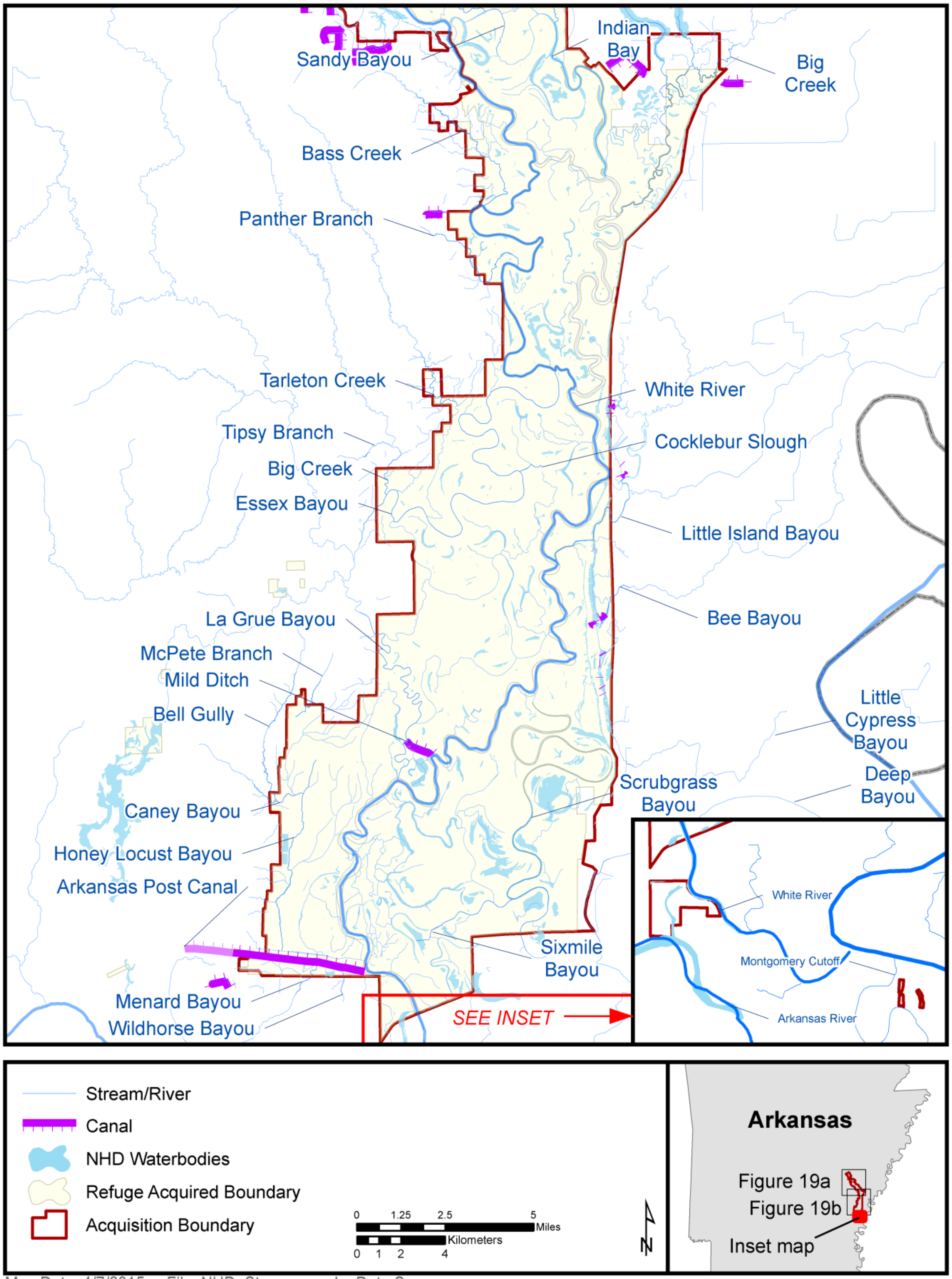


Figure 19a. National Hydrography Dataset (NHD) streams with mileage inside the Northern Unit of the Dale Bumpers White River National Wildlife Refuge acquisition boundary.



Map Date: 4/7/2015 File: NHD_Streams.mxd Data Sources:
NHD High Resolution Flowlines and Waterbodies, USFWS Boundaries, ESRI Basemaps

Figure 19b. National Hydrography Dataset (NHD) streams with mileage inside the Southern Unit of the Dale Bumpers White River National Wildlife Refuge acquisition boundary.

5.1.3 Lakes/Ponds

As inventoried by the NHD, there are a total of 197,785 acres of unnamed lakes/ponds and 225,642 acres of named lakes/ponds within the RHI. Within the refuge acquisition boundary, the NHD contains 10,223 acres of named and unnamed lakes/ponds including 30 named features; 9,202 acres fall within acquired lands (Table 7, Figure 20a and 20b). Refuge staff have indicated that the NHD does not capture many local names for the lakes/ponds found on the refuge, and may under represent the total acreage of lakes and ponds. According to the CCP, the refuge contains 356 natural lakes, sloughs and ponds which are intricately and hydrologically connected with the White River (USFWS 2012). It may not be possible to develop a complete inventory of these features without comprehensive LiDAR for the refuge area. All of the lakes are dependent on overflow conditions from the White and Mississippi Rivers, and approximately one-third dry during drought conditions (USFWS 2009a).

The refuge is also affected by operation of the flood control lakes on the upper White River and its tributaries (i.e., Beaver, Table Rock, Bull Shoals, Norfork, Greers Ferry and Clearwater Lakes) which are managed by the Corps (USACE 1998; also see section 5.4.3). This system can regulate flows on the White River by "desynchronizing" flows and storing water to be distributed over the course of the year (decreasing peak winter/spring flows and increasing summer flows), but its influence decreases as distance downstream increases (USFWS 2012).

5.1.4 Springs and Seeps

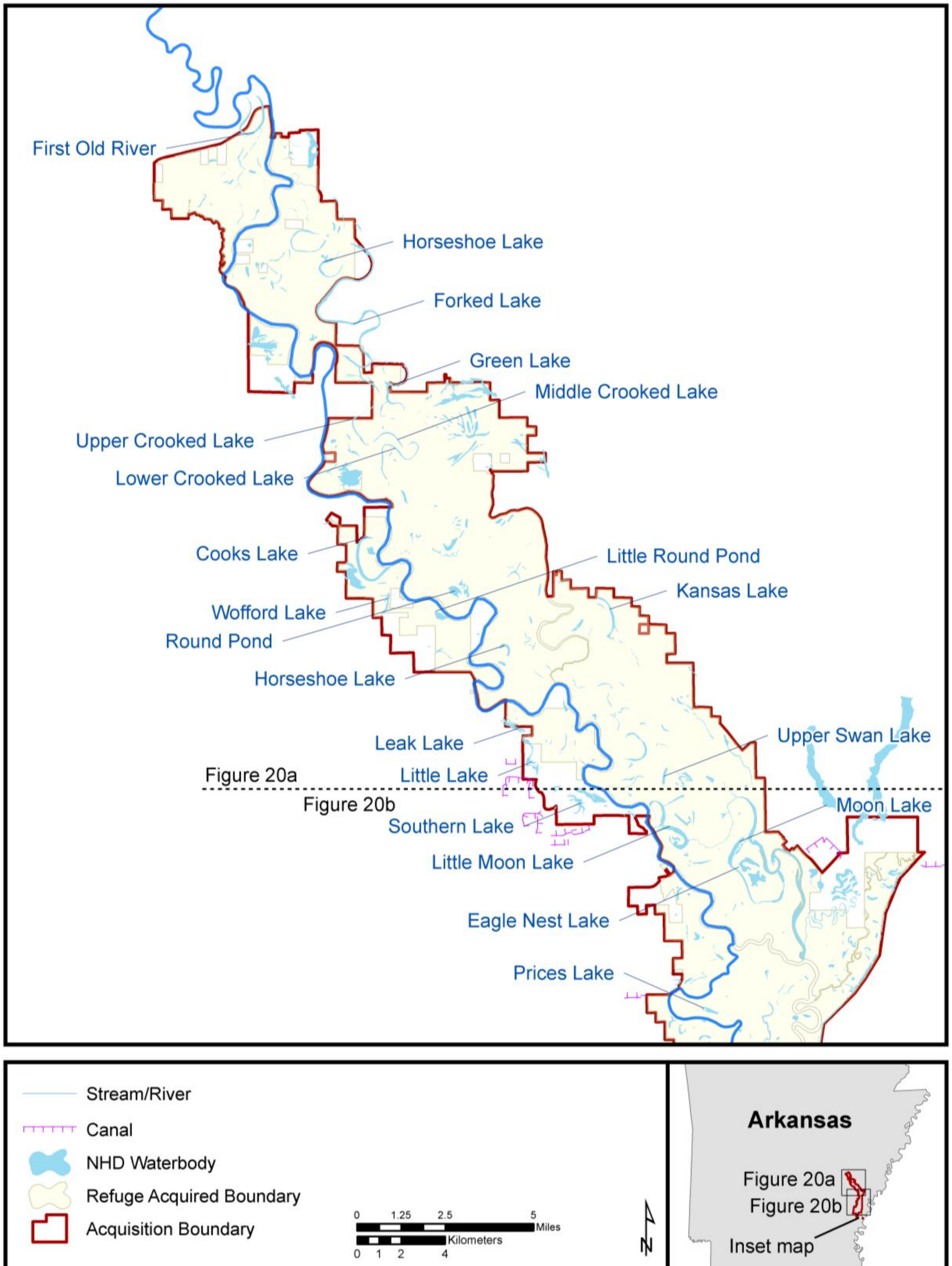
There are no springs within the refuge acquisition boundary; however, springs are abundant in the Upper White Basin, particularly within the Salem and Springfield Plateau sections of the Ozark Plateaus physiographic province. Large springs with discharges exceeding 100 cfs (i.e., first-magnitude springs) are common in some areas of the Salem Plateau (Imes and Smith 1990, cited in Adamski et al. 1995). Interaction between surface and groundwater is relatively high in the Salem and Springfield Plateaus; streams have relatively flat flow-duration curves, indicating well-sustained flow from surface or groundwater storage (Hedman et al. 1987, cited in Adamski et al. 1995). Losing streams (streams that recharge the groundwater system) are also present in this region. There is moderate surface-groundwater interaction in portions of the MAV. Water levels at some locations within the alluvial aquifer are known to fluctuate with streamflow (Albin et al. 1967; Lamonds et al. 1972, cited in Adamski et al. 1995; shown in Figure 31). Within the counties encompassing the refuge, springs were known to occur near the towns of DeWitt (La Grue and Cold springs) in Arkansas County and Helena (Big Springs) in Phillips County (AGS 1937). However, these springs are not inventoried in the NHD, and their current status is unknown.

Table 7. Acres of National Hydrography Dataset (NHD) named and unnamed lakes/ponds within refuge acquisition and acquired boundaries. [Source: USGS 2013b].

Name	**Acres within acquisition boundary**	**Acres within acquired boundary**
*(unnamed)**	*8484*	*7564*
Alligator Lake	40	40
Big Horseshoe Lake	38	38
Big White Lake	27	27
Columbus Lake	25	25
Dismal Swamp	0*	190**
Dry Lake	57	57
East Moon Lake	106	106
Escronges Lake	56	56
Goose Lake	82	82
H Lake	62	62
Hole in the Wall Lake	1	1
Lake Bayou	49	30
Little Moon Lake	20	20
Long Lake	60	60
Lower Taylor Lake	31	31
Lower White Lake	37	37
Moon Lake	116	116
Moon Lakes	32	32
Oxbow Lake	48	48
Paradise Bayou	44	44
Parish Lake	96	96
Prairie Lake	67	67
Prices Lake	25	25
Sandy Slough	73	63
Southern Lake	0	0
Swan Lake	95	95
Upper Taylor Lake	18	18
Waters Bayou	407	145
White Lake	21	21
Yancopin Lake	6	6
Total	***10223***	***9202***

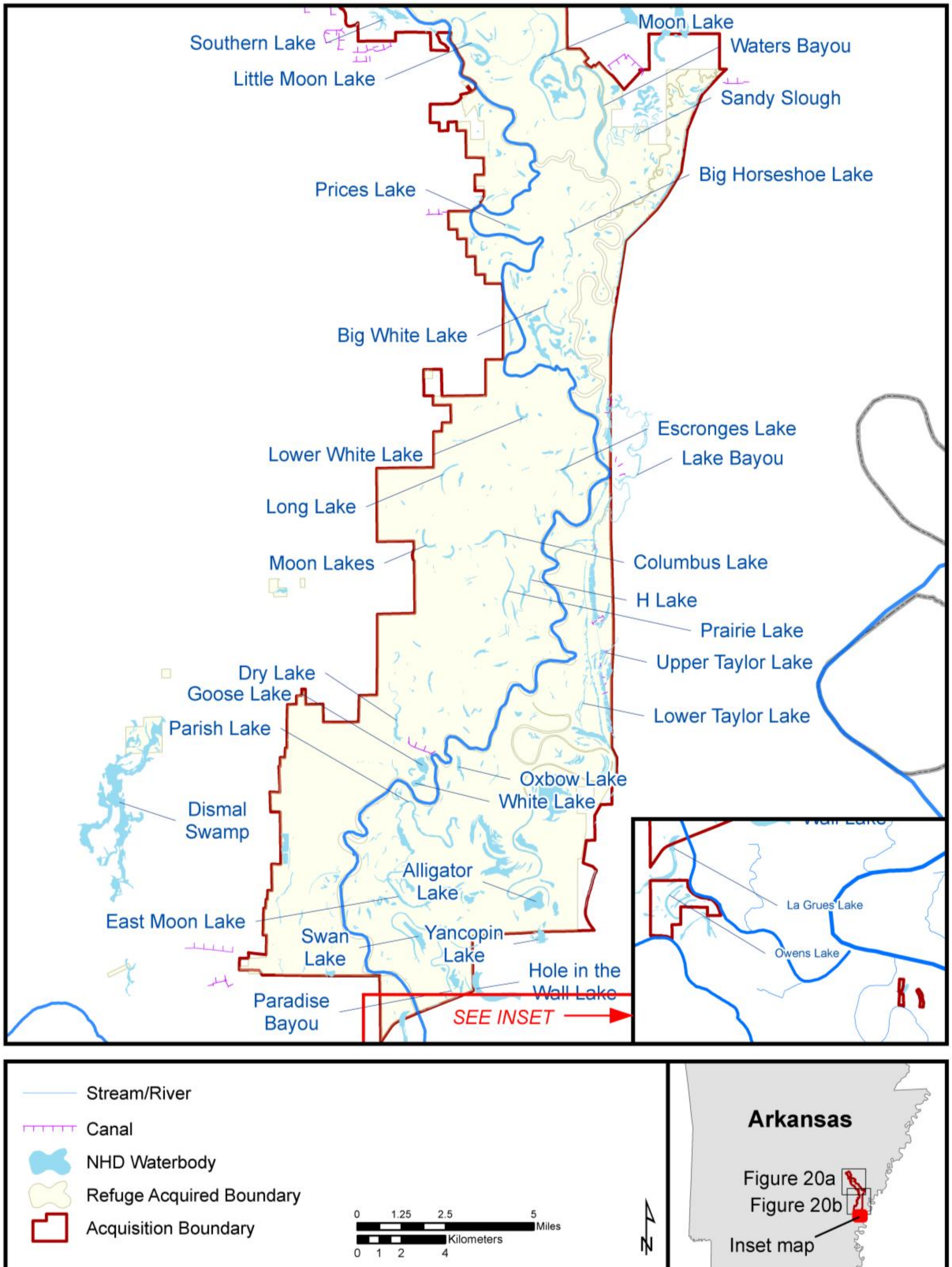
* The NHD does not capture many local names for waterbodies

** Dismal Swamp is located on a small portion of acquired refuge land that is outside the formal Dale Bumpers National Wildlife Refuge acquisition boundary.



Map Date: 4/7/2015 File: NHD_Waterbodies.mxd Data Sources:
NHD High Resolution Flowlines and Waterbodies, USFWS Boundaries, ESRI Basemaps

Figure 20a. National Hydrography Dataset (NHD) named and unnamed lakes/ponds within the Northern Unit of the Dale Bumpers White River National Wildlife Refuge acquisition boundary.



Map Date: 4/7/2015 File: NHD_Waterbodies.mxd Data Sources:
NHD High Resolution Flowlines and Waterbodies, USFWS Boundaries, ESRI Basemaps

Figure 20b. National Hydrography Dataset (NHD) named and unnamed lakes/ponds within the Southern Unit of the Dale Bumpers White River National Wildlife Refuge acquisition boundary.

5.1.5 Wetlands

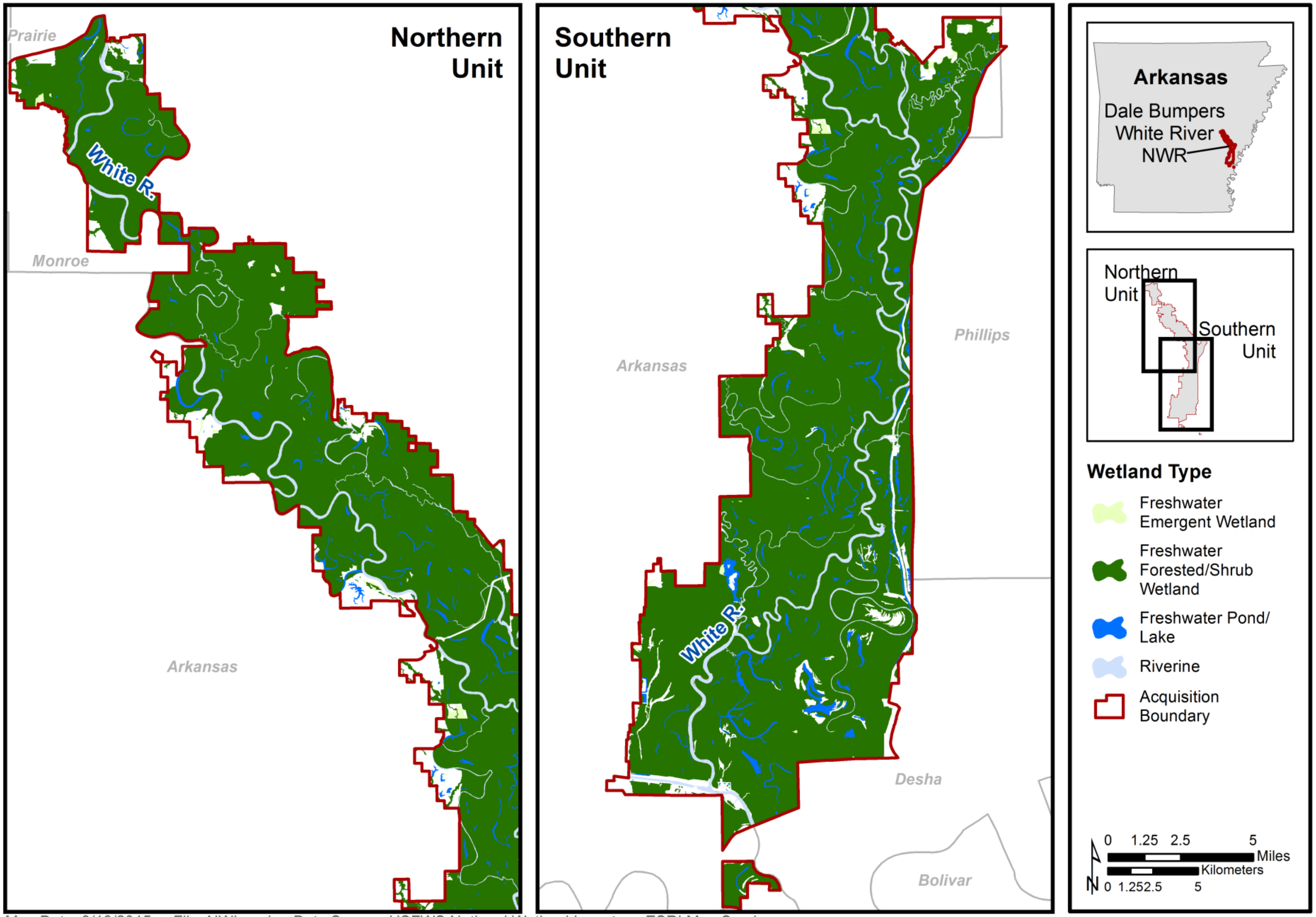
The National Wetland Inventory (NWI) was established in 1974 to provide information on the extent of the nation's wetlands (Tiner 1984). NWI produces maps of wetland habitat as well as reports on the status and trends of the nation's wetlands. Using the Classification of Wetlands and Deepwater Habitats of the United States (Cowardin et al. 1979) wetlands have been inventoried and classified for approximately 90% of the conterminous United States and approximately 34% of Alaska. Cowardin's classification places all wetlands and deepwater habitats into five "systems": marine, estuarine, riverine, lacustrine, and palustrine. Most of the wetlands in the United States are either estuarine or palustrine (Tiner 1984). The predominant wetland systems at DBWRNWR are defined in Cowardin et al. (1979) as either Palustrine, Lacustrine, or Riverine:

> *Palustrine:* The Palustrine System includes all nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean derived salts is below 0.5% (e.g., inland marshes, bogs, fens, and swamps).
>
> *Lacustrine:* The Lacustrine System includes wetlands and deepwater habitats with all of the following characteristics: (1) situated in a topographic depression or a dammed river channel; (2) lacking trees, shrubs, persistent emergents, emergent mosses or lichens with greater than 30% areal coverage; and (3) total area exceeds 8 hectares (ha) (20 acres). Similar wetland and deepwater habitats totaling less than 8 ha are also included in the Lacustrine System if an active wave-formed or bedrock shoreline feature makes up all or part of the boundary, or if the water depth in the deepest part of the basin exceeds 2 meters (m) (6.6 feet) at low water. Lacustrine waters may be tidal or nontidal, but ocean derived salinity is always less than 0.5%.
>
> *Riverine:* The Riverine System includes all wetlands and deepwater habitats contained within a channel, with two exceptions: (1) wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and (2) habitats with water containing ocean-derived salts in excess of 0.5 ‰. A channel is "an open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of standing water" (Langbein and Iseri 1960).

The different systems can be broken down into subsystems, classes and hydrologic regimes based on the wetland's position in the landscape, dominant vegetation type, and hydrology.
More than 96% of the land within the DBWRNWR acquired boundary and more than 94% of the land within the acquisition boundary is classified as wetlands according to the NWI (Table 8, Figure 21). The wetlands are primarily palustrine with large Freshwater Forested/Shrub areas. Approximately 150,000 acres of the refuge are forested (USFWS 2012). Wetland habitat delineated by the NWI shows 141,885 acres of freshwater forested/shrub wetland (i.e., moist and wet bottomland forests and swamp forests).

Table 8. Wetland habitat delineated by the National Wetland Inventory (NWI) inside the Dale Bumpers White River National Wildlife Refuge acquired and acquisition boundaries. [Source: USFWS undated].

Habitat Type	System	Acres on Refuge	Percent of Total	Acres within Acquisition Boundary	Percent of Total
Freshwater Emergent	Palustrine	383.9	0.3	487.4	0.3
Freshwater Forested/Shrub Wetland	Palustrine	141885.1	94.4	147855.3	85.7
Freshwater Pond	Palustrine	1121.5	0.7	1223.1	0.7
Lake	Lacustrine	4344.2	2.9	4532.9	2.6
Riverine	Riverine	2625.3	1.7	7947.9	4.6
Upland/Unclassified		6286.4	4.2	10394.6	6.0
All Wetlands		150360.1	96.0	162046.6	94.0
Total		***156646.4***	***100***	***172441.2***	***100.0***



Map Date: 3/18/2015 File: NWI.mxd Data Source: USFWS National Wetland Inventory, ESRI Map Service.

Figure 21. National Wetlands Inventory (NWI) land cover within the Dale Bumpers White River National Wildlife Refuge acquisition boundary.

5.2 Infrastructure

5.2.1 Water Control Structures

There are 81 water control structures on the refuge, 37 of which are currently functioning (Figure 22, Figure 23, Figure 24). These structures were constructed beginning in the 1930s by the CCC for waterfowl management, and increased in number through the 1960s. Additionally, there are five irrigation wells that are used for water management (Section 5.2.3). By the 1980s many of the structures had fallen into disrepair and were abandoned. For instance, some of the lakes have water control structures on them that are no longer functional). Other structures become non-operational at times because they get blocked by beaver dams or other obstructions. In the current state, only small ponds, moist-soil impoundments, green tree reservoirs, and crop lands can be managed using water control structures and irrigation wells. The CCP outlines several specific objectives to repair, remove or replace existing water control structures and construct new structures as necessary to manage habitat, including fisheries. One of the strategies stated in the CCP is to document the location of all culverts and water control structures on the refuge (USFWS 2012). An inventory of information currently available on water control structure and culvert locations and specifications is found in Appendix B.

5.2.2 Impoundments, Moist Soil Impoundments and Green Tree Reservoirs

The refuge seasonally manages 8,500 acres of bottomland habitat as GTRs for wintering waterfowl (USFWS 2012; Table 9, Figure 22). Current management of the GTRs focuses on maintaining suitable hunting conditions as opposed to forest productivity and sustainability; however, the GTRs cannot be actively managed due to water management constraints (described below). Only the Levee A and B impoundments can be hunted; since 2008 their fall flooding has been delayed until November. One of the objectives for the GTRs is to manage them to more closely emulate natural hydrologic regimes (wet-dry cycles) and utilize openland habitats (i.e., cropland and moist-soil impoundments) for extended flooding and avian habitat when the GTRs are not flooded (USFWS 2012). GTRs are irrigated using water from the Arkansas Post Canal, groundwater and rainfall/backwater flooding (USFWS 2009a).

The Farm Unit contains between 320 and 350 acres (varies annually) of open agricultural fields where rice, milo, soybeans, corn, wheat and Japanese millet are grown cooperatively and managed through flooding to provide habitat for migratory waterfowl. Additionally, 340 acres of moist-soil impoundments also provide water management capability for migratory waterfowl (Figure 23); however, the Demonstration Area and Dry Lake (the two largest moist-soil units with 'high waterfowl use') do not offer full water management capability because the White River backs into them each year during the fall/winter. When deeply flooded, this makes much of the food provided in these impoundments inaccessible to dabbling ducks. Because of the likelihood of deep flooding in these impoundments in December and January, it has been recognized that these impoundments should be utilized to provide 'early water' (i.e., October – November) for early migrating waterfowl. If managed for 'early water', this would maximize the probability that dabbling ducks can utilize food produced in these impoundments by ensuring it is shallowly flooded. Even though these areas will experience deep flooding, they are highly utilized by diving ducks during these periods. If not managed for 'early water', many of the dabbling ducks miss the opportunity to utilize food produced in these impoundments.

As of June 2012, there were almost 500 beaver dams identified on the refuge. Prolonged flooding as a result of beaver dams has converted over 6,000 acres of forest to wetland scrub/shrub habitat, with an additional 200 – 300 acres projected to be converted per year without increased beaver control. Currently, refuge management consists of dam removal during the summer months and population control (trapping and shooting) during the fall and winter months (USFWS 2012), thus the actual number of beaver dams on the refuge is likely much lower.

5.2.3 Water Supply Wells

The Farm Unit has two electric irrigation wells and one diesel irrigation well used for farming and winter flooding for migratory waterfowl habitat (Figure 23). The specific flow rates of these three wells are unknown, but are around 1,500 gpm. There are two other active wells on the refuge, located on the Turner Tract (Figure 24; approximately 2,000 gpm) and the Demonstration Area (Figure 23; minimum 2,500 gpm). In 2011 seven domestic and irrigation wells, originally drilled between the 1930s and 1970s, were sealed, abandoned and/or closed (USFWS 2011a, 2011b).

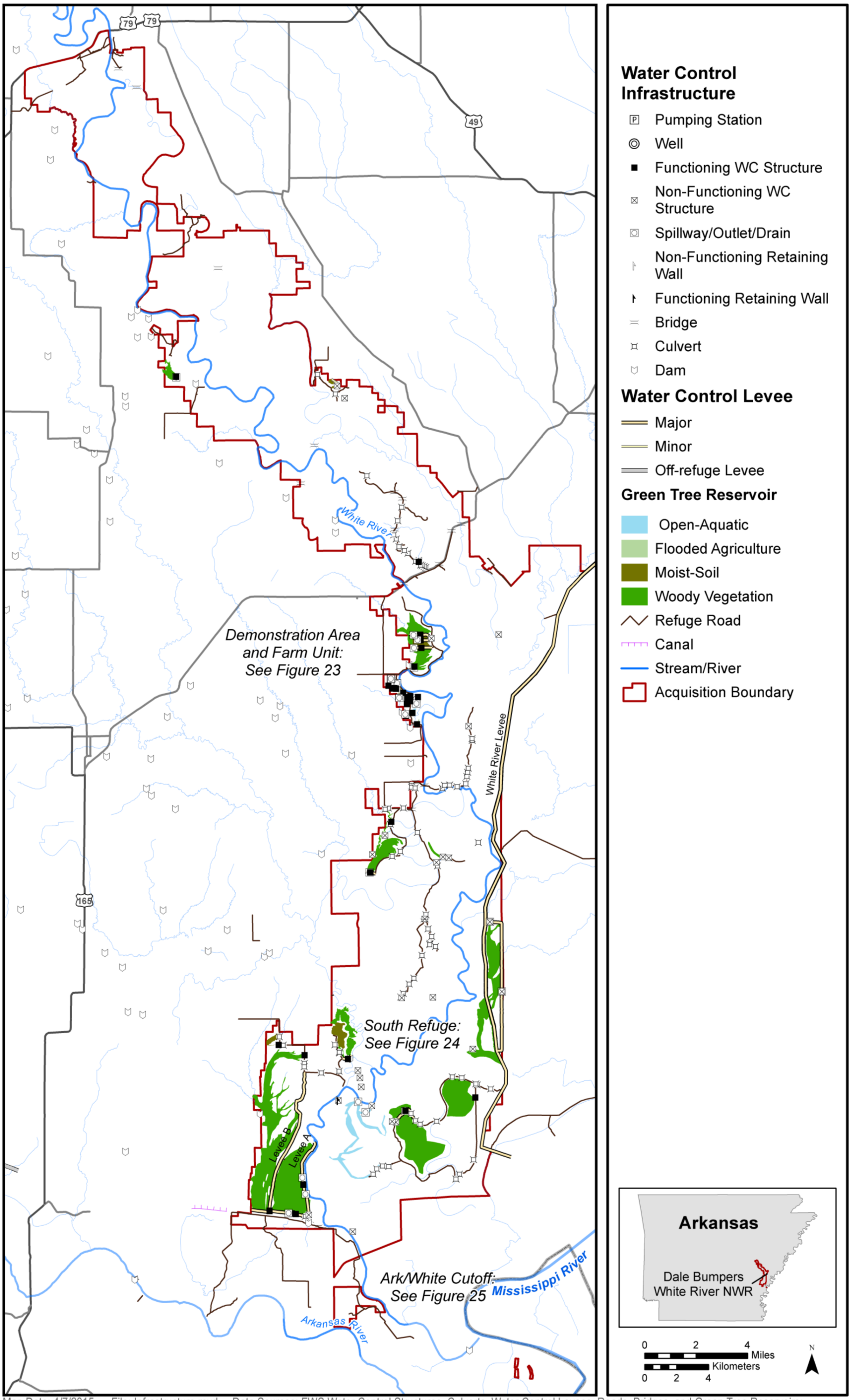
5.2.4 Inventory Dams

The Montgomery Point Lock and Dam is located at the confluence with the Mississippi River, immediately south of the refuge acquisition boundary (Figure 25). The dam allows barge traffic to enter the White River during periods of low flow on the Mississippi River (USFWS 2012). Additionally, the Norrell Lock and Dam (i.e., Lock 1) is located on the Arkansas Post Canal at the southern end of the refuge (Figure 24, Figure 25). These dams and others located outside the refuge boundaries but within the RHI are further discussed in Section 5.4.4.

Levees on the refuge are tall enough to be categorized as “dams” and classified according to their hazard potential (low, significant, high) (Ron Hollis, USFWS, written communication, November 27, 2013). The thirty-one dams/levees shown in Figure 22 total 51.5 miles in length, with 96% (49.4 miles) of that total defined as having a major hydrologic impact to the refuge. Detailed information on lengths and condition of dams on the refuge is available in Appendix B.

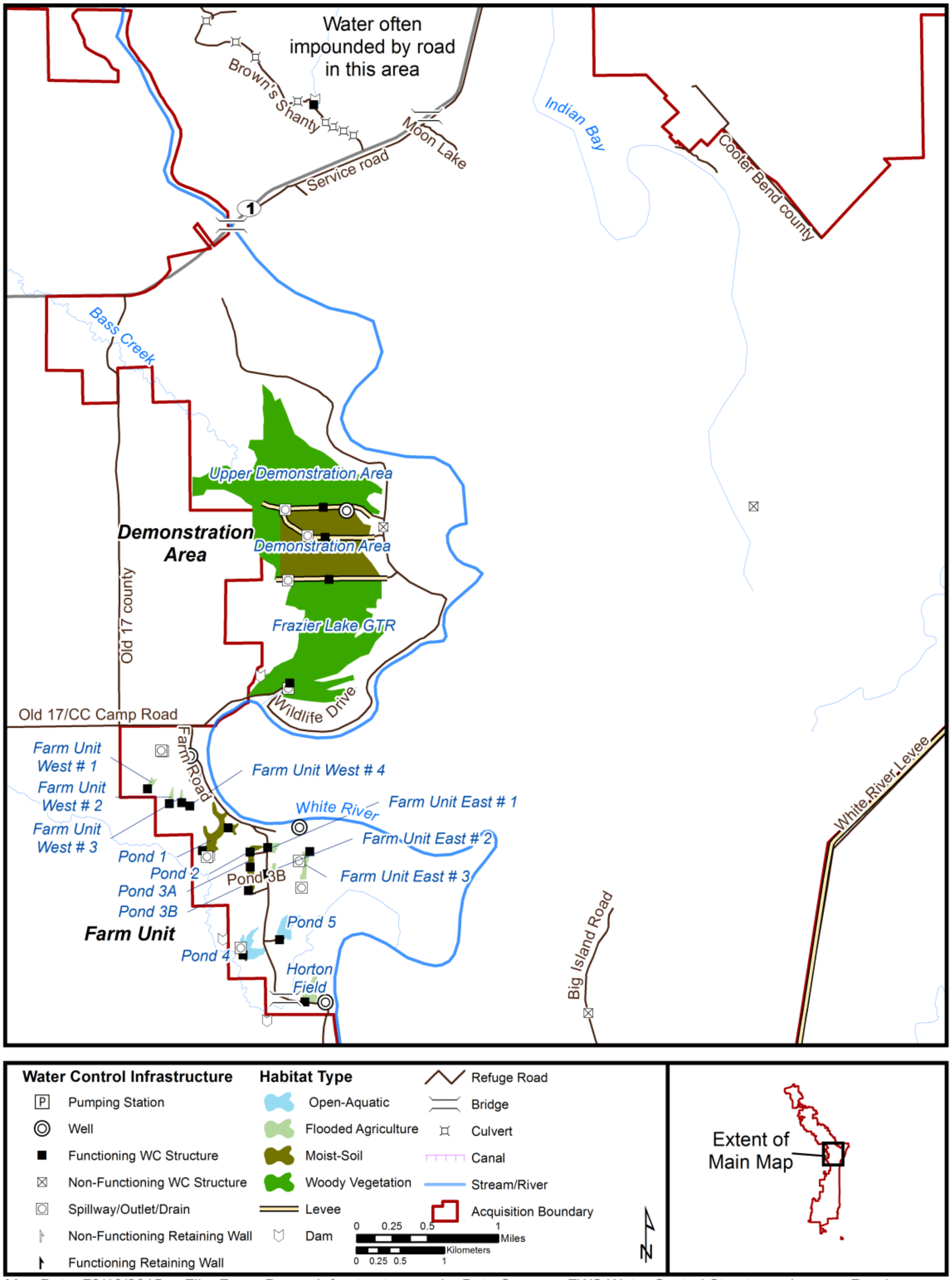
5.2.5 Dikes and Levees

The White River is enclosed by a levee system and/or uplands beginning approximately 8 miles from its mouth at the Mississippi River and extending northward for approximately 50 river miles (Section 5.4.4.4). This system causes lower flows to result in higher elevations of flooding than under pre-settlement hydrologic conditions. There are 25 levees (totaling 45.9 miles) on the refuge (USFWS 2012; Figure 22, Figure 23, Figure 24). Levee management is controlled by the Drainage District, USACE and USFWS. In 1938, the refuge issued an easement to the White River Levee Board (i.e., Drainage District) to construct and maintain (through grazing, mowing and hay production) the White River Levee for flood control which was built the following year (Section 5.4.4.4). The USFWS currently manages the portion of the White River Levee located on the east side of the refuge through cooperative agreements with the Levee Board. Other major functional levees on the refuge include Levee A (4.6 miles, levee A impoundment), Levee B (6.6 miles, levee B impoundment) and Duck Rest Levee (5.7 miles, bottomland/GTR). There are several large compromised or non-functioning levees on the refuge including: an earthen levee at Reservoir A at Jack’s Bay that washed out in 2002; Willow Lake Levee which has been severely eroded from beaver digging and associated weather influences; and Mossy Lake Levee, which separates White River from seven lakes, is breached and continues to erode (USFWS 2012). Detailed information on lengths and condition of levees on the refuge is available in Appendix B. Section 5.4.4.4 addresses other levees located outside the refuge boundaries but within the RHI that affect the quantity and timing of floods on the refuge.



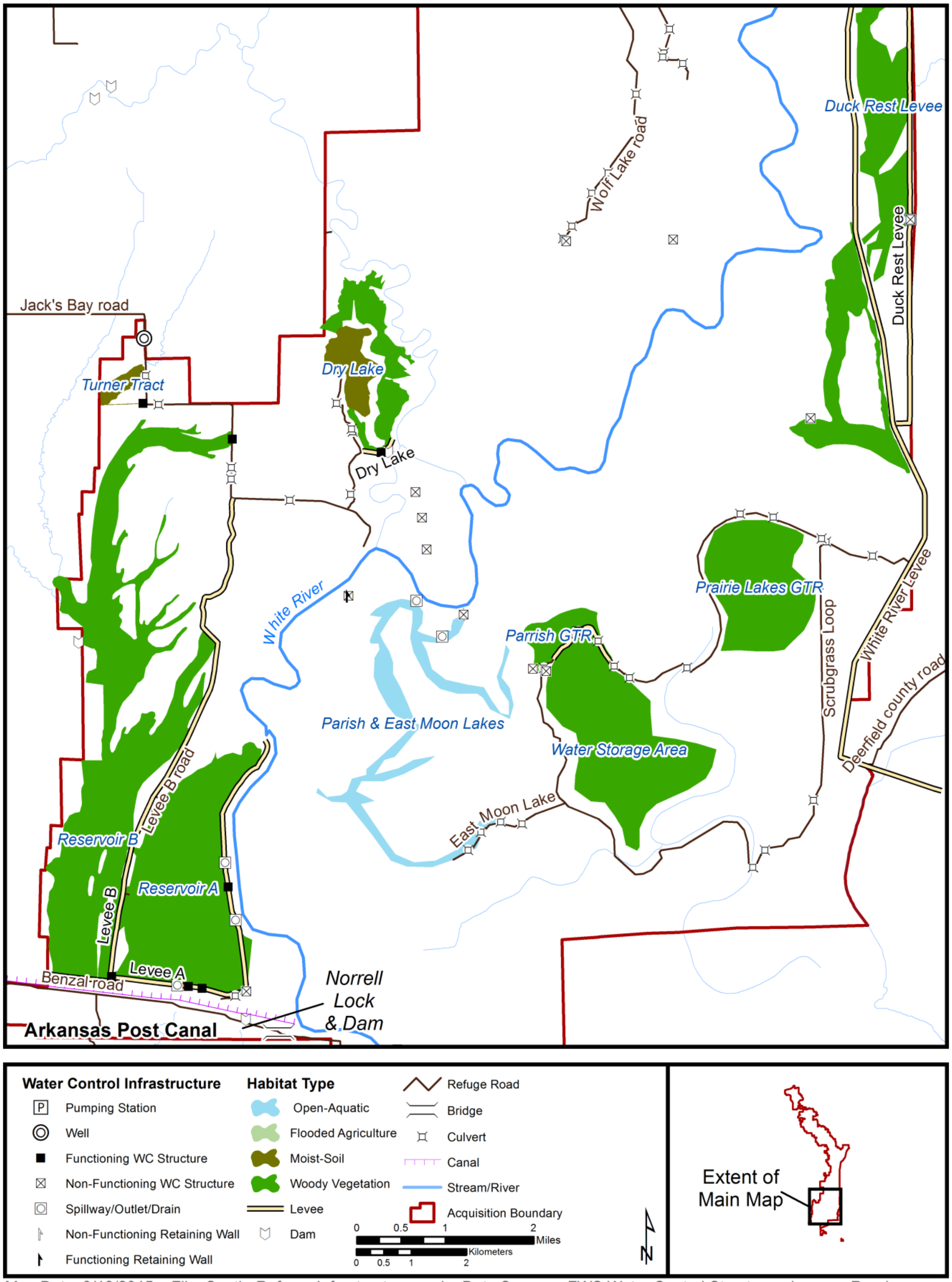
Map Date: 4/7/2015. File: Infrastructure.mxd Data Sources: FWS Water Control Structures, Culverts, Water Control Levees, Roads, Bridges, and Green Tree Reservoirs; ANRC Dams; NHD Flowlines; ESRI Map Service.

Figure 22. Infrastructure within and in the vicinity of the Dale Bumpers White River National Wildlife Refuge acquisition boundary.



Map Date: 73/18/2015 File: Farm_Demo_Infrastructure.mxd Data Sources: FWS Water Control Structures, Levees, Roads, Bridges, and GTRs, ANRC Dams and Levees, NHD High Resolution Flowlines and Waterbodies, ESRI Map Service.

Figure 23. Infrastructure within the Demonstration Area and Farm Unit of Dale Bumpers White River National Wildlife Refuge.



Map Date: 3/18/2015 File: South_Refuge_Infrastructure.mxd Data Sources: FWS Water Control Structures, Levees, Roads, Bridges and GTRs, ANRC Dams and Levees, NHD High Resolution Flowlines and Waterbodies, ESRI Topo Service.

Figure 24. Infrastructure in the southern portion of Dale Bumpers White River National Wildlife Refuge.

Figure 25. Infrastructure along the Ark/White Cutoff. [Adapted from USACE 2013e].

Table 9. Impoundments within the Dale Bumpers White River National Wildlife Refuge acquisition boundary. [Source: USFWS date unknown].

Name	Water Control	Habitat Type	Cover Type	Year Built	Acres
Farm Unit East # 1	Complete	Flooded Ag	Ag Crop	1991	3.0
Farm Unit East # 2	Complete	Flooded Ag	Ag Crop	1991	2.4
Farm Unit East # 3	Complete	Flooded Ag	Ag Crop	1994	4.8
Farm Unit West # 1	Complete	Flooded Ag	Ag Crop	2004	2.0
Farm unit West # 2	Complete	Flooded Ag	Ag Crop	2004	1.9
Farm Unit West # 3	Complete	Flooded Ag	Ag Crop	2004	1.2
Farm Unit West # 4	Complete	Flooded Ag	Ag Crop	2004	0.6
Horton Field	Complete	Flooded Ag	Ag Crop	1992	9.1
Total acres of Flooded Ag Habitat Type					***25.0***
Demonstration Area	Partial	Moist-Soil	Moist-Soil	1950	196.8
Dry Lake	Partial	Moist-Soil	Moist-Soil	1966	219.3
Kansas Lake WRP	None	Moist-Soil	Moist-Soil	2000	41.6
Pond 1	Complete	Moist-Soil	Moist-Soil	1992	19.9
Pond 2	Complete	Moist-Soil	Moist-Soil	1990	2.3
Pond 3A	Complete	Moist-Soil	Moist-Soil	2010	2.7
Pond 3B	Complete	Moist-Soil	Moist-Soil	2010	6.1
Turner Tract	Complete	Moist-Soil	Moist-Soil	2012	67.1
Total acres of Moist-Soil Habitat Type					***555.8***
Pond 4	Partial	Open-aquatic	Open-aquatic	1961	12.2
Pond 5	Partial	Open-aquatic	Open-aquatic	1961	11.8
Surround Pond	None	Open-Aquatic	Open-Aquatic	1966	7.0
Total acres of Open-aquatic Habitat Type					***31.0***
Cooks Lake Reservoir	Partial	Woody Vegetation	Shrub Swamp	2009	126.3
Dry Lake	Partial	Woody Vegetation	Hardwoods	1966	394.5
Duck Rest Levee	Partial	Woody Vegetation	Hardwoods	--	738.0
Frazier Lake GTR	Partial	Woody Vegetation	Hardwoods	1954	345.4
Lower Taylor Lake	None	Woody Vegetation	Hardwoods	1939	589.6
Parrish GTR	None	Woody Vegetation	Hardwoods	1950	189.7
Prairie Lakes GTR	Partial	Woody Vegetation	Hardwoods	1955	904.4
Reservoir A	Complete	Woody Vegetation	Shrub Swamp	1962	1746.7
Reservoir B	Complete	Woody Vegetation	Hardwoods	1962	2546.3
Thomas Bayou	Partial	Woody Vegetation	Hardwoods	1962	495.5
Upper Demonstration Area	Partial	Woody Vegetation	Shrub Swamp	1950	289.1
Water Storage Area	Partial	Woody Vegetation	Shrub Swamp	--	1341.3
West of Bear Lake	None	Woody Vegetation	Hardwoods	1940	44.3
Total acres of Woody Vegetation Habitat Type					***9751.2***
Parish & East Moon Lakes	None	Unknown		--	602.7
Total acres of Unknown Habitat Type					***602.7***
Total acres of impoundments					**10965.6**

5.2.6 Roads

According to the GIS data used in the CCP, the refuge maintains 72 listed roads totaling 98 miles (95 miles are gravel and 3 miles are paved) (Figure 22). In addition, there are approximately 477 miles of dirt, truck roads, lanes and trails used for forest management. Of those, 357 miles are used for wildlife-dependent recreation (i.e., hunting, fishing). There are six designated foot trails for hiking totaling five miles (USFWS 2012). During dry periods, nearly every body of water on the refuge is accessible via the network of roads and trails (FHWA 2005).

Roads can affect flooding characteristics on the refuge by impounding or diverting flows and increasing flow velocities at culverts (FHWA 2005). One example is an area between Brown's Shanty Road at the east end of Little Moon Lake, which was constructed in the 1940s to allow access to the Northern Unit, and Highway 1 (Figure 23). Water crosses the road at a low-water crossing when the St. Charles gage reaches 22.8 feet. Throughout the rest of the year the "connection channel" remains dry. Although culverts along these roads are functional, the roads restrict and impound the flow of water during periods of flooding. The CCP states the refuge's desire to reduce road impacts through strategies such as minimizing new construction, discouraging ATV usage and implementing seasonal road closures during extremely wet conditions. Additionally, the CCP mentions the need to restore hydrologic connectivity where dirt fills or small culverts were used (USFWS 2012).

5.2.7 Other Water Resources Infrastructure

The refuge has 24 campgrounds and 18 improved (concrete) boat ramps for access to the river, lakes and bayous. The majority of the campgrounds and boat ramps are located in the Southern Unit of the refuge. There are also over 100 small, unimproved (i.e., primitive) boat ramps (clearings between trees or packs with gravel or rip-rap) only accessible by ATV that primarily provide access to lakes and bayous. Boat ramps on the river are maintained mostly by the Arkansas Game and Fish Commission (AGFC); the Levee Board and USACE also maintain a number of boat ramps (FHWA 2005; USFWS 2012).

Currently, the refuge actively maintains 11 bridges: five in the Northern Unit and six in the Southern Unit (FHWA 2005). In addition, the refuge CCP includes plans to construct 25 new bridges if funding is available, which may include temporary bridges for forest management or logging activities, bridges where there is currently no road crossing (e.g., at Green River and Walker Cypress), or bridges to replace culverts. A temporary bridge was installed at Mussel Shoals in the summer of 2013. The CCP also includes plans to replace culverts with bridges in order to restore hydrology at Kansas Bayou, Sycamore Log Crossing, and Scrub Grass Bayou (USFWS 2012).

The refuge includes permanently maintained open lands under right-of-way or easement restrictions for power transmission lines (400 acres), an underground oil and gas pipeline (190 acres), highways (State Highway 1 and U.S. Highway 79; 140 acres), levees (710 acres) and canals (430 acres). These lands increase habitat diversity on the refuge, providing habitat for species not otherwise supported by refuge management (USFWS 2012).

5.3 Water Monitoring

5.3.1 Surface Water

This section presents information on federal and state surface water quantity and quality monitoring locations in the 8-digit HUs closest to and containing the DBWRNWR acquisition boundary. Sections 5.4 and 5.5 address historic monitoring and trends for water quantity and quality at the RHI scale.

5.3.1.1 Hydrography

White River flows are regulated by flood control and hydropower dams located on the upper White River (further described in sections 5.4.4 and 5.4.6). The USGS maintains monitoring stations that measure discharge and stage along the White River upstream of the refuge, as well as along the downstream rivers that contribute to water levels on the refuge via backwater flooding. There are 292 USGS surface water quantity monitoring sites (stream and lake gages and sites that were periodically measured for water levels) within the RHI. Ten active and historic sites are within 10 miles of the DBWRNWR acquisition boundary. Table 10 includes these sites, as well as the gage on the Mississippi River at Helena (07047970, #6 in Table 10, Figure 26). The gage at DeValls Bluff (07077000; Site #2 in Table 10, Figure 26) is the closest active station to the refuge, with a period of record for discharge beginning in 1949.

The USACE web site RiverGages.com lists the locations of 30 active sites which measure water quantity (Stage, Precipitation, Pool Level, or Head Water) within the Upper and Lower White River Basins (USACE undated-a). Thirteen of these sites overlap with current or historic USGS surface water stations, due to a history of shared management duties between the two agencies. Generally, the USACE gages have longer periods of record than the USGS sites for stage. Table 10 and Figure 26 show the stations within 10 miles of DBWRNWR, as well as active stations at the Arkansas Post Canal and on the Mississippi River at Helena, AR. Site ID is only applicable to gages managed by the Memphis District of the USACE. Information available on RiverGages.com includes flood stage elevation and record high stage information for each site. USACE and USGS use different datums for many of the co-managed stations; as such, data values may not be directly comparable.

During the summer of 2012, USGS National Wetlands Research Center staff installed at least one water level recorder in six impoundments/GTRs on the refuge as a part of a forest habitat assessment. In addition, the refuge monitors gages located on wetland management units; however, readings are not tied to elevation.

Table 10. USGS and USACE surface water quantity monitoring stations near Dale Bumpers White River National Wildlife Refuge**.** Duplicate numbers indicate stations which have been co-managed. [Sources: USACE date unknown; USGS 2013a].

# on Figure 26	Site ID	Name	Agency	Type	Begin	End
1	CR114	Cache River At Brasfield, AR	USACE	Stage	1911	current
2	07077000	White River at DeValls Bluff, AR	USGS	Discharge	10/1/1949	current
2	WR115	White River At DeValls Bluff, AR	USACE	Stage	1909	current
3	07077790	CACHE RIVER AT 100 YDS BELOW DREDGING, AR	USGS	Flow, Stage	8/31/1977	3/19/1980
4	07077800	WHITE RIVER AT CLARENDON, ARK.	USGS	Discharge	10/1/1928	9/30/1993
4	WR116	WHITE RIVER AT CLARENDON, AR	USACE	Stage	1886	current
5	07078000	LAGRUE BAYOU NEAR STUTTGART, ARK.	USGS	Discharge	10/1/1935	9/30/1954
6	07047970	MISSISSIPPI RIVER AT HELENA, ARK.	USGS	Discharge	1/1/1928	9/30/1977
6	MS133	Mississippi River At Helena, AR	USACE	Stage	1871	current
7	07077960	BIG CREEK NEAR WATKINS CORNER, ARK.	USGS	Discharge	4/17/1974	10/4/1983
8	07077820	WHITE RIVER AT ST. CHARLES, ARK.	USGS	Discharge	4/17/1974	9/13/1994
8	WR118	White River At St. Charles, AR	USACE	Stage	1911	current
9	WR123	WHITE RIVER PUMPING STATION (GRAHAM BURKE-RIVERSIDE) NEAR MELLWOOD, AR.	USACE	Stage	1987	current
10	07078285	White River at AR Post Canal, Near Nady, AR	USGS	Discharge	10/10/1972	10/4/1983
11		Arkansas Post Canal at Lock 2 - HW	USACE	Pool level, Precip	1911	2013
12	07265280	Arkansas River at Pendleton, AR	USGS	Stage	9/6/1962	current
13	07265283	AR River @ Dam No.2 near Gillett, AR	USGS	Discharge	10/10/1972	9/12/1994
14	07078337	WHITE RIVER AT MILE 1.2 NR. STINSON, AR.	USGS	Discharge	5/4/1991	15/5/1992

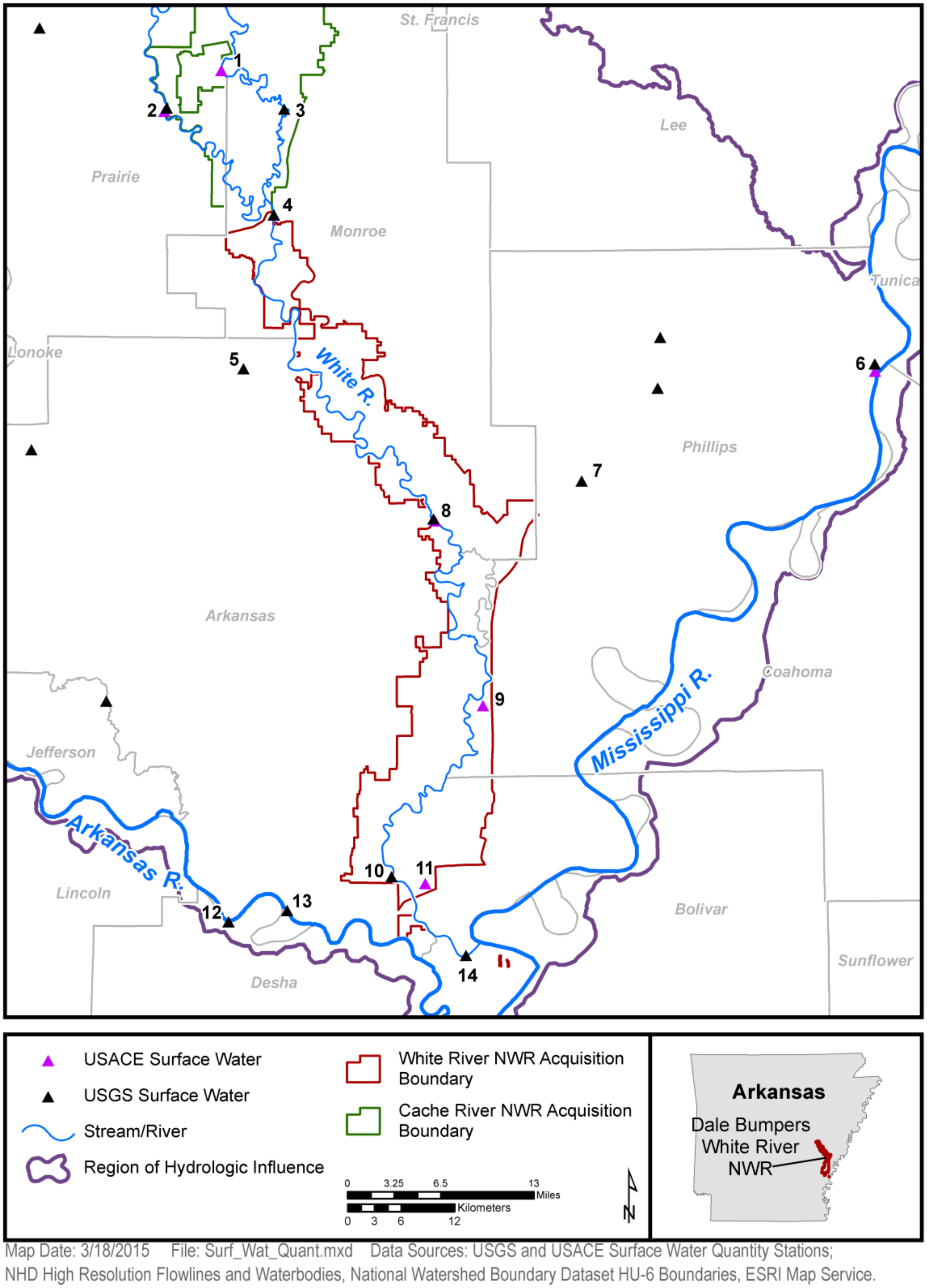


Figure 26. Surface water quantity monitoring near Dale Bumpers White River National Wildlife Refuge. Information for numbered sites in Table 10.

5.3.1.2 Water Quality Monitoring

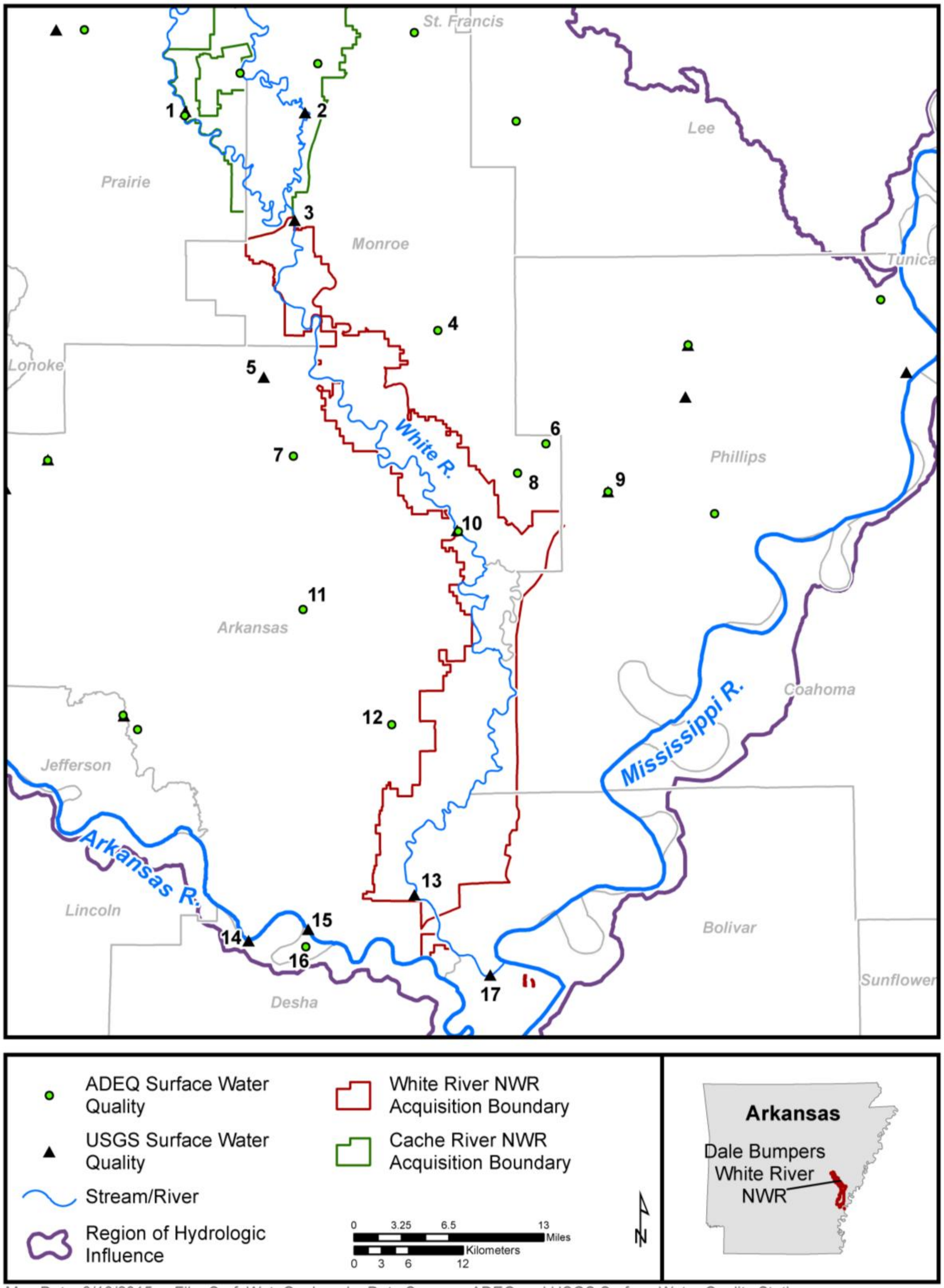
Multiple agencies conduct water quality monitoring within the RHI. The USGS has collected water quality data at 292 active and historic surface water sites within the RHI. Ten of these sites are within 10 miles of the acquisition boundary for DBWRNWR (Table 11, Figure 27). Site 07077000 (White River at DeValls Bluff, AR) is the closest active monitoring site to the refuge, with a period of record beginning in 1945 (Site #1 in Table 11, Figure 27). It has been monitored for a variety of water quality parameters, including temperature, specific conductance, dissolved oxygen, pH, phosphorous, and dissolved solids.

The Arkansas Department of Environmental Quality's (ADEQ) Water Quality Monitoring Program includes the monitoring of the chemical parameters in the water of rivers, streams and lakes within the State. Statewide, the monitoring network of rivers and streams includes over 160 stations that are sampled monthly, over 100 stations that are sampled on a bi-monthly or quarterly schedule and an additional 30 – 50 stations that are intensively sampled over a short period of time for special purposes. Within the RHI, there are 306 surface water sampling locations with the following types: channelized stream, industrial facility, lake, reservoir, and river/stream. Ten stream sampling sites are within five miles of the refuge acquisition boundary (Table 11, Figure 27). Site WHI0036, White River at St. Charles, AR, is located on the river within the acquisition boundary (#10 in Table 11, Figure 27). It has been sampled on a monthly basis since 1990 for a variety of parameters, including turbidity, pH, dissolved oxygen, and temperature. Detailed monitoring data for this site is located in Appendix C. Data for the ADEQ stations listed in Table 11 can be obtained by searching the ADEQ Surface Water Quality Monitoring Data Search Page (ADEQ 2013).

There are 19 USACE sites from which water quality data (water temperature, dissolved oxygen, specific conductance) is collected in the Upper White Basin; however, none of the Lower White Basin sites near the refuge are used to monitor water quality.

Table 11. ADEQ and USGS surface water quality monitoring near Dale Bumpers White River National Wildlife Refuge. Duplicate numbers indicate stations which are co-located or in close proximity. [Sources: USGS 2013a; ADEQ 2013].

# on Figure 27	Site ID	Name	Agency	Type	Begin	End
1	WHI0031	White River at DeValls Bluff, Arkansas	ADEQ	Stream	3/25/1974	
1	07077000	White River at DeValls Bluff, AR	USGS	Stream	11/6/1945	8/28/2013
2	07077790	Cache River at 100 yards below dredging, AR	USGS	Stream	8/31/1977	3/19/1980
3	07077800	White River at Clarendon, AR	USGS	Stream	10/1/1947	7/1/1986
4	WHI0074	Boat Gunwale Slash at Hwy. 146 near Deep Elm, Arkansas	ADEQ	Stream	10/1/1983	
5	07078000	Lagrue Bayou Near Stuttgart, AR	USGS	Stream	6/11/1929	2/22/1955
6	UWCPC01	Big Cypress Creek at Hwy. 1, 4 mi. n.e. of Crossroads	ADEQ	Stream	6/1/1994	
7	UWLGB01	Lagrue Bayou at Hwy. 33 at Lagrue	ADEQ	Stream	6/1/1994	
8	WHI0073	Prairie Cypress Creek at Hwy. 1 near Crossroads, Arkansas	ADEQ	Stream	10/1/1983	
9	WHI0037	Big Creek near Watkins Corner, AR	ADEQ	Stream	4/17/1974	
9	07077960	BIG CREEK NEAR WATKINS CORNER, ARK.	USGS	Stream	4/17/1974	9/13/1983
10	WHI0036	White River at St. Charles, Arkansas	ADEQ	Stream	4/17/1974	
10	07077820	WHITE RIVER AT ST. CHARLES, ARK.	USGS	Stream	4/17/1974	9/13/1994
11	UWLLB01	Little Lagrue Bayou at Hwy. 1 near Dewitt, AR	ADEQ	Stream	6/1/1994	
12	UWLGB02	Lagrue Bayou at Hwy. 17 at Lagrue Springs	ADEQ	Stream	6/1/1994	
13	07078285	White River at AR Post Canal, Near Nady, AR	USGS	Stream	10/10/1972	9/6/1983
14	07265280	Arkansas River at Pendleton, AR	USGS	Stream	9/6/1962	6/19/1989
15	07265283	AR River @ Dam No.2 near Gillett, AR	USGS	Stream	10/10/1972	9/12/1994
16	ARK0020	Arkansas River at Dam No. 2	ADEQ	Stream	11/4/1969	
17	07078337	WHITE RIVER AT MILE 1.2 NR. STINSON, AR.	USGS	Stream	5/4/1991	5/5/1992



Map Date: 3/18/2015 File: Surf_Wat_Qual.mxd Data Sources: ADEQ and USGS Surface Water Quality Stations; NHD High Resolution Flowlines and Waterbodies, National Watershed Boundary Dataset HU-6 Boundaries, ESRI Map Service.

Figure 27. Surface water quality monitoring near Dale Bumpers White River National Wildlife Refuge. Information on numbered sites is listed in Table 11.

5.3.1.3 Aquatic Habitat and Biota

While anthropogenic stressors and practices have drastically changed the landscape and impacted the aquatic habitat and biota within the Lower White River Basin, unique delta ecosystems are still present in areas, some of which occur exclusively within the boundaries of DBWRNWR. These delta ecosystems have provided researchers an opportunity to collect information and study the aquatic habitats and biota that are somewhat unique to the White River Basin. The "White River Comprehensive Report" (Hoover et al. 2009) was a thorough summary of studies and surveys within the basin. In this report, the fisheries resources of the basin, sensitivity to environmental disturbances, and means of conserving and enhancing fish populations were discussed and summarized. Additional research conducted within the White River Basin has included work on fish assemblages (Filipek 1990; Layher and Phillips 1999; Clark et al. 2007; Lubinski et al. 2008), mussel communities (Gordon 1982; Christian 1995; Johnson et al. 1998), and anthropogenic impacts on the aquatic habitat and fauna (USACE 2008a; Hoover et al. 2009). Additionally, some of the research has focused exclusively on aquatic habitats and biota within the lower White River and within the DBWRNWR boundary. These efforts include surveys of the aquatic habitats for freshwater Mollusca taxa (Gordon et al. 1994), aquatic macroinvertebrates (Chordas et al. 1996), and fish communities and fish species richness (Buchanan 1997; Clark et al. 2007). These field studies, particularly those conducted within DBWRNWR, play an integral role in understanding the aquatic resources of the White River Basin. The associated aquatic habitats and biota of DBWRNWR could be greatly impacted by anthropogenic stressors occurring throughout the entire basin. The only way to really understand the dynamics of this complex system is with inventory, monitoring, and continued research efforts focusing on the aquatic habitats and the aquatic biota that depends upon that habitat.

Biological Inventories

The earliest known efforts to describe the various aquatic biota within Arkansas began in the mid- to late 1800s (Girard 1859; Sampson 1891). Many of these Arkansas efforts were from species inventory records documented in volumes from the Pacific Railroad Survey by the U.S. War Department in the mid-1800s. For example, Girard (1859) initiated the first recorded attempts to describe the fish taxa in Arkansas and Baird (1859) recorded reptile species accounts during surveys of the lands for the construction of the Pacific Railroad; this included records of reptiles found in Arkansas, some of which are associated with aquatic habitats. Subsequent efforts followed and included additional fish inventories and mussel surveys. One of the earliest, most thorough fish inventories in Arkansas was conducted by S. E. Meek between 1889 –1896. In "A Catalogue of the Fishes of Arkansas" (Meek 1891) and in additional efforts (Meek 1894), efforts were made to exhaustively describe all of the fishes known to inhabit the waters of the state. In these publications, Meek summarized previous sampling efforts, provided general habitat descriptions for many of the state's streams, and documented the presence of 137 fish species. During the same time, Sampson (1891) identified Mollusca shells (exclusive of Unionidae) collected in Arkansas and later published some of these accounts in a summary (Sampson 1894). Also, Call (1895) collected and described native mussels (Unionidae) from 25 counties in Arkansas. Historic species accounts and records for aquatic fauna from other taxa groups are limited.

Comprehensive survey records compiled and available from the Arkansas Natural Heritage Commission (ANHC) document historic and current aquatic species accounts throughout Arkansas. These inventory records include information for the White River Basin and assist in inventorying "aquatic elements of special concern", including state listed threatened or endangered taxa. Additionally, other efforts and publications also have built upon early historic records and provide additional inventory collections of the various aquatic species found throughout the state. Gordon (1980) identifies a total of 223 taxa of Mollusca as occurring in Arkansas, including 36 aquatic gastropods (snails and slugs) and 80 freshwater bivalves (mussels and clams).

A review of the freshwater mussel family Uniondae in Arkansas (Harris et al. 2009) identified 85 recognized species, many of which occur within the White River Basin. The Fishes of Arkansas (Robison and Buchanan 1988) describes 215 species of fish found within the state. Layher et al. (date unknown) surveyed the fish fauna of Arkansas' large rivers and reported the White River as having the highest number of species collected (61) and the second highest number of individual fishes collected (6,530) of all rivers sampled. The Amphibian and Reptiles of Arkansas (Trauth et al. 2004) provides comprehensive records for known occurrences and distributions of salamanders, frogs, toads, turtles, snakes, lizards, and alligators within the state. Efforts are currently being conducted to describe crayfish taxa within Arkansas (Brian Wagner, personal communication, December 10, 2013).

Numerous aquatic species inventories and associated studies have been conducted specifically within the Lower White River Basin, including DBWRNWR. However, most of these efforts have focused on fish and mussel taxa. Although limited in this regard, these inventories and studies provide very specific information for the targeted fish and mussel taxa. Some of these efforts were undertaken as part of master theses or doctoral dissertations (Christian 1995; Peck 2005; Hayes 2010), environmental assessments for proposed construction (AHTD 1987; Harris 1989; Christian 2006; ESI 2006), or in response to navigational/commercial dredging projects (Clarke 1985; Harris 1997; Christian 2009).

Robison (2006) identified 177 fish species as being found within the White River Basin, 138 of which were documented in the Lower White River Basin. Layher et al. (date unknown) sampled wadeable streams across Arkansas; over half of the 61 fish species collected were documented within the White River below Clarendon, Arkansas, and adjacent to refuge boundaries. Within the boundary of DBWRNWR, Buchanan (1997) collected a total of 62 fish species in the Indian Bayou watershed. Of these 62 species, 13 species were from the Family Percidae (Buchanan 1997). Keith (1987) reported on the species richness (51 species) of Delta ecoregion reference streams and identified the five most abundant fish families (% of all species) as: Centrarchidae (30%), Cyprinidae (17%), Percidae (11%), Ictaluridae (9%), and Catostomidae (4%). In comparison, the Indian Bayou mainstream fish community and associated family dominance differed and was unique when compared to other Delta streams. It was comprised of: Cyprinidae (27%), Percidae (25%), Centrarchidae (20%), Catostomidae (6%), and Ictaluridae (6%). The uniqueness of the Indian Bayou community is primarily associated with its rich assemblage of darters (Family Percidae). No other Delta ecoregion stream in Arkansas, regardless of watershed size, is known to have as many darter species (Buchanan 1997). Additionally, Eggleton et al. (2010) sampled 16 floodplain lakes within DBWRNWR to assess littoral fish assemblages and sampling gear efficiency. They collected over 27,000 fish that represented 64 species and 20 families (Eggleton et al. 2010: Table 2).

Christian (1995) performed one of the most intensive inventories of the White River mussel taxa. In this survey, Christian assessed the status of over 100 known historic mussel beds, all within the Lower White River Basin. In additional efforts, Christian (2007) identified 23 mussel species at Aberdeen (RM 91; within the section of the lower White River flowing through DBWRNWR) and reported that the mussel bed area, species densities and richness, and population estimates were similar to those reported in a 1999 survey (Harris and Christian 2000). Population estimates indicate that the Aberdeen mussel bed supports the largest community standing crop of all mussel beds identified and surveyed, with estimates at >440,000 individuals (Harris and Christian 2000). Also, the identification of 54 freshwater Mollusca taxa, including mussels, clams, and freshwater snails within DBWRNWR represents over 88% of the molluscan species recorded for the Mississippi Alluvial Valley portion of the White River Basin (Gordon et al. 1994). Davidson (2005) conducted a mussel survey of the Maddox Bay Run-out located on DBWRNWR near Lawrenceville and collected a total of 662 live individuals representing 19 species. All mussels encountered were common species reported from lowland streams in the Mississippi Alluvial Valley in Arkansas (Davidson 2005).

While limited information exists for other aquatic taxa (e.g., amphibians, aquatic reptiles, crayfish, aquatic insects), especially in regards to abundance and distribution within the Lower White River Basin, a few studies have been beneficial. One of the only known inventories to specifically describe crayfish taxa in the Lower White River Basin was conducted in 2005 by AGFC biologists (Brian Wagner, personal communication, December 10, 2013). Chordas et al. (1996) conducted one of the most thorough aquatic macroinvertebrate inventories (with an emphasis on aquatic insects) in the Lower White River Basin, and more specifically, within the boundaries of DBWRNWR. This work examined over 15,000 individuals representing 219 taxa, of which insects comprised 76% of all organisms. Insect Orders included Coleoptera (61%), Hemiptera (18%), Odonata (8%), Diptera (6%), Megaloptera (4%), Ephemeroptera (2%), Trichoptera (2%), and Collembola and Plecoptera (both <1%). The non-insect fauna was comprised of decapod crustaceans (crayfish) (6%), amphipods (6%), Mollusca (5%), and isopods (5%). Non-insect taxa that were also collected but comprised less than one percent of the total including: Bryozoa, Hydracarina, Mysidacea, Nematoda, and Nematomorpha (Chordas et al. 1996). For all other aquatic taxa, various species observational records comprise most of the information available. Examples of this type of information would include species accounts reported by the public and recorded observations from biologists conducting other routine field work.

Biological Monitoring

Within the White River Basin, biological monitoring efforts have addressed multiple issues including water availability (e.g., magnitude and timing of water levels and flows), water quality, habitat preferences, Federally listed threatened and endangered species or species of concern, aquatic fauna movement and distribution, and invasive species introductions. These efforts have helped to better understand how this complex ecosystem is influenced by various environmental and anthropogenic stressors. Furthermore, biological monitoring illustrates (and will continue to show) how these issues impact the basin and have lasting effects on the habitat and aquatic biota of DBWRNWR.

Several taxa specific monitoring efforts have been conducted in the lower White River and within DBWRNWR waters. Filipek (1990) conducted a radio telemetry project that documented movement patterns and habitat preferences of *Polyodon spathula* (paddlefish) within the mid- to lower White River. This study helped with identifying specific spawning habitat for the species and allowed researchers to monitor the population within the White River and establish harvest regulations. Clark-Kolaks et al. (2007) monitored adult and juvenile *P. spathula* in floodplain lakes. This study further supports the idea that juvenile paddlefish use floodplain lakes as nursery habitat and thereby emphasizes the importance of connectivity of these floodplain lakes to the river and their relevance to refuge waters. Holt et al. (2007) studied *Scaphirhynchus platorynchus* (shovelnose sturgeon) in the lower White River to monitor, evaluate, and propose management recommendations for the species, and more specifically establish harvest regulations in efforts to conserve the population. In working with AGFC biologists, Wood and Krul (2008) evaluated the genetic traits of *S. platorynchus* from the lower White River. This report documented that the White River shovelnose sturgeon represented a more homogenous population in terms of its group membership than sturgeons compared from other basins. Buchanan (1997) conducted an 18-year monitoring effort of the fishes in Indian Bayou within DBWRNWR, which he identified as being unique primarily due to the diversity and abundance of darter (Percidae) species. Although individual species vary in their sensitivity, darters are generally sensitive to environmental disturbance and serve as preferred indicator species over other taxon of native fishes (Buchanan 1997).

Harvest reports for mussels are completed annually by commercial shell takers and submitted to AGFC. These reports assist AGFC biologists in monitoring mussel populations and harvest rates. Harris and Christian (2000) summarized the commercial harvest reports of mussels taken from the White River between 1990 – 1998 and reported that White River mussel harvest estimates exceeded 137,000 pounds in 1991 and

260,000 pounds in 1996. The White River maintains a diverse and aggregated mussel fauna in the lower basin. Within DBWRNWR, from Clarendon (RM 99) downstream to the confluence with the Arkansas Post Canal (RM 10), the lower White River supports some of the finest examples of big river mussel beds in the southeastern United States (Harris and Christian 2000).

From 2005 – 2007 and in 2012, DBWRNWR participated in a national Abnormal Amphibian Monitoring project. Sampling sites were located in Jacks Bay, the North Unit and the Levee section. Drought conditions during this time period limited sampling efforts. Of the samples collected on DBWRNWR, none contained abnormal frogs (Hemming et al. 2008; USFWS 2008). However, DBWRNWR is in close proximity to "hotspot clusters" of abnormalities identified from other area refuges within the southeast (Reeves et al. 2013).

Threatened and Endangered Species

Six Federally-listed (threatened or endangered) aquatic species have been historically or are currently documented in the Lower White River Basin and include four mussel taxa (*Potamilus capax* fat pocketbook; *Lampsilis abrupta* pink mucket; *Quadrula cylindrical cylindrical* rabbitsfoot; *Leptodea leptodon* scaleshell), one fish taxon (*Scaphirhynchus albus* pallid sturgeon), and one plant taxon (*Lindera melissifolia* pondberry). These six Federally-listed aquatic taxa of the Lower White River Basin represent one quarter of such species documented within Arkansas. Of all aquatic taxa, mussels comprise most of the statewide Federal listings, with at least fourteen species. However, one of these, *Epioblasma turgidula* (turgid blossom), is considered extirpated from the state (Bill Posey, personal communication, January 3, 2014) and most likely extinct throughout its historic range (Haag 2012: Table 10.1 pg. 333). Also statewide, there are four Federally-listed fish taxa, including *Etheostoma moorei* (yellowcheek darter) which is endemic to the upper Little Red River drainage within the White River Basin. Other Federally-listed aquatic taxa include: *Cambarus zophonastes* (cave crayfish), *C. aculabrum* (cave crayfish), and *Cryptobranchus alleganienses bishopi* (Ozark hellbender).

Similarly, the ANHC identifies 59 "special concern" aquatic taxa as occurring in, or as being reported from, the Lower White River Basin (Table 12). The "special concern" status indicates that these species are listed as Federally threatened or endangered, state threatened or endangered, or of conservation concern and warrant active inventory efforts. These species include 21 fish taxa, 18 mussel taxa, 7 crustacean taxa, 6 amphibian taxa, 5 reptile taxa, 1 insect taxon, and 1 plant taxon (Table 12). Of the 59 "special concern" aquatic taxa, 21 have been identified as potentially occurring within or in proximity to DBWRNWR boundaries (Table 13).

Table 12. Aquatic Elements of Special Concern, Lower White River Watersheds. [Source: ANHC 2014a].

Scientific Name	Common Name	Federal Status	State Status	Global Rank	State Rank
Animals-Invertebrates					
Allocrangonyx hubrichti	Hubricht's long-tailed amphipod	-	INV	G2G3	S1?
Caecidotea brevicauda	an isopod	-	INV	GNR	S1
Caecidotea foxi	an isopod	-	INV	GNR	S1
Crangonyx obliquus	an amphipod	-	INV	G5	S3?
Cyprogenia aberti	western fanshell	-	INV	G2G3Q	S2
Lampsilis abrupta	pink mucket	LE	SE	G2	S2
Lampsilis siliquoidea	fatmucket	-	INV	G5	S3
Leptodea leptodon	scaleshell	LE	SE	G1G2	S1
Ligidium elrodii	an isopod	-	INV	G4G5	S2
Ligumia recta	black sandshell	-	INV	G4G5	S2
Lirceus louisianae	an isopod	-	INV	GNR	S1
Macrobrachium ohione	Ohio shrimp	-	INV	G4	S1?
Obovaria jacksoniana	southern hickorynut	-	INV	G2	S2
Obovaria olivaria	hickorynut	-	INV	G4	S3
Pleurobema cordatum	Ohio pigtoe	-	INV	G4	S1
Pleurobema rubrum	pyramid pigtoe	-	INV	G2G3	S2
Potamilus alatus	pink heelsplitter	-	INV	G5	S1
Potamilus capax	fat pocketbook	LE	SE	G2	S1
Quadrula apiculata	southern mapleleaf	-	INV	G5	S2
Quadrula cylindrica cylindrica	rabbitsfoot	LT	SE	G3G4T3	S2
Quadrula metanevra	monkeyface	-	INV	G4	S3S4
Somatochlora ozarkensis	Ozark emerald	-	INV	G3	S1
Toxolasma lividum	purple lilliput	-	INV	G3Q	S2
Uniomerus declivis	tapered pondhorn	-	INV	G5Q	S2
Uniomerus tetralasmus	pondhorn	-	INV	G5	S2
Villosa lienosa	little spectaclecase	-	INV	G5	S3
Animals-Vertebrates					
Acipenser fulvescens	lake sturgeon	-	INV	G3G4	S1
Ambystoma talpoideum	mole salamander	-	INV	G5	S3
Ammocrypta clara	western sand darter	-	INV	G3	S2?
Anguilla rostrata	American eel	-	INV	G4	S3
Atractosteus spatula	alligator gar	-	INV	G3G4	S2?
Chrysemys dorsalis	southern painted turtle	-	INV	G5	S3
Crystallaria asprella	crystal darter	-	INV	G3	S2?
Cycleptus elongatus	blue sucker	-	INV	G3G4	S2
Deirochelys reticularia miaria	western chicken turtle	-	INV	G5T5	S3
Desmognathus conanti	spotted dusky salamander	-	INV	G5	S1
Erimyzon sucetta	lake chubsucker	-	INV	G5	S2?
Etheostoma fusiforme	swamp darter	-	INV	G5	S2?
Etheostoma parvipinne	goldstripe darter	-	INV	G4G5	S2
Hiodon alosoides	goldeye	-	INV	G5	S2?
Hyla avivoca	bird-voiced treefrog	-	INV	G5	S3
Lethenteron appendix	American brook lamprey	-	INV	G4	S2?
Lithobates areolatus circulosus	northern crawfish frog	-	INV	G4T4	S2
Moxostoma pisolabrum	pealip redhorse	-	INV	G5	S2?

Scientific Name	Common Name	Federal Status	State Status	Global Rank	State Rank
Mugil cephalus	striped mullet	-	INV	G5	S1?
Nerodia cyclopion	Mississippi green watersnake	-	INV	G5	S3
Notropis maculatus	taillight shiner	-	INV	G5	S3
Notropis sabinae	sabine shiner	-	INV	G4	S2?
Noturus flavus	stonecat	-	INV	G5	S1
Phenacobius mirabilis	suckermouth minnow	-	INV	G5	S1
Platygobio gracilis	flathead chub	-	INV	G5	S1?
Polyodon spathula	paddlefish	-	INV	G4	S2?
Pseudacris illinoensis	Illinois chorus frog	-	INV	G5T3	S1
Regina grahamii	Graham's crayfish snake	-	INV	G5	S2
Regina rigida sinicola	gulf crayfish snake	-	INV	G5T5	S3
Scaphiopus holbrookii	eastern spadefoot	-	INV	G5	S2
Scaphirhynchus albus	pallid sturgeon	LE	SE	G2	S1
Umbra limi	central mudminnow	-	INV	G5	SH
Plants-Vascular					
Zannichellia palustris	horned-pondweed	-	INV	G5	S2S3

Table 13. Aquatic Elements of Special Concern, Dale Bumpers White River National Wildlife Refuge. [Source: ANHC 2014b].

Scientific Name	Common Name	Federal Status	State Status	Global Rank	State Rank
Animals-Invertebrates					
Cyprogenia aberti	western fanshell	-	INV	G2G3Q	S2
Lampsilis abrupta	pink mucket	LE	SE	G2	S2
Ligumia recta	black sandshell	-	INV	G4G5	S2
Obovaria olivaria	hickorynut	-	INV	G4	S3
Quadrula apiculata	southern mapleleaf	-	INV	G5	S2
Quadrula cylindrica cylindrica	rabbitsfoot	LT	SE	G3G4T3	S2
Quadrula metanevra	monkeyface	-	INV	G4	S3S4
Toxolasma lividum	purple lilliput	-	INV	G3Q	S2
Animals-Vertebrates					
Atractosteus spatula	alligator gar	-	INV	G3G4	S2?
Crystallaria asprella	crystal darter	-	INV	G3	S2?
Cycleptus elongatus	blue sucker	-	INV	G3G4	S2
Erimyzon sucetta	lake chubsucker	-	INV	G5	S2?
Etheostoma fusiforme	swamp darter	-	INV	G5	S2?
Hiodon alosoides	goldeye	-	INV	G5	S2?
Lethenteron appendix	American brook lamprey	-	INV	G4	S2?
Moxostoma pisolabrum	pealip redhorse	-	INV	G5	S2?
Mugil cephalus	striped mullet	-	INV	G5	S1?
Notropis maculatus	taillight shiner	-	INV	G5	S3
Notropis sabinae	sabine shiner	-	INV	G4	S2?
Polyodon spathula	paddlefish	-	INV	G4	S2?
Scaphirhynchus albus	pallid sturgeon	LE	SE	G2	S1

At this time, waters within the boundaries of DBWRNWR are not known to contain any Federally-listed aquatic taxa. However, several taxa are in proximity and the likelihood exists that refuge waters could contribute to the life history needs for some, or all, of these taxa. Single pink mucket specimens were documented in the main stem of the lower White River at RM 99 (Clarendon, AR) and RM 63.5 (Lambert's Landing Bend) (Christian 1995). This indicates that a relict population might exist within this reach of the river which meanders through the boundaries of DBWRNWR. Rabbitsfoot is one of the most recent mussel taxon to be listed (USFWS 2013d) and has been documented throughout much of the main stem of the White River that flows through adjacent refuge boundaries (Harris et al. 1997: Figure 14). Additionally, in 2010, the USFWS had a final rule and determined it necessary to list *S. platorynchus* (shovelnose sturgeon) as threatened due to similarity of appearance with *S. albus* (pallid sturgeon) (USFWS 2010b). This ruling applies to known sympatric waters for the two species. Recent efforts to track and monitor pallid sturgeon indicates that the species uses the lower, undammed reach of the Arkansas River. A small section of the DBWRNWR boundary borders this section of the Arkansas River. As additional studies are conducted or more species accounts documented, this ruling may eventually apply directly to the lower White River and associated tributaries, thereby directly affecting the refuge.

USFWS and AGFC biologists periodically sample for various aquatic biota within the White River Basin. Recent efforts have included monitoring for invasive species, sampling for species of concern, or reporting on the status and distribution of rare, threatened, or endangered species. For example, USFWS and AGFC have collaboratively been monitoring *Atractosteus spatula* (alligator gar) within the lower White River and in other basins where the species historically occurred. Monitoring efforts for aquatic invasive species, such as *Channa argus* (northern snakehead), are on-going since the initial confirmation of this species in 2008 in eastern Arkansas. Subsequent sampling within other waterbodies helped biologists identify the extent of the distribution of the species within Arkansas. In 2009, a large-scale control and containment effort was conducted in an attempt to reduce the population (Holt and Farwick 2009). After this effort, short- and long-term monitoring sites were established at northern snakehead "hot spots." Most of these sites were within tributaries of the Big Creek watershed. The confluence of Big Creek and White River is bordered by DBWRNWR. Additional aquatic invasive species known to be established in waters adjacent to and on the refuge include *Hypophthalmichthys molitrix* (silver carp), *H. noblis* (bighead carp), *Ctenopharyngodon idella* (grass carp), and *Cyprinus carpio* (common carp).

5.3.2 Groundwater

For the purposes of this WRIA, water quality and quantity sampling conducted at spring sites is included with groundwater monitoring information.

5.3.2.1 Groundwater Level Monitoring

Groundwater levels are monitored by a variety of agencies including USGS and the Arkansas Natural Resources Commission (ANRC). A very large number of irrigation wells have been sampled since concerns about the long-term sustainability of the alluvial aquifer first arose in the mid-twentieth century. As a result, the USGS lists 33,874 wells within the RHI. Well names are derived from the Public Land Survey System (PLSS) Section-Township-Range location of the well plus additional letter and number identifiers which subdivide the sections into increasingly specific quarters. For example, well 08S02W01CBA1 is located in section 1 of township 8 south, range 2 west. "CBA1" means that the well is the first well within the southwest ("C") quarter of section 1, which is further subdivided into quarter-quarters ("B" = southeast), each of which are further subdivided into quarter-quarter-quarters ("A" = northeast). Figure 28 depicts the quarter naming conventions within sections.

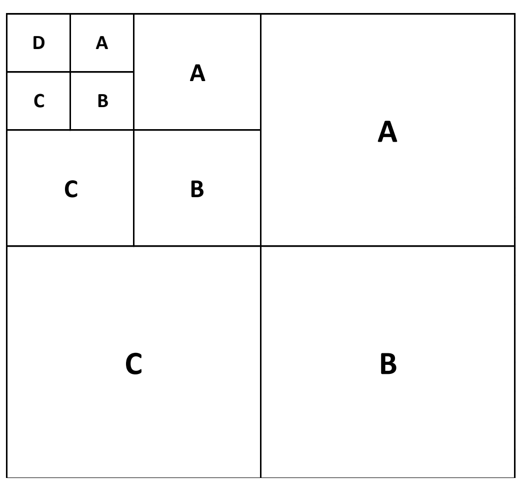


Figure 28. Illustration of naming conventions for section areal subunits.

The majority of these wells are located below the fall line, within the Mississippi Embayment aquifers. There are 19,817 monitored groundwater wells within the Lower White Basin. Of those, 4,142 are within ten miles of DBWRNWR; however, only 34 are located on the refuge. Ten of these wells have had groundwater level measurements conducted by USGS (Table 14, Figure 29). Sections 5.4.2 and 5.4.3 present data from historic and current groundwater monitoring studies conducted by USGS in the MAV and near DBWRNWR.

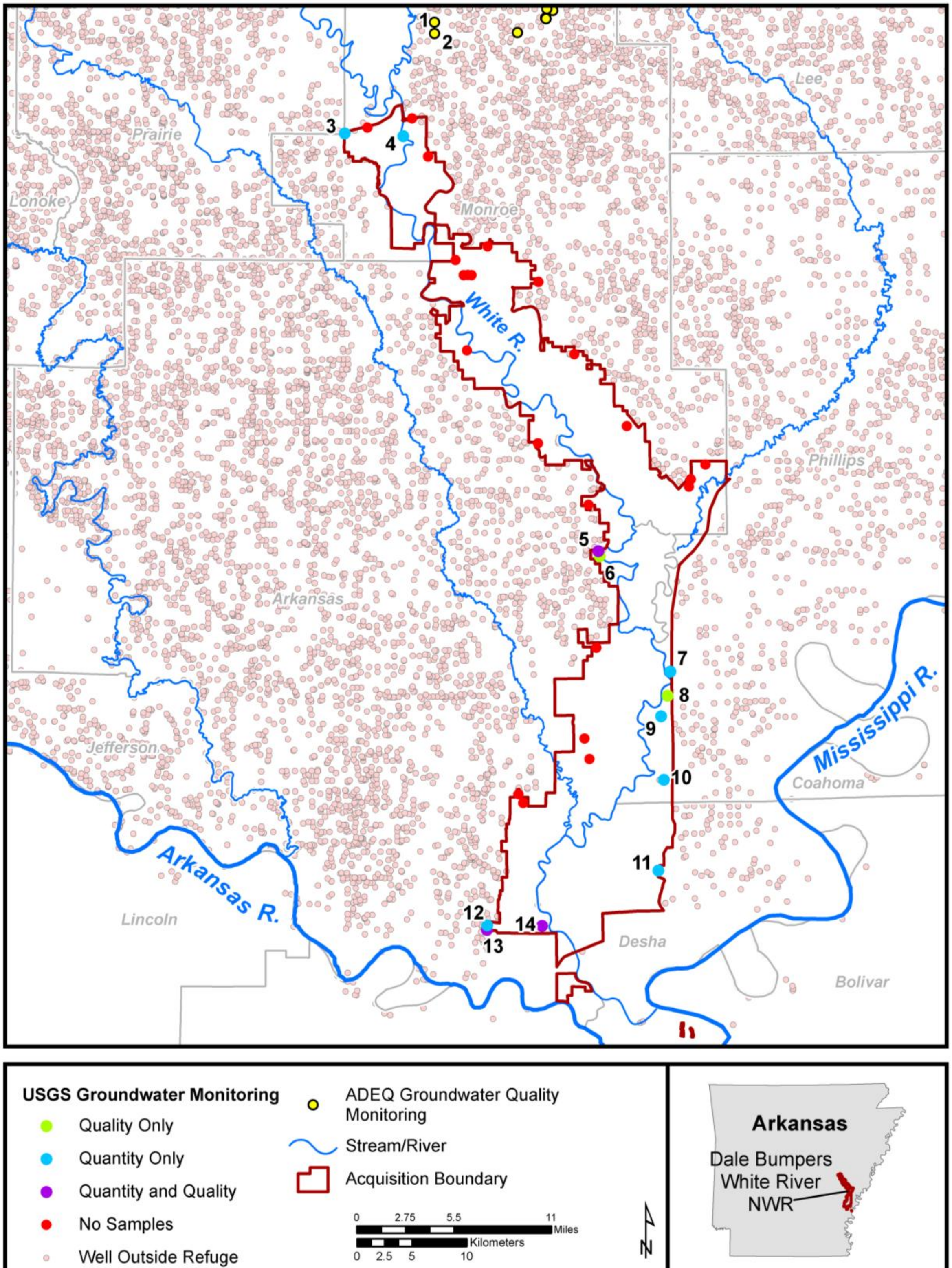
Table 14. Groundwater monitoring within and near Dale Bumpers White River National Wildlife Refuge. [Sources: ADEQ 2013; USGS 2013a].

# on Figure 29	Site ID	Name	Agency	Date Start	Date Stop	Ground-water Level Measure-ments	Quality Samples
1	MON325	Monroe County Irrigation Well 325	ADEQ	8/25/1998	7/5/2011		162
2	MON326	Monroe County Irrigation Well 326	ADEQ	8/25/1998	7/12/2011		162
3	344000091222701	01N03W30CCC1	USGS	3/16/1961	8/16/1962	15	
4	343949091185801	01N03W34BAB1	USGS	6/13/1967	7/15/1993	6	
5	341929091073901	04S01W28BAA1	USGS	6/2/1985	4/17/2013	17	4
6	341912091074301	04S01W28BAD1	USGS	2/10/1962	2/10/1962		27
7	341331091033901	05S01W25DAD1	USGS	1/25/1973	3/4/1974	6	
8	341221091035001	05S01W36DDD1	USGS	5/21/1968	12/21/1971		63
9	341121091041501	06S01W12BAB1	USGS	2/14/1973	4/1/1976	12	
10	340816091040901	06S01W25DBC1	USGS	3/8/1973	4/1/1976	6	
11	340351091043501	07S01W24CCA1	USGS	1/30/1973	4/1/1976	11	
12	340120091144601	08S02W04CBC1	USGS	10/16/1957	6/30/1971	918	
13	340107091144701	08S02W04CCC1	USGS	7/10/1957	3/19/1971	37	13
14	340116091113101	08S02W01CBA1	USGS	8/12/1966	3/25/1997	29	28

5.3.2.2 Groundwater Quality Monitoring

Within the RHI, USGS has measured groundwater quality at 812 locations. On the refuge, groundwater quality samples have been collected at five wells (Table 14, Figure 29).

ADEQ's groundwater quality monitoring includes ambient monitoring and research-oriented monitoring, such as investigations of pesticides in groundwater in eastern Arkansas, nutrient and bacteria transport in shallow aquifer systems in northwest Arkansas, and saltwater intrusion into shallow aquifers in south-eastern Arkansas. The ambient groundwater monitoring program was developed to document existing groundwater quality in various aquifers throughout the state. The monitoring program currently consists of 195 well and spring sites in twelve different monitoring areas within the state. Each area of the state is sampled every three years. The refuge is located closest to the Brinkley Monitoring Area, which encompasses the town of Brinkley and surrounding areas in northern Monroe County. The Brinkley Monitoring Area was last sampled in 2011 (ADEQ 2012). A full suite of inorganic parameters is analyzed for the samples, including all major cations, anions and trace metals. In areas where industry, landfills, and other facilities which store, manufacture or dispose organic chemicals, semi-volatile and volatile organic analyses are performed in addition to inorganic analyses. Similarly, areas with row-crop agriculture commonly include pesticide analyses. Within the RHI, there are 188 well monitoring sites and 46 spring sites. Of these sites, two sampling sites are at irrigation wells within five miles of the refuge acquisition boundary (MON325 and MON326, Site #1 and #2 in Table 14, Figure 29). It is noteworthy that although these sites should be sampled every three years according to program guidelines, there are only two sample dates (1998 and 2011) listed in the ADEQ online database for each well (ADEQ 2013). Detailed monitoring data for these sites is compiled in Appendix C.



Map Date: 3/18/2015 File: GW.mxd Data Sources: USGS Groundwater Stations; ADEQ Groundwater Monitoring Stations; NHD High Resolution Flowlines and Waterbodies, National Watershed Boundary Dataset HU-6 Boundaries, ESRI Map Service.

Figure 29. Groundwater monitoring on and near Dale Bumpers White River National Wildlife Refuge.

5.4 Water Quantity and Timing

5.4.1 Historical Streamflows

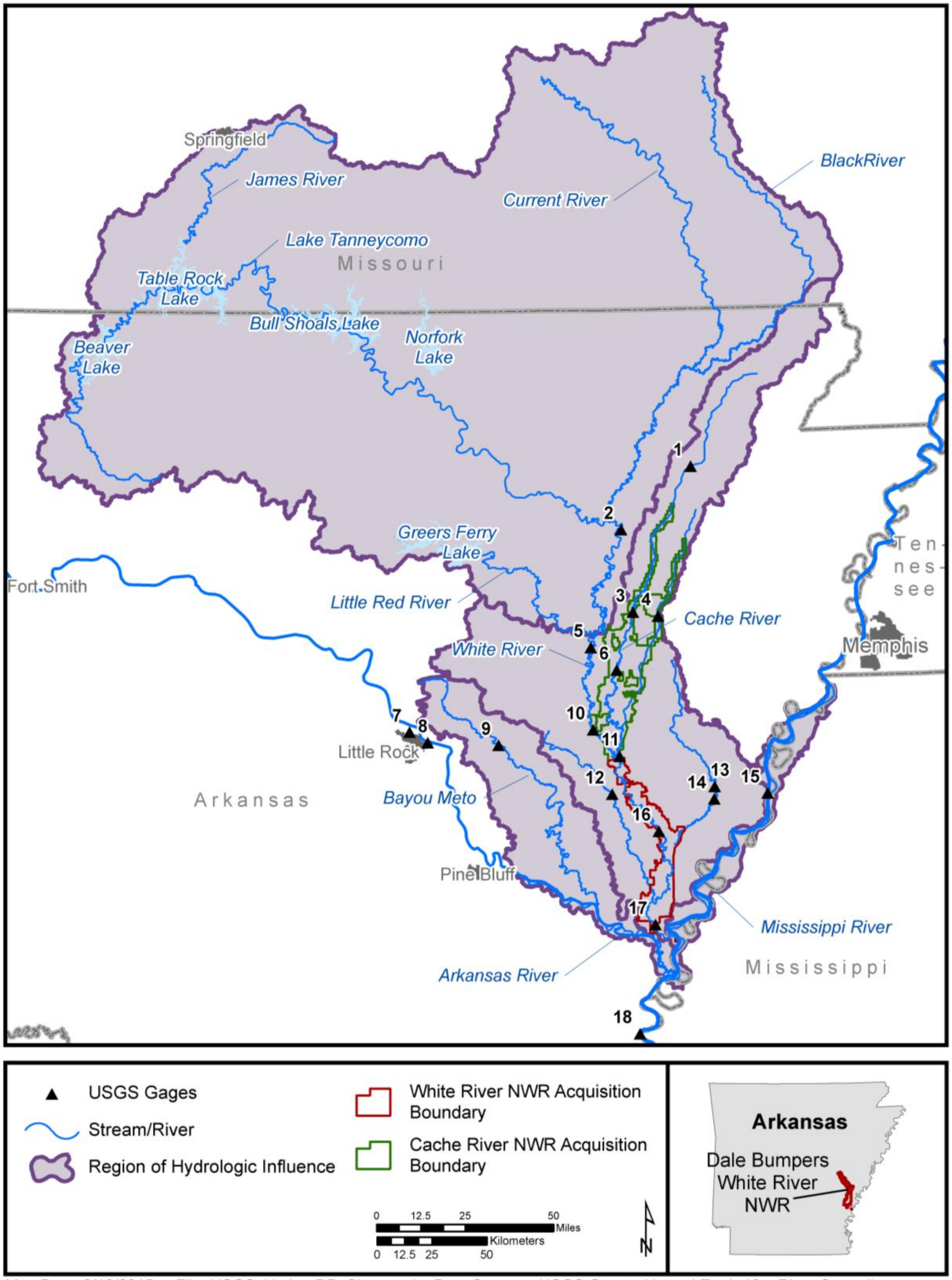
The Hydro-Climatic Data Network (HCDN) is a network of USGS stream gaging stations that are considered well suited for evaluating trends in streamflow conditions. Sites in the network have periods of record that exceed 20 years and are located in watersheds that are relatively undisturbed by surface water diversions, urban development, or dams.

There are no HCDN gages within the same 8-digit HU as the DBWRNWR. The closest HCDN gage is located on the Cache River in Egypt, AR; however, the fact that this gage is in a different HU renders data from this station unsuitable for analysis of hydrologic processes on DBWRNWR. The closest USGS gage to DBWRNWR within the same 8-digit HU is located on the White River at Clarendon, AR. The station has a period of record from 1928 to 1981. Historical streamflow data from this station are presented in Section 4.7.1.3.

In 2012, the USGS constructed a hydrologic database containing detailed streamflow information and analysis for 26 gage sites in contributing watersheds for Cache River NWR and DBWRNWR (Table 15, Figure 30; Buell et al. 2012). Appendix D details the periods-of-record for gage height and discharge for these stations.

Table 15. U.S. Geological Survey (USGS) surface water quantity monitoring sites within the region of hydrologic influence (RHI) used in USGS hydrologic database. [Source: Buell et al. 2012].

# on Figure 30	USGS Station Number	Station Name	8-digit Hydrologic Unit	Drainage Area (mi²)
1	07077380	Cache River at Egypt, AR	08020302	701
2	07074500	White River at Newport, AR	11010013	19900
3	07077500	Cache River at Patterson, AR	08020302	1040
4	07077700	Bayou DeView near Morton, AR	07077700	421
5	07076750	White River at Georgetown, AR	08020301	22400
6	07077555	Cache River at Patterson, AR	08020302	1170
7	07263450	Arkansas River at Murray Dam near Little Rock, AR	11110207	158138
8	07263500	Arkansas River at Little Rock, AR	11110207	136000
9	07264000	Bayou Meto near Lonoke, AR	08020402	207
10	07077000	White River at DeValls Bluff, AR	08020301	23400
11	07077800	WHITE RIVER AT CLARENDON, ARK.	08020303	25555
12	07078000	LAGRUE BAYOU NEAR STUTTGART, ARK.	08020402	175
13	07077950	BIG CREEK AT POPLAR GROVE	08020304	385
14	07077952	BIG CREEK NEAR POPLAR GROVE, ARK.	08020304	459
15	07047970	MISSISSIPPI RIVER AT HELENA, ARK.	08020100	937700
16	07077820	WHITE RIVER AT ST. CHARLES, ARK.	08020303	25732
17	07078300	WHITE RIVER AT BENZAL, ARK.	08020303	27743
18	07265450	MISSISSIPPI RIV NR ARKANSAS CITY, ARK.	08030100	1130600



Map Date: 3/18/2015 File: USGS_Hydro_DB_Sites.mxd Data Sources: USGS Gages, Natural Earth 10m River Centerlines, NHD Flowlines, National Watershed Boundary Dataset HU-6 Boundaries, ESRI Topo Service.

Figure 30. US Geological Survey (USGS) surface water quantity monitoring sites within the Region of Hydrologic Influence (RHI) used in USGS hydrologic database.

The hydrologic-data derivatives include statistical-summary data and hydrologic metrics as well as the Indicators of Hydrologic Alteration (IHA) parameters and Environmental-Flow Components (EFCs) (Richter et al. 1996; TNC 2009). The IHA software package was developed by Richter and The Nature Conservancy (TNC) to provide a tool for calculating the characteristics of natural and altered hydrologic regimes. This is accomplished through a series of statistics that are organized into parameter groups, which include the following categories: magnitude of monthly water conditions (I1), magnitude and duration of annual extreme water conditions (I2), timing of annual extreme water conditions (I3), frequency and duration of high and low pulses (I4), and rate and frequency of water condition changes (I5). There are also five EFC groups that relate hydrologic patterns to ecological function: monthly low flows (E1), extreme low flows (E2), high-flow pulses (E3), small floods (E4), and large floods (E5). Each parameter group category contains one or more statistical parameters. The hydroecological-flow characterization process, background and development of ecological-flow methodologies, and commonly used assessment techniques, including IHA and its application in this analysis, are discussed in detail in Buell et al. (2012).

The IHA and EFCs data for six stations in close proximity to DBWRNWR and with at least 20 years of discharge record were examined in greater detail to provide a summary of the issues affecting both NWRs within a regional context. These stations are 07077000 (White River at DeValls Bluff, AR), 07077380 (Cache River at Egypt, AR), 07077500 (Cache River at Patterson, AR), 07077555 (Cache River near Cotton Plant, AR), 07077700 (Bayou DeView near Morton, AR), and 07077800 (White River at Clarendon, AR) (Figure 30). In this analysis, stream discharge and gage height hydrologic data were used when available.

Table 16 summarizes the trends analysis results for station 07077800 (White River at Clarendon, AR). The table reports the IHA and EFC parameters exhibiting a significant trend at the $p \leq 0.025$ level over the period of record. A p-value of 0.025 was deemed significant (John Faustini, personal communication, September 19, 2013). All trends for gage height (period of record, 1886 – 2009) and flow (1929 – 1981) agree in direction. For example, analysis of the magnitude of monthly water conditions indicates significant upward trends for flow and gage height in August, September, and December. While the IHA method allows "estimation of the magnitude of impacts but does not enable strong inferences regarding the cause" (Richter et al. 1996), higher flows in August could be the result of unseasonal runoff of surplus water from irrigation. Some areas (particularly the Cache subbasin) suffer from unseasonal surplus drainage from agricultural fields during what historically would have been the driest time of the year (Jason Phillips, USFWS, personal communication, May 23, 2013). Small flood duration and small flood fallrate, however, indicate significant positive trends for flow but with smaller p values for gage height. Potentially, dredging of the White River at Clarendon could affect the strength of the trend in these parameters as indicated by gage height. Nearly all parameters demonstrated an increasing trend; however, significant decreasing trends in 1-day maximum flows, low pulse duration, rise rate and extreme low frequency were identified at the station.

Table 16. Significant trends at station 07077800 (White River at Clarendon, AR). [Source: Buell et al. 2012].

Parameter	Trend	p value (Gage height)	p value (Flow)	Parameter Group
December	increasing	0.01	0.025	I1: Magnitude of monthly water conditions
August	increasing	0.001	0.005	
September	increasing	0.001	0.005	
1-day minimum	increasing	0.001	0.001	I2: Magnitude and duration of annual extreme water conditions
3-day minimum	increasing	0.001	0.001	
7-day minimum	increasing	0.001	0.001	
30-day minimum	increasing	0.001	0.001	
90-day minimum	increasing	0.001	0.001	
1-day maximum	decreasing	0.05	0.05	
Base flow index	increasing	0.001	0.001	
Low pulse duration	decreasing	0.001	0.025	I4: Frequency and duration of high and low pulses
Rise rate	decreasing	0.005	0.05	I5: Rate and frequency of water condition changes
Number of reversals	increasing	0.001	0.001	
August Low Flow	increasing	0.001	0.005	E1: Monthly low flows
September Low Flow	increasing	0.001	0.05	
Extreme low freq.	decreasing	0.001	0.01	E2: Extreme low flows
High flow duration	increasing	0.01	0.05	
High flow fall rate	increasing	0.025	0.05	E3: High-flow pulses
Small Flood duration	increasing	0.25	0.005	E4: Small floods
Small Flood fallrate	increasing	0.5	0.05	
Large flood duration	increasing	0.05	0.005	E5: Large Floods

5.4.2 Historical Groundwater

Ackerman (1996) developed a hydrologic budget and predevelopment regional potentiometric surface for the alluvial aquifer. Model simulations indicate that, prior to development and the advent of pumping, groundwater in the alluvial aquifer generally followed the land surface slope southward down the Mississippi River Valley, and toward major rivers. Based on this model, surface water features such as rivers would have received most of the predevelopment outflow from the alluvial aquifer.

Pumping of groundwater from the alluvial aquifer for the cultivation of rice began in the Grand Prairie and Cache areas in the early twentieth century. Throughout the aquifer, pumping rates have generally increased, with large increases in the early 1950s and between 1973 and 1982 (Ackerman 1996), and from the early 1990s to 2000 (Schrader 2006; Clark and Hart 2009).

By the early 1980s, water levels had declined from 60 to 90 feet in wells in the alluvial aquifer in the Grand Prairie and Cache River areas (Ackerman 1996; Renken 1998). These areas most likely saw earlier and larger well drawdowns as compared to other areas within the MAV due to a combination of sustained history of groundwater extraction and the local thickness of the confining unit (Ackerman 1996). Water levels generally declined throughout both areas except for near rivers, an indication that, in a reversal of predevelopment conditions, surface water features were recharging the alluvial aquifer. Figure 31 shows close agreement between hydrographs from stream gages on the White (A) and Cache (B) rivers and those taken from nearby wells, indicating linkage between surface water features and the alluvial aquifer in these areas.

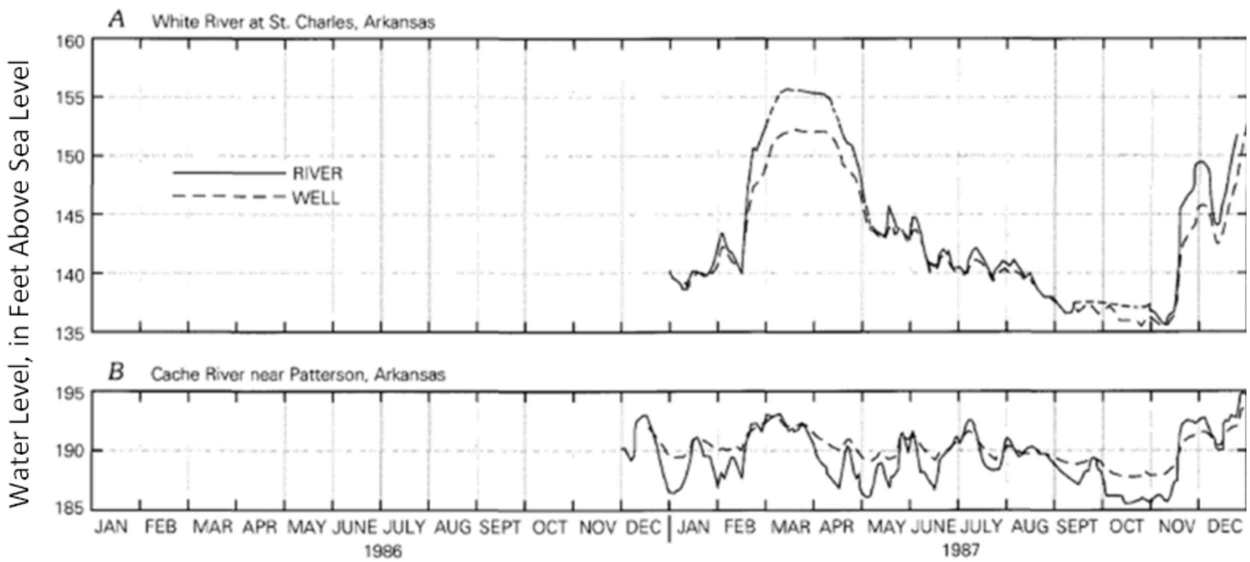


Figure 31. Hydrographs showing water levels for wells within the alluvial aquifer and nearby rivers within the RHI. Modified from Ackerman 1996.

Konikow (2013), citing work from the Mississippi Embayment Regional Aquifer Study MERAS (Clark and Hart 2009), estimates that groundwater withdrawals have increased 132% in the agricultural areas of Arkansas from 1985 to 2000. Total net volumetric depletion for the entire Mississippi Embayment aquifer system between 1900 and 2008 is estimated at 182 cubic kilometers (km^3) (44 cubic miles (m^3)). The most dramatic depletion rates are estimated to have occurred between 1991 and 2000 (5.9 km^3/yr; 1.4 m^3/yr) and between 2001 and 2008 (8.1 km^3/yr; 1.9 m^3/yr).

As demand from the alluvial aquifer increased and yields decreased, the deeper Sparta aquifer was increasingly used for irrigation. Like the alluvial aquifer, predevelopment lows in the predevelopment potentiometric surface were located only in areas of natural groundwater discharge. The location of potentiometric lows has changed and now depressions are in areas with large withdrawals from wells. Water now tends to flow to the southwest, toward major pumping in the Grand Prairie area (Renken 1998). Additionally, large withdrawal rates from the middle Claiborne aquifer have induced downward leakage of water into the middle Claiborne aquifer from the upper Claiborne and the Mississippi River Valley alluvial aquifers (Renken 1998). Appendix E includes groundwater modeling results for the alluvial and Middle Claiborne aquifers which detail locations of potentiometric (i.e. water level) lows.

In 2008, the USGS released previously unpublished historic aquifer test data for 206 tests within 21 hydrogeologic units in 51 counties in Arkansas. These data include 32 tests on wells in alluvium/terrace deposits of the alluvial aquifer and the Sparta aquifer, conducted between 1942 and 1988, that fall within the RHI (Pugh 2008). Descriptive statistics were reported for hydrologic units with 2 or more tests. However, considering the increases in pumping rates which took place within the RHI during the range of testing dates, statistics computed based on groupings of sites may not be representative, as aquifer parameters (especially transmissivity and storage coefficient) could be changing significantly over time as water levels have declined. Table 17 details data released for wells within the RHI. Multiple methods were used to calculate transmissivity, storage coefficient, and other factors; see Table 2 in the full report for details on specific methods used for each test.

Table 17. U.S. Geological Survey (USGS) aquifer test data for sites within the Region of Hydrologic Influence (RHI). Modified from Pugh 2008.

USGS Site ID	Year	County	Discharge[1]	Static Water Level[2]	Water-level Drawdown[3]	Specific Capacity[4]	Transmiss-ivity[5]	Hydraulic Conductivity[6]	Storage Coefficient[7]
Alluvium									
340704091145101	1942	Arkansas	570	--	--	--	14700	--	0.018
342742091260401	1955	Arkansas	725	--	--	--	122000	--	0.034
345833091512002	1955	Lonoke	450	--	2.63	171	12000	--	0.0016
350551091060101	1955	Woodruff	1400	--	--	--	32000	--	0.01
350551091060101	1970	Woodruff	1300	46.38	13.79	94.3	--	---	--
353120091021101	1971	Poinsett	1543	39.02	--	--	48000	--	0.001
345057091530001	1998	Lonoke	980	--	--	--	16500	300	0.004
345410091493401	1998	Lonoke	820	--	--	0.06	24000	400	--
342752091250101	--	Arkansas	650	--	--	--	44100	---	--
345506091502901	--	Lonoke	650	--	--	--	8610	166	--
362849090304501	--	Clay	--	--	--	--	30500	--	0.0011
Terrace									
345055092032401	1959	Lonoke	800	35	4.67	35	9400	--	0.04
345842091333601	1961	Prairie	890	--	--	--	17000	--	--
344901091143401	1961	Monroe	1200	--	--	--	24000	--	--
345313091114701	1962	Monroe	550	39.8	2.38	231	23000	--	0.00038
352829091114501	1964	Jackson	150	--	--	--	10600	--	0.08
352829091114501	1964	Jackson	--	17.89	0.56	--	--	--	--
351643091201501	1969	Woodruff	1510	--	--	--	41000	--	--
355035091103401	1969	Jackson	1080	--	--	--	41700	--	0.0041
360112090423501	1969	Greene	1570	--	--	--	19400	--	0.001
351643091201501	1969	Woodruff	20	24.11	9.9	2.02	--	--	--
355035091103401	1970	Jackson	954	23.3	1.32	723	--	--	--
360112090423501	1970	Greene	1580	54.73	7.26	218	--	--	--
342916091005801	1972	Phillips	1080	19.06	2.61	414	34000	--	0.001

USGS Site ID	Year	County	Discharge[1]	Static Water Level[2]	Water-level Drawdown[3]	Specific Capacity[4]	Transmiss-ivity[5]	Hydraulic Conductivity[6]	Storage Coefficient[7]
Sparta Sand									
342754090362101	1966	Phillips	550	--	--	--	7100	--	--
343324090545401	1966	Phillips	532	--	--	--	5700	--	0.0004
345618091150901	1976	Monroe	1000	11.64	2.28	439	14000	--	0.0008
945616091150201	1977	Monroe	750	12.15	4.57	164	14000	--	0.0004
342321091295501	--	Arkansas	2250	37	11	205	1700	--	--
342632091322701	--	Arkansas	1460	--	--	--	19100	--	--
342839091303201	--	Arkansas	1150	--	--	--	17400	--	--
345313091101401	--	Monroe	--	--	--	--	31000	--	--

1 = gallons per minute
2 = feet below surface
3 = Static level – Production level in feet
4 = gallons per minute per foot
5 = square feet per day
6 = feet per day
7 = dimensionless
-- indicates no data provided

5.4.3 *Current and Projected Future Groundwater Resources*

Each year, according to the requirements of Act 154 of 1991, the ANRC prepares Groundwater Protection and Management reports. The 2013 report covers water level data from 469 wells from spring 2011 to spring 2012 and also evaluates water level trends over the past 10 years (ANRC 2013a).

Of the wells monitored in the alluvial aquifer, 52.9% showed declines in static water levels over the reporting period. During irrigation season (March to October 2011) the average drawdown was -2.93 feet. Given an average recharge of 2 feet during the fall and winter months, the long-term historical drawdown rate is 1 foot per year. Precipitation rates were average during the reporting period (as opposed to 2012 when drought was exceptional). When examining the data from the last decade, more than three-quarters of the wells monitored (76.3%) showed declines. Arkansas County experienced the second highest drawdown rate (-0.33 feet) of the counties within the Grand Prairie Study Area and was the third highest user of water from the alluvial aquifer in the state in 2009 (ANRC 2013a; Table 18). Additionally, there was a small portion of northern Desha County with average declines of -3 to -2 feet (ANRC 2013a: Figure 5).

In the Sparta-Memphis sands aquifer, 52.9% of the wells sampled showed declines. The average decline in the Grand Prairie Study Area was -0.58 feet; however, wells in north-central Arkansas County experienced substantially greater declines (average of -2.74 feet). Arkansas County was the second highest user of water from the Sparta-Memphis sands aquifer in the state in 2009 (ANRC 2013a; Table 18).

Table 18. 2009 agricultural irrigation withdrawals of groundwater in counties encompassing Dale Bumpers White River National Wildlife Refuge.
[Source: USGS data published in ANRC 2013a].

	Alluvial aquifer		**Sparta-Memphis Sand**	
County	**Mgal/day**	**# of wells**	**Mgal/day**	**# of wells**
Arkansas	337.76	2097	36.58	174
Desha	272.03	1968	--	--
Monroe	267.89	2236	--	--
Phillips	243.60	1927	--	--

Monthly water use statistics (groundwater and surface water), based on applications reported to the ANRC, are available by county and by 8-digit HUC (up to 7 HUCs at a time) by querying the Aggregated Water-Use Data System (ANRC and USGS 2014). An initial search for the four counties encompassing the refuge showed 1,576,532.66 acre-feet of groundwater were reported in 2012, the most recent annual report.

The USGS also monitors water levels in the alluvial aquifer (Section 5.3.2.1). The most recent USGS report, based on water levels in 2004, measured water levels in 684 wells in the alluvial aquifer (USGS/ANRC measured 361; NRCS measured an additional 337), and constructed a map of change in the potentiometric surface of the aquifer from similar data collected in 2000. Wells were sampled in Arkansas (28), Desha (4), Monroe (6) and Phillips (3) counties; depths ranged from 32 to 181 feet. Most of the wells were irrigation wells sampled during pumping, but public supply and industrial wells were also sampled. Changes in water levels throughout the study area ranged from -31.1 feet in Prairie County to +16.3 feet in Arkansas County, with a mean change of -0.7 feet. Water level contours along the Arkansas and White Rivers indicated that the direction of flow within the aquifer was away from the rivers, an indicator that both rivers were losing flow to recharge the aquifer (Schrader 2006).

In addition to monitoring, the USGS conducts research to predict the effects of sustained pumping on aquifer yields and groundwater movement, as well as simulations to model the effects of changes in pumping rates and locations. Ackerman (1996) used 1985 pumping rates to project the sustainability of resources in the alluvial aquifer, and to estimate potential for areas suitable for an increase in groundwater pumping based on continuous pumping from 1982 to 2022. Some areas in the northwestern Grand Prairie area and adjacent to the west side of Crowley's Ridge were projected to be unable to support development, with modeled saturated thicknesses of less than 25 feet. Moderate to severe drawdowns (modeled saturated thicknesses of 50 to 75 feet or 50 to 25 feet) were predicted for areas along the White River between Grand Prairie and Cache (White, Woodruff, and Monroe counties). Areas east of the Southern Unit of DBWRNWR in Phillips and Arkansas Counties were described as "optimum for potential ground water development," where saturated thicknesses were modeled to be greater than 100 feet.

Gillip and Czarnecki (2009) updated a MODFLOW-2000 digital groundwater-flow model of the alluvial aquifer (Reed 2003) to include water use and water level data from 1995 to 2005 as a part of the model validation. Using 2005 water-use rates, they simulated two scenarios: one where current usage was applied through 2049 and one where 2005 water-use rates were increased 2% annually until 2049. The first scenario resulted in 779 square miles of "dry cells," areas where the aquifer was modeled to be completely dewatered with no water available for withdrawal. The second scenario resulted in 2,910 square miles of dry cells. In both scenarios, the dry cells were concentrated in the Grand Prairie area and Cache River area west of Crowley's Ridge, within the RHI.

A digital groundwater flow model for the Sparta Aquifer projected that maintained 1995 pumping rates would result in relatively minor (less than 10 feet) water level declines in the Grand Prairie area. The same model, using the 1980 through 1995 rate of pumping change and projected through 2027, predicted water level declines of 100 to over 200 feet in the Grand Prairie area (Hays et al. 1998).

An assessment of the role that pumping in Jackson and Woodruff Counties has on groundwater levels and flow rates into and out of counties located along the western side of Crowley's Ridge demonstrated the potential detrimental effects of groundwater withdrawals at the current rate on the alluvial aquifer (Reed 2003; Czarnecki 2010). Lower White Basin water-level fluctuations in the alluvial aquifer were shown to respond to climate variability. Groundwater-flow model results show a reduced capacity of the alluvial aquifer to produce water in new areas and indicate the vulnerability of groundwater and stream baseflow to climate change (Czarnecki and Schrader 2013). Simulation of future pumping from the Sparta aquifer in the Bayou Meto-Grand Prairie area of eastern Arkansas for the 30-year period from 2007 through 2037, indicates further potential for reductions in baseflow (Clark et al. 2011).

5.4.4 Hydrologic Alterations

5.4.4.1 Large Irrigation Projects

Due to declining water levels in the surficial alluvial aquifer and the deeper Sparta aquifer resulting from extensive drilling for agricultural irrigation in east-central Arkansas, a number of alternative irrigation projects have been proposed to alleviate pressures on groundwater resources. The Grand Prairie Area Demonstration Project (GPADP) was authorized in 2000 with the intended purpose of providing supplemental water for irrigation by storing excess surface water and importing water from the White River. The project area encompasses 362,662 acres of land in Arkansas, Prairie, Lonoke and Monroe counties to the west of the DBWRNWR. The specific components of the GPDAP include: improvements in on-farm water distribution systems and farm management practices to increase irrigation efficiencies; defining a "safe yield" for the Alluvial Aquifer to prevent further water level declines; supplementing existing on-farm reservoirs by converting an additional 8,849 acres (88,493 acre-feet) of cropland (primarily in soybean production) to storage reservoirs; and diverting 487,700 acre-feet of water annually from the White River northeast of DeValls Bluff to the tracts within the study area. The final component of the project includes construction of a 1,640-cfs pump station as well as distribution canals, pipelines, water control structures and other related infrastructure. In addition to required mitigation for habitat loss, the plan includes several environmental features, including increased seasonal flooding of harvested rice fields to benefit waterfowl; in-stream weirs to provide minimum pools for fish during irrigation withdrawals; and restoration of native tallgrass prairie vegetation (USACE 1999, 2009a).

Though construction of the on-farm features of the GPADP began in 2000, lawsuits filed by environmental groups led to significant project delays. In 2008, after addressing concerns about potential impacts to the ivory-billed woodpecker, the project was reinitiated (USACE 2009a, 2013a). As of August 2012 the project was approximately 23% complete, with elements of the pump station, approximately 250 on-farm storage reservoirs and over 200 tailwater recovery structures constructed (ANRC 2012), and pipeline construction is underway. Potential impacts of the project on the refuge include: altered hydrology of the White River from water diversions; potential off-refuge wetland impacts due to the construction of tailwater recoveries and storage reservoirs; enforcement of on-farm conservation measures; and increased agricultural runoff containing pesticides, fertilizers and heavy metals (USACE 1999, 2007a). The GPADP has the potential to reduce the stage of the White River by as much as one foot during certain times of the year, thus hydrologic and biological monitoring plans have been developed by the Corps to measure flow variability and assess impacts to bottomland hardwood forests such that operations can be adaptively managed (USACE 2007a). Additionally, a water quality monitoring program will be implemented to assess any impacts following project construction (USACE 1999).

The GPADP is not the only irrigation project with the potential to impact DBWRNWR; several other irrigation projects have been proposed that could exacerbate existing alterations to White River hydrology from navigation, irrigation and regulated flow releases (USACE 1999). These projects include the Little Red Irrigation Project and the North Prairie Irrigation Study (NRCS date unknown; Figure 32).

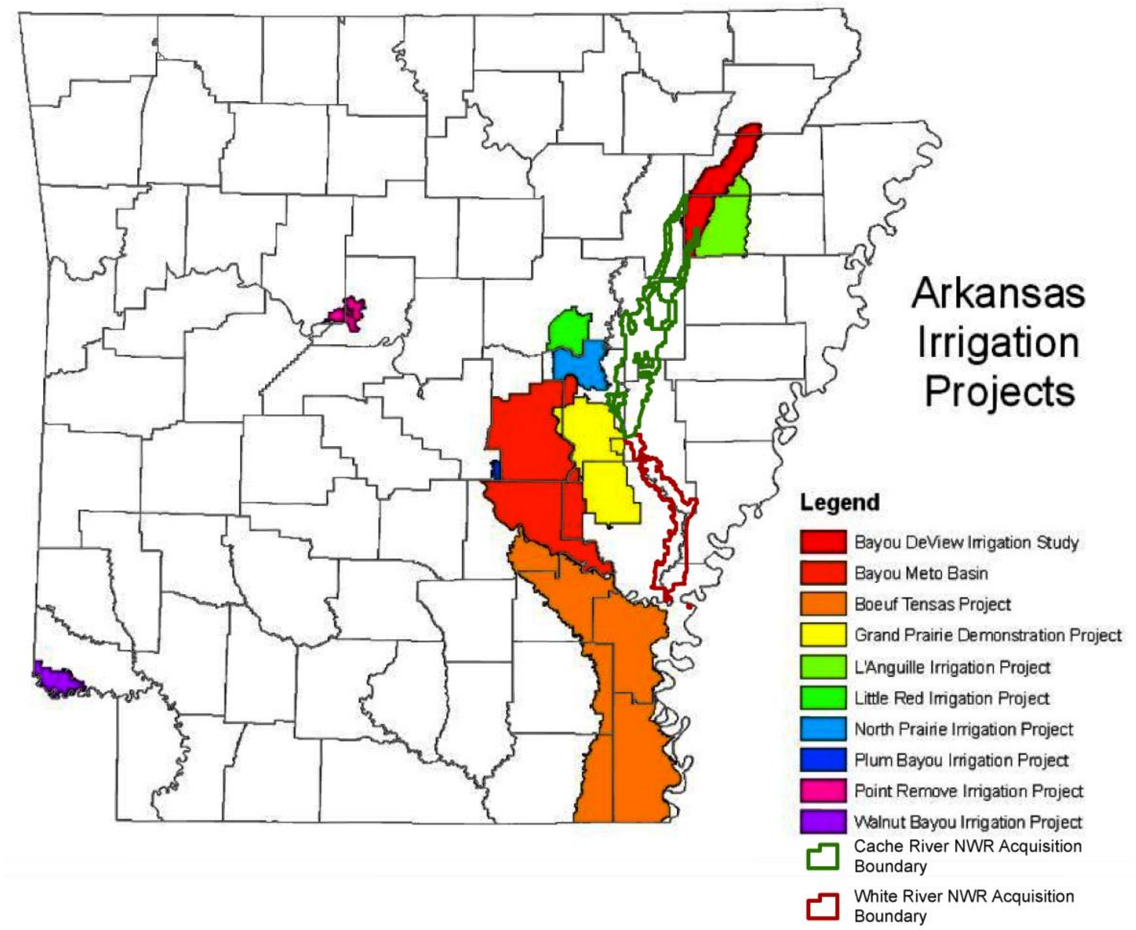


Figure 32. Location of Arkansas irrigation projects currently underway or being planned. [Source: NRCS date unknown].

5.4.4.2 Dams

In 1911, the United States Congress granted approval for the construction of the Powersite Dam on the White River at Ozark Beach by Empire Electric Company. When completed this structure created the 24-mile, approximately 2,100-acre Lake Taneycomo, which at the time was considered one of the largest impoundments of water in the United States for the production of electric power (Empire District Electric Company 2009). Since then three major reservoirs have been added on the upper White River (Bull Shoals 1951, Table Rock 1959, and Beaver Lake completed in 1966) and three on major tributaries to the upper White River—one each on the North Fork River (Norfork Lake 1944), the Black River (Clearwater Lake 1948), and the Little Red River (Greers Ferry Lake 1962) (Figure 33). These reservoirs were constructed by the Corps primarily for flood control and hydropower generation, but also for public water supply, recreation, and the ecological needs of fish and wildlife, under the authorization of various flood-control acts (USACE 2011a) and partly in response to the catastrophic floods of 1915, 1927, and 1937 (Arkansas Studies Institute 2011). Together these USACE dams impound 5,364,700 acre-feet of water for flood control and another 4,616,200 acre-feet for power generation (USACE 2013b). These large dams alter the magnitude, frequency, duration, and timing of hydrologic events on the White River which in turn affect species in the NWR; dam releases often result in higher flows and longer periods of inundation in bottomland hardwood forests. Releases take approximately one week to affect the refuge and their timing, in association with flooding from the Mississippi River, is a critical component of the stage and duration of flood events on the refuge (USFWS 2012).

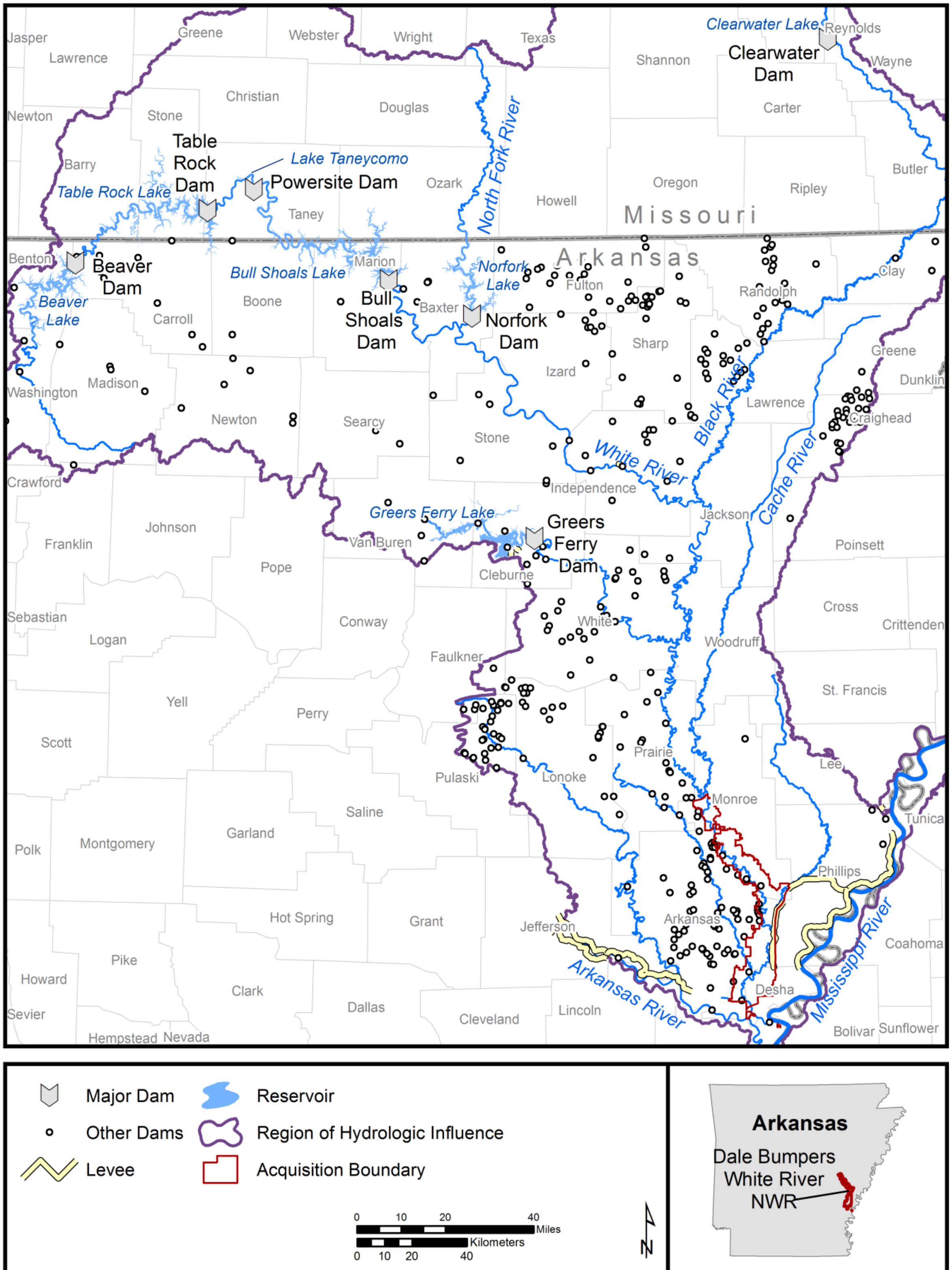
However, the large dams are only part of the story. The White River RHI contains a total of 399 dams built primarily for recreation, but also performing flood protection and irrigation functions (USACE 2013c; USGS 2013b) which alter hydrology on a more local scale. The majority of the dams in the RHI store less than 200 acre-feet of water and the vast majority are privately owned. Though separate from the regulated flows from the larger dams (USACE 1998), the smaller dams can aggravate the changes in the timing, frequency, and magnitude of flows from regulation at upstream dams including higher periodic flows, longer periods of inundation for bottomland hardwood communities in the NWR along with corresponding low baseflows.

5.4.4.3 Navigation

The White River has been maintained as a navigation channel since 1892 through dredging and snagging. In 1960 the Rivers and Harbors Act authorized deeper dredging that is dependent on gage readings at Clarendon, AR. Currently the White River is maintained at 8 feet deep and 125 feet wide from its mouth to Augusta, AR (RM 198) when the Clarendon gage is 12 feet or greater or 5 feet when the gage is below 12 feet. Additionally, the channel is dredged to 4.5 feet from Augusta to Newport, AR (RM 255). Annual maintenance dredging is conducted between July and October (USACE 1999). The existing authorization only provides barge access to Newport about 50% of the year; thus, several proposals have been made to improve navigation by conducting deeper dredging (USACE 2009a). The Water Resources Development Act (WRDA) of 1986 authorized enlargement to 9 feet in depth and 200 feet in width, which would allow barge traffic 95% of the year from the Arkansas Post Canal to Newport (USACE 2009a, 2009b). This project, currently known as the White River Navigation Improvement Project, has subsequently been deauthorized, modified and reauthorized several times, with the most recent plan consisting of a bottom width of 125 feet and a depth of 9 feet. Planning studies are still underway (USACE 2009b); however, the White River was last dredged in 2009 (at critical crossings only) and no future maintenance activities are scheduled due to insufficient funding levels (USACE 2013d). The White River averages two barge trips per week, exclusively for grain shipments, between December and April (USFWS 2012).

The Arkansas Post Canal was constructed along a natural connection between the Arkansas and White rivers in order to expedite barge traffic (Figure 25) (USFWS 2012). The canal is part of the McClellan-Kerr Arkansas River Navigation System (MKARNS), a 445-mile navigation channel constructed between 1963 and 1970 that spans from the Montgomery Point Lock and Dam on the White River to the confluence of the Arkansas and Verdigris rivers near Tulsa, Oklahoma (USACE undated-a,b; American Canal Society 2006). The Arkansas Post Canal is located at the southern end of the refuge and extends from White River RM 10 to the Arkansas River (USFWS 2012). It is 300 feet wide and a minimum of 9 feet deep and includes two locks, Lock 1 (i.e., Norell; RM 10.3) and Lock 2 (RM 13.3). The Arkansas Post Canal averages 15 tows per day throughout the year. The Montgomery Point Lock and Dam was installed to allow barge traffic to enter the White River during periods of low flow in the Mississippi River. Annual dredging is required to maintain the 12-foot minimum depth where the White River joins the Arkansas Post Canal (USFWS 2012).

Prior to creation of the Arkansas Post Canal, the White River naturally flowed into the Arkansas River through a historic cutoff; however, this cutoff was closed because of dangerous cross-currents that adversely impacted navigation. During certain hydrologic events (e.g., when Arkansas River levels are lower than those of the White River) headcutting has occurred as the rivers try to re-establish that connection. If a full breach between the rivers formed there would be substantial loss of bottomland hardwoods and wetlands, as well as severe disruption to navigation on the MKARNS. The Corps conducted a feasibility study between 1999 and 2009 to evaluate long-term solutions, but it did not produce an alternative that was both economically and environmentally viable. The plan with the greatest net benefit required raising the levee by 5 feet and would require USFWS land; however, the purpose of the project is not compatible with USFWS land uses. Currently the Corps is continuing to operate and maintain the structures, including the Melinda structure, and make repairs as failures occur, but a long-term solution is still needed (Figure 25). The USFWS and USACE have proposed a Three Rivers Reconnaissance Study to evaluate long-term solutions that are compatible with and provide benefits to navigation, aquatic ecosystem restoration and recreation uses. They are also seeking to add ecosystem restoration to the MKARNS project authority (USACE 2013e, 2014).



Map Date: 3/18/2015 File: Major_Dams_Levees.mxd Data Sources: ANRC Dams and Levees, NHD High Resolution Flowlines and Waterbodies, National Watershed Boundary Dataset HU-6 Boundaries, ESRI Topo Service.

Figure 33. Major dams, reservoirs and levees within the Region of Hydrologic Influence (RHI).

Additionally, the Mississippi River is entrained into an unnaturally narrow channel for navigation, causing it to downcut the channel bed and flow at lower elevations during moderate to low flow periods. During low flow periods, the Mississippi River may be unnaturally draining the White River and its tributaries, causing down-cutting, bank scouring and increasing the need for maintenance dredging (USFWS 2012). A comprehensive inventory of the problems caused by channel maintenance, with some specific to the refuge, and potential opportunities to address them is presented in the Summary Report of the Preliminary General Reevaluation Report for the White River Navigation Improvement Project (USACE 2003). Dredging has also created enormous headcutting on the White River and sloughs, particularly as a result of closing the historic cutoff between the Arkansas and White Rivers during construction of MKARNS. Overall, these navigation projects have altered the timing and frequency of flood events on the White River. Combined with the levee system described below, these alterations have resulted in more extensive, prolonged and deeper inundation at the southern end of the refuge. As mitigation for MKARNS, the USACE constructed a water delivery system that consisted of a series of delivery ditches. The system was originally designed to deliver water to Dry Lake via gravity flow from MKARNS at Lock B into Levee B impoundment; however, most of the delivery ditches are silted in as a result of agricultural operations on adjacent lands and this system not practical for delivering water to Dry Lake (USFWS 2012).

Until recently, dredged material from the entrance of the White River was disposed of on uplands at the southern end of the refuge; however, a long-term dredge disposal alternative was found to be necessary (USFWS 2012; CDM Smith and FTN Associates 2013). The current practice for disposing of material dredged from the White River is to slurry it into the Mississippi River (CDM Smith and FTN Associates 2013). However, there are still occurrences where spoil may be deposited on refuge lands. At the time of this writing, the Corps and refuge staff are working to determine a long-term solution.

5.4.4.4 Flood Control Levees

Following the devastating “Great Flood” of 1927, the Flood Control Act of 1928 authorized the USACE to undertake the Mississippi River and Tributaries (MR&T) project. The MR&T project includes levees for containing flood flows; floodways for diverting excess flows past critical reaches of the Mississippi River; channel improvement and stabilization; and tributary basin improvements such as dams, reservoirs and pumping plants. It is the largest flood control project in the world (USACE undated-c). In total, the MR&T includes 3,787 miles of embankments and floodwalls, of which 2,216 miles are along the mainstem Mississippi River (USACE 2007b).

The White River is enclosed by levees and/or uplands beginning approximately 8 miles from its mouth to approximately RM 50 (USFWS 2012). The White River backwater levee spans 40.2 miles along the eastern side of the refuge in Phillips and Desha counties (Figure 33). The system also includes two outlet structures, Little Island Bayou and Deep Bayou, which drain to the White and Mississippi rivers, respectively, as well as the Graham-Burke Pumping Station. The Little Island Bayou structure can be operated to control stages in the backwater area to benefit fish and wildlife. Construction of the White River backwater levee began in 1938 and it reached full grade and section in 1960. Along with the Mississippi River levee between Old Town and Laconia Circle, the White River backwater levee provides protection from White River flooding and backwater flooding from the Mississippi River (USACE 2008b). As part of mitigation for the White River backwater levee, the Corps operates the Graham Burke Pumping Station to hold water on a portion of the east side of the levee on refuge land during the fall and winter for waterfowl. Shortly after the pumping station was built, the Corps negotiated a lower water level than was originally agreed upon, resulting in less habitat for wintering waterfowl (Arthur Hitchcock, written communication, July 16, 2014).

The White River levee system has had the greatest impact of all modifications to the hydrology of the lower White River. The levee system constricts the floodplains of the White and Mississippi rivers, causing lower flows to result in higher elevations than they did prior to levee construction (USFWS 2012). Along with increased flood levels on the remaining floodplain, the levees lengthen the period of inundation and increase flow velocities within the mainstem of the river, which can accelerate river bed and bank scour (FHWA 2005). Other levees farther upstream on the White River protect towns and agricultural areas, including the White River Levee District levee from Augusta to Clarendon, AR which protects agriculture in Woodruff, Prairie and Monroe counties (USACE undated-d).

5.4.4.5 Cache River Channelization and Restoration

Beginning in the early 1900s and continuing until the early 1930s, local drainage districts channelized the upper portion of the Cache River basin, from Grubbs at the north end of the Cache River NWR acquisition boundary, to its headwaters (USFWS 2009b). In total, 89 miles of the upper Cache River and 65 miles of upper Bayou DeView have been channelized (Jason Phillips, USFWS, personal communication, May 23, 2013). The Flood Control Act of 1950 authorized the USACE to conduct the Cache River Basin Project as a feature of the MR&T project. The project plan included clearing, realignment and enlargement of 140 miles of the Cache River channel and 91 miles of tributary streams, including Bayou DeView, to facilitate agricultural drainage and prevent flooding. Construction began in the 1970s, but was stopped due to local opposition; however, by that time approximately seven miles of the lower Cache River had already been channelized, a portion of which lies within the Cache River NWR boundary (USFWS 2009b). Plugs were placed in upstream openings of at least six meanders, converting them from lotic to lentic habitats by isolating them from upstream riverine flow and causing them to experience the accumulation of deep fine sediment. Dredged material was deposited along the channelized reaches (USACE 2011b). The completed portion of the project did not affect flooding of the BLH forest and very little clearing occurred (USACE 2011b).

USACE and TNC have proposed to restore a portion of the channelized reach located in Monroe County, partially within the Cache River NWR boundary. The project involves removing plugs from the upstream end of the upper three meanders to reestablish the channel into a meander and using closure weirs to divert flow from the channel to the meanders (USACE 2011b). This project is intended to improve habitat for aquatic species, such as freshwater mussels, and help restore hydrologic function of the landscape and Cache/White River drainage (USFWS 2009b). A construction contract for the first phase of the project was awarded in March 2013 (USACE 2013f). Phase I was completed in the summer of 2014. Phase II awaits funding and has not been scheduled.

5.4.5 Arkansas Minimum Flows and Levels

5.4.5.1 Minimum Flow

Minimum flow in a river is generally defined as the minimum (not the most desirable) flow amount or lake level necessary to protect the fish and wildlife habitat, aquatic life, water quality, recreation, aesthetic beauty, navigation or transportation. As defined by ANRC (2009) minimum flow in Arkansas is "the quantity of water required to meet the largest of the following instream flow needs as determined on a case by case basis: 1) Aquifer recharge, 2) Fish and wildlife, 3) Interstate compacts, 4) Navigation, 5) Water quality" (ANRC 2009). Minimum flow is usually measured in elevation (feet above MSL) at a gage. During periods of water shortage, minimum streamflows may take priority over other uses and needs. However, minimum streamflow levels (elevations) do not ensure a specific streamflow (cfs) or compel flow augmentation from reservoirs, impoundments, or any other sources (ANRC 2009). Section 5.6 contains more detailed information on water law in Arkansas, including definitions of riparian rights and excess surface water, as well as how these laws may impact DBWRNWR.

Several minimum flows have been established within the White River Basin. The Water Resource Development Acts of 1999 and 2000 authorized increases in reservoir storage to provide for minimum flows on the White River in Beaver Lake (1.5 ft), Table Rock Lake (2 ft), Bull Shoals Lake (5 ft), Norfork Lake (3.5 ft) and Greers Ferry Lake (3 ft). A Reallocation Report in 2004 resulted in Section 132 of the Energy and Water Development Appropriations Act (EWDAA), which authorized implementation of the Bull Shoals and Norfork Lake minimum flows, but not on the other lakes and eliminated consideration of alternative plans. The authorized purposes of the minimum flows were to provide fish and wildlife enhancements while maintaining seasonal flood control, hydropower releases and recreational use on the lakes (USACE 2009c). Minimum flow releases below Bull Shoals dam began on July 4, 2013.

Below Bull Shoals Dam, Section 314 of the ANRC Rules for the utilization of Surface Water divides the White River into three reaches: Reach 1, from Bull Shoals to the Calico Rock gage; Reach 2, Calico Rock to the Newport gage, and Reach 3, from Newport to the confluence with the Mississippi River (Figure 34). Minimum flows have been established for registered riparian and permitted non-riparian use classes for each reach, allowing preference for registered riparian users through prolonged withdrawals (lower minimum flows) (Table 19). Minimum flow rules go into effect when registered riparian and non-riparian withdrawal levels exceed 300 cfs from the mainstem of the White River. When minimum flow rules are in effect, all out-of-stream withdrawals must cease when the representative gage drops below threshold levels designated for each class (ANRC 2009). Table 19 details minimum flows established for Reach 3, which flows through DBWRNWR.

Figure 34. White River reaches and gages governing withdrawals from the mainstem when minimum streamflow rules are effect for Bull Shoals dam. [Source: ANRC 2009].

Table 19. Minimum Streamflows for the White River from Newport to the confluence of the Mississippi River. [Source: ANRC 2009].

	Registered Riparian Use		**Non-Riparian Permit Holders**	
	Clarendon Gage level (ft)	Flow (cfs)	Clarendon Gage Level (ft)	Flow (cfs)
January	15.0	15,900	17.2	19,610
February	15.0	15,900	18.7	22,700
March	16.1	17,590	21.0	27,610
April	16.1	17,590	24.2	36,940
May	16.1	17,590	24.1	36,640
June	9.0	7,125	18.0	21,220
July	9.0	7,125	11.5	10,670
August	9.0	7,125	10.8	9,650
September	9.0	7,125	10.8	9,650
October	9.0	7,125	10.8	9,650
November	10.8	9,650	11.8	11,050
December	15.0	15,900	16.1	17,590

5.4.5.2 Instream Flow

Instream flow, which is synonymous with environmental or ecological flow, includes the concept that a regime of varying water flows and levels is necessary for aquatic ecosystems to function properly (Poff et al. 1997; Richter et al. 2003). The term may also be used specifically in law to denote water which is expressly dedicated to remain in the stream channel and which should not be diverted for other purposes. Optimum flow is used by some states and groups to describe a targeted “best” flow if environmental and habitat issues were the priority concern (SARP 2013). Instream flow is usually measured in cfs.

The Tennant method is one of the most common methods for establishing instream flows in the United States. It establishes different levels of flows based on the quality of physical habitat (depth and velocity) they provide (e.g., 10% of the mean flow as a minimum, 30% of mean flow as ‘satisfactory’) (Jowett 1997). Recognition that a minimum threshold was not sufficiently protective of aquatic habitats led to several states setting higher flow thresholds, such as by setting thresholds that vary seasonally (Richter et al. 2012). In 1987, AGFC established the “Arkansas Method” as their instream flow policy, which is used to inform permitting of surface water withdrawals to riparian users by the ANRC. The Arkansas Method sets seasonal minimum flows as: 60% of mean monthly flow (MMF) from November through March, 70% MMF from April through July, and 50% MMF or median monthly flow from July through October (SARP 2013). A combination of the Tennant and the Arkansas method currently define minimum flows in Arkansas.

Arkansas is in the process of updating its water plan with the possibility of addressing limitations in its current water allocation strategies by adopting an environmental flow approach (Poff et al. 2010) which could better address changes to the magnitude, frequency, duration, and timing of streamflow since the introduction of upstream dams. ANRC is currently working with AGFC, TNC, USGS and other agencies to replace the Arkansas Method with the Environmental Limits of Hydrologic Alteration (ELOHA) approach to establishing statewide environmental flows. Research intended to provide the scientific foundation for the environmental flow standards is currently underway; however, it will likely take ten or more years before empirical, risk-based ecological impact/flow relationships are available statewide (Fish and Wildlife Flows Subgroup 2013). Objectives of this research include classification of stream types based on hydrology and geomorphology, and the development of detailed regional-level hydrology-biology response relationships for the Ozarks (Magoulick 2011). For example, an important native refuge species, the paddlefish, *Polyodon spathula*, requires certain flows to cue spawning and other life-cycle behaviors. One goal of such an environmental flow approach would be to sustain native aquatic populations at the expense of nuisance species such as Asian carp.

In the interim, the Fish and Wildlife Flows Subgroup of the Arkansas Water Plan has advocated continued use of the Arkansas Method, with possible refinements, to inform safe yield and excess water calculations in the 2014 water plan. As there are no statutes, regulations or policies preventing the ANRC from adopting an implementing a new methodology for establishing instream flows, the Fish and Wildlife Flows Subgroup is currently developing a framework to guide the development and application of any new or refined methods to ensure it is scientifically and socioeconomically credible (Fish and Wildlife Flows Subgroup 2013).

Overall, the allocation of flows for fish and wildlife remains a low priority. According to the most recent information available, in 2010, water withdrawals for agricultural irrigation, livestock, and aquaculture accounted for 80% of water use in Arkansas (Maupin et al. 2014).

5.4.6 Land Use Activities Affecting Water Quantity and Timing

Hydrologic stresses on the refuge include those from historic land use activities and continued practices of hydropower regulation; channelization and ditching; agricultural, municipal, and industrial water use, both surface-water and groundwater withdrawal; dredging for navigation-channel maintenance; and climate variability (Buell et al. 2012).

Land use in the RHI has fundamentally altered historical flooding patterns. Increases in population since European settlement; the progression in the region from subsistence farming to large scale cash crops like cotton, rice, and soybeans; irrigation to support agriculture; and, beginning in the early 1900s, flood control work as well as large-scale power generation have left an indelible mark. The geomorphology of the entire LMAV has been affected by the addition of dams, dikes, revetments, and levees in three primary ways: (1) channel simplification and reduced dynamism, (2) lowering of channel-bed elevation, and (3) disconnection of the river channel from the floodplain and attendant loss of wetlands (Alexander et al. 2012). Drainage and land clearing, primarily for agricultural production, has reduced forest cover in the region to about 26% of the original extent in the LMAV (Gardiner and Oliver 2005). Hydrology in the LMAV has changed at large and small scales. As mentioned in Section 5.4.4, unnatural drainage of the White River by an artificially lowered Mississippi River is manifesting itself in down-cutting, bank scouring, and an increasing need for White River dredging to maintain navigation (USFWS 2012). Longstanding effects on the geomorphology, vegetation communities, hydrology, and soils of the basin from the anthropogenic landscape changes described in Section 4.6 may be irreversible for all practical purposes (Klimas et al. 2009).

The federal Flood Control Acts of 1944 and 1965 contained a policy of bottomland hardwood conversion, and the 1965 Act included as a part of its justification the induced clearing of 4.9 million acres in the LMAV (USFWS 2012). Much of this took place in the Cache River/Lower White River Basin. As described in Section 4.6, the LMAV has undergone the most widespread loss of bottomland hardwood forests in the United States.

In 1969, comparison of small-scale (1:125,000) aerial photographic imagery of the LMAV with conventional imagery of the region in 1950 identified major shifts in land use (Frey and Dill 1971). Cropland had replaced forest areas as the dominant land use. In 1969 cropland occupied 57% in the LMAV. Forest covered 31% and other uses (grassland, transitional, urban, and miscellaneous) accounted for 12% (Figure 35).

Less than two decades earlier, forest land predominated with 48%, and cropland ranked second with 41%. From 1950-1969 the LMAV gained 37% more cropland. Some 3.8 million acres of forest, 0.2 million acres of grassland, and 0.1 million acres of miscellaneous areas shifted to crop use. Offsetting these increases, 0.2 million acres of cropland reverted to forest and 0.2 million acres shifted to grassland, urban, and miscellaneous use. Grassland accounted for about 4% of the area in both 1950 and 1969. Large areas totaling 4.1 million acres were cleared during 1950 – 1969. Land was cleared at notably rapid rates (20% to 29% of total area) in Cross, Lawrence and Jackson counties (Frey and Dill 1971).

Currently, over 18% of the RHI consists of federal, state, or private conservation land including 23 USACE parks, three national forests, two national parks, and three NWRs. The Upper White subbasin is 59% forest, 30% pasture, 9% cropland and 2% other. The Lower White subbasin, conversely, is 73% cropland, 24% forest (approximately 43% of forest is public land), and 3% other (Jason Phillips, USFWS, personal communication, May 22, 2013; as modified from the National Land Cover Dataset 2006). The pace of land use conversion to agriculture in the RHI has slowed considerably since the early 1980s. Between 1992 and 2006, the Lower White subbasin lost approximately 5% of its agricultural land following a trend that holds for the entire Lower White Basin (Table 20). For the most part, losses of agricultural land were replaced by increases in urban land uses or other uses that differ from the pre-agricultural state. The refuge itself saw the lowest total change in land use with the largest change being from open water to wetland (Table 20).

The greatest current threat, to refuge biotic communities, results from alterations to the hydrologic regime occurring in the RHI beyond the refuge's border. Flow alteration and channel modification related to upstream reservoir operation, channel modification related to dredging, and agricultural water use are the primary current hydrologic stresses for the refuge (Buell et al. 2012). Maintaining natural variability is a critical strategy for sustaining the ecological integrity of refuge resources. The variability in streamflow which supported native aquatic species has become increasingly unsustainable within the context of current upstream water withdrawals and historic land use change in the RHI, particularly with respect to flood control and power generation. Between 2000 and 2006, conservation practices were applied to a combined total of 3.14 million acres in the LMAV; however, the loss of original hydrodynamics and connectivity with regional flows limits the restoration of ecosystem services (Faulkner et al. 2011).

Table 20. 2006 land use composition and land use change from 1992 to 2006 for the White River National Wildlife Refuge and the 8-digit hydrologic units of the analysis RHI. [Sources: 2006 National Land Cover Database (Fry et al. 2006), 1992 National Land Cover Database (Vogelmann et al. 2001)].

	2006 Land Use Composition[b,c]							Net Land Use Change from 1992 to 2006[d]							
Analysis Unit[a]	Water	Urban	Barren	Forest	Grassland	Agriculture	Wetland	Water	Urban	Barren	Forest	Grassland	Agriculture	Wetland	Total Percent Change[e]
Subbasin (8-digit HU)															
08020100	20.4	2.8	1.8	3.1	0.4	25.0	46.5	-0.6	2.2	0.1	0.5	0.4	0.3	-2.9	3.5
08020301	3.1	5.0	0.1	24.8	1.1	52.7	13.2	0.7	3.9	0.0	-3.8	1.1	-5.3	3.5	9.2
08020302	1.4	4.9	0.0	7.9	0.0	73.8	11.8	0.4	4.1	-0.1	-0.9	0.0	-5.4	1.8	6.4
08020303	3.2	4.3	0.1	6.6	0.1	55.4	30.3	-0.4	3.5	0.0	0.7	0.1	-4.2	0.3	4.6
08020304	0.7	5.4	0.0	2.1	0.0	79.3	12.5	0.2	4.4	0.0	-1.2	0.0	-3.8	0.2	4.9
08020401	6.9	2.7	0.6	1.2	0.1	59.5	29.1	0.1	2.1	-0.1	-1.3	0.1	-4.1	3.1	5.5
08020402	5.0	8.9	0.0	11.3	0.6	57.7	16.5	0.4	4.8	0.0	-2.9	0.6	-5.3	2.4	8.2
11010001	3.7	5.3	0.2	60.7	2.1	27.7	0.3	-1.2	4.1	0.0	-1.6	1.5	-2.7	-0.2	5.7
11010002	0.9	11.1	0.2	39.2	1.6	46.5	0.4	-0.6	6.5	0.1	4.0	-0.3	-9.5	-0.2	10.7
11010003	2.8	5.2	0.3	62.2	2.7	26.5	0.2	-0.9	4.1	0.2	-2.8	2.0	-2.5	-0.1	6.3
11010004	0.9	5.0	0.2	69.6	2.9	20.8	0.5	-0.1	4.1	-0.3	-7.1	2.9	0.0	0.4	7.4
11010005	0.2	3.2	0.1	80.0	2.2	14.2	0.1	-0.6	3.1	0.0	-3.6	1.7	-0.5	-0.1	4.8
11010006	1.8	4.0	0.1	65.3	2.1	26.4	0.2	-0.5	3.8	0.0	-2.9	1.5	-1.7	-0.1	5.3
11010007	0.7	4.4	0.3	63.1	1.8	24.6	5.1	-0.1	3.5	0.2	-3.6	1.3	-1.3	0.0	5.0
11010008	0.3	3.6	0.1	75.0	1.6	18.0	1.5	-0.2	3.4	0.0	-2.6	1.3	-1.9	0.1	4.8
11010009	1.3	4.3	0.1	38.0	2.1	47.5	6.8	-0.1	3.7	-0.1	-1.9	2.0	-4.2	0.5	6.3
11010010	0.4	5.2	0.2	62.1	2.7	29.3	0.2	0.0	4.5	-0.4	-10.4	2.7	3.4	0.2	10.8
11010011	0.2	3.7	0.1	65.7	2.1	27.9	0.3	-0.1	3.5	-0.1	-4.0	1.8	-1.3	0.2	5.5

Analysis Unit[a]	2006 Land Use Composition[b,c]							Net Land Use Change from 1992 to 2006[d]							Total Percent Change[e]
	Water	Urban	Barren	Forest	Grassland	Agriculture	Wetland	Water	Urban	Barren	Forest	Grassland	Agriculture	Wetland	
Subbasin (8-digit HU)															
11010012	0.4	5.1	0.1	60.5	3.0	30.6	0.4	-0.1	4.8	-1.1	-8.5	3.0	1.8	0.1	9.7
11010013	1.8	6.4	0.0	14.2	0.7	65.4	11.4	0.1	4.4	0.0	-1.7	0.7	-6.0	2.5	7.7
11010014	3.0	4.6	0.1	67.2	3.5	20.1	1.5	-0.4	3.8	0.0	-6.6	3.4	-0.7	0.6	7.8
Refuge															
White River	5.1	1.5	0.1	1.9	0.1	1.8	89.4	-2.5	1.4	0.0	-0.2	0.1	-0.7	1.9	3.4

[a]Land use composition was summarized at subbasin and subregion hydrologic unit scales as well as for the DBWRNWR.

[b]Land use composition calculated as percentage of area

[c]Land use classified based on modified Anderson level 1 land-cover classifications (Fry et. al. 2009)

[d]Percentage land use change between 1992 and 2006. Negative values reflect a decrease in aerial coverage of land use.

[e]Cumulative percentage of the analysis unit that experience land use change between 1992 and 2006.

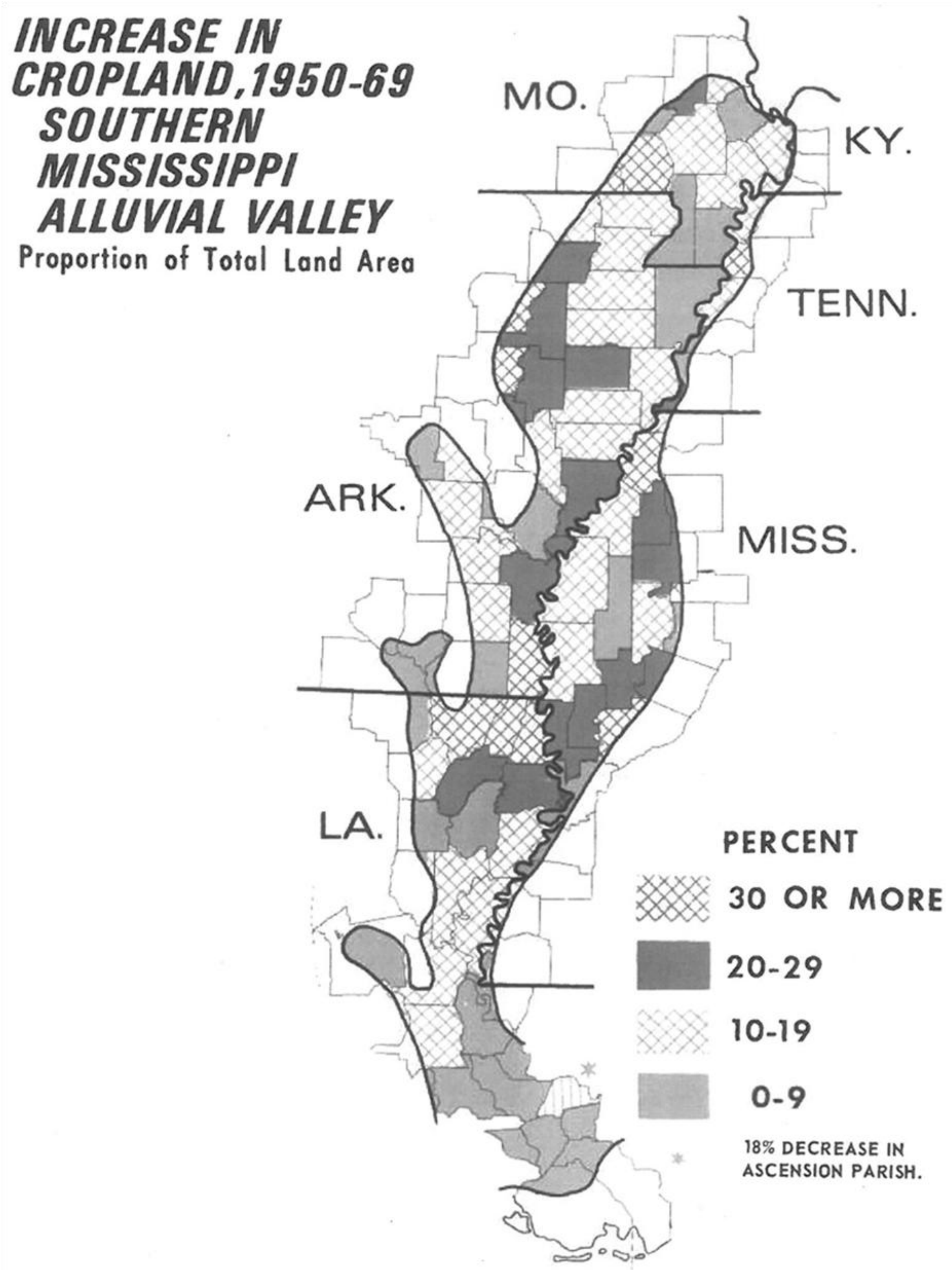
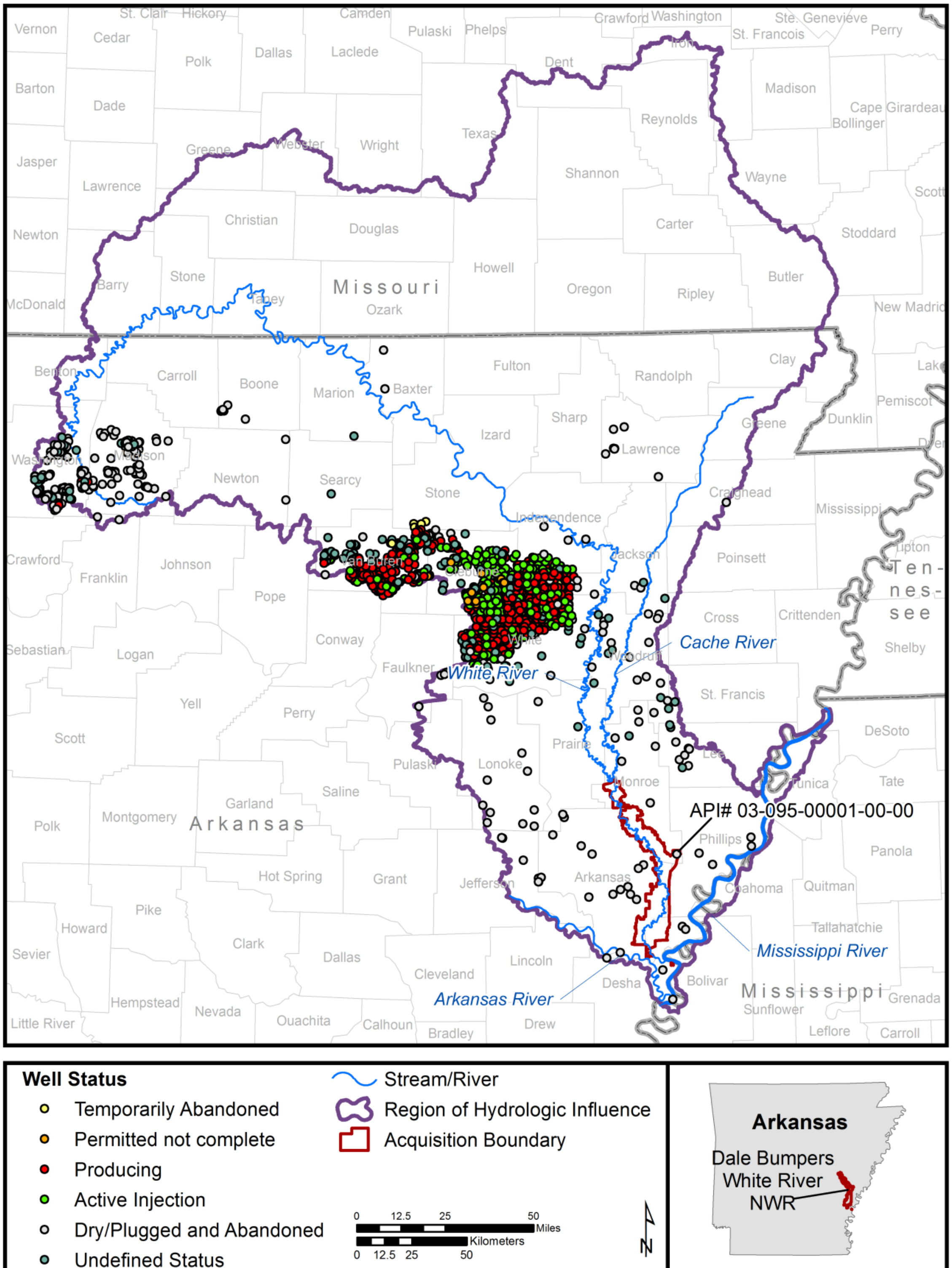


Figure 35. Increase in cropland, 1950-1969, within the Mississippi Alluvial Valley (MAV). [Source: Frey and Dill 1971].

Continued groundwater withdrawals for agricultural irrigation, as discussed in Section 5.4.3, are predicted to further impact stream baseflows in the future. Additionally, other land use activities such as hydraulic fracturing in the Fayetteville Shale, may impact groundwater withdrawal rates. The Fayetteville Shale is a Mississippian-age natural gas formation that stretches across north-central Arkansas, from Fort Smith to beyond Little Rock (University of Arkansas and Argonne National Laboratory Date unknown). It encompasses a 9,000 square mile area. Shale gas production through hydraulic fracturing requires a supply of water for drilling and fracturing activities. Large volumes of water mixed with hydraulic fluid are injected into the well at high pressures to fracture the shale, and then as the pressure is released water begins to return to the surface (flowback water). The Argonne National Laboratory estimated that current number of wells in the Fayetteville Shale play require an annual volume of 4.1 to 5.8 billion gallons of water in all stages of the development process, which is 11.2 to 15.8 million gallons/day assuming water is required evenly over an entire year. For comparison, this constitutes less than 1% of the total volume of water withdrawn per day within Arkansas (Veil 2011). Water supplies can be obtained from groundwater wells or surface water bodies such as lakes, reservoirs and streams, or recycled from previous fracturing operations (i.e., flowback water). One of the major operators in the Fayetteville Shale play constructed a 500 acre-foot reservoir to capture excess water from the Little Red River, which would supply the water needed for 200 to 2,000 new wells. Water would only be withdrawn during periods of high flow, such as storm events or power generation releases from Greers Ferry Dam (Arthur et al. 2008). Other operators are also utilizing small (1- to 5-acre) reservoirs through the Fayetteville Shale region and piping water to individual well pads. Water produced from the Fayetteville Shale generally has good quality for reuse (Veil 2011). Groundwater use for drilling and fracturing activities is a primary concern, given declining water levels in the alluvial aquifer due to irrigation demands. Depending on the amount and depth of additional water withdrawals for hydraulic fracturing, local and regional groundwater impacts could occur and exacerbate existing conditions (USFWS 2007).

A dataset of oil and gas wells was compiled for the RHI from county well inventories acquired from the Arkansas Oil and Gas Commission (AOGC). Drilling for hydraulic fracturing within the RHI is focused on a five-county area between western Conway County and eastern White County, roughly corresponding to the Little Red River subbasin. There are a few scattered wells in additional surrounding counties, including Prairie, Woodruff and Phillips counties (Figure 36). Most of the wells drilled near the refuge were found to be dry, and were plugged or abandoned. One plugged/abandoned well, API#03-095-00001-00-00, is located within the refuge acquisition boundary (Figure 36).



Map Date: 3/18/2015 File: Oil_Gas_Wells.mxd Data Sources: Arkansas Oil & Gas Commission wells, NHD High Resolution Flowlines and Waterbodies, National Watershed Boundary Dataset HU-6 Boundaries, ESRI Topo Service.

Figure 36. Oil and gas wells within the Region of Hydrologic Influence (RHI). Wells with an undefined status are assigned a "type of work" code that is not listed on the AR Oil and Gas Commission (AOGC) key.

5.5 Water Quality Conditions

Primary surface water quality concerns on the refuge are degradation from nutrients, pesticides and silt resulting from agricultural activities (USFWS 2009a). While some of these problems originate from on-refuge land use activities (particularly farming and road/levee construction), the majority stem from non-point sources of erosion and runoff outside the refuge's boundaries. Areas ponded by beavers also collect large silt loads during high water events, which changes substrate conditions and aquatic habitat characteristics. Additionally, septic discharge is considered a minor problem, and oil and gas development in adjacent counties, along with gas pipeline construction, have the potential to affect water quality. Other potential sources of water contamination on the refuge include: spills associated with commercial barge traffic on the White River and the Arkansas Post Canal, spillage from railroad and/or highway traffic, and contamination from pesticides used by agricultural operations (USFWS 2009b).

A Contaminant Assessment Process (CAP) was conducted for the refuge in 2003 and 2004. A CAP is an information gathering process and initial assessment of a NWR in relation to environmental contaminants. Mean DDT (dichlorodiphenyltrichloroethane) concentrations in benthic fish tissues collected from DBWRNWR waters exceeded the Predator Protection Level (PPL) of 1,000 nanograms per gram (ng/g), while DDT concentrations in predatory fish tissues were below this level. Mean concentrations of toxaphene in both benthic and predatory fish tissues exceeded the lowest biological effects value (400 ng/g), while the maximum concentration in benthic fishes also exceeded the PPL. DBWRNWR had a high number of current use pesticides (CUP) detections from both off and on-refuge sampling sites. Levels of trifluralin that were detected on-refuge exceeded either the lowest LC50 data (11 micrograms per liter [µg/L]) or aquatic life criteria value (0.2 µg/L) for the White River. Azinphos-methyl, metribuzin, trifluralin, chlorpyrifos, metolachlor, atrazine, diazinon, and phorate all exceeded aquatic life criteria values from nearby off-refuge sites (Irwin 2004). The 2012 Final CAP Report for DBWRNWR also indicated that mercury was a documented contaminant, evidenced by high concentrations in fish tissue samples, but did not provide any additional information.

5.5.1 Federal and State Water Quality Regulations

5.5.1.1 Designated Uses

The lower White River and its tributaries are designated by the ADEQ for the following uses: propagation of fish and wildlife, primary (i.e., full body such as swimming) and secondary (e.g., boating, fishing) contact recreation and domestic, agricultural and industrial water supply (ADEQ 2012). For each use, specific water quality criteria must be met and for waters that are classified for multiple uses, the criteria to protect the most sensitive use are applicable (Arkansas Pollution Control and Ecology Commission 2011).

5.5.1.2 Water Quality Standards

ADEQ is responsible for water quality regulation and Clean Water Act (CWA) reporting. Arkansas' surface water quality standards, established under Regulation No. 2 of the Arkansas Water and Air Pollution Control Act, include designation of uses for all waters, development of narrative or numeric criteria designed to prevent impairment of the designated uses, and an anti-degradation policy. Water quality standards must be reviewed and updated at least every three years; the most recent Triennial review took place in 2013.

5.5.1.3 NPDES

As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program regulates point sources that discharge pollutants into waters of the United States. NPDES permits are required for operation and sometimes construction associated with domestic or industrial wastewater facilities or activities (e.g., wastewater treatment facilities, mines, etc.). In Arkansas the U.S. Environmental Protection Agency (EPA) has delegated administration of the NPDES permit program to ADEQ.

5.5.1.4 Groundwater Regulations

Groundwater is protected by laws at both the federal and state levels. The EPA is responsible for groundwater protection through the Safe Drinking Water Act (SDWA), which was intended to protect the quality of groundwater serving as a source for public water supply wells through the requirement of maximum contaminant level standards for drinking water. SDWA established the Underground Injection Control, Wellhead Protection, and Source Water Protection Programs, which are administered by the Arkansas Department of Health (ADH).

The Clean Water Act is primarily a surface water program; however, the EPA recommends that states apply 15% of CWA Section 106 grant monies (for point-source contamination) toward developing and implementing groundwater protection programs. CWA section 319 funds (non-point sources) may also be used for groundwater protection projects (EPA 2009).

Arkansas has no permit system to specifically protect groundwater quality. Responsibility for administration of groundwater regulations is divided among several state agencies. As previously mentioned, protection of groundwater wells primarily used for public supply falls to the responsibility of ADH. ANRC is responsible for investigation of potential contaminant sources, and for any follow-up investigation of verified sources of contamination. ADEQ conducts groundwater studies and oversees the cleanup of contaminated sites.

5.5.2 Impaired Waters, TMDLs, and NPDES Permits

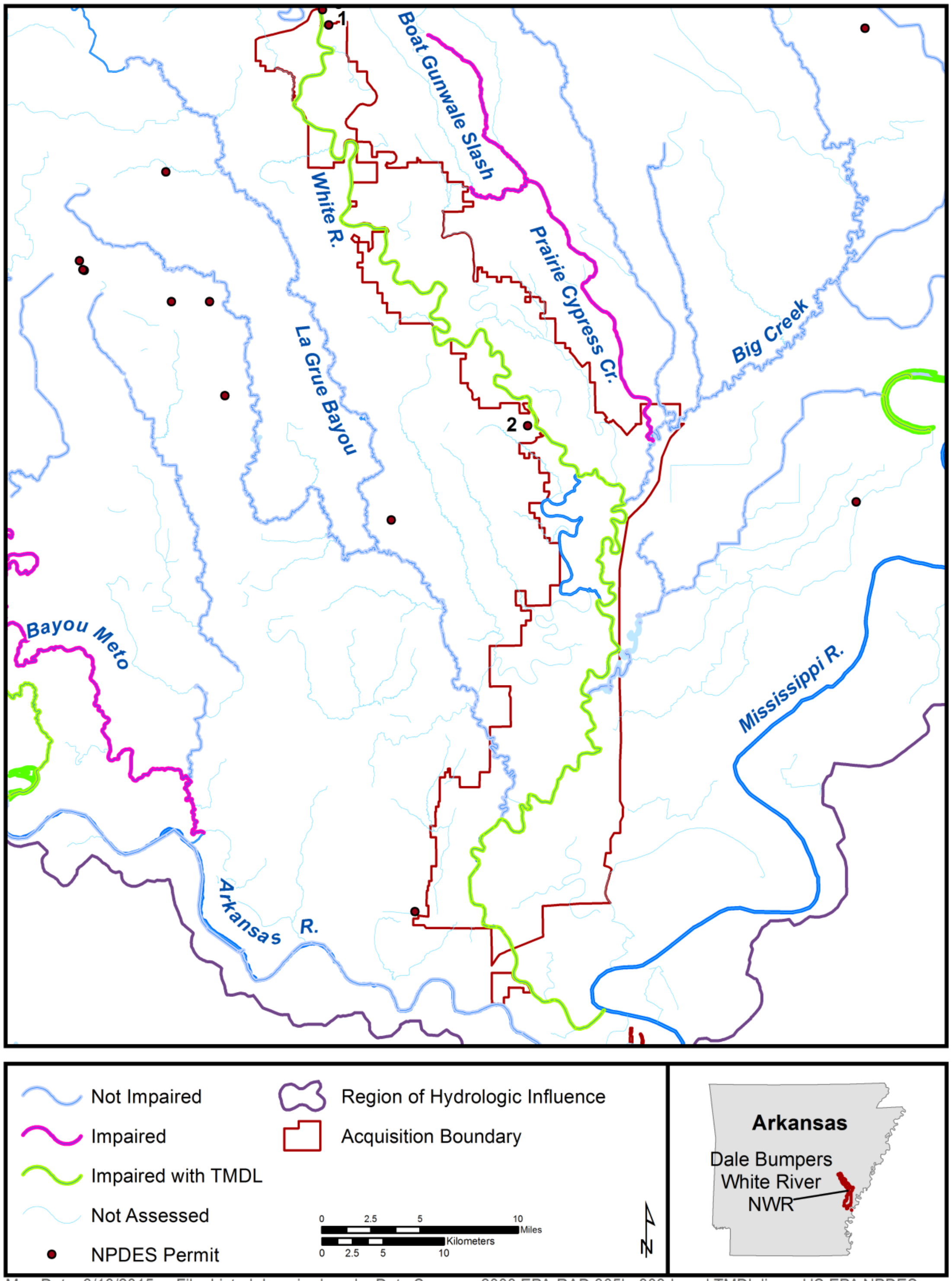
5.5.2.1 Impaired Waters and TMDLs

In order to meet Clean Water Act requirements, the six major river basins within the state have been allocated into 38 water quality planning segment groups based on hydrological characteristics, human activities, geographic characteristics, etc. For the purposes of this WRIA, the 2008 Integrated Water Quality Monitoring and Assessment Report is being used, as the 2012 list has yet to be EPA-approved and may not be approved until the 2014 list is published. The primary database for the 2008 Integrated Water Quality Monitoring and Assessment Report is from the ADEQ Ambient and Roving Water Quality Monitoring Networks. The networks include the AWQMN (Ambient Water Quality Monitoring Network) stations that are sampled monthly and the RWQMN (Roving Water Quality Monitoring Network) stations that are sampled bi-monthly. The RWQMN Stations are divided into five groups geographically and are sampled for two years on a rotating schedule.

The RHI for DBWRNWR falls within two of the six major ADEQ basins: the White River Basin (Basin 4) and the Mississippi River Basin (Basin 6). Common sources of impairment within the DBWRNWR RHI include dissolved oxygen, bacteria, turbidity, and nutrients (total phosphorus, nitrate and ammonia).

Impaired waters and waterbodies with total maximum daily loads (TMDLs) within or near the DBWRNWR acquisition boundary are shown in Figure 37. The White River has a TMDL for oxygen demand that encompasses dissolved oxygen and turbidity. In 2008, three additional waterbodies on the refuge did not meet their designated uses. Boat Gunwale Slash and Prairie Cypress Creek did not meet the aquatic life use due to inadequate dissolved oxygen and agriculture was identified as the primary source of the problem; this condition occurs during the season when flows are diminished and water temperatures are elevated (ADEQ 2012). Big Creek did not meet its agriculture and industrial use designation due to chloride and total dissolved solids; however, the location and spatial extent of the impairment is not known. Agriculture was identified as both the primary and secondary source of the problems (USFWS 2012).

The most current information for waterbodies with established TMDLs (or TMDLs in development) in the White River Basin is listed in Table 21. Table 22 lists waterbodies within the White River Basin which meet requirements for the establishment of a TMDL, where a TMDL is not yet in development.



Map Date: 3/18/2015 File: Listed_Impaired.mxd Data Sources: 2008 EPA-RAD 305b, 303d, and TMDL lines; US EPA NPDES Sites; NHD High Resolution Flowlines; ESRI Map Service.

Figure 37. 2008 listed impaired waters, Total Maximum Daily Loads (TMDLs) and National Pollutant Discharge Elimination System (NPDES) permits near the Dale Bumpers White River National Wildlife Refuge. Numbered NPDES permit locations are discussed in text. Big Creek is listed as impaired; however the spatial extent of the impairment is unknown.

Table 21. Waterbodies in White River Basin with TMDLs that are active or in development and causative pollutants. [Source: ADEQ 2008]

Waterbody Name	Causative Pollutant
OSAGE CREEK NEAR BERRYVILLE	Phosphorus Total
HARDING CREEK	Bacteria
COOPER CREEK	Bacteria
REED'S CREEK	Bacteria
LAKE FRIERSON	Turbidity
STRAWBERRY RIVER (2 TMDLs)	Bacteria, Turbidity
NORTH FORK RIVER	Oxygen Demand
HICKS CREEK	Nitrate
SOUTH FORK LITTLE RED RIVER	Bacteria
MIDDLE FORK LITTLE RED RIVER	Bacteria
HOLMAN CREEK	Nitrate and Nitrogen Ammonia
REED'S CREEK	Bacteria
TEN MILE CREEK	Bacteria
OVERFLOW CREEK	Bacteria
CYPRESS BAYOU 8020301-010	Bacteria
CYPRESS BAYOU 8020301-011	Bacteria
WHITE RIVER (2 TMDLs)	Oxygen Demand, Turbidity
OLD TOWN LAKE	Phosphorus Total
WEST FORK	Turbidity
CACHE RIVER	Turbidity
VILLAGE CREEK	Turbidity
BAYOU DEVIEW	Turbidity
WABBASEKA BAYOU	Turbidity

Table 22. Waterbodies in White River Basin requiring TMDLs. Asterisks indicate waterbodies that are partially or wholly located on the refuge. [Source: ADEQ 2008].

Waterbody Name	Waterbody Type	Parameters Assessed Using the Impaired Surface Waters Rule (IWR)	Priority for TMDL Development
Leatherwood Creek	Stream	Dissolved Oxygen	Low
Kings River	Stream	Total Dissolved Solids (TDS-Salinity/Chlorides/Sulfates)	Low
Holman Creek	Stream	TDS	Low
Beaver Reservoir	Lake	Sediment	High
*White River	Stream	Dissolved Oxygen	High
*White River	Stream	TDS, Sediment	Medium
West Fork	Stream	TDS, Sediment	Medium
Kings River	Stream	TDS, Dissolved Oxygen	Low
Crooked Creek	Stream	Temperature, TDS	Low
Hicks Creek	Stream	Fecal Coliform	High
North Fork River	Stream	Dissolved Oxygen	High
Bear Creek	Stream	TDS	Low
*Big Creek	Stream	Dissolved Oxygen	Low
Strawberry River	Stream	Fecal Coliform	Low
Spring River	Stream	Temperature, Dissolved Oxygen	Low
Warm Fork Spring River	Stream	Dissolved Oxygen, TDS	Medium
Greenbrier Creek	Stream	Dissolved Oxygen, Fecal Coliform	Low
*Big Creek	Stream	Fecal Coliform	Low
Cache River	Stream	Metals (other than Mercury), TDS	Low
Lake Frierson	Lake/Reservoir	Metals (other than Mercury), Sediment	
Fourche River	Stream	Sediment	Low
Eleven Point	Stream	Dissolved Oxygen	Low
Current River	Stream	Dissolved Oxygen, Sediment	Low
Black River	Stream	Dissolved Oxygen	Low
Village Creek	Stream	Dissolved Oxygen, Sediment	Low
Departee Creek	Stream	Metals (other than Mercury)	Low
Glaise Creek	Stream	Fecal Coliform, Metals (other than Mercury)	Low
Overflow Creek	Stream	Fecal Coliform, Metals (other than Mercury)	Low
Bull Bayou	Stream	Fecal Coliform, Metals (other than Mercury)	Low
Cypress Bayou	Stream	Pathogens, Fecal Coliform	Low
Bayou Des Arc	Stream	Metals (other than Mercury)	Low
Bayou DeView	Stream	Metals (other than Mercury), Sediment	Low
Wattensaw Bayou	Stream	Dissolved Oxygen	Low
*Big Creek	Stream	TDS (Chloride)	Low
*Prairie Cypress	Stream	Dissolved Oxygen	Low
Wabbaseka Bayou	Stream	Dissolved Oxygen	Low
Bayou Meto	Stream	Metals (other than Mercury), Dioxins, Dissolved Oxygen	Low
Bayou Two Prairie	Stream	Dissolved Oxygen	Low
Pickthorne Lake	Lake	Nutrients	Low

5.5.2.2 NPDES

Within the RHI there are a total of 505 NPDES permitted facilities (Table 23, Figure 37). Only seven of the permitted facilities are considered "major," and which are categorized as either:

- Publicly Owned Treatment Works (POTWs) with design flows ≥1 MGD or that serve a population ≥10,000 or cause significant water quality impacts, or
- Non-POTW discharges surpassing a point threshold based on criteria such as toxic pollutant potential, flow volume and water quality factors such as impairment of receiving water or proximity of discharge to coastal waters (EPA 2013b).

There are two major facilities that discharge into the White River within the refuge acquisition boundary: the City of Clarendon and the City of St. Charles (Sites # 1 and #2 in Figure 37). ADEQ has a monitoring station located at the City of St. Charles discharge site (Site #10 in Table 11, Figure 27). The remaining facilities are classified as "non-major" dischargers because they do not meet the above criteria, or are facilities that discharge without an NPDES permit.

Table 23. National Pollutant Discharge Elimination System (NPDES) permits in the Dale Bumpers White River National Wildlife Refuge Region of Hydrologic Influence (RHI). [Source: EPA 2013a].

NPDES Permit Type	Quantity
NPDES Major	7
NPDES Non-Major	474
NPDES Unpermitted	24
Total	***505***

5.5.3 Groundwater Quality

Currently there are no known groundwater quality problems on the refuge; however, saltwater intrusion into the alluvial aquifer as a result of heavy drawdown of water, irrigation practices and area hydrogeology has been detected in the southeast part of the state (ADEQ 2004). This intrusion, which is occurring in northeast Monroe county and southern Woodruff county (approximately 50 miles north of the refuge), has rendered the water no longer suitable for irrigation, thus placing greater pressure on surface water from the White River and other sources (USFWS 2012).

In general water in the alluvial aquifer is suitable for most uses; however, two characteristics, hardness and high concentrations of iron and manganese, limit usefulness for public supply. As a result, groundwater from the alluvial aquifer is only used for public supply (with treatment) in areas where other suitable sources are not available (Ackerman 1996).

As a part of a larger USGS study, water quality was sampled at 138 wells in the alluvial aquifer in 2004 (Schrader 2006). Specific conductance (an indicator of the relative salinity of water) and dissolved chloride concentrations were measured. The study found that areas of Arkansas and Monroe counties have relatively high values of specific conductance (i.e., greater than 1,200 micro Siemens per centimeter [µS/cm]). The highest measured dissolved chloride concentration (200 milligrams per liter [mg/L]) occurred at a well in Arkansas County. This may be due to movement of water containing elevated concentrations of dissolved solids from deeper formations in response to pumping.

Focazio et al. (2000) analyzed the occurrence of arsenic in groundwater resources throughout the U.S. and found an area in Woodruff County, along the lower Cache River, with elevated arsenic concentrations (>10 µg/L) in 18 alluvial aquifer wells. Most contamination occurs in shallow groundwater in localized areas (EPA 2009).

5.5.4 Land Use Activities Affecting Water Quality

As introduced in Section 5.4.4 and typical of such projects in the MAV, river engineering in the RHI has had a profound effect on water resources in the refuge. Regulated discharge not only changes the magnitude, duration, and timing of discharge downstream, it changes the physical and chemical condition of water as well as ecological conditions downstream. Dams result in upstream-downstream shifts in biotic and abiotic patterns and processes (Ward and Stanford 1995). Regulation of discharges from dams typically results in alternating series of lentic and lotic ecological functioning reaches affecting physical (temperature), chemical (nutrients—nitrogen and phosphorus, organic matter, metals, and others), and biological characteristics at the population, community, and ecosystem levels. The extent of these changes downstream from the dam is a function of the size of the impoundment, changes to hydrology, downstream channel geomorphology, and number, size, and nature of tributary inflows and riparian conditions (Alexander et al. 2012). As such, local effects of hydrologic alterations on water quality can vary throughout the basin. For instance, channel engineering projects in the MAV have generally caused sediment transport to decline (Alexander et al. 2012); however, sediment deposition in the Lower White subbasin has historically been high due to channel straightening, tillage, and the lack of riparian buffers. Changes in the types of sediment transported and deposited in the lower river have been evident. The lower White River used to have much more gravel than at present. Dams have reduced the transport of this material downstream from the upper White River.

One effect of building dams in the MAV is to reduce annual variations in water level, making the terrestrial floodplain more accessible to humans. The altered terrestrial floodplain has been replaced by a different ecosystem maintained in a state of immaturity by the practice of agriculture. In a natural system, floods deliver nutrient-rich sediments to the floodplain floor and the river delta, acting as a natural fertilizer to the floodplain soils. Dams trap sediments and reduce peak flood discharges, keeping water flows within the channel banks, as designed. This modification to the flow regime prevents nutrient-rich sediments from replenishing the floodplain remaining instead suspended in streamflow or deposited within the channel (Alexander et al. 2012). Meanwhile regional changes to land cover have led to increased runoff and erosion from agriculture and have led to impaired water quality and increased in-stream sedimentation.

Ongoing water quality issues typically relate to land application of agricultural fertilizers and pesticides, erosion and deposition of sediment, and municipal and industrial wastewater discharge (Buell et al. 2012). Kleiss et al. (2000) found that nitrogen concentrations in the MAV generally were in the middle range of the national data, whereas total phosphorus concentrations were in the 67th to 93rd percentile. Using regression equations, measured discharge, and grab samples, Goolsby et al. (1999) estimated the total nitrogen yield for the Upper White River Basin as 412 kilograms per square kilometer per year ($kg/km^2/yr$) and the total phosphorous yield as 44 $kg/km^2/yr$. Alexander et al. (2008) determined that corn and soybean cultivation (24%) and atmospheric deposition (24.8%) were the largest contributors of nitrogen, whereas phosphorus originates primarily from animal manure on pasture and rangelands (51%) followed by lands where corn and soybeans are grown (15.3%) in the Upper White River Basin.

Sediment transport is of primary concern on the refuge; however, the majority of sources of erosion and sediment transport occur outside the refuge boundaries. Sediment loading in the Lower White subbasin is primarily the result of erosion from agricultural fields and loessal parent material transported to a straightened network insufficiently protected by riparian buffers. Agriculture was indicated as a primary and secondary source of dissolved oxygen depletion on the refuge, leading to impairment of three waterbodies (Boat Gunwale Slash, Prairie Cypress Creek and Big Creek) (USFWS 2012).

As described in Section 5.4.6, drilling for natural gas in the Fayetteville Shale is occurring in north-central Arkansas, in areas northwest of the refuge. Gas wells have the potential to affect water quality in shallow aquifers as fluids are lost during the various steps of gas production (drilling, hydraulic fracturing and storage and handling of flowback water) or spills affecting surface water. Potential transport pathways include leakage from the earthen pits used to store fluids, pipe leakage and overflows or spills during transport. The Fayetteville Shale is a dry formation, meaning gas consists primarily of methane as opposed to "natural gas liquids" such as ethane, butane, propane and pentane (Kresse et al. 2012), thus the formation generates very little produced water (University of Arkansas and Argonne National Laboratory date unknown). Flowback water is probably a blend of injected hydraulic fluids (primarily water), residual formation salts and naturally occurring brine (Kresse et al. 2012). In Arkansas this water is primarily disposed of under general land application permits issued by ADEQ. Flowback water is stored in lined pits prior to land application. Water with low chloride concentrations (less than 1,500 parts per million [ppm]) is utilized on roads for dust suppression, whereas water with chloride concentrations exceeding 5,000 ppm is disposed of in wells (Arthur et al. 2008).

The USGS investigated the groundwater quality in shallow domestic wells in the vicinity of the Fayetteville Shale and found that gas production is not detrimentally affecting water quality in those wells (Kresse et al. 2012). However, spills of flowback water into nearby surface waters (via overflows, broken transmission lines or other pathways) could have a substantial negative effect on aquatic organisms. Papoulias and Velasco (2013) found that spilled hydraulic fluid was the cause of a significant fish kill in a Kentucky stream. The spilled fluid released toxic levels of heavy metals and decreased the pH to 5.6. Elevated chloride concentrations can also harm fish and other aquatic organisms.

5.6 Water Law/Water Rights

In 2014, the USFWS Office of the Solicitor prepared a memo on state water laws in Region 4 (Brown-Kobil 2014), which is the basis for much of the information presented in this section.

5.6.1 State Water Law Overview

The ANRC (formerly known as the Arkansas Soil and Water Conservation Commission) registers surface and groundwater withdrawals, which requires that users report their water use for the past year. Owners of wells capable of producing at least 50,000 gallons per day are required to register with the state and pay an annual registration fee (ADEQ 2012). The ANRC (i.e., Commission) issues permits for non-riparian surface water use (i.e., power plants, industries, large-scale irrigation projects). There is no permit system to protect groundwater quality (EPA 2009).

Water law in Arkansas has developed from General Assembly legislation, state agency regulatory programs, and case law developed by the courts (ANRC 2011). Water is regulated under the Arkansas Water Resources Development Act (Ark. Code Ann. § 15-22-6), Arkansas Groundwater Protection and Management Act (Ark. Code Ann. § 15-22-9), the Arkansas Water and Air Pollution Control Act (Ark. Code Ann. § 8-4), the Arkansas Irrigation, Drainage and Watershed Improvement District Act (Ark. Code Ann. §§ 14-117-101 to -427), and the Regional Water Distribution District Act (Ark. Code Ann. § 14-116-101 to -406). Arkansas is a riparian reasonable use state with use of surface water considered a property right as long as use does not unreasonably harm another riparian landowner's use. Groundwater use follows similar logic in that a landowner may use groundwater from a well on their land as long as the use does not unreasonably harm another landowner's groundwater use (Rowan et.al. 2013). Laws governing water in the state are closely tied to the type of water involved. For example, surface water and groundwater are governed under different rules as are waters in a reservoir vs. free-flowing water.

5.6.1.1 Public Trust Doctrine

Lands under navigable waters in the state of Arkansas are held in trust for the people. This follows the English common law doctrine in which the sovereign held title to the beds of navigable and tidal waters as a trustee for the benefit of the people. Upon admission to the Union in 1836, the state of Arkansas gained title to the beds of navigable lakes and streams (ARNC 2011). In 1980, the Arkansas Supreme Court expanded the definition of "navigable" to include not only commercial use but recreational use (e.g., fishing in flatbottomed boats, canoeing, floating, etc.) as well (268 Ark. 227 1980).

5.6.1.2 Riparian Water Rights

Technically, "riparian" refers to rivers and streams, while "littoral" refers to lakes, but the term "riparian rights" includes lakes, streams, and rivers. Thus, the only way to obtain riparian rights is to purchase riparian property. On navigable waters, a riparian landowner owns to the ordinary high water mark (OHWM)—a point indicated by vegetation and the nature of the soil —and the state owns the stream bed (ARNC 2011). The OHWM is defined in the Arkansas code as "the line delimiting the bed of a stream from its bank, that line at which the presence of water is continued for such length of time as to mark upon the soil and vegetation a distinct character"(Ark. Code Ann. § 15-22-202). If the water is non-navigable, the riparian owner has rights to the center of the stream. For navigable waters, the public has the right to use the water and beds "for the purposes of bathing, hunting, fishing, and the landing of boats" in addition to navigation and commerce (Craig 2007- *Anderson v. Reames,* 161 S.W.2d 957, 960-61 (Ark. 1942)). Even if one part of the streambed in a navigable stream is owned by the state and the remainder is private property, a person has a right to be anywhere on that stream, provided that person remains afloat and does not wade onto the privately-owned portion of the streambed without the landowner's permission.

5.6.1.3 Navigable Waters

The White and Cache Rivers would be classified as navigable water under the Arkansas navigability test as they are both capable of being used as a highway for commerce and/or used for recreation. As such, the water bottom (below high water mark), is owned by the state of Arkansas. The state navigability test does not require that streams be navigable for the entire year (268 Ark. 227 1980).

5.6.1.4 Transfer of Surface Water

Non-riparian landowners can apply to the ARNC for surface water rights. Before approving a non-riparian application, the ARNC has to calculate "excess surface water" to determine if the water resources are available. Excess surface water was defined by the General Assembly in 1985 as 25% of the amount of water left over after calculating the amount of water required for specific needs which include existing riparian rights as of June 28, 1985; water needs of federal water projects existing on June 28, 1985; the firm yield of all reservoirs in existence on June 28, 1985; maintenance of minimum streamflows for fish and wildlife, water quality, aquifer recharge requirements and navigation; and future water needs of the basin of origin as projected in the Arkansas Water Plan (Ark. Code Ann. § 15-22-304). In 1995 the definition of excess surface water was amended for the White River Basin only, such that "a transfer shall not exceed on a monthly basis an amount which is fifty percent of the monthly average of each individual month of excess surface water" (Ark. Code Ann. § 15-22-304(e)) (Perkins 2002). The 1990 Arkansas Water Plan included calculations of excess surface water for the five major water basins of the state taking into account projected riparian uses, minimum streamflow requirements for fish and wildlife, and navigation needs to the year 2030. When the ARNC evaluates a non-riparian permit for water rights, the proposed use is evaluated against the figures calculated in 1990 to make sure excess surface water levels have not been exceeded (ARNC 2011). The 2014 Arkansas Water Plan is currently under development and will evaluate projected water needs to the year 2050. A published draft of the proposed rules and an open public comment period are anticipated in 2015.

Examples of reasons for obtaining a surface water transfer permit include irrigation, hydrologic fracturing of natural gas wells, municipal water supply, industrial cooling water, and mining. The largest project to date is the Grand Prairie Irrigation Project (Section 5.4.4). The greatest growth in non-riparian intrabasin transfer permits has resulted from development of the Fayetteville Shale from the petroleum industry. As of March 3, 2010, the Commission had received 726 applications from gas companies (ARNC 2011).

5.6.1.5 Allocation of Surface Water

In times of shortage, the ANRC may on its own initiative, or on the petition of any person claiming to be affected by such shortage of water, after a notice and hearing, allocate the available water among the users affected by the shortage in a manner that each may obtain an equitable portion of the available water (138 C.A.R.R. 003 § 307.1). There are uses that are excluded from an allocation process including "…water stored in federal impoundments" (ANRC Rules § 307.2). There are also reserved water uses that are excluded from an allocation process such as domestic and municipal-domestic, minimum streamflow, and federal water rights. Minimum streamflow is the "quantity of water necessary to support interstate compacts, navigation, fish and wildlife, water quality, and aquifer recharge" (Ark. Code Ann. § 15-22-202). The ARNC adopted minimum streamflow rules for the White River in 2009 (ANRC 2011; Section 5.4.5). Federal water rights are not defined in the Arkansas code; however, the ANRC rules state that "there may be some water over which the United States has a preemptive right that is superior to the rights of others" (ANRC Rules § 307.7). The water uses considered in this rule were uses such as interstate compacts and navigation. As of 2011, the ANRC had not declared a shortage or initiated allocation procedures (ANRC 2011).

5.6.1.6 Surface Water Withdrawals

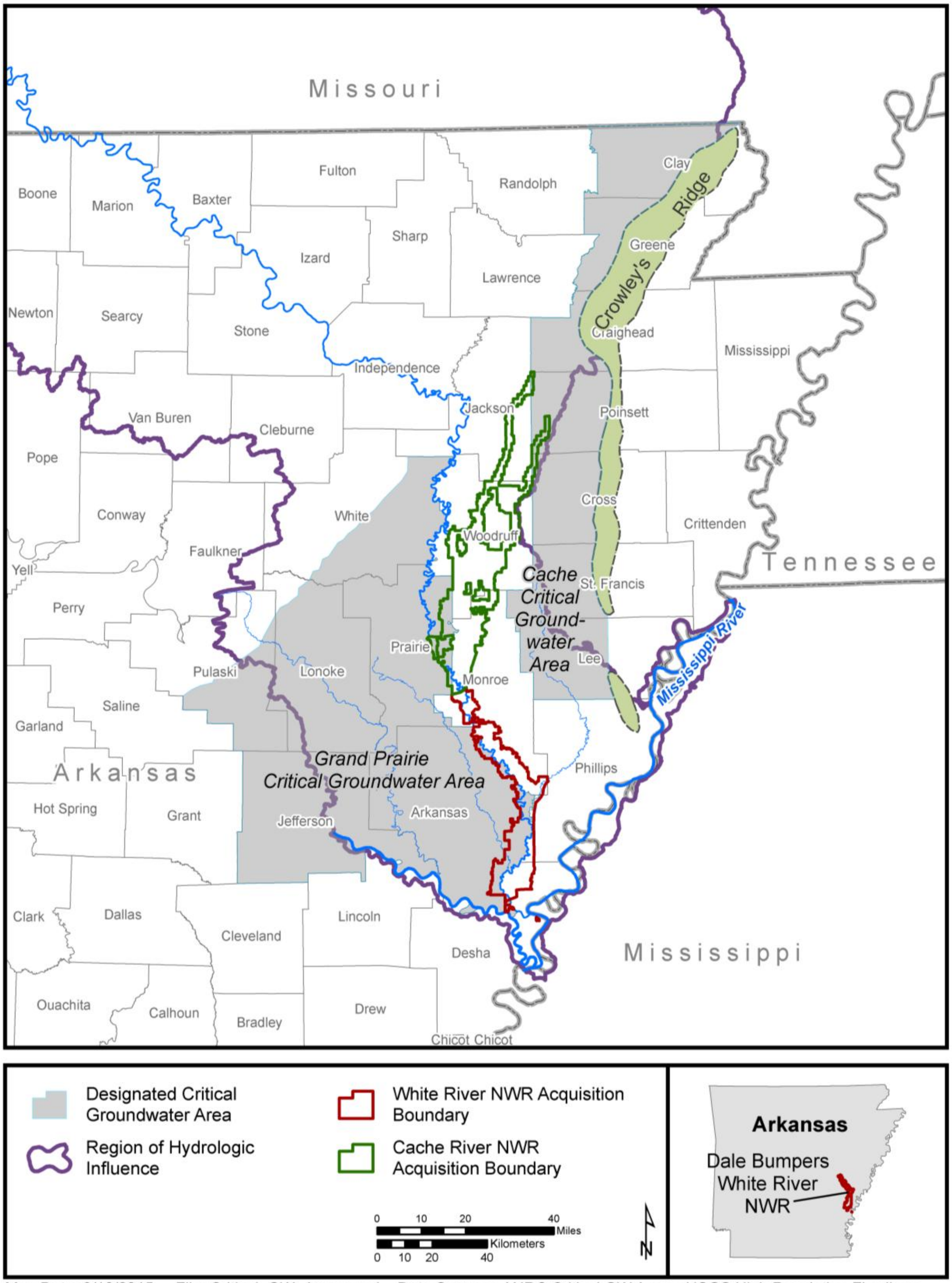
As summarized by Brown-Kobil (2014): The Arkansas Soil and Water Conservation Commission regulates water in the state which follows the riparian rule of reasonable use. Any person who diverts water from any stream, lake, or pond, except those natural lakes or ponds in the exclusive ownership of one person, shall register with the Commission or with his/her local conservation district (Ark. Code Ann. § 15-22-215(a)). Once registered, the Commission will issue a certificate of registration (Id. at § 15-22-215(e)). A "person" is defined as any natural person, partnership, firm association, cooperative, municipality, county, public or private corporation, and any state or local government agency (Ark. Code Ann. § 15-22-202(8); Arkansas Groundwater Protection Act, Ark. Code Ann. § 15-22-903(10)). While these statutory definitions do not include federal agencies in the definition of a person, state regulations do include federal agencies in the definition of a person (138 C.A.R.R.003 § 301.3(DD)).

Non-riparian users are required to obtain a water use permit, regardless of the volume of water proposed for use. The ANRC, in cooperation with the USGS, collects and compiles reported monthly water use (surface water and groundwater) data for several categories, including irrigation and livestock use, in its Aggregated Water-Use Data System (AWUDS; ANRC and USGS 2014). Water-use data for domestic (self-supplied) and livestock (stock) are not required to be reported to ANRC.

5.6.1.7 Groundwater Withdrawals

As summarized by Brown-Kobil (2014): The 1991 Arkansas Groundwater Protection Act, Ark. Code Ann. § 15-22-901 to 914, authorizes the Commission to designate critical groundwater areas (Id. at § 15-22-903(6)). The statute's purpose declares that conservation of groundwater may require limit of withdrawals in critical groundwater areas through the issuance of water rights (Id. at § 15-22-902). After public notice and hearing, the Commission has the power to declare a critical groundwater area and to allocate water rights (Id. at § §15-22-908, 909). If the Commission "declares" an area to require water rights, no one may withdraw groundwater or construct a new well without first obtaining a water right (Id. at §15-22-909).

Under the 1991 Arkansas Groundwater Protection Act, no regulation of groundwater resources occurs until a critical area is designated. The ANRC has designated three critical groundwater areas to date; however, the ANRC has never regulated these areas (ANRC 2013b). Most of the DBWRNWR that is located west of the river in Arkansas and Prairie counties lies within the Grand Prairie Critical Ground Water Area (Figure 38). As described above, reported groundwater use for several categories is available by county or HUC in ANRC's AWUDS (ANRC and USGS 2014). If the ARNC issued a declaration of necessity and followed procedures to do so, a regulatory program could be initiated and water rights issued (ANRC 2011).



Map Date: 3/18/2015 File: Critical_GW_Areas.mxd Data Sources: ANRC Critical GW Areas; USGS High Resolution Flowlines and Waterbodies, National Watershed Boundary Dataset HU-6 Boundaries, ESRI Topo Service.

Figure 38. Critical Groundwater Areas in Arkansas. Critical Groundwater Areas digitized from ANRC undated.

As summarized by Brown-Kobil (2014): To obtain water rights, one must file an application with the Commission which will publish a notice in a newspaper with statewide circulation (Ark. Code Ann. § 15-22-910(b)). Anyone adversely affected may request a hearing with the Commission within 15 days of publication of the notice (Id). The Commission will give "preference" (as opposed to priority) groundwater rights to sustaining life, maintaining human health, and finally increasing wealth (Id). Groundwater rights are only issued for a beneficial use (Ark. Code Ann. §15-22-911(a)). "Beneficial use" means the use of water in such quantity as is economical and efficient and which use is for a purpose and in a manner which is reasonable, not wasteful, and is compatible with the public interest (Id. at § 15-22-903(3)). This should include groundwater used for wildlife and habitat. The Commission has the right to limit withdrawals when issuing a water right, which are time limited as well (Id. at § 15-22-911(b)(1) & (c)). If competing applications for the same groundwater right are before the Commission specifying the same priority, it will give preference to a renewal application over an initial one and consideration to reasonable beneficial use (Id. at §15-22-911(d)).

5.6.1.8 Diffused Surface Water

Water law and regulation in Arkansas is tied to the type of the water involved (e.g., watercourses, streams, and lakes) and the location of the landowner who wishes to use the resource (e.g., riparian landowner, non-riparian landowner). Water that has not become part of a natural channel, lake, or pond is considered "Diffused surface water." Arkansas code defines "diffused surface water" as "water occurring naturally on the surface of the ground other than in natural channels, lakes, or ponds" (Ark. Code Ann. § 15-22-202). Arkansas case law has developed rules for determining liability for landowners' actions to manage diffused surface water, whether the landowner takes steps to prevent it from coming onto low lying land or whether removing excess water from land by filling and/or draining (ARNC 2011).

5.6.2 Legal or Regulatory Issues Potentially Affecting the Refuge

The refuge does not have formal water rights or filed permit applications (USFWS 2009a). As described in Section 5.2.3, the refuge has five irrigation wells for groundwater withdrawals. As noted above, the refuge is located within and near the Grand Prairie Critical Ground Water Area; however, the ANRC has not yet begun to regulate groundwater resources in the designated areas. Minimum flows have been initiated for the White River below Bull Shoals Dam; however, it is uncertain how these will affect the refuge.

5.6.3 Aspects of State Water Law that May Negatively Affect the Station

As summarized by Brown-Kobil (2014): It is unclear whether USFWS is able, based purely on state law, to secure water rights to surface water by registering with the Arkansas Soil and Water Commission since the state does not consider a federal agency a person. Regardless, state law does acknowledge that Federal Reserve water rights have priority over other uses (which are usually the case regardless whether a state's code actually recognizes this) in times of shortage, and this should be sufficient for USFWS and DBWRNWR to secure its water rights in Arkansas.

6 Assessment

In this section, the focus will be to highlight and briefly discuss the perceived major threats or issues of concern related to the water resources on the refuge. The primary drivers of these threats are the anthropogenic and environmental stressors occurring within the White River Basin (including the White and Cache Rivers) and influences from the Arkansas and Mississippi Rivers, which are located at the extreme southern portion of the refuge, all of which comprise the RHI for the refuge. For discussion and context purposes, the perceived threats or issues of concern are identified by two temporal categories: 1) urgent/immediate issues (those for which impacts have already manifested) and, 2) long term issues (currently not an immediate threat but if current practices continue, then impacts are likely).

6.1 Water Resource Issues of Concern

The size and complexity of the RHI and the refuge's location within the RHI lends to a multitude of perceived threats and issues of concern that can directly or indirectly impact the water resources. More specifically, the White River Basin is a dynamic hydrologic unit (includes two HUC-6 basins; Upper White [110100] and Lower White [080203]) that drains over 17.7 million acres. In addition to this immense drainage basin, issues are further exacerbated by influences from the Mississippi River and Arkansas River, which can impede the drainage efficiency of the White River. These additional constraints account for two additional HUC-6 basins (Lower Mississippi-Helena [080201] and Lower Arkansas [080204]) in the RHI. These additional contributions add over an additional 1.4 million acres to the RHI, and thereby bring the total area of drainage for the RHI to over 19 million acres.

Specific threats and issues of concern as related to anthropogenic changes within the basin are most associated with water quantity and water quality issues. Anthropogenic changes within these hydrologic units, such as the construction of dams and levees, groundwater withdrawals for agriculture practices, and conversion of bottomland hardwoods to agricultural fields, greatly influence the hydrology within the basin, and ultimately, on the refuge. These generalized changes eventually lead to more specific and common issues on the refuge such as: seasonal water quality issues (e.g., high temperatures, low dissolved oxygen, etc.), alteration of the natural flow regime (e.g., timing, magnitude, and duration of floods or low flows), channel incision or sedimentation, and water rights issues.

To further assist in assessing any perceived resource threats or issues of concern on the refuge, a *Needs Assessment* was conducted in February 2013 (USFWS 2013c). Within the *Needs Assessment*, refuge staff identified the top three environmental threats that currently impact the refuge resources as: 1) water quantity and quality conditions (specifics were flood frequency, erosion, sedimentation), 2) environmental contaminants, and 3) invasive and native nuisance species (e.g., feral hogs, Asian carp, and beaver). When specifically asked to identify the top issues or concerns regarding threats to the refuge's water (quantity) supply, the following were identified: 1) altered river flows from flood control and navigation or irrigation projects, and 2) unseasonal flooding from irrigation run-off (altered hydroperiod). When specifically asked to identify the top issues or concerns regarding threats to the refuge's water quality, the following were identified: 1) agricultural run-off, 2) sedimentation/silt, and 3) head cutting (increased erosion rates).

6.1.1 Urgent/Immediate Issues

6.1.1.1 Water Quantity

Threats or issues of concern include alterations to the availability of surface and groundwater on a seasonal scale and how anthropogenic and environmental changes disturb or alter those water resources.

Surface Water

- Dams utilized for flood control and hydropower generation on the USACE reservoirs in the upper basin greatly affect the timing and availability of the water resources for the refuge through controlled releases. One of the most problematic issues with these controlled releases is the timing. Often, large releases from the USACE reservoirs coincides with high water events on the Arkansas and Mississippi Rivers, thereby slowing the drainage capabilities and causing a "stacking effect" of the surface water. This stacking effect results in areas on the refuge becoming routinely inundated for longer periods of time. The result is too much water during the bottomland hardwoods growing season, thereby potentially damaging those forests. This holding back of the water in the spring also alters peak flow timing. While the subsequent gradual releases throughout the spring and into the summer keeps water off of agricultural fields, it does not aid in the proper management of lower bottomland hardwood forests.
- Proposals to divert surface water from the White River have been made. One example is the Grand Prairie Area Demonstration Project (GPADP), which is currently under construction with a water intake pumping station on the White River near DeValls Bluff, approximately 35 miles upstream from the refuge (USFWS 2012). This will divert "excess" water from the river to be utilized by farmers and agricultural practices in the community. The GPADP has the potential to reduce the stage of the White River by as much as one foot during certain times of the year (e.g., during late spring and throughout the summer months) which would coincide with farming practices. Thus, hydrologic and biological monitoring plans have been developed to measure flow variability and assess impacts to bottomland hardwood forests such that operations can be adaptively managed (USACE 2007a).
- Several other irrigation projects have been proposed that could exacerbate existing alterations to White River hydrology from navigation, irrigation and regulated flow releases (USACE 1999) and include: the Little Red River Irrigation Project and the North Prairie Irrigation Study (NRCS Date unknown).
- Arkansas state government does not currently provide much enforcement on minimum flow requirements during a time of shortage. With the development of a revised state water plan (anticipated publishing of draft rules and an open comment period for 2015), efforts to monitor and maintain minimum flows might become of interest. Generally, in the Delta Region of the state, there is no strong political push to take action because of the economic value of the agriculture industry, often resulting in little to no emphasis on fish and wildlife resources.

Groundwater

- Alteration of water levels, flow and availability is an issue that impacts groundwater as well as surface water. Due to the political interests and agricultural ties associated with the Delta Region of the state, little enforcement authority exists that regulates the impacts to the associated aquifers. This is unlikely to change until, and unless, groundwater availability becomes an issue that impacts agricultural practices.
- Excessive groundwater pumping can cause streams to lose water through infiltration into the aquifer once the aquifer has been dewatered below the water level in the stream. Documentation shows that wells in proximity to the refuge are starting to fail. This indicates that the aquifer is being depleted (i.e., groundwater use is occurring at an unsustainable rate) and the water table is decreasing over time (Bill Prior, AGS, personal communication, May 22, 2013).
- If overdraw of the aquifer continues for an extended time, the capacity of the aquifer to store and release water could be permanently decreased. As the aquifer is depleted, compaction causes loss

in porosity that may be partially or wholly irreversible, leading to a permanent reduction in the ability of the aquifer to store and transmit water.

6.1.1.2 Water Quality

- ADEQ has identified the White River and some associated tributaries (e.g., Cache River) as either an Impaired Waterbody with Completed TMDLs or as a Water Quality Limited Waterbody (ADEQ 2008). The *causes* (i.e., siltation/turbidity, dissolved oxygen, metals, total dissolved solids, or unknown) of these designations have been identified as being associated with *sources* such as agriculture, hydropower, surface erosion, and in some instances, unknown.
- Low dissolved oxygen concentrations impact fish and mussel communities during the warm summer months. Fish communities often experience dies-offs in July and August because of low dissolved oxygen concentrations and high water temperatures often associated with the numerous shallow lakes found throughout the refuge. Occasional kills can also sometimes be attributed to point source releases of anoxic water from agricultural fields and irrigation ditches.
- Increased turbidity also impacts fish, mussel, and aquatic vegetation communities and is often associated with run-off from agriculture practices or is a result from the additional flood pulses associated with the releases from the dams in the upper basin that increase the duration of sediment-laden loads being transported throughout the system.
- Excess nutrient loads as related to agriculture and municipality discharges in the White River (and associated tributaries) are a concern and are further compounded by the enormity of the watershed. ADEQ monitors water quality for environmental contaminants throughout the state and has identified waters for the 303(d) list of impaired streams and has subsequently determined the TDMLs for several waterbodies within the watershed (ADEQ 2008).

6.1.1.3 Geomorphology

- Sedimentation and erosion are major issues and are related to the manipulated flood pulses and installation of levee and road systems throughout the basin and on the refuge. When the water is diverted or redirected from the natural hydrology, impacts downstream can potentially be magnified. This is easily seen in areas where incision, bank/head cutting, and collapse are prominent. Due to the anthropogenic manipulation of the system throughout the basin, it is difficult to accurately determine how much of the sediment load is naturally or artificially created.
- Ongoing dredging in the Mississippi River may be affecting the upstream hydrology because the bed of the Mississippi River is constantly being altered and lowered, thereby potentially affecting the lower end of the refuge by altering the natural drainage capacity of the White River.

6.1.1.4 Invasive and Native Nuisance Species

- Current invasive or native nuisance species posing a threat to refuge resources (terrestrial and aquatic) include: feral pigs, beaver, loblolly pine, kudzu, Chinese privet, and Asian carp (i.e. silver and bighead carp). Most of these are have been inventoried and/or are being monitored on the refuge. At this time, feral pigs and beaver have been identified as the greatest threats to refuge resources (USFWS 2013c).
- The biggest issue with feral pigs is with ground disturbance. Their rooting and wallowing cause sediment issues from soil disturbance. They also compete for food sources with other large native mammals (i.e., white-tail deer, wild turkeys, and black bear).
- Beavers are a nuisance and pose a threat from the construction of dams and huts. These structures divert and pool water into areas that can cause damage. The damage is often to the bottomland

hardwoods and other species that cannot tolerate extended periods of flooding. Also, the structures add to the hydrological alterations and thereby complicate resource management practices.

- Another potential threat to the aquatic biota resources on the refuge is the northern snakehead. As an invasive species, the northern snakehead could have a potential adverse impact to native fish populations. Northern snakeheads have been documented in watersheds adjacent to the refuge and most likely, it is only a matter of time before their presence is confirmed in refuge waters.

6.1.2 Long Term Issues

6.1.2.1 Impacts Related to Climate Change

- Although the specific impacts climate change will have on the White River system are not known with certainty, issues related to climate change (e.g., altered rainfall patterns and amount, extended periods of drought, etc.) could potentially magnify the influences of other identified threats (e.g., agriculture practices) and challenges currently impacting the system.
- Climate models project continued warming in the southeastern United States, and an increase in the rate of warming through 2100. The projected rates of warming are more than double those experienced since 1975, with the greatest temperature increases projected to occur in the summer. By 2080, projected mean temperature increases range from about 4.5°F under a low CO^2 emissions scenario to 9°F (10.5°F in summer) under a higher CO^2 emissions scenario (Karl et al. 2009).
- Based upon information contained within the EPA website on climate change (EPA 2014), changes in rainfall amounts provide evidence that the water cycle is already altered (USGCRP 2009), including a 20% increase of rainfall over the past 50 years associated with the more intense storm events (USGCRP 2009).
- Increases in ambient temperature can increase water temperatures placing additional stress on the aquatic ecosystems within the White River Basin and subsequently on the refuge's aquatic resources.
- Warmer temperatures increase the rate of evaporation of water into the atmosphere, in effect increasing the atmosphere's capacity to "hold" water (USGCRP 2009) and potentially drying out some areas while providing increased precipitation to other areas. Potential evapotranspiration in the vicinity of the refuge is projected to increase, especially during the summer, which could lead to increased moisture stress for plants and decreased availability of water for management of the refuge's impoundments during the summer and fall.
- Arkansas has been identified as experiencing increased drought conditions, with the Delta Region identified as having a significant trend of increased drought (USGCRP 2009).

6.1.2.2 Agriculture

- Commodity markets and the overall economy greatly dictate the types and quantities of crops being produced annually, thereby, potentially requiring more water for production of certain crops (e.g., rice). During such increases and fluctuations in the types of crops being produced, increase in water demands (surface and ground) should be expected.

6.2 Needs/Recommendations

Several of the identified needs and recommendations coincide with those found within other refuge planning documents, more specifically, the CCP. Where appropriate, the associated CCP objectives and strategies as related to aquatic resources and hydrology should be prioritized based on information contained within this WRIA and as is practical for refuge implementation/operations.

6.2.1 Immediate

- Acquire a complete LIDAR (Light Detection and Ranging) dataset for the entire refuge. By doing so, the development if an inundation model can be developed to better understand the hydrological processes occurring throughout the refuge.
- To improve hydrological flows within the refuge, take out culverts and replace with low-water crossings. Increase connectivity and restore more of the natural hydrology where permissible.
- Develop style and installation standards for water control structures to facilitate increased flow, water dispersion, and fish passage in target areas, and when new construction projects are initiated, keep these as a guideline/template to follow and reference.
- Populate a complete road crossing location map. Identify areas that could be targeted for new structures or for replacing old structures and prioritize based on biological (e.g., aquatic species) and management needs.

6.2.2 Long term

Recommendations to begin addressing potential impacts include: 1) Identify species that are most likely to be negatively impacted by effects of climate change, as well as generalist species that may benefit from changes; 2) Increase contiguity of footprint of NWR lands; 3) Establish decision-making processes that place individual refuges within a system context, and coordinate local actions with regional/national objectives and respective partners. Efforts to identify and monitor the environmental impacts associated with the introduction of non-native invasive species should also be considered.

6.2.2.1 Partnerships

Many agencies and citizen groups are active partners in conservation, management and sustainability of the White River basin. In order to most effectively manage and protect this complex watershed, continued, enhanced, and expanded future support of these and other partnerships is critical. Establishing new partnerships with agencies and entities where previous coordination and collaboration did not exist is also imperative. These partnership opportunities can potentially provide additional resources and perspectives on issues regarding the water resources within the watershed and on the refuge. One such recommendation would be to work with the Arkansas Geological Survey (AGS), Arkansas Natural Resources Commission (ANRC), and U.S. Geological Survey (USGS) regarding groundwater issues.

Work to strengthen communication/partnership with USACE Little Rock District. This relationship has not been as positive as the refuge's relationship with the Vicksburg and Memphis Districts of USACE. The Memphis District has been receptive to changing management practices with regards to endangered species.

6.2.2.2 Water Quantity Information

Critical data are needed for the refuge, documenting the magnitude, frequency, timing, and duration of stream flows needed throughout the year. As part of this data need, it is recommended that current USGS gages in the vicinity of the refuge be maintained, and an analysis of critical data gaps in gage data (for both surface water and groundwater) be completed in order to evaluate the need for additional gages and monitoring wells. Additional surface water and groundwater information can be obtained from various state and federal agencies, including ADEQ, AGS, USGS, and USACE.

6.2.2.3 Groundwater Information

Additional research is needed to document and evaluate groundwater contributions to surface flow in the White River throughout the year. Analysis of aquifer hydrogeology and vulnerability to contamination for the physiographic region that includes the upper and lower White River watersheds is also needed.

As agriculture land use practices continue in the watershed, and climate change influences both aspects of surface water and groundwater recharge and discharge, the need for long-term groundwater information will increase. Continued and supplemental monitoring of active wells within the watershed should be maintained and be implemented throughout the basin. Efforts should be made to collaborate with state and federal partners to effectively identify issues regarding the respective aquifers and how adverse long-term impacts to those aquifers could affect the aquatic resources on the refuge.

6.2.2.4 Water Quality Monitoring

Evaluation of TMDLs in the watershed and monitoring of those associated impaired streams should continue over time. In addition, potential research could focus on biological monitoring, as well as nutrient and sediment modeling for those impaired streams within the watershed, providing information useful for species restoration efforts.

Research and outreach regarding Best Management Practices (BMPs), and both the correct implementation and evaluation of BMP effectiveness, are needed for reductions in sedimentation and excess nutrients/contaminants which are often a result of land use, including forestry and agriculture practices.

Specific water monitoring objectives for the refuge should be developed and implemented, either as part of the IMP for the refuge, or as a stand-alone document. Water monitoring efforts are tied to critical baseline information needs in the adaptive management framework; targeting ecological integrity while meeting refuge, Regional, and National level Water Resources Inventory and Monitoring Goals and Objectives (USFWS 2010a; USFWS 2013c). Specific tasks should ideally supplement existing water monitoring work already being conducted in the watershed and in proximity to the refuge (e.g., ADEQ monitoring sites and efforts). Given projected mean temperature increases of 4.5 to 9 °F by 2080, additional water temperature monitoring to establish baseline conditions and detect future trends that could impact aquatic species should be considered. Sedimentation work (e.g. Total Suspended Solids (TSS), bedload transport, and turbidity) recorded for varied discharges are especially needed. Additional biological monitoring for indicator species with documented life-history traits related to flow conditions could also be explored and based on Richter et al. (2003) information. Directly linked to biological monitoring is a critical data need for taxonomic research and basic natural history research (especially life histories and flow dependencies) for species in the White River and associated tributaries, such as Indian Bayou.

6.2.2.5 Infrastructure and Barriers

Continue to implement recommended immediate actions as available resources allow. Efforts to restore the hydrologic connectivity could be accomplished by altering levees, low water crossings, dams, and other structures. This will also address fish passage issues. Efforts should be made to evaluate the effectiveness of installing fish passage structures (in lieu of culverts) on the refuge where practical and feasible. Specific areas should be identified to provide better connectivity to potential spawning and nursery habitats for large riverine species (e.g., alligator gar *Atractosteus spatula* and paddlefish *Polyodon spathula*). Such species require and utilize backwater and inundated areas seasonally and during various aspects of their life history.

6.2.2.6 Long-term Planning

As identified as a strategy in the refuge CCP under *Objective 2-6: Water Control*, and through the use of this WRIA and the completed HGM analysis, the development of a detailed water management plan for the refuge should be considered. The plan should include information for management practices pertaining to inundation frequency and impacts to resources affected. Also include any actions that can be taken to facilitate improvements to the hydrological regime on the refuge, including subsequent drainage of inundated areas as appropriate.

An IMP is needed for DBWRNWR. The IMP will allow for better planning in trying to identify appropriate inventory and monitoring of the water resources on the refuge. This also relates to *Objective 2-8: Inventory, Monitoring, and Research* within the refuge's CCP.

Consideration to pursue National Wild and Scenic River status for the White River or tributaries within the lower drainage should be considered. Wild and scenic status would afford greater protection to these unique waters, and recognition of the recreational and aesthetic value of the watershed.

Development of a protocol for removing barriers (culverts, abandoned water control structures, etc.) will be helpful in addressing fish passage and restoring the natural hydrology as much as possible. Work with partners such as USGS to develop flood inundation models to assess and identify priority areas for such restoration/construction projects.

Stay informed on the status of the Arkansas State Water Plan. Once completed, review the plan and evaluate whether there are additional actions that can be taken based on information it contains to better address water resource issues on the refuge.

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8 Appendices