TMDLS FOR LAKES LISTED FOR MERCURY IN FISH TISSUE FOR THE OUACHITA RIVER BASIN, ARKANSAS

May 25, 2004

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Prepared for

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EXECUTIVE SUMMARY

The Arkansas 2002 Section 303(d) List includes three lakes in the Ouachita River basin that are impaired due to excess concentrations of mercury in fish. While there have been no known violations of the numeric mercury water quality standard and fishable designated use for these water bodies, these lakes are not meeting the narrative water quality standard and designated uses of fishable water bodies. A basin-wide approach is being used in this TMDL due to similar ecoregions and watershed characteristics and because of similar causative factors such as atmospheric and geologic contributions.

The Ouachita River basin is in the Ouachita Mountain, South Central Plain, and Mississippi Alluvial Plain ecoregions. It has gently rolling topography, with hilly uplands, flat wooded uplands, terraces, and floodplains. Land use in the basin is 71% forest with 13% in wetlands. There is one NPDES point source with permit mercury limits in the basin. There are seven air emission point sources with permit mercury limits. The geology of the Ouachita Mountains contains rocks with relatively high, naturally occurring mercury concentrations. The soils in the basin reflect this geology and also receive mercury from atmospheric deposition.

Arkansas has a numeric mercury water quality standard of 0.012 µg/L. There have been no known violations of the numeric water quality standard, but clean sampling procedures and ultra-trace level analyses have not been used. There are fish consumption advisories throughout the lower Ouachita River basin in both Arkansas and Louisiana because of mercury contamination of fish. The Mercury Action Level in Arkansas for fish consumption advisories is 1 mg/kg. The target mercury level for total mercury for all fish species in this TMDL is 0.8 mg/kg, using a 20% Margin of Safety (MOS) for the Action Level.

The TMDL was developed using a two-step approach. The first step estimated the mercury loads from the NPDES facility with a mercury permit limit, municipal wastewater treatment facilities, local emission point sources, regional atmospheric deposition, watershed nonpoint sources, and natural background. In the second step, maximum and average largemouth bass tissue mercury concentrations measured in the lakes were used to estimate the reduction in fish tissue mercury needed to achieve the target levels. A linear relationship was assumed between mercury in fish and mercury loading to the basin. The reduction factor to achieve target fish tissue mercury levels was then used to determine the reduction needed in basin mercury loading.

The predominant sources of mercury loading to the Ouachita River basin are from atmospheric deposition and watershed nonpoint source and background loads. Less than 1% of the load came from the point source wasteloads. Reduction factors to reduce fish tissue concentrations to target levels ranged from 1.3 to 2.2. Target mercury loads to achieve the target fish tissue mercury levels ranged from 47,024 g/yr to 589,315 g/yr. Estimated reductions in mercury loading to the Ouachita River basin as a result of implementation of mercury emission regulations and erosion BMPs were calculated. These reductions were predicted to achieve the mercury target loads based on largemouth bass tissue mercury meeting the target fish tissue mercury levels.

This TMDL was developed using the best available information on mercury levels in the environment and waste streams, and current water quality standards. This TMDL may need to be revised in the future as new information becomes available that would have a bearing on the assumptions on which this TMDL is based.

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1.0 INTRODUCTION

The Arkansas 2002 Section 303(d) List included three lakes impaired due to excess concentrations of mercury in fish within the Ouachita River watershed for which TMDLs had not been developed. Table1.1 (all tables and figures are located at the end of their respective chapter) identifies the lakes not included in previous TMDLs that are on the 303(d) List due to elevated mercury in fish.

For consistency with previously developed fish tissue mercury TMDLs in the Ouachita River basin, and because of similar ecoregion and watershed characteristics, and potentially similar causative factors such as atmospheric and geologic contributions, the TMDL development is based on a basin-wide approach to the Ouachita River watershed. For this TMDL, the Ouachita River basin has been defined to include the Ouachita River, Saline River, Bayou Bartholomew, and their tributaries located within the hydrologic unit codes (HUC) 08040201, 08040202, 08040203, 08040204, 08040205, and 08040207 (Figure 1.1). This is the same basin that was used for the previous fish tissue mercury TMDLs in the Ouachita River basin.

This watershed is of critical concern because of litigation over the 303(d) process in Arkansas and the pervasiveness of mercury contamination. While there have been no known violations of the numeric water quality standard and the fishable designated use for these water bodies, these lakes are not meeting the narrative water quality standard and designated uses of fishable water bodies. Therefore, development of a TMDL is required. This TMDL is being conducted under EPA Contract #68-C-02-108, Work Assignment #0-19.

Table 1.1. Lakes in the Ouachita River basin on 303(d) List.

Waterbody Name	HUC	On 303(d) List	Fish Consumption Advisory	Priority
Big Johnson	08040202	Yes	Yes	High
Grays Lake	08040204	Yes	Yes	High
Lake Monticello	08040204	Yes	Yes	Low

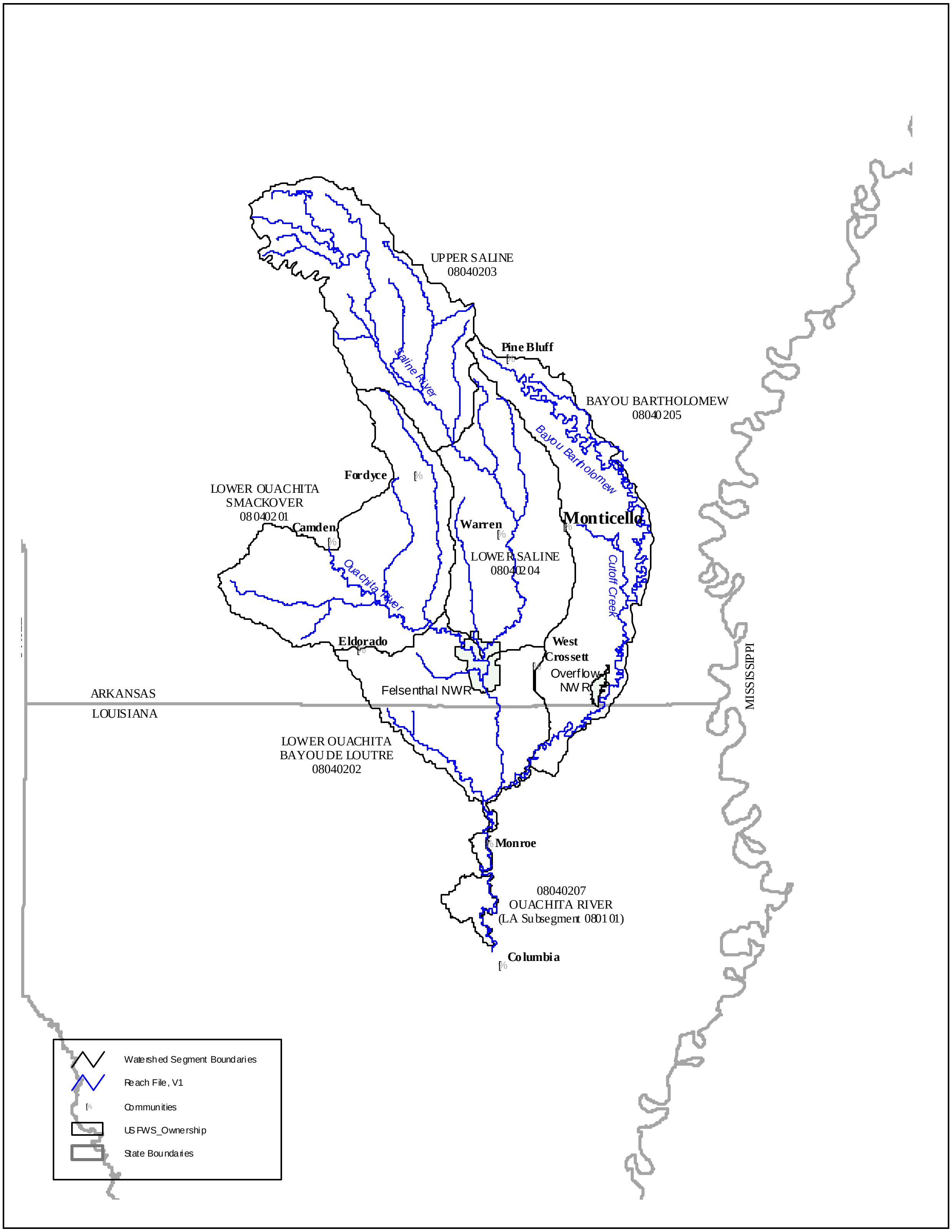

Figure 1.1. Drainage basin for the study area.

2.0 DESCRIPTION OF BASIN

2.1 Ecoregions

The Ouachita River basin includes portions of the Ouachita Mountain, South Central Plain, and Mississippi Alluvial Plain ecoregions (Omernick 1987). The Saline River and Ouachita River headwaters are in the Ouachita Mountain ecoregion and arise in the Ouachita Mountains of west central Arkansas (Figure 2.1). The upper section of each river drains a portion of the Ouachita Mountains, which are composed mostly of sandstone and shale. Near Malvern, Arkansas, the Ouachita River enters the South Central Plain ecoregion where the character of the river changes. Here the river gradient decreases significantly, and the river gradually changes into more of a lowland stream (lower riffle to pool ratio) (Figure 2.2). The Saline River enters the South Central Plain ecoregion near Benton, Arkansas, where the character of the river has similar changes to those of the Ouachita River.

The headwaters of Bayou Bartholomew begin northwest of Pine Bluff, Arkansas in the Mississippi Alluvial Plain ecoregion. Bayou Bartholomew meanders through southeast Arkansas and into northeast Louisiana before emptying into the Ouachita River near Sterlington, Louisiana. The watershed is located within both the South Central Plain and the Mississippi Alluvial Plain ecoregions.

2.2 Topography

The following description of the topography of the watershed was taken from county soil surveys (USDA 1958; 1967; 1968; 1972; 1973; 1976; 1979; 1980). The majority of the Ouachita and Saline Rivers watershed is in the South Central Plain ecoregion. The topography of this area can be described as nearly level or gently rolling to hilly uplands, terraces, and floodplains. Slopes are mainly 1% to 8% but can range from 0% to 20%. The Bayou Bartholomew watershed is in the Mississippi Alluvial Plain and South Central Plain ecoregions. The topography of this area can be described as level to moderately steep, with the main topographic divisions consisting of rolling uplands, flat wooded uplands, terraces, and floodplains. Slopes are mainly 1% to 8%, but range from 0% to 20%.

2.3 Soils

Soil characteristics for the watershed are also provided by the county soil surveys (USDA 1958; 1967; 1968; 1972; 1973; 1976; 1979; 1980). Most of the soils in the watershed are classified as loamy. Soil series that are common in the watershed area are Amy, Cahaba, Ouachita, Pheba, Savannah, Smithton, and Ruston. These soils are classified as silty loams or sandy loams.

2.4 Land Use

Land use in the watershed is predominantly forest land (Figure 2.3). Areas and approximate percentages of each land use in the watershed are listed in Table 2.1.

Prior to development, the watershed basin was predominantly covered with thick growths of hardwoods and pines. Only a small part of the basin was prairie. As settlers arrived in the early 1800s, agriculture grew steadily until the outbreak of World War II, and then declined. In the 1930s, reforestation efforts were begun to restore once cleared land to woodland. Lumbering has become the chief source of income. Much of the forested land is managed for the production of pulpwood, poles, and saw logs.

Farming practices are fairly uniform throughout the basin. Rice and cotton are typically planted in April through May and soybeans are planted later in May through June. Wheat is planted in October and November. Irrigation is primarily by flooding. Rice is flooded in May, soybeans are irrigated in June through July, and cotton is irrigated in July. Rice fields are typically drained in late August through September. Much of the crop land is bare from November through March.

2.5 Description of Hydrology

USGS daily stream flow data were retrieved for gages on the Ouachita River near Camden, Arkansas; on the Saline River near Rye, Arkansas; on Bayou Bartholomew near Garrett Bridge, Arkansas; and on the Ouachita River at the Arkansas/Louisiana state line. Basic information and summary statistics for these gages are summarized in Table 2.2.

Average annual precipitation for the watershed is approximately 54 inches (Hydrosphere 2000). Mean monthly precipitation totals for the watershed are shown on Figure 2.4. The mean monthly precipitation values are highest for March and lowest for July. Precipitation data from three stations within each of the five HUCs was used to calculate the annual and monthly mean precipitation for the watershed.

2.6 Point Sources

Information on NPDES point source discharges in the watershed was obtained by searching the Permit Compliance System (PCS) on the EPA website. The PCS search identified a total of 176 facilities with NPDES permits within the watershed. Of these 176 permitted facilities, 43 were city municipal wastewater treatment plants (WWTPs). ENSCO, Inc. (NPDES permit no. AR0037800) located in Union County was the only facility that was identified as having an NPDES permit limit for mercury. ENSCO has a facility flow rate of 1.29 MGD and a permit limit of 0.2 µg/L for total recoverable mercury. None of the other NPDES facilities had permit mercury limits. However, ADEQ used clean sampling procedures and ultra-trace level analyses to sample for mercury in five municipal WWTPs in Arkansas during 1995 (Allen Price, personal communication 2001). The average mercury concentration for these WWTPs was 0.015 µg/L. Clean sampling procedures and ultra trace level analyses have not been used to sample any other types of facilities, so no information is available on mercury for these facilities. A listing of the NPDES permitted facilities is included in Appendix A.

Information on local air emission sources in the airshed (airshed is defined as all counties within 100 km of the Ouachita River watershed boundary) was obtained by searching the 1999 National Emissions Inventory (NEI) on the EPA website. The NEI includes point sources, area sources, and mobile sources. A search was done of the maximum achievable control technology (MACT) source category, which includes the number of sources and total hazardous air pollutant (HAP) emissions for each MACT source category included in the NEI. The database search for the airshed resulted in about 1,000 air emission sources in nine MACT source categories. The MACT standards are emission limitations developed under Section 112(d) of the Clean Air Act (National Emissions Standards for Hazardous Air Pollutants). The limitations are based on the best demonstrated control technology or practices in similar sources to be applied to major sources emitting one or more of the listed toxic pollutants. A listing of the air emission sources of mercury is included in Appendix B.

Table 2.1. Acreage and percent of land use categories in the Ouachita River basin.

Land Use	10^6 Acres (mi^2)	Percent
Forest	3.62 (5,657)	70.5
Pasture	0.4 (635)	7.9
Cropland	0.33 (514)	6.4
Wetland (forest/nonforested)	0.66 (1,026)	12.8
Water	0.02 (32)	0.4
Urban and Other	0.10 (155)	1.9
TOTAL	5.13 (8,020)	100

Table 2.2. Information for stream flow gaging stations.

	Ouachita River near Camden, Arkansas	Saline River near Rye, Arkansas	Bayou Bartholomew at Garrett Bridge, Arkansas	Ouachita River at Arkansas/Louisiana State Line
USGS gage number	07362000	07363500	07364133	07364100
Descriptive location	Ouachita County on US Highway 79 at Camden, 3.4 miles downstream from Ecore Fabre Bayou, at mile 354.1	Bradley County on State Highway 15, 3.6 miles southwest of Rye, at mile 71.0	Located in Lincoln County on downstream side of bridge on State Hwy 54, 1.9 miles upstream from Flat Creek at Garrett Bridge	Union City near Arkansas/Louisiana state line
Drainage area (mi^2)	5,357	2,102	380	10,787
Period of record	Oct. 1928 to Sept. 2002	Oct. 1937 to Sept. 2002	Oct. 1987 to Sept.2002	April 1958 to Sept. 2002
Mean flow (cfs)	7,706	2,619	548	4,581
Minimum flow (cfs)	125	4	0.3	190
Maximum flow (cfs)	243,000	14,500	5,220	19,200
Flow (cfs) that is exceeded:				
80% of the time	791	65	16	1,500
50% of the time	3,460	679	197	3,020
20% of the time	19,400	7,470	1,600	7,250

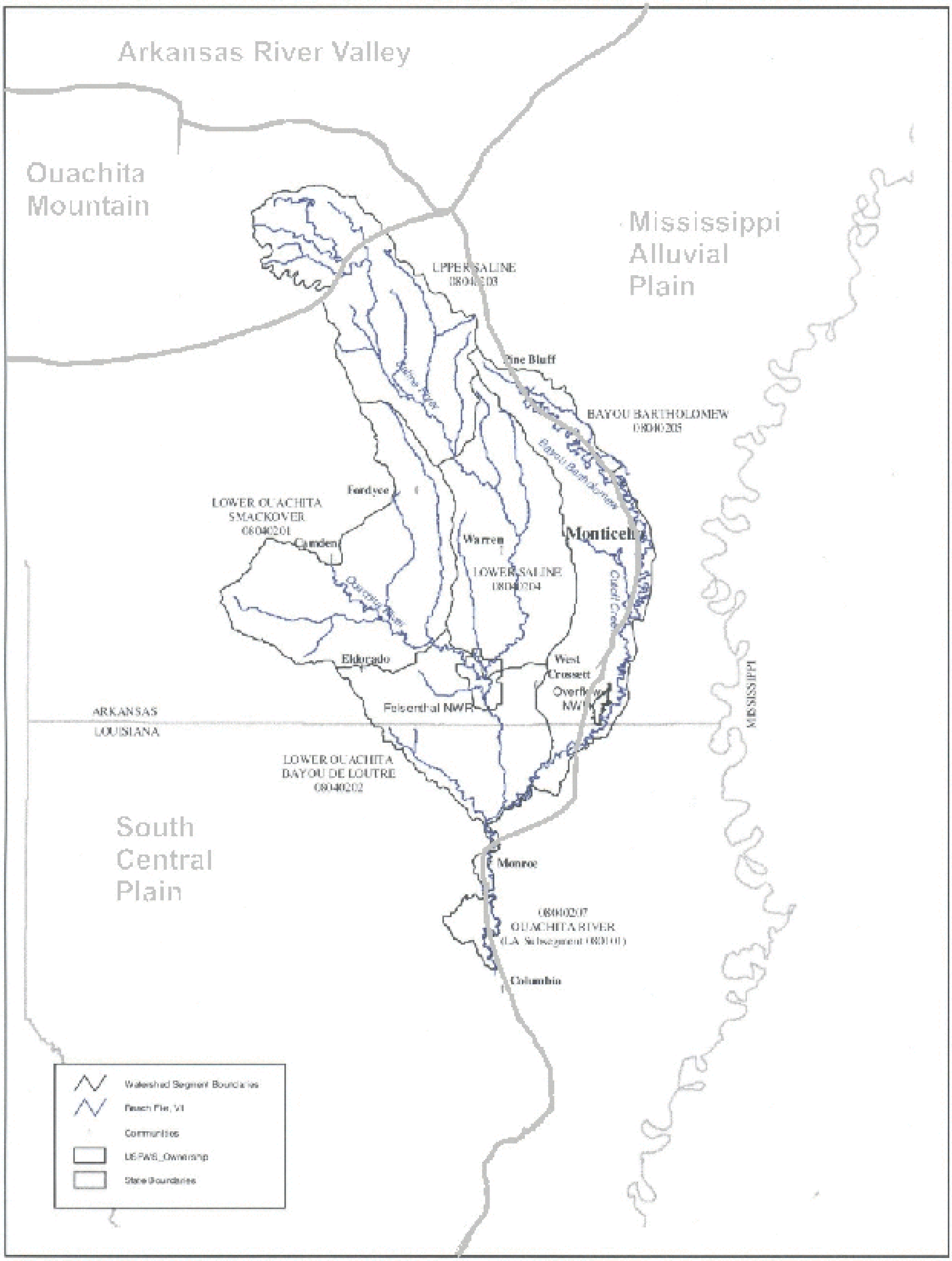

Figure 2.1. Ouachita River basin and associated HUC codes included in the TMDL

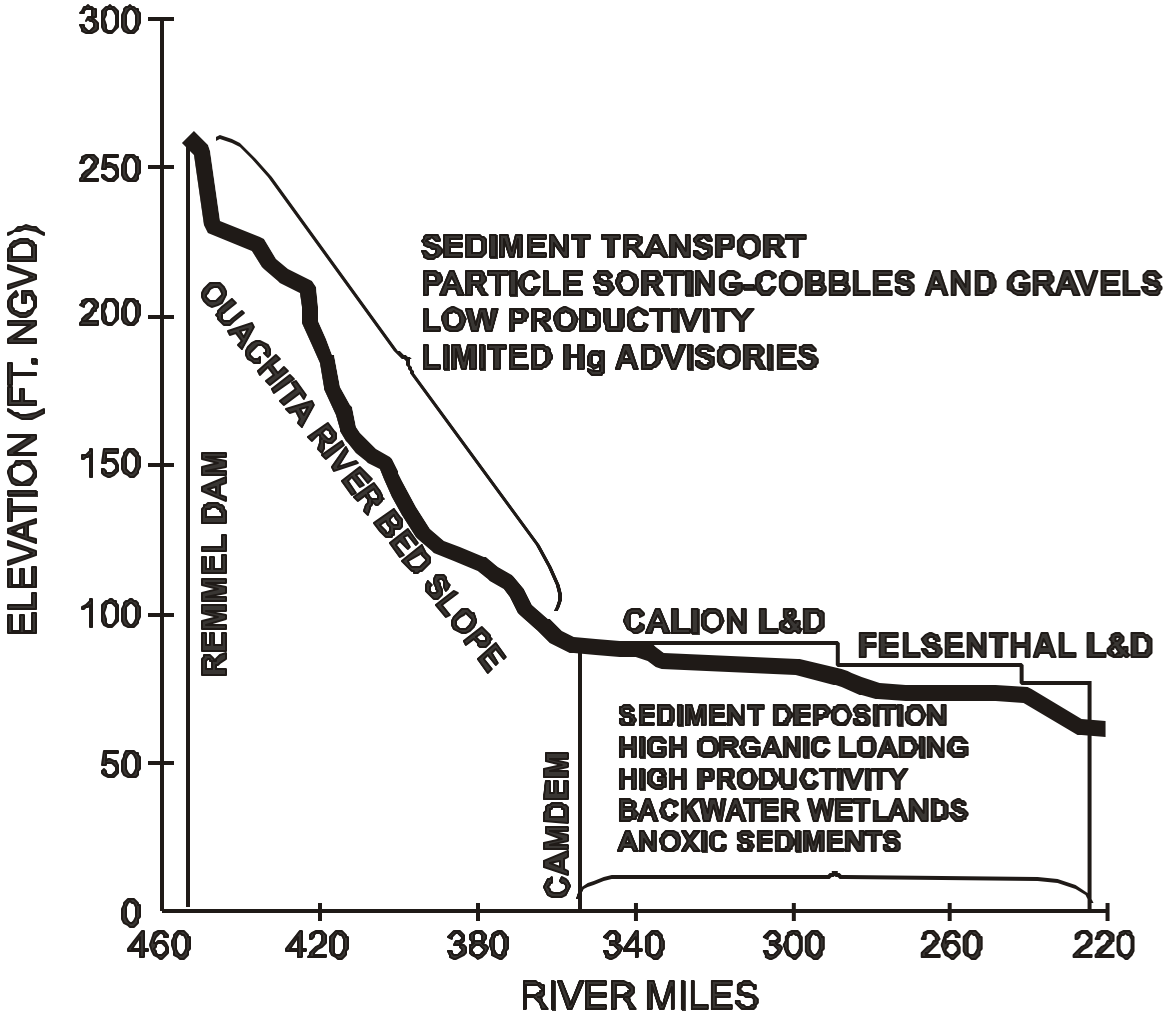

Figure 2.2. Differences in stream characteristics above and below Camden, which is the general vicinity where consumption advisories begin in the southern half of the state.

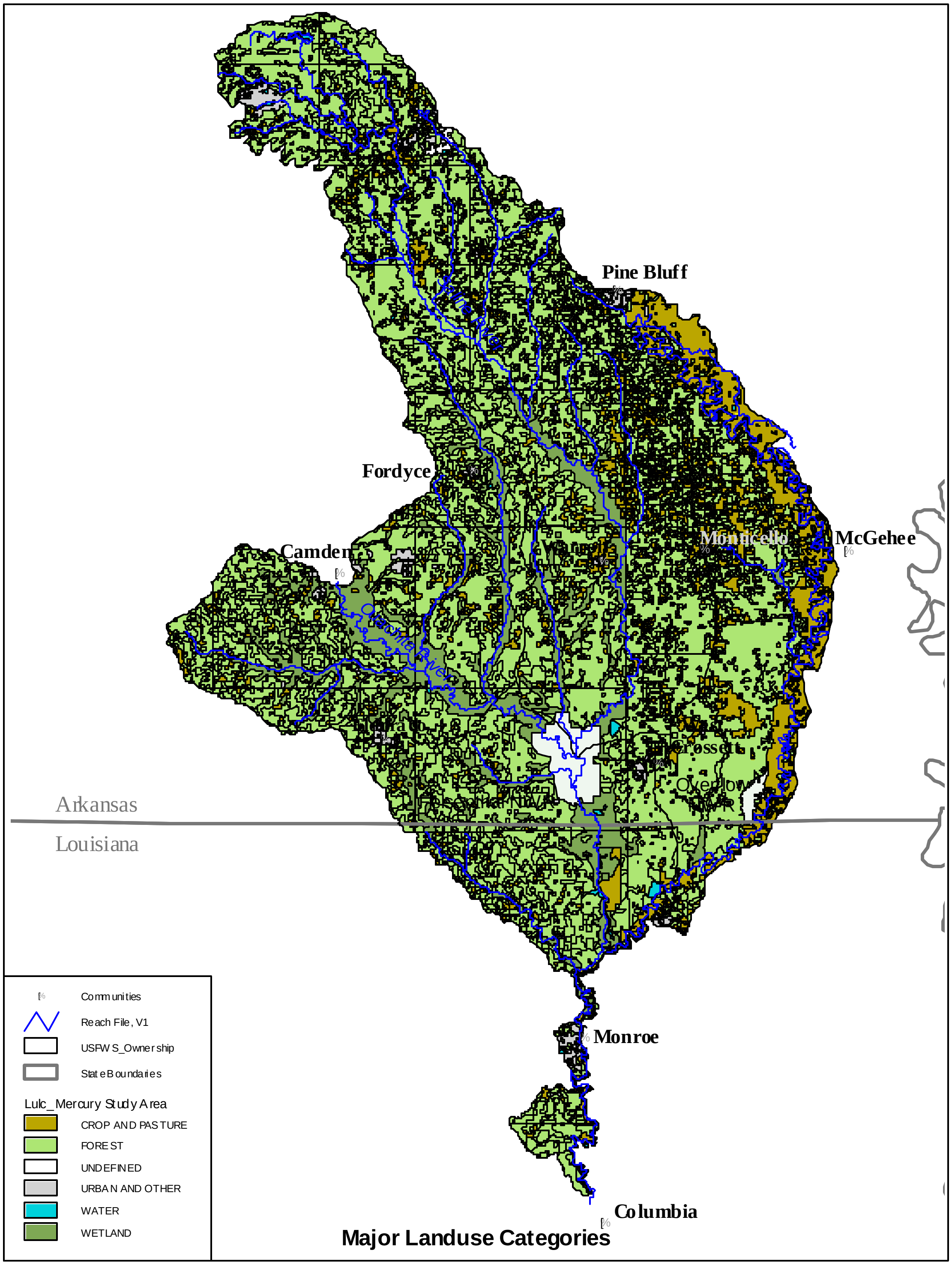

Figure 2.3. Land use within the Ouachita River basin.

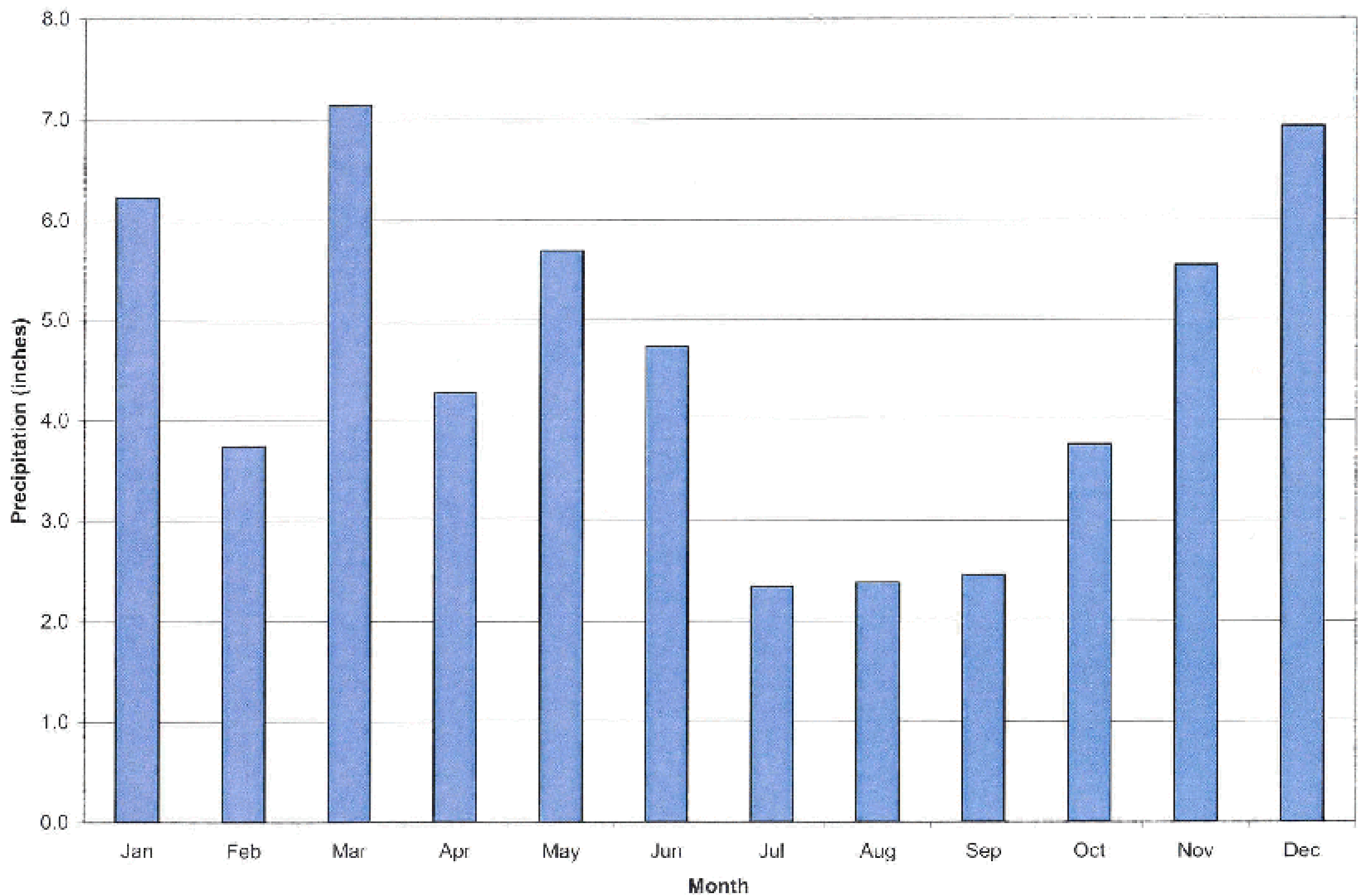

Figure 2.4. Mean monthly precipitation.

3.0 WATER QUALITY STANDARDS AND EXISTING WATER QUALITY CONDITIONS

3.1 Water Quality Standards and Fish Tissue Action Levels

The State of Arkansas has developed water quality standards for waters of the State (ADEQ 2002). The standards are defined according to ecoregions and designated uses of the waterbodies. The Ouachita River basin lies within three ecoregions: the Ouachita Mountain ecoregion, the South Central Plain ecoregion, and the Mississippi Alluvial Plain ecoregion. Designated uses for the Ouachita River basin from Remmel Dam to the Arkansas State Line include primary and secondary contact recreation; protection and propagation of fisheries, shellfish and other forms of aquatic life; and domestic, industrial and agricultural water supply. Some waterbodies within the Ouachita basin are also designated as extraordinary resource waters, natural and scenic waterways, and ecologically sensitive waterbodies. The mercury water quality standard for Arkansas waters for all ecoregions is 0.012 µg/L, expressed as total recoverable mercury. Although this water quality standard is to protect aquatic life, it was developed to protect humans from consuming aquatic life contaminated by mercury. There is no correction factor for hardness or other constituent concentrations. The narrative standard for toxic substances in Section 2.508 (Regulation No. 2, ADEQ 1998) is “Toxic substances shall not be present in receiving waters, after mixing, in such quantities as to be toxic to human, animal, plant, or aquatic life or to interfere with the normal propagation, growth, and survival of the indigenous aquatic biota.” The fish consumption Action Level in Arkansas is based on the FDA Action Level of 1.0 mg/kg (wet weight).

This TMDL uses fish tissue monitoring data as a means to determine whether the “fishable” use is being met and the reductions needed to achieve the designated use. The “fishable” use is not attained if: (1) the fish and wildlife propagation is impaired and/or (2) if there is a significant human health risk from consuming fish and shellfish resources. The lakes that are the subject of this TMDL, as indicated above, were listed in the 2002 303(d) List based on elevated fish tissue mercury concentrations, and are in violation of narrative standards for toxic substances.

3.2 Existing Mercury Concentrations in Water and Fish Tissue

There have been no exceedances of the mercury water quality standard in the Ouachita River basin in Arkansas because of mercury. The analytical procedures used previously (1992-1994) had a detection limit of 0.2 µg/L and all samples were less than the detection limit. No more recent analysis of mercury in ambient water has been performed (Allen Price, ADEQ, personal communication October 6, 2003). Currently, the waterbody concentrations of mercury and methyl mercury are unknown. In the future, clean sampling and analysis procedures might facilitate the estimation of loading through water column monitoring.

Fish were collected by the Arkansas Game and Fish Commission per EPA (1995) from 1993 through 1999 throughout the Ouachita River basin, including the Ouachita River and its tributaries and lakes within the basin (Armstrong et al. 1995; Nat Neheus, ADEQ, personal communication August 29, 2003). Fish mercury concentrations are summarized in Table 3.1 and shown on Figure 3.1. Fish consumption advisories are in place for mercury contamination in portions of the Ouachita River basin based on the FDA guideline of 1 mg/kg. The locations of these fish consumption advisories are shown on Figure 3.1.

3.3 Additional Water Quality Data

Additional water quality data were obtained from the EPA STORET system. The stations, agency code, HUC, and period of record (POR) for this study are listed in Table 3.2. Water quality data are also summarized on Figures 3.2 through 3.4 for sulfate, total organic carbon (TOC), and pH. These three constituents have been demonstrated to be correlated with fish mercury concentrations and can affect the bioaccumulation and bioavailability of mercury for methylation and subsequent uptake of methylmercury through the food chain (Armstrong et al. 1995, EPA 1998). The overlapping ranges of moderate sulfate and TOC concentrations with lower pH values in the lower portion of the Ouachita River basin provides an environment conducive to microorganisms that methylate mercury (Armstrong et al. 1995). These conditions likely contribute to the elevated fish mercury concentrations in this area.

In addition, significant wetland acreage is also located in this portion of the Ouachita River basin. Wetland ecosystems have conditions that are particularly suited to organisms that methylate mercury (Rudd 1995).

Table 3.1. Maximum fish tissue Hg concentration mg/kg (wet weight) for largemouth bass and other species of concern in the Ouachita River basin.

Station	Bass (includes largemouth and spotted bass species) Max Hg Concentration mg/kg	Others (includes all other species collected) Max Hg Concentration mg/kg	Others Common Name
BAYOU BARTHOLOMEW AT BAXTER	1.29		
BAYOU BARTHOLOMEW AT HWY 425 LA	1.39		
CALION LAKE	1.02		
CHAMPAGNOLLE CREEK	1.34	1.52	BOWFIN
CORNIE BAYOU	0.90		
DOLLAR SLOUGH AREA OF FELSENTHAL NWR	2.64	0.70	DRUM
LAKE FELSENTHAL	1.10		
LAKE WINONA	1.48		
LOWER OUACHITA RIVER ABOVE CAMDEN	0.45	<0.2	SUCKERS
LOWER OUACHITA RIVER AT DALLAS CO. ACCESS	0.55	0.29	SUCKERS
LOWER OUACHITA RIVER BELOW TWO BAYOU	0.59		
MORO CREEK ABOVE STATE PARK	1.42	1.41	SPOTTED GAR
MORO CREEK AT HWY 160	1.56	1.58	CHANNEL CATFISH
MORO CREEK AT HWY 275	0.90	1.18	BOWFIN
OUACHITA AND SALINE RIVERS NEAR CONFLUENCE	2.44	0.46	SMALLMOUTH BUFFALO
OUACHITA R- PIGEON HILL	1.40	0.40	BLACK CRAPPIE
OUACHITA R.- BELOW FELSENTHAL	1.36	1.86	FLATHEAD CATFISH
OUACHITA RIVER ABOVE CAMDEN	0.71	0.65	REDHORSE
OUACHITA RIVER- ABOVE LAPILE CREEK	0.21	0.61	BLUEGILL
OUACHITA RIVER AT CHERRY HILL ACCESS	0.89		
OUACHITA RIVER AT DALLAS CO. ACCESS	0.41	0.25	SUCKERS
OUACHITA RIVER AT GRIGSBY FORD	0.52	0.75	REDHORSE
OUACHITA RIVER BELOW HWY. 82	2.41	0.43	SMALLMOUTH BUFFALO
OUACHITA RIVER AT MCGUIRE ACCESS	0.60		
OUACHITA RIVER AT PIGEON HILL	1.10	0.80	SUCKERS

Station	Bass (includes largemouth and spotted bass species) Max Hg Concentration mg/kg	Others (includes all other species collected)	
		Max Hg Concentration mg/kg	Others Common Name
OUACHITA RIVER BELOW CALION L&D		1.38	FLATHEAD CATFISH
OUACHITA RIVER BELOW COFFEE CREEK	1.20		
OUACHITA RIVER BELOW COVE CREEK (REMMEL DAM)	0.46	0.40	GOLDEN REDHORSE
OUACHITA RIVER BELOW SMACKOVER CREEK	1.13	0.52	CARP
OUACHITA RIVER BELOW TATES BLUFF	0.35	0.37	REDHORSE
OUACHITA RIVER BELOW WEST TWO BAYOU	0.70		
OUACHITA RIVER NEAR FRIENDSHIP	0.55		
OUACHITA RIVER NR ODEN	0.98		
SALINE R. BELOW L'AIGLE CREEK	1.78	1.50	CRAPPIE
SALINE RIVER - ASHLEY AND BRADLEY COUNTIES	1.70		
SALINE RIVER AT COWFORD'S ACCESS, CLEVELAND CO.	1.09	0.52	DRUM
SALINE RIVER AT HIGHWAY 4	1.72	0.91	DRUM
SALINE RIVER AT HWY. 79	0.84	0.48	BLACK CRAPPIE
SALINE RIVER AT I-30 BRIDGE	0.80		
SALINE RIVER AT JENKINS FERRY	0.78	0.72	REDHORSE
SALINE RIVER AT LEES FERRY	0.64	0.81	CHANNEL CATFISH
SALINE RIVER AT LONGVIEW ACCESS, ASHLEY CO.	0.99	1.90	DRUM
SALINE RIVER AT MT. ELBA	1.87	1.13	CHANNEL CATFISH
SALINE RIVER AT OZMENT BLUFF, DREW CO.	1.10	1.47	REDHORSE
SALINE RIVER AT PRAIRIE ISLAND ACCESS BRADLEY CO.	0.66	1.29	BLACK CRAPPIE
SALINE RIVER- FITZHUGH ACCESS	0.86	0.56	BLACK CRAPPIE
SALINE RIVER NR EAGLE CREEK, BRADLEY CO.	1.79	1.84	FLATHEAD CATFISH
SHALLOW LAKE AREA OF FELSENTHAL NWR	1.34	1.36	SPOTTED GAR
SMACKOVER CREEK	0.97	0.71	BOWFIN
WILDCAT-FELSENTHAL	1.91	1.51	BLACK CRAPPIE
OUACHITA RIVER NEAR STATE LINE	1.02	1.45	DRUM
OUACHITA RIVER NEAR STERLINGTON LA	1.24	0.92	BLACK CRAPPIE

Station	Bass (includes largemouth and spotted bass species) Max Hg Concentration mg/kg	Others (includes all other species collected)	
		Max Hg Concentration mg/kg	Others Common Name
OUACHITA RIVER NEAR RIVERTON	1.07	0.99	DRUM
OUACHITA RIVER NEAR COLUMBIA	0.37	1.56	BOWFIN
GRAYS LAKE - CLEVELAND CO.	1.78	1.18	FLATHEAD CATFISH
BIG JOHNSON LAKE - CALHOUN CO	1.71	1.17	CHAIN PICKEREL
LAKE MONTICELLO	1.93	1.4	CHANNEL CATFISH

Note: This List of stations and maximum Hg concentrations was derived from the fish tissue database provided by ADEQ. The data was compiled by FTN Associates.

Table 3.2. Water quality monitoring stations in the Ouachita River basin, agencies, HUC, and POR.

ID	Station	Agency	HUC	POR
50357	OUA137A	1116APCC	08040201	94-97
50039	OUA02	1116APCC	08040206	92-present
50042	OUA05	1116APCC	08040206	92-present
50046	OUA08A	1116APCC	08040202	92-present
50285	OUA08B	1116APCC	08040202	92-97
50094	OUA10A	1116APCC	08040204	92-present
50277	OUA117	1116APC	08040204	92-present
50278	OUA118	1116APCC	08040204	92-present
50358	OUA137B	1116APCC	08040201	94-97
50359	OUA137C	1116APCC	08040201	94-97
50360	OUA137D	1116APCC	08040201	94-97
50276	OUA16	1116APCC	08040203	92-present
50261	OUA18	1116APCC	08040203	92-present
50158	OUA26	1116APCC	08040203	92-present
50159	OUA27	1116APCC	08040201	92-present
50160	OUA28	1116APCC	08040201	92-present
50189	OUA37	1116APCC	08040201	92-present
50193	OUA42	1116APCC	08040203	92-present
50194	OUA43	1116APCC	08040204	92-present
50266	OUA47	1116APCC	08040201	92-present
05UWS030	UWCHCO1	21ARAPCC	08040201	94-96
B080190020	580010018	21LA10RS	08040206	92-98
S081465010	58010068	21LA10RS	08040206	92-98
S080190020	58010018	21LA10RS	08040206	92-98
B083305010	58010015	21LA10RS	08040206	92-98
50051	OUA13	1116APCC	08040205	90-98
50165	OUA33	1116APCC	08040205	90-98
05UWS036	UWBYB01	21ARAPCC	08040205	94-96
05UWS040	UWBYB02	21ARAPCC	08040205	94-98
05UWS041	UWBYB03	21ARAPCC	08040205	94-98
05UWS038	UWCOC01	21ARAPCC	08040205	94-98

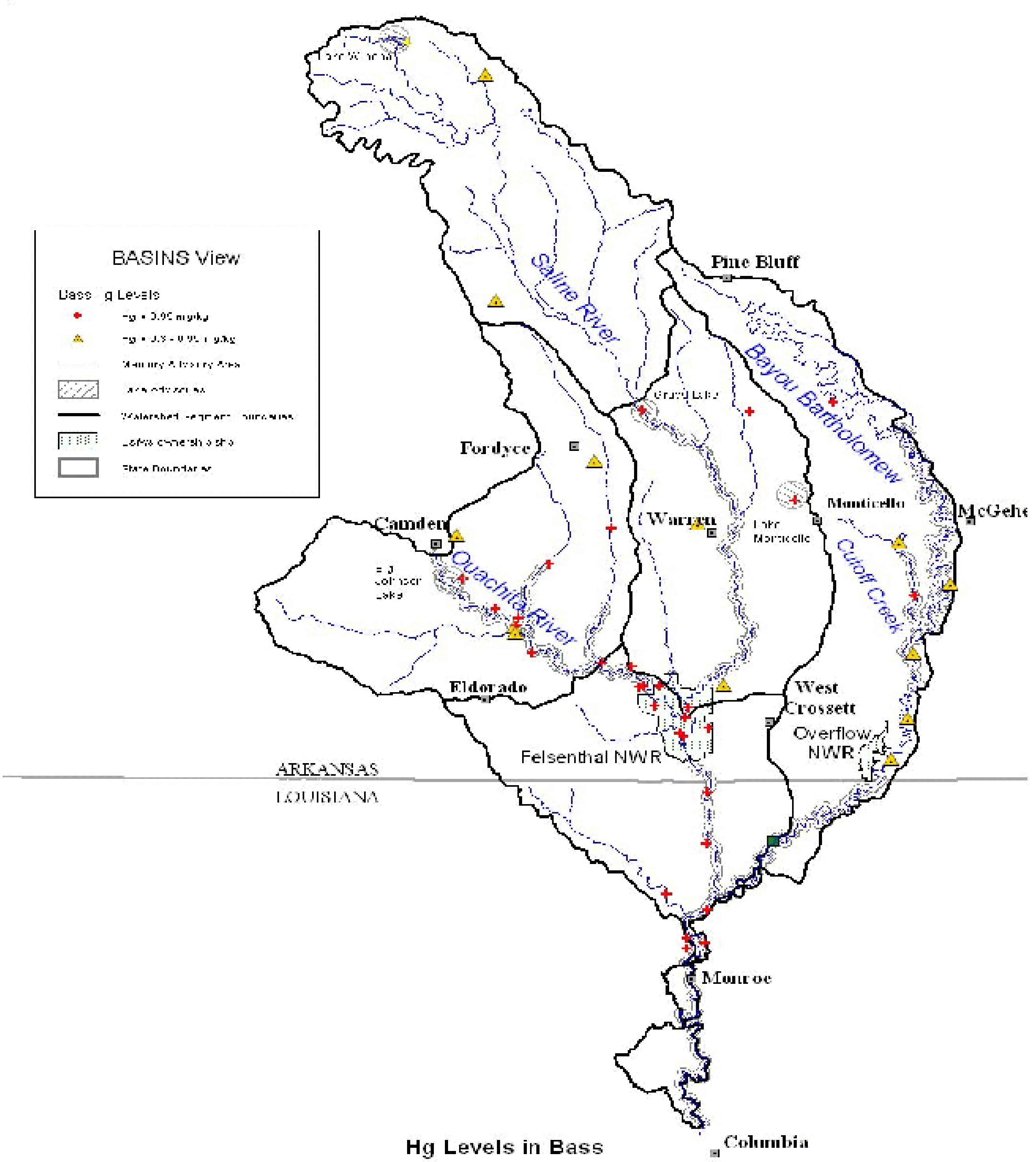

Figure 3.1. Fish consumption advisory areas in the Ouachita River basin. Maximum largemouth bass tissue mercury (Hg) concentrations for composite samples are shown on the map.

05UWS039	UWCOC02	21ARAPCC	08040205	94-98

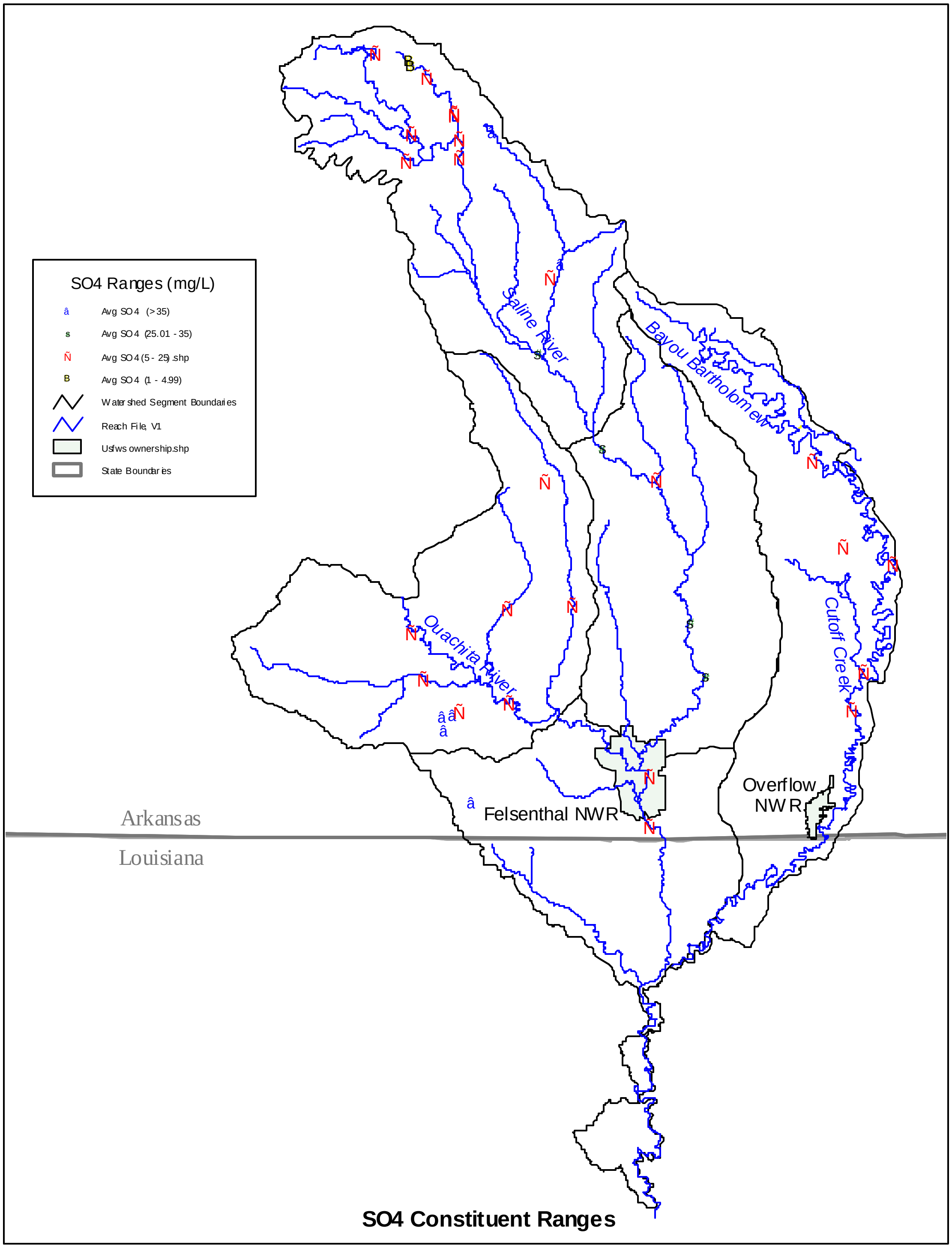

Figure 3.2.Average sulfate concentration (mg/L) ranges in the Ouachita River basin.

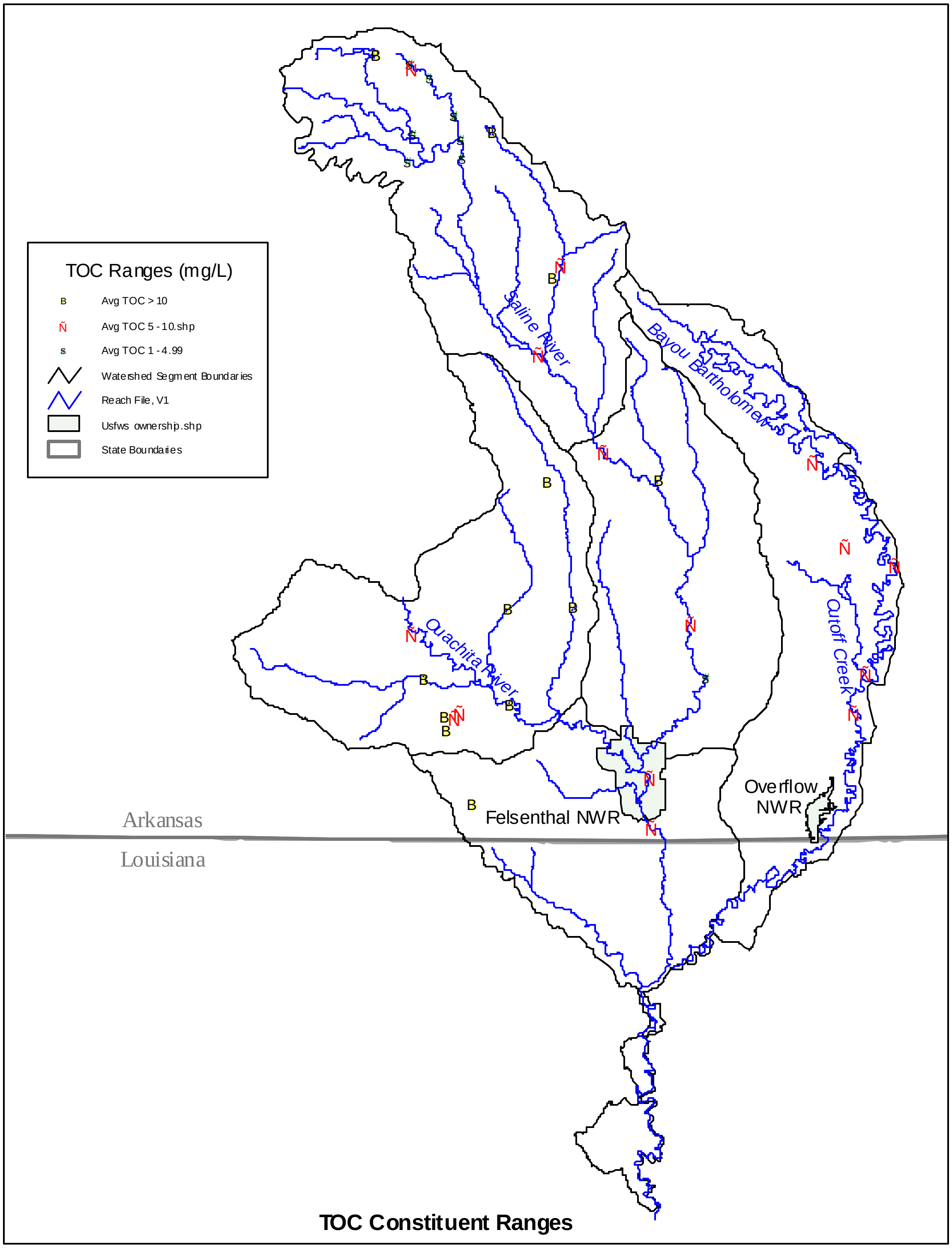

Figure 3.3.Average TOC concentration (mg/L) ranges in the Ouachita River basin.

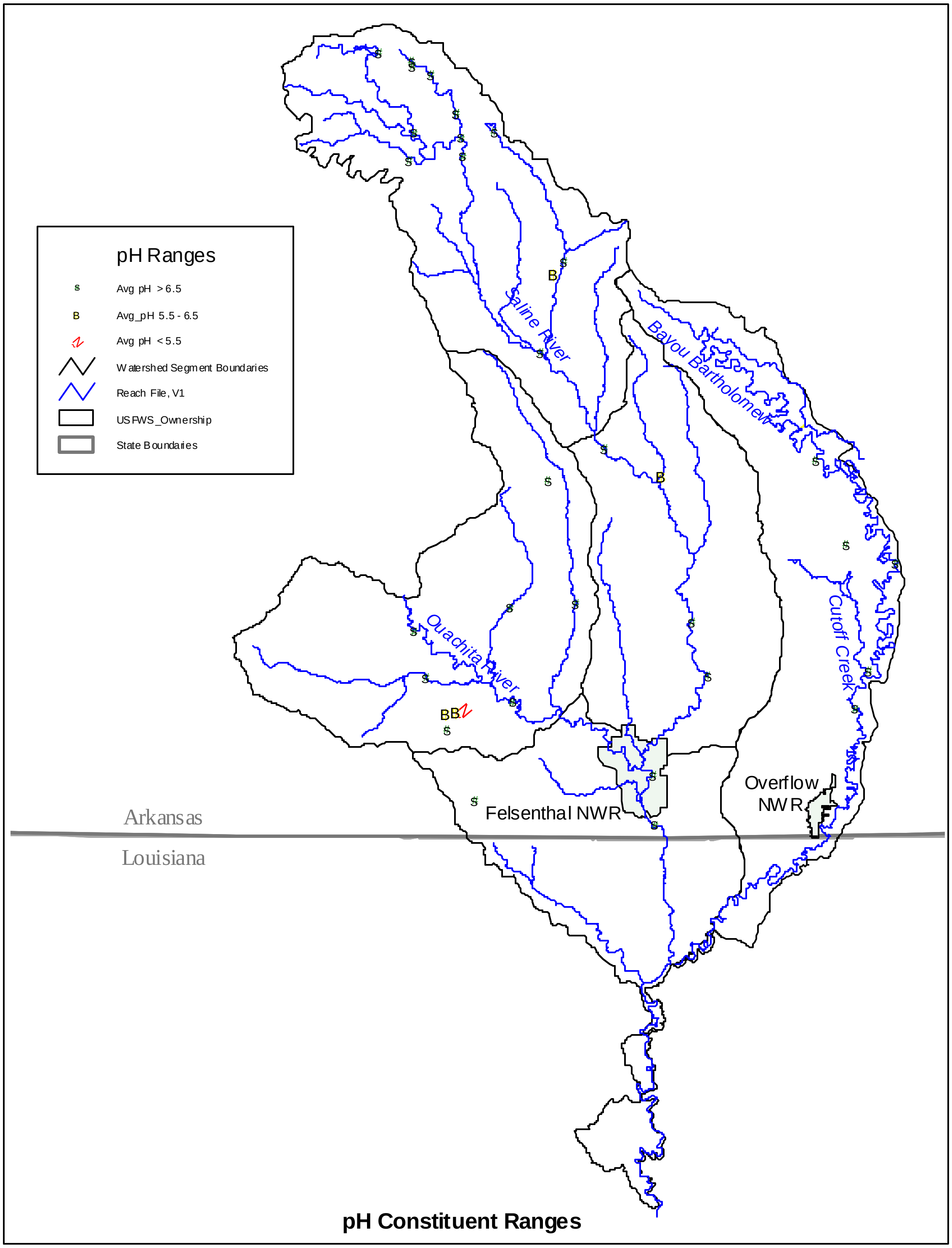

Figure 3.4.Average pH value ranges for Ouachita River basin.

4.0 DEVELOPMENT OF THE TMDL

4.1 Loading Capacity

The loading capacity of water bodies (i.e. the amount of mercury that can be introduced without adverse effects) differs on a site specific basis due to (1) inputs or load of mercury to the waterbody, (2) environmental conditions within the waterbody that mediate methylation and bioaccumulation, and (3) the food web or food chain through which mercury bioaccumulates (Armstrong et al. 1995).

4.2 Conceptual Framework

Mercury is unlike many other metals because it has a volatile phase at ambient temperatures and can be transported in a gaseous, soluble, or particulate form (Figure 4.1). Mercury is emitted to the atmosphere in both elemental gaseous Hg(0) and divalent Hg(II) forms. Anthropogenic direct emissions, natural emissions, and indirect re-emission of previously deposited mercury are major sources of mercury to the atmosphere (Figure 4.1). Gaseous Hg(0) is relatively insoluble and is capable of being transported long distances. However, ozone or other oxidizing agents in the atmosphere can convert Hg(0) to Hg(II). Hg(II) is much more soluble and can sorb onto particulates, resulting in both wet and dry mercury deposition within local (i.e., 100 km from the source, EPA 2001) and regional areas (EPRI 1994). Some Hg(II) can also be chemically reduced to Hg(0). Hg(0) can be transported long distances and contribute to regional and global background concentrations.

Local sources of atmospheric mercury are typically within about a 100 km radius of a site (EPA 2001). Regional sources of atmospheric mercury are loosely defined as other sources within a geographical area such as the Southeast, South, or Upper Midwest, while global sources include intercontinental contributions of mercury. Atmospheric mercury deposition can include contributions from all three sources.

In addition to atmospheric deposition, mercury can also enter waterbodies from point source effluent discharges and watershed nonpoint source contributions. These watershed nonpoint sources include naturally occurring mercury in rocks and soils, and anthropogenic mercury in soils from current and historical atmospheric deposition (Figure 4.1).

The primary mercury species of concern for bioaccumulation and biomagnification through the food chain is the organic, or methylmercury, form (Figure 4.2). It is the transformation of inorganic mercury to methylmercury that results in its accumulation and biological magnification through the food chain (Figure 4.2). Methylmercury binds with protein in muscle tissue of fish and other living organisms. Because it is lost very slowly from fish tissue (Trudel and Rasmussen 1997), methylmercury concentrations continue to increase throughout the life of the fish as long as methylmercury is in the environment and in its prey species. Older, larger fish typically have higher mercury concentrations than younger, smaller fish.

Anaerobic environments in the sediments of wetlands, streams, rivers, and lakes or reservoirs; and in the anaerobic hypolimnions of lakes and reservoirs create environments that are particularly suitable for mercury methylation. Also, fish tissue mercury concentrations in new reservoirs (less than 15 to 20 years after impoundment) are typically higher than fish tissue mercury concentrations in older reservoirs. Wetlands also create environments that are very conducive to mercury methylation. Wetlands and new reservoirs contribute to elevated fish tissue mercury concentrations in the Ouachita River basin.

A number of studies have been done on sources of mercury exposure to fish in Arkansas (Armstrong et al. 1995, Lin and Scott 1997, Scott and McKimmey 1997, Shirley 1992). This work has led to the conclusion that the geology of the area contributes to mercury in Arkansas water bodies. Mercury concentrations in the Ouachita Mountains geologic formations ranged from 0.01 mg/kg to 3.0 mg/kg (Stone et al. 1995). Mercury was mined commercially in areas south of the Ouachita Mountains. The Ouachita River basin receives drainage from these areas of known high mercury geology (Figure 4.3). The mercury studies in Arkansas also found a high incidence of higher mercury concentrations in soils located over geologic formations with high mercury concentrations (Armstrong et al. 1995). Underlying parent geological material contributes to the formation of the overlying soils, particularly in these watersheds where soils are thin. The idea that mercury from geologic sources is contributing to high mercury levels in sediments and fish is well documented and accepted by the scientific community in Arkansas (Lin and Scott 1997). Therefore, geologic sources are included in the mercury loading estimate and TMDL.

In summary, TMDLs for mercury must consider that mercury can exist as a gas as well as in solution or particulate forms. Mercury loads arise from atmospheric deposition contributed by both local and regional/global emission sources, point source effluent discharges, natural geological formations, and soils. However, after deposition or loading to the system, mercury can also be lost through volatilization and re-enter the atmospheric pool. It is the organic form as methylmercury that is biologically accumulated and magnified through the food chain. Once in fish, it is lost very slowly and continues to accumulate through time.

4.3 TMDL Formulation

A two step approach was used to estimate loading and the reductions required to achieve the designated fishable use in the Ouachita River basin waterbodies. Loading was estimated from both point and nonpoint sources in the first step (Section 4.4), while load reduction factors were calculated based on safe fish tissue Hg concentrations in the second step (Section 4.5). These two elements were then used to develop the TMDL (see equation below). This approach is similar to that used in previous fish tissue mercury TMDLs. In this TMDL annual loads are used rather than daily loads. Annual loads are more appropriate because the concern with this TMDL study is the long term accumulation of mercury, rather than short term acute toxicity events.

TMDL = (EL/RF) x SF, where

TMDL	=	total maximum daily load (use annual loads in this study, g/yr)
RF	=	Reduction Factor
EL	=	Existing total load (includes point, nonpoint and background sources
SF	=	Site specific factor(s) (requires study, but could be based on measured sulfate, organic carbon, alkalinity or pH values that influence mercury methylation and bioaccumulation. Assumed to be 1 in this study).

4.4 Existing Load

The existing mercury load to the Ouachita River basin was estimated as the first step in developing the TMDL. Mercury sources to the Ouachita River and its tributaries included both nonpoint and point sources, corresponding to load and wasteload allocations, respectively. The equation below shows the sources of mercury included in the estimate of the existing load.

Existing Load = RAD + LAD + SOIL + GEOL + NPDES + WWT

Where:

RAD =	regional atmospheric deposition - deposition of mercury emissions from regional and global sources
LAD =	local atmospheric deposition - deposition of mercury emissions from local sources (within 100 km of the basin)
SOIL =	soil deposited mercury erosion - mercury in eroded soils that come from atmospheric deposition
GEOL =	soil geologic erosion - mercury in eroded soils that come from breakdown of rock with high mercury content
NPDES =	mercury in effluent of NPDES permitted discharger with a permit mercury limit
WWT =	mercury in effluent from permitted municipal waste water treatment plants

4.4.1 Nonpoint Sources

Nonpoint sources of the existing load included regional and local atmospheric deposition, soil deposited mercury erosion, and soil geologic erosion.

4.4.1.1 Total Atmospheric Deposition

Data for regional atmospheric deposition were obtained from the National Atmospheric Deposition Program website. There are no mercury deposition monitoring stations in the state of Arkansas, therefore the two monitoring stations closest to the watershed were utilized (for a map showing locations of all the NADP mercury deposition monitoring sites, see http://nadp.sws.uiuc.edu/mdn/sites.asp). Data from monitoring locations LA10, in Franklin Parish, Louisiana, and TX21, in Gregg County, Texas, were used to represent atmospheric deposition of Hg in the watershed (Figure 4.4). Station LA10 is approximately 70 miles from Felsenthal NWR and Station TX21 is approximately 175 miles from Felsenthal NWR. Station LA10 had data available for 1999 through 2002 and station TX21 had data available for 1996 through 2002 (NADP 2003). The data from these stations for 1999 through 2002 was used to estimate total atmospheric deposition and are summarized in Table 4.1. Total atmospheric deposition is the sum of wet and dry deposition. Wet deposition is the mercury removed from the atmosphere during rain events. Dry deposition is the mercury removed from the atmosphere on dust particles, sorption to vegetation, gaseous uptake by plants or other processes during non-rainfall periods (EPA 1997). The average value of the wet deposition reported at the two stations was 13.2 $\mu g/m^2/yr$. Dry deposition was assumed to be 50% of wet deposition (EPA 2001). Therefore total deposition equal wet deposition times 1.5, or 19.8 $\mu g/m^2/yr$.

Precipitation data were also available from the NADP website (NADP 2003) and are summarized in Table 4.1. These data were compared with precipitation data for the Ouachita River watershed during the same period, which were obtained from Hydrosphere (2000) and are summarized in Table 4.1 (see Appendix C: Ouachita River Precipitation Estimate). During the period from 1999 through 2002 average annual precipitation at the NADP stations and the study area were very similar (1.31 vs 1.36 m/yr (Table 4.1). Therefore, the mercury deposition rates measured at the NADP stations are assumed to be representative of conditions in the Ouachita River basin.

The estimated atmospheric mercury deposition rate of 19.8 $\mu g/m^2/yr$ was used to determine the mercury loading to streams, lakes, reservoirs, and wetlands from atmospheric deposition. Table 4.2 shows the area of each of the five HUCs that are included in this TMDL and Subsegment 080101 covered by streams, lakes, reservoirs, and wetlands (BASINS Version 2.0 1999). The sum of the stream, lake, reservoir, and wetland areas was multiplied by 19.8 $\mu g/m^2/yr$ to obtain an atmospheric mercury load of 55,090 g/yr.

4.4.1.2 Local Atmospheric Deposition

Total atmospheric deposition can be partitioned into local and regional sources. The Louisiana and Texas mercury deposition monitoring stations are assumed to include both local emission sources similar to those in Arkansas and regional and global inputs. Local atmospheric deposition for the watershed was estimated based on data from the EPA Emission Factor and Inventory Groups 1999 National Emissions Inventory (NEI) database. The NEI is a complete national inventory of stationary and mobile sources that emit hazardous air pollutants (HAPs). Point and nonpoint hazardous air pollutant emission access data files were downloaded from the 1999 national emission inventory web site (http://www.epa.gov/ttn/chief/net/1999inventory.html). These files contain annual total loads for all known sources of the 188 EPA listed hazardous air pollutants for each state.

In this TMDL study, local sources are defined as sources within the watershed and within all counties within a distance of 100 km around the watershed boundary. The area within which these local sources are located is referred to as the "airshed". The NEI data files list the counties in which sources are located, therefore the airshed boundary is determined by county boundaries and if a portion of a county falls within 100 km of the watershed boundary, then the entire county is included as part of the airshed. The airshed boundary for the watershed is shown on Figure 4.5. The airshed contains 160,672 km^2. The mercury emissions for each MACT category found within the airshed and the Hg(II) emissions calculated from the MACT data that contribute to the local atmospheric deposition are shown in Table 4.3. MACT categories not included in Table 4.3 (e.g., medical waste incineration) were not present in the airshed, but could contribute to the global/regional atmospheric mercury load.

The calculation of the local source deposition ratio was based on a simplification of the method used in Savannah River Mercury TMDL (EPA 2001) and was performed as follows. Divalent mercury (Hg(II)) is the dominant form of mercury in both rainfall and most dry deposition. An estimate of the Hg(II) emitted from MACT category sources in the airshed was calculated based on source speciation percentages (Table 4.3). The total estimated Hg (II) deposition from all sources within the watershed was 227,427 g/yr (Table 4.3). Since the watershed is only a fraction of the airshed the emitted mercury may or may not fall within the watershed boundary. Therefore, the mercury deposition rate to the watershed due to local sources was determined by dividing the Hg(II) emissions of the airshed (227,427 g/yr) by the airshed area (160,672 km^2). This calculation provided a local source deposition estimate of 1.4 µg/m^2/yr.

4.4.1.3 Regional Atmospheric Deposition

The regional deposition rate was set equal to the total deposition rate (19.8 µg/m^2/yr) minus the local source deposition rate (1.4 µg/m^2/yr). Based on the analysis of the local sources, approximately 7% (3,929 g/yr) of the mercury deposition can be attributed to local sources and 93% (51,161 g/yr) can be attributed to global and regional sources.

4.4.1.4 Soil Deposited Mercury and Geologic Erosion

Sediment load for the watershed was based on erosion rates of agricultural, barren, and forest land use areas. The land use areas were based on information from Basins 2.0. Erosion rates were estimated based on information from USDA Natural Resource Conservation Service (Bloodworth and Berc 1998), Handbook of Nonpoint Pollution (Novotny and Chesters 1981), and Ozark-Ouachita Highlands Assessment Report (USDA FS 1999). Cropland erosion rates average 3.4 tons/year. Cropland with highly erodible soils have rates of 6.2 to 6.4 tons/year and cropland with soils that are not highly erodible have rates of 2.3 to 2.4 tons/year. Forest land erosion rates ranged from 0.2 to 0.8 tons/year. There was a small percentage of urban and barren land within the watershed. The areas associated with urban and barren land uses were included in the calculations with cropland erosion rates applied. Table 4.4 shows the total area, agricultural land area, forest land area, and barren land area for each of the 5 HUCs and subsegment 080101. Percentages of the basin area in each land use are also included. Table 4.5 shows the sediment loads (tons of sediment per year) calculated by multiplying the erosion rates by the land use areas within each HUC and subsegment 080101 (Table 4.4).

Indirect atmospheric mercury contributions in overland flow during rain events were not estimated. The majority of the watershed is forested (Table 4.4), and overland flow during rain events in forested lands is minimal (Waring and Schlesinger 1985). Therefore, it was assumed that indirect atmospheric contributions via overland flow during rain events would not be significant.

Given that geologic weathering contributes to soils, a portion of the mercury in soil would come from mercury sources in the underlying geology. In this TMDL study the portion of soil mercury contributed by geologic sources (soil/geologic erosion) was estimated and categorized as background load. In addition, on-going and historical atmospheric mercury deposition over the past several decades, if not centuries, has also contributed mercury to the soils. While some of this mercury was likely re-emitted to the atmosphere, some of this previously deposited mercury would sorb to the soils and be transported to receiving waters. This portion of the load was the nonpoint source load (soil/deposited mercury erosion).

A number of measurements of mercury in rock formations in the Ouachita Mountains (Stone et al. 1995) and sediments in the Ouachita River basin (Armstrong et al. 1995) were available (Figure 4.6). Mercury concentrations measured in both rock and sediments in Arkansas exhibited a large degree of variability (Figure 4.7). To get an idea of the range of possible soil/geologic erosion (background) and soil/deposited mercury erosion loads, three loads were calculated. The upper boundary load was calculated using 90th percentile rock and sediment mercury concentrations measured in Arkansas (Table 4.6). The lower boundary load was calculated using 10th percentile rock and sediment mercury concentrations from the same data set. The load considered to be most realistic (likely) was calculated using the geometric means of shale (0.09 mg/kg) and sediment (0.16 mg/kg) mercury concentrations. Shale mercury was used for the most likely load calculation because it is very common in the Ouachita Mountains and is the most easily erodible rock analyzed (Armstrong et al. 1995).

Estimates of the soil/geologic erosion (background) mercury load were calculated by multiplying the rock mercury concentration by the total sediment loading for each HUC (Table 4.5) to obtain the mercury in g/yr (Table 4.7). The soil/deposited mercury erosion load was estimated by multiplying the non-geologic soil mercury concentration by the tons of sediment per year. The non-geologic soil mercury concentration was calculated as the sediment mercury concentration minus the rock mercury concentration (Table 4.6). Therefore, the upper boundary non-geologic soil mercury concentration was 0.05 mg/kg, the lower boundary concentration was 0.01 mg/kg, and the most likely concentration was 0.07 mg/kg. The loads calculated using these rock and sediment concentrations are shown in Table 4.7.

4.4.2 Point Sources

There is only one NPDES permitted source in the basin with mercury limits in its permit. The point source discharge receiving stream is Boggy Creek. Boggy Creek drains to Bayou de Loutre. There is no fish consumption advisory for Boggy Creek or Bayou de Loutre. To estimate the wasteload allocation, the NPDES point source discharge is assumed to be discharging at its permit mercury limit 24 hours/day, 7 days/week. This assumption is considered conservative because it is unlikely that this occurs. In addition, it is assumed there was no mixing zone and an end-of-pipe wasteload allocation was used. This is consistent with the Great Lakes Initiative for managing bioaccumulative pollutants. Dilution is not assumed because of the persistence and non-conservative nature of mercury.

Municipal wastewater treatment facilities were also assumed to discharge some mercury because mercury at low levels has been measured in these facilities in Arkansas and other U.S. regions. ADEQ conducted a monitoring study of five municipal wastewater treatment plants in Arkansas using clean sampling procedures and ultra-trace level analyses and found an average concentration of about 0.015 µg/L of mercury in municipal discharges (Allen Price, ADEQ, personal communication 2001). This mercury concentration was assumed for all the municipal facilities within the basin and mercury wasteloads estimated for these sources.

4.4.2.1 NPDES Point Source

Table 4.8 shows the results of calculations for NPDES sources. ENSCO, Inc., AR, was the only NPDES permitted source found with a mercury limit in their permit. Their permit limit is 0.2 µg/L and their discharge was listed as 1.29 MGD. Multiplying these values together, and converting units, resulted in a conservative mercury loading estimate of 356 g/yr.

4.4.2.2 Municipal Wastewater Treatment Plants

An estimate of the contribution of mercury to the watershed from municipal wastewater treatment (WWT) plants was also calculated (Table 4.9). The list of city municipal WWT plants was obtained from the PCS search done for NPDES permitted facilities (see Appendix A). An assumption was made for the mercury concentration in the wastewater discharge. The concentration used was 0.015 µg/L, which was multiplied by the discharge from the city WWT plants obtained from the PCS search. The resulting estimated mercury loading from municipal wastewater discharges was 675 g/yr.

4.4.3 Summary of Existing Load

The total mercury load to the portion of the Ouachita River and its tributaries included in this study, on both an annual and a daily basis, is shown in Table 4.10. The municipal and NPDES permitted point source contributions are very small (<1%) compared to the atmospheric and watershed nonpoint source contributions. The upper boundary and most likely soil/deposited mercury erosion and soil/geologic erosion mercury loads account for the majority of the mercury load to the Ouachita River basin. With the lower boundary soil/deposited mercury erosion and soil/geologic erosion mercury loads, regional atomospheric deposition accounts for the majority of the mercury load to the Ouachita River basin. Therefore, soils, geology, and regional air deposition are the primary contributors to the mercury load in the Ouachita River basin.

4.5 Reduction Factors

In the second step of the TMDL development process reduction factors were estimated using the maximum and the average of measured largemouth bass tissue concentrations in the three impaired lakes and back calculating the decrease needed in fish tissue concentration to achieve the target fish tissue mercury concentration.

If the mercury body burden of the primary fish species of concern were reduced to less than 1.0 mg/kg the water bodies would no longer be subject to fish consumption advisories due to mercury and achieve their designated, fishable uses. Therefore, the mercury reductions used to develop the

TMDLs were based on the required reduction in fish tissue mercury concentrations needed to achieve the fish tissue mercury target level 0.8 mg/kg. This target level tissue mercury concentration provides a 20% margin of safety for the Arkansas fish consumption Action Level. A linear relationship was assumed between mercury source reduction and reductions in fish tissue mercury concentrations. This relationship is consistent with steady-state assumptions and the use of bioaccumulation factors. However, interactions of both inorganic and organic mercury with sulfide, organic carbon, and other water quality constituents can affect its bioavailability for both methylation and uptake (Armstrong et al. 1995; EPA 1997, 1998).

In order to establish the reductions needed in edible fish tissue, the worst case and average body burden were divided by the target tissue mercury concentrations. The worse case body burden was the highest mercury concentration of composite filet samples of largemouth bass sampled from the impaired lakes (Table 4.11). The average body burden was the average of mercury concentrations measured in largemouth bass in a waterbody (Table 4.12). This approach follows and builds on the precedence established in *Mercury TMDLs for Segments Within Mermentau and Vermillion-Teche River Basins* (EPA 2000).

4.6 TMDL

The target mercury loads calculated using the reduction factors are shown in Table 4.13. These target mercury loads represent 23% to 55% reductions of the estimated current basin mercury loads.

Table 4.14 provides a mercury mass balance with reductions in mercury loads from the various sources based on implementation of mercury emission controls and erosion best management practices (BMPs) in the watershed. The assumptions used to devleop the reduced mercury loads in Table 4.14 are described in the following sections. In comparing these reduced total basin mercury loads to the target mercury loads (Table 4.13) it appears that existing emission controls and BMPs can be expected to reduce average, and possibly even maximum, largemouth bass tissue mercury concentrations to below the Arkansas fish consumption advisory level.

4.6.1 Wasteload Allocation

The analysis of NPDES point sources in the watershed indicates that the cumulative loading of mercury from these facilities is less than 1% of the total estimated current loading (Table 4.12). Even if this TMDL were to allocate none of the calculated allowable load to NPDES point sources (i.e., a wasteload allocation of zero), the applicable water quality standards for mercury would not be attained in the waterbody because of the very high mercury loadings from nonpoint and background sources. At the same time, however, EPA recognizes that mercury is an environmentally persistent bioaccumulative toxic with detrimental effects to human fetuses even at minute quantities, and as such, should be eliminated from discharges to the extent practicable. Taking these two considerations into account, this TMDL, therefore, provides that mercury contributions from the city municipal WWT plants not exceed the mercury water quality standard for Arkansas (0.012 µg/L). No change in mercury limits is provided for the NPDES point source with permit limits for mercury (Table 4.14).

4.6.2 Load Allocation

Existing MACT regulations of mercury emissions will account for some of the needed reductions in mercury deposition in the Ouachita River basin. Final rules for mercury emissions are in effect for three of the MACT categories identified as local mercury sources to the Ouachita River basin. Table 4.15 lists these MACT categories and the expected reductions in their mercury emissions as a result of the implementation of the final rules. Overall, local sources of mercury deposition would be expected to be reduced by 22%. Existing regulations reducing mercury emissions from power generation, municipal waste combustion, medical waste incineration, and hazardous waste combustion are expected to reduce national mercury emissions by about 50% (see Section 6.0). Therefore, regional sources of atmospheric mercury deposition could also be expected to be reduced by about 50%.

Tables 4.14 and 4.16 show reductions in the atomospheric mercury load as a result of implementation of MACT regulations. Table 4.16 shows a mercury mass balance with only atmospheric mercury loads reduced. In these tables the local atmospheric deposition load has been set to 78% of the current local atmospheric deposition load (shown in Table 4.12) to reflect the expected 22% reduction. The regional atmospheric deposition load has been set to 50% of the current regional atmospheric deposition load (shown in Table 4.12) to reflect the expected 50% reduction.

The reduced loads for the soil/deposited mercury also take into account reductions in atmospheric deposition sources. Reducing atmospheric deposition should result in less mercury in soils from atmospheric deposition. The sum of the reduced atmospheric deposition load to the basin (local and regional) is about 48% less than the current atmospheric deposition load to the basin (Table 4.12). Therefore, the soil/deposited mercury loads shown in Tables 4.14 and 4.16 were reduced by 48%.

The total basin loads for the Most Likely and Lower Boundary scenarios shown in Table 4.16 are less than the target loads based on average fish tissue mercury concentrations in the water bodies being less than the Arkansas fish consumption advisory Action Level (Table 4.13). Therefore, mercury emission regulations could reduce fish consumption advisories in the listed water bodies and the Ouachita River basin. Mercury emission limits for additional source categories are either proposed or planned (EPA 2002). Therefore, further reductions would be expected in both local and regional atmospheric mercury loads to the basin in the future. It is uncertain what the magnitude of these reductions would be.

Additional reductions in the basin mercury load may be possible with the application of best management practices (BMPs) to reduce erosion. Reducing erosion would reduce both the soil/deposited mercury erosion and the soil/geologic erosion mercury loads. Table 4.17 shows the reduction in sediment loads to the Ouachita River basin that would occur if the erosion rates for agricultural and barren land uses were the same as the erosion rate for forest land (0.2 tons/acre/yr). This erosion rate is equivalent to approximately a 90% reduction in erosion from the agricultural and barren lands. Although it is not likely that implementing BMPs would actually reduce erosion rates on agricultural or barren lands this much, the erosion rate of 0.2 tons/acre/yr was used to show the best possible conditions for the basin.The soil/deposited mercury erosion load shown in Table 4.14 also incorporates the reduction in mercury from atmospheric deposition (i.e. the load calculated from the lower erosion rate was reduced by 48%).

The nonpoint and background loads shown in Table 4.14 are based on the lowest possible erosion rates. Comparing the basin loads in Table 4.14 to the target loads in Table 4.13 indicates that it should be very possible to reduce average, and even maximum largemouth bass tissue mercury concentrations to below the Arkansas mercury consumption advisory Action Level.

4.6.3 Unallocated Reserve

The conservative estimates used throughout these analyses, including the conservative reduction factors should provide an unallocated reserve for mercury loading to the Ouachita River and its tributaries.

Table 4.1. Deposition estimates for the Ouachita River basin.

NADP Data Summary			Precipitation Data (1999 - 2002)		NADP Data Summary		
Station	**Year**	**Rain Gauge (m/yr)**	**HUC**	**Avg. Precip. (m/yr)**	**Station**	**Year**	**Wet Total Hg Deposition (μg/m²/yr)**
TX21	1999	0.93	8040201	1.45	TX21	1999	10.3
TX21	2000	1.18	8040202	1.48	TX21	2000	14.4
TX21	2001	1.68	8040203	1.25	TX21	2001	15.3
TX21	2002	0.99	8040204	1.37	TX21	2002	8.4
LA10	1999	1.32	8040205	1.09	LA10	1999	13.3
LA10	2000	1.08	8040207	1.48	LA10	2000	11.7
LA10	2001	1.75			LA10	2001	18.6
LA10	2002	1.52			LA10	2002	14.0
	Average	1.31	Average	1.36		Average	13.2
Dry + Wet = Average wet x 1.5 = 19.8 μg/m²/yr							

Table 4.2. Mercury deposition load to streams, lakes, reservoirs, and wetlands in the Ouachita River basin.

	Atmospheric Deposition to Lakes, Reservoirs, Wetlands				
Subbasin	**Streams (acres)**	**Lakes Reservoirs (acres)**	**Wetlands (acres)**	**Lakes Reservoirs & Wetlands (km²)**	**Hg Deposition to waterbodies (g/yr)**
8040201	–*	1,597	265,811	1,082.16	21,478
8040202	3,383	5,269	180,740	766.44	15,211
8040203	–	4,172	11,502	63.43	1,259
8040204	–	2,033	152,706	626.21	12,428
8040205	1,460	2,386	46,139	20228	4,015
Subsegment 08010	4,463	434	3,802	35.20	699
Total	9,306	15,891	660,700	2,775.72	55,090
Regional	(18.4 μg/m²/yr)				51,161
Local	(1.42 μg/m²/yr)				3,929

*No estimate of areas in streams and canals available in the BASINS land use data for these subbasins.

Table 4.3. Local source mercury emissions within the airshed based on 1999 NEI report data.

MACT Category	Number of Sources	Total Emissions (kg/yr)	Hg(II) Speciation Percentage	Hg(II) (g/yr)
0105 - Industrial Combustion Coord Rule: Stationary Internal Combustion Engines	13	0.02	10%	2
0107 - Industrial/Commercial/Institutional Boilers and Process	670	81.9	30%	24,570
0502 - Petroleum Refineries - Catalytic Cracking, Catalytic Reforming, & Sulfur Plant Units	2	3.4	30%	1,031
0801 - Hazardous Waste Incineration	7	263.9	20%	52,791
0802 - Municipal Landfills	73	0.28	0%	-
1626 - Pulp & Paper Production	64	154.6	30%	46,374
1640 - Miscellaneous Organic Chemical Processes	43	0.01	30%	2
1807 - Industrial Combustion Coord Rule: Industrial, Commercial & Other Waste Incineration	90	0.61	20%	121
1808 - Utility Boilers	9	254.8	30%	76,439
Emissions reported without a MACT code	352	87.0	30%	26,098
Total	1,323	846.6		227,427

Table 4.4. Erosion sources for the Ouachita River basin, by subbasin.

Subbasin	Subbasin Area (acre)	Agricultural Land (acre)	Agricultural Land (% of Basin Area)	Forest Land (acre)	Forest Land (% of Basin Area)	Barren Land (acre)	Barren Land (% of Basin Area)	Total Percent of Basin
8040201	1,162,920	68,607	5.9	802,703	69	9,405	0.8	76
8040202	825,028	54,119	6.6	570,188	69	1,014	0.1	76
8040203	1,097,220	90,928	8.3	955,312	87	20,572	1.9	97
8040204	967,583	118,368	12.0	688,661	71	334	0.0	83
8040205	1,080,000	403,618	37.4	603,832	56	1,216	0.1	93
080101	97,482	11,523	11.8	66,457	68	–	0.0	80
Total Watershed	**5,230,233**	**747,163**	**14.3**	**3,687,153**	**70**	**32,541**	**0.6**	**85**

Table 4.5. Sediment load estimated for Ouachita River basin, by subbasin.

	Agricultural Land		**Forest Land**		**Barren Land**		
Subbasin	**Erosion Rate (tons/acre/ year)**	**Sediment (tons/year)**	**Erosion Rate (tons/ acre/year)**	**Sediment (tons/year)**	**Erosion Rate (tons/ acre/year)**	**Sediment (tons/year)**	**Total Sediment (tons/year)**
8040201	2.4	164,657	0.2	160,541	2.4	22,572	347,769
8040202	2.4	129,886	0.2	114,038	2.4	2,434	246,357
8040203	2.4	218,227	0.2	191,062	2.4	49,373	458,662
8040204	2.4	284,083	0.2	137,732	2.4	802	422,617
8040205	2.4	968,683	0.2	120,766	2.4	2,918	1,092,368
080101	2.4	27,656	0.2	13,291	2.4	–	40.947
Total Watershed		1,793,192		737,431		78,098	2,608,721

Table 4.6. Mercury concentrations (mg/kg) used to estimate erosion mercury loads.

	Upper Boundary	Most Likely	Lower Boundary
Sediment Mercury	0.30	0.16	0.02
Rock Mercury	0.25	0.09	0.01
Non-geologic Soil Mercury (Sediment-Rock)	0.05	0.07	0.01

Table 4.7. Load estimated from erosion sources in Ouachita River basin, by subbasin.

Subbasin	Total Sediment (tons/yr)	Upper Boundary		Most Likely		Lower Boundary	
		GeologicErosion (g/yr)	Deposited Mercury (g/yr)	GeologicErosion (g/yr)	Deposited Mercury (g/yr)	GeologicErosion (g/yr)	Deposited Mercury (g/yr)
8040201	347,769	78,874	15,775	28,395	22,085	3,155	3,155
8040202	246,357	55,874	11,175	20,115	15,645	2,235	2,235
8040203	458,662	104,025	20,805	37,449	29,127	4,161	4,161
8040204	422,617	95,850	19,170	34,506	26,838	3,834	3,834
8040205	1,092,368	247,749	49,550	89,190	69,370	9,910	9,910
080101	40,947	9,287	1,857	3,343	2,600	371	371
Total Watershed	2,608,721	591,658	118,332	212,997	165,664	23,666	23,666

Table 4.8. Mercury load estimated from NPDES permitted source, assuming permit limit equals the mercury concentration in the effluent.

HUC	Discharge (MGD)	Permit Limit Hg (µg/L)	Mercury (ng/day)	Mercury (g/yr)
ENSCO	1.29	0.2	9.77E+08	356

Table 4.9. Mercury load estimated from municipal wastewater treatment plants assuming an average concentration of 0.015 µg/L.

HUC	City Discharge (MGD)	Estimated Hg (µg/L)	Mercury (µg/day)	Mercury (g/yr)
8040201	7.75	0.015	4.40E+08	161
8040202	7.44	0.015	4.22E+08	154
8040203	9.49	0.015	5.39E+08	197
8040204	3.62	0.015	2.05E+08	75
8040205	4.2	0.015	2.41E+08	88
Total	32.5		1.85E+09	675

Table 4.10.Existing mercury load calculated for Ouachita River basin.

	Upper Boundary			Most Likely			Lower Boundary		
	Loading Rate		**Percent of Total Load**	**Loading Rate**		**Percent of Total Load**	**Loading Rate**		**Percent of Total Load**
Source Type	**(g/yr)**	**(g/d)**		**(g/yr)**	**(g/d)**		**(g/yr)**	**(g/d)**	
Point Source									
NPDES Point Source	356	1	0.0%	356	1	0.1%	356	1	0.3%
Municipal WWT	675	2	0.1%	675	2	0.2%	675	2	0.7%
Non Point Source									
Regional Atmospheric Deposition	51,161	140	6.7%	51,161	140	11.8%	51,161	140	49.5%
Local Atmospheric Deposition	3,929	11	0.5%	3,929	11	0.9%	3,929	11	3.8%
Soil/Deposited Hg Erosion	118,332	324	15.4%	165,664	454	38.1%	23,666	65	22.9%
Background									
Soil/Geologic Erosion	591,658	1,621	77.2%	212,997	584	49.0%	23,666	65	22.9%
Total	766,110	2,099	100%	434,782	1,191	100%	103,453	283	100%

Source load allocation based on:
a) 18.4 µg/m2/yr Regional atmospheric deposition to lakes, reservoirs, & wetlands
b) 1.42 µg/m2/yr Local atmospheric deposition to lakes, reservoirs, & wetlands
c) 0.25, 0.09, and 0.01 mg/kg Hg concentration in soil from geologic sources
d) 0.05, 0.07, and 0.01 mg/kg Hg concentration in soil due to atmospheric deposition
e) 2.4 tons/acre erosion rate for agricultural and barren lands
f) 0.2 tons/acre erosion rate for forested lands
g) Permit limit for NPDES point source of 0.2 µg/L Hg and 1.29 MGD discharge rate
h) City municipal discharges at 0.015 µg/1 Hg and 32.4 MGD discharge rate

Table 4.11.Reduction factor needed to reduce maximum body burden to target level.

Location	Maximum Largemouth Bass Hg Concentration (mg/kg)	Reduction Factor to Achieve Target Level*
Big Johnson Lake	1.71	2.1
Grays Lake	1.78	2.2
Lake Monticello	1.93	2.4
Average		2.2

* Target Level = 0.8 mg/kg

Table 4.12.Reduction factor needed to reduce average body burden to target level.

Location	Average Largemouth Bass Hg Concentration (mg/kg)	Reduction Factor to Achieve Target Level*
Big Johnson Lake	0.91	1.1
Grays Lake	1.18	1.5
Lake Monticello	0.96	1.2
Average		1.3

* Target Level = 0.8 mg/kg

Table 4.13.Comparison of target mercury loads and existing mercury loads for the Ouachita River basin.

	Upper Boundary Loading Rate (g/yr)	Most Likely Loading Rate (g/yr)	Lower Boundary Loading Rate (g/yr)	Percent Reduction
Existing Ouachita River Basin Hg Load	766,110	434,782	103,453	
Target Load based on Arkansas Maximum Reduction Factor (2.2)	348,232	197,628	47,024	55%
Target Load based on Arkansas Average Reduction Factor (1.3)	589,315	334,447	79,479	23%

Table 4.14. Ouachita River basin mercury mass balance with mercury loads reduced due to mercury emission controls and erosion best managment practices.

Source Type	Upper Boundary		Most Likely		Lower Boundary	
	Loading Rate (g/yr)	Percent of Total Basin Load	Loading Rate (g/yr)	Percent of Total Basin Load	Loading Rate (g/yr)	Percent of Total Basin Load
Point Source (WLA)						
NPDES Point Source	356	0.1%	356	0.3%	356	0.9%
City Municipal WWT	540	0.2%	540	0.4%	540	1.3%
Non Point Source (LA)						
Regional Atmospheric Deposition	25,580	10.1%	25,580	19.4%	25,580	61.1%
Local Atmospheric Deposition	3,065	1.2%	3,065	2.3%	3,065	7.3%
Soil/Deposited Hg Erosion	21,071	8.3%	29,499	22.4%	4,214	10.1%
Background						
Soil/Geologic Erosion	202,617	80.0%	72,942	55.3%	8,105	19.4%
Total	253,229	100.0%	131,982	100.0%	41,860	100.0%

Source load allocation based on:
a) 9.2 µg/m^2/yr Regional atmospheric deposition to lakes, reservoirs, and wetlands
b) 0.71 µg/m^2/yr Local atmospheric deposition to lakes, reservoirs, and wetlands
c) 0.25, 0.09, and 0.01 mg/kg Hg concentration in soil from geologic sources
d) 0.05, 0.07, and 0.01 mg/kg Hg concentration in soil due to atmospheric deposition
e) 0.2 tons/acre erosion rate for agricultural, barren, and forest lands
f) Permit limit for NPDES point source of 0.2 µg/L Hg and 1.29 MGD discharge rate
g) City municipal discharges at 0.012 µg/L and 32.4 MGD discharge rate

Table 4.15. Reductions in local atmospheric mercury sources based on existing MACT regulations.

MACT Category	Percent Reduction	Source	Current Hg(II) Load (g/yr)	Expected Hg(II) Load (g/yr)
0801 - Hazardous Waste Incineration	55%	EPA Hazardous Waste Combustion FAQs website	18,220	8,199
1626 - Pulp & Paper Products	59%	Table VII-2 Federal Register April 15, 1998 Vol. 63, No. 72	62,882	25,781
1807 - Industrial Combustion Coord Rule: Industrial, Commercial, and Other Waste Incineration	34%	Table 4 Federal Register December 1, 2000 Vol. 65	1,697	1,120
Airshed total local source mercury load			212,921	165,223

Table 4.16. Mercury mass balance with atmospheric sources reduced based on MACT regulations.

	Upper Boundary		Most Likely		Lower Boundary	
Source Type	Loading Rate (g/yr)	Percent of Total Load	Loading Rate (g/yr)	Percent of Total Load	Loading Rate (g/yr)	Percent of Total Load
Point Source						
NPDES Point Source	356	0.1%	356	0.1%	356	0.5%
City Municipal WWT	540	0.1%	540	0.2%	540	0.8%
Non-Point Source						
Regional Atmospheric Deposition	25,580	3.7%	25,580	7/8%	25,580	39.0%
Local Atmospheric Deposition	3,065	0.4%	3,065	0.9%	3,065	4.7%
Soil/Deposited Hg Erosion	61,532	9.0%	86,145	26.2%	12,306	18.8%
Background						
Soil/Geologic Erosion	591,658	86.7%	212,997	64.8%	23,666	36.1%
Total	682,731	100.0%	328,683	100.0%	65,513	100.0%

Table 4.17. Sediment load estimated for Ouachita River basin, by subbasin, with erosion rates for agricultural and barren land set to 0.2 tons/acre/year.

HUC	Agricultural Land Sediment (tons/year)	Forest Land Sediment (tons/year)	Barren Land Sediment (tons/year)	Total Sediment (tons/year)
8040201	13,721	160,541	1,881	176,143
8040202	10,824	114,038	203	125,064
8040203	18,186	191,062	4,114	213,362
8040204	23,674	137,732	67	161,473
8040205	80,724	120,766	243	201,733
Subsegment 080101	2,305	13,291	-	15,596
Total Watershed	149,453	737,431	6,508	893,371

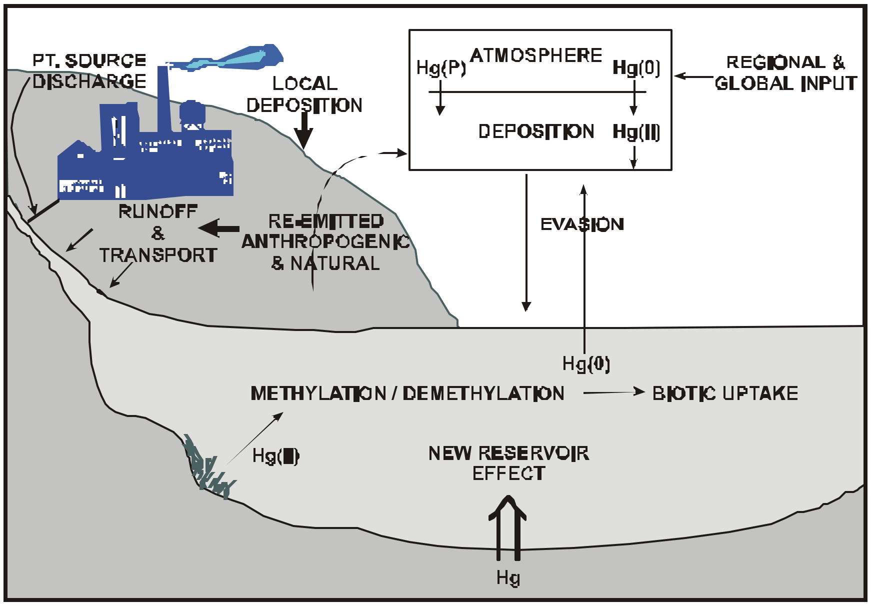

Figure 4.1. General mercury cycle showing atmospheric transport and deposition, point, nonpoint source and natural background contributions, and the effects of new reservoirs on mercury release into the environment (after Mason et al. 1994).

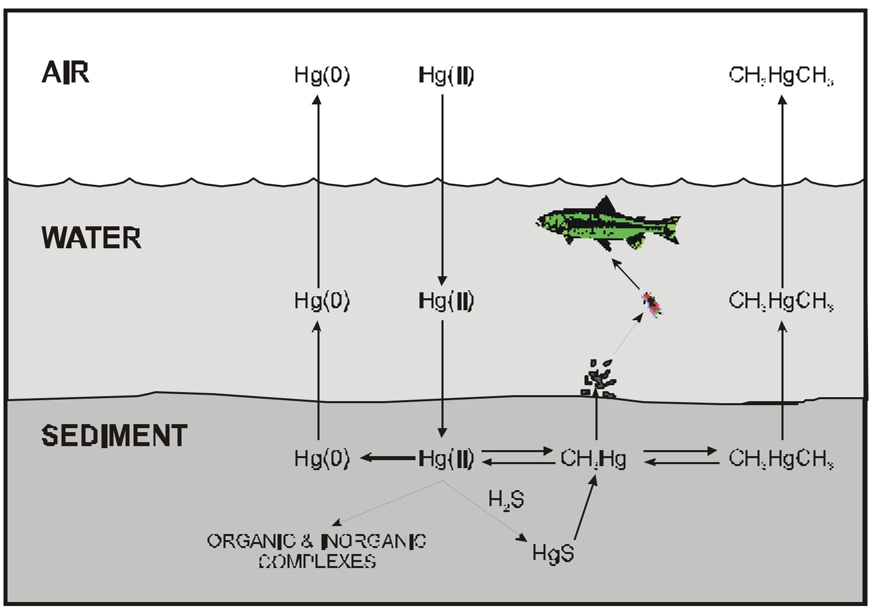

Figure 4.2. Pathways for mercury species through the aquatic ecosystem, including methylation and demethylation, evasion or loss from the water to the atmosphere, and sedimentation and burial in the sediment (after Winfrey and Rudd 1990).

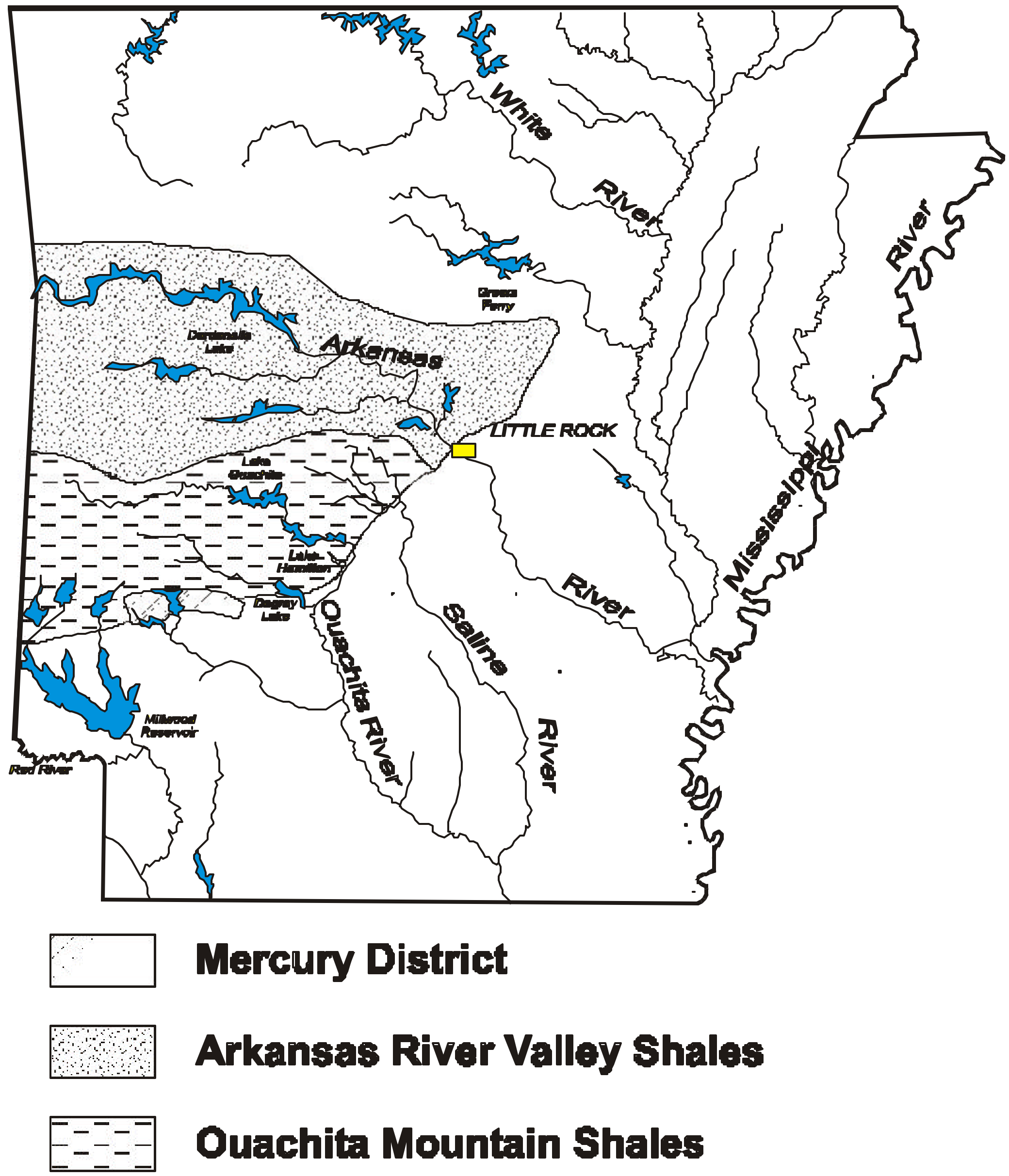

Figure 4.3. Shale formations and mercury district in Arkansas and relation to the Ouachita River basin from Armstrong et al. (1995).

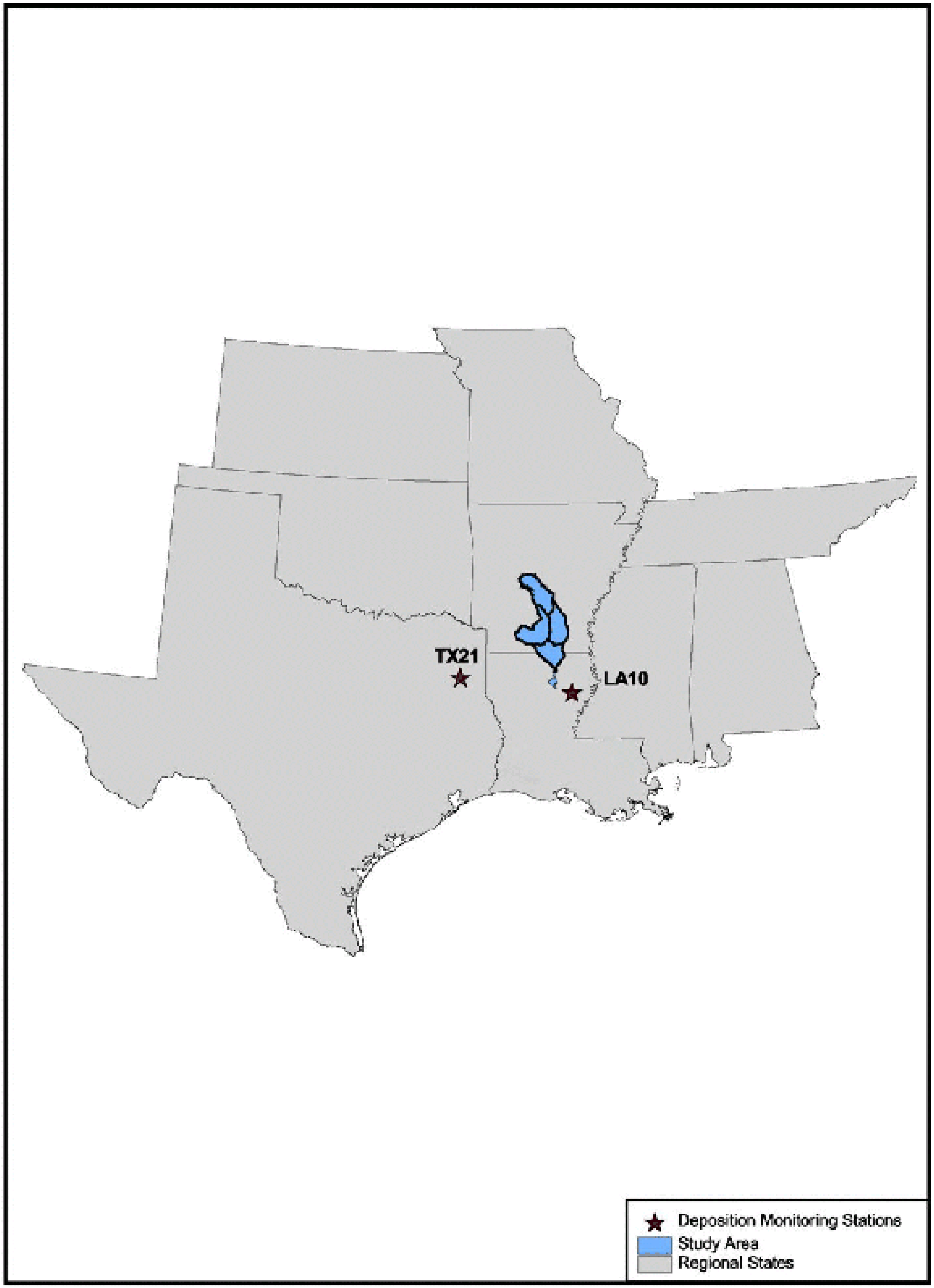

Figure 4.4. Location of NADP monitoring stations LA10 Franklin Parish, LA and TX21 Gregg County, TX.

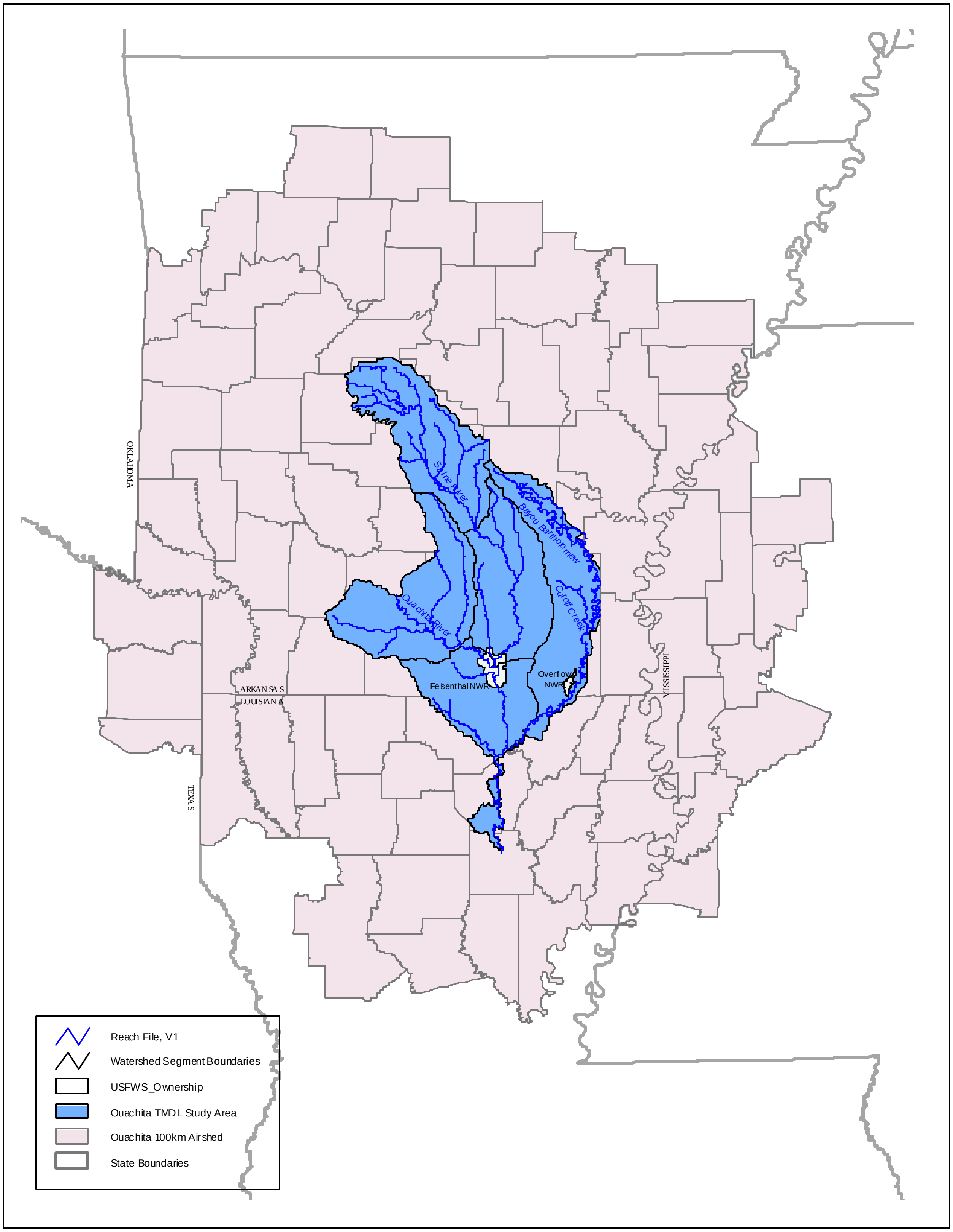

Figure 4.5. Airshed boundary for the Ouachita River basin watershed.

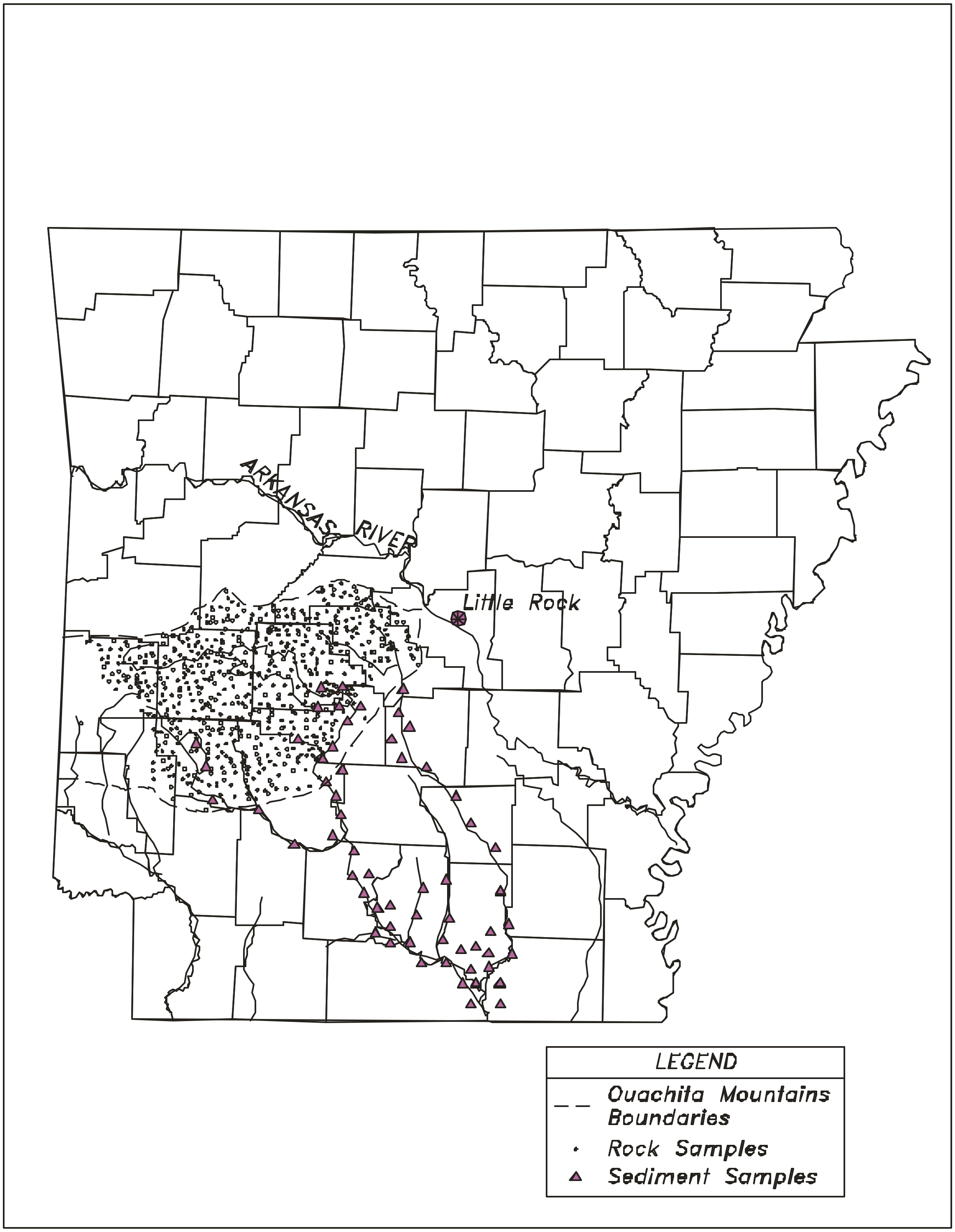

Figure 4.6. Sediment (triangle) and rock (dot) sampling locations for mercury analysis (Stone et al. 1995, Armstrong et al. 1995).

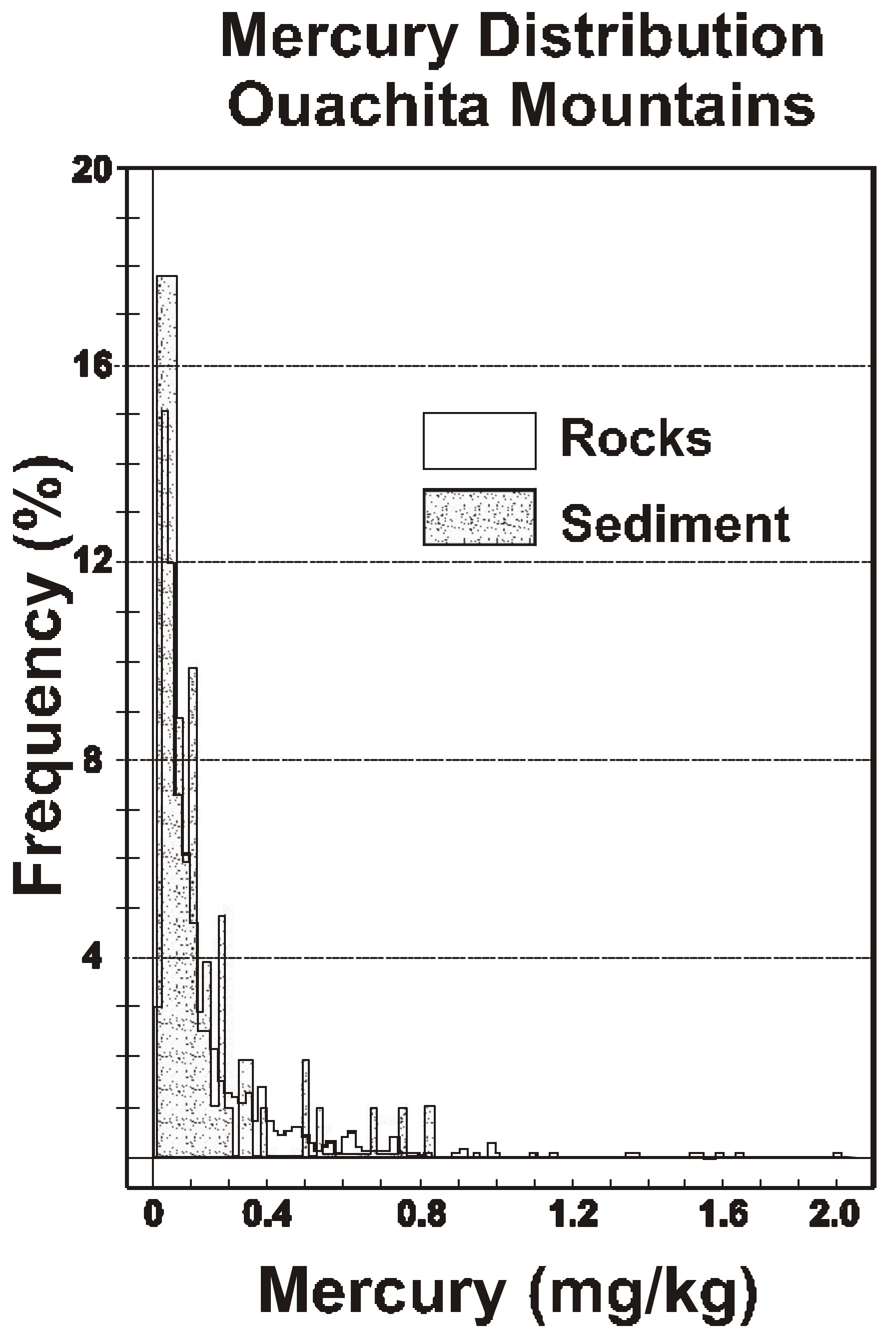

Figure 4.7. Distribution of mercury concentrations in sediment and rock samples from Stone et al. (1995).

5.0 MARGIN OF SAFETY, SEASONAL VARIATIONS, AND CRITICAL CONDITIONS

5.1 Margin of Safety

A margin of safety (MOS) accounts for uncertainty concerning the relationship between load allocations and water quality. In this case, it accounts for uncertainty and variability related to fish tissue mercury concentrations, estimates of loading, and the assumption of a linear relationship between fish tissue concentration and system load. This TMDL incorporates MOS factored into the reduction factors, the wasteload allocations, and the load allocations through conservative assumptions. Use of a target mercury level of 0.8 mg/kg for the Arkansas mercury fish consumption Action Level results in an explicit MOS of 20% for the TMDL.

5.2 Seasonal Variations and Critical Conditions

Wet deposition is greatest in the winter and spring seasons. Mercury loads fluctuate based on the amount and distribution of rainfall, and variability of localized and regional/global sources. The use of annual loads integrates short-term and seasonal variability. Inputs should continue to be estimated through wet deposition and additional monitoring.

Mercury methylation is expected to be highest during the summer. High temperatures promote biological activity, higher predator feeding rates, and anoxic conditions in lakes and reservoirs. These factors enhance mercury bioaccumulation during the summer months. However, given the long depuration times for fish and relatively mild winters in southern Arkansas, seasonal changes in fish tissue mercury body burden are expected to be relatively small. Inherent variability of mercury concentrations between individual fish of the same and/or different size categories is expected to be greater than seasonal variability.

Because of local geology, soils, natural vegetation, and topography, some areas of the Ouachita River and its tributaries are more susceptible to mercury methylation than others. For example, the steeper gradients in the upper portion of the Ouachita and Saline Rivers, without impoundments, results in generally lower fish tissue mercury concentrations. In the lower portion of the Ouachita and Saline Rivers and their tributaries, organic matter and sulfate concentrations are higher, and alkalinity and pH values are lower, which makes the systems more susceptible to mercury methylation. In addition, reservoirs are also likely contribute to the increased mercury concentrations in fish.

6.0 REASONABLE ASSURANCE: ONGOING AND FUTURE REDUCTIONS IN EMISSIONS

Reasonable assurance is needed that water quality standards will be attained. Mechanisms to assess and control mercury loads, including strategies and regulatory controls, which would be national in scope, will aid implementation of TMDLs for specific basins. In addition, this TMDL will be reassessed periodically and may be modified to take into account available data and information, and the state of the science.

6.1 Regulatory Controls

As rules and standards pursuant to the Clean Air Act have been developed, proposed, and promulgated since 1990, compliance by emitting sources as well as actions taken voluntarily have already begun to reduce emissions of mercury to the air across the U.S. EPA expects a combination of ongoing activities will continue to reduce mercury emissions to the air over the next decade. EPA currently regulates emissions of mercury and other hazardous air pollutants (HAPs) under the MACT program of Section 112 of the Clean Air Act, and under a corresponding new source performance standard (NSPS) program under Sections 111 and 129 of the Act. Section 112 authorizes EPA to address categories of major sources of HAPs, including mercury, by issuing emissions standards that, for new sources, are at least as stringent as the emissions control achieved by the best performing similar source in the category, and, for existing sources, are at least as stringent as the average of the best performing top 12% (or 5 facilities, whichever is greater) of similar sources. EPA may also apply these standards to smaller area sources, or choose to apply less stringent standards based on generally available control technologies (GACT). Sections 111 and 129 direct EPA to establish MACT-equivalent standards for each category of new and existing solid waste incineration units, regulating several specified air pollutants, including mercury.

In 1996 the U.S. eliminated the use of mercury in most batteries under the Mercury Containing and Rechargeable Battery Management Act. This action is reducing the mercury content of the waste stream which is further reducing mercury emissions from waste combustion. In addition, voluntary measures to reduce use of mercury containing products, such as the voluntary measures committed to by the American Hospital Association, also will contribute to reduced emissions from waste combustion.

EPA expects to propose a regulation under Section 112 that will limit mercury emissions from chlor-alkali plants, chlorine production facilities which use the mercury cell technology. In addition, under the Integrated Urban Air Toxics Strategy, which was published in 1999, EPA is developing emissions standards under Section 112 for categories of smaller sources of air toxics, including mercury, that pose the greatest risk to human health in urban areas. These standards are expected to be issued by 2004.

6.2 Expected Reductions in Mercury Emissions

Based on the EPA's NEI, the highest emitters of mercury to the air include coal-burning electric utilities, municipal waste combustors, medical waste incinerators (MWIs), chlor-alkali plants, and hazardous waste combustors (HWCs). EPA has issued a number of regulations under Sections 112, 111, and 129 to reduce mercury pollution from several of these source categories. Relevant regulations that EPA has established to date under the Clean Air Act include, among others, those listed below.

- The source category of municipal waste combustion (MWC) emitted about 20% of total national mercury emissions into the air in 1990. EPA issued final regulations under Sections 111 and 129 for large MWCs on October 31, 1995. Large combustors or incinerators must comply with the rule by December 2000. These regulations reduce mercury emissions from these facilities by about 90% from 1990 emission levels.

- MWIs emitted about 24% of total national mercury emissions into the air in 1990. EPA issued emission standards under Sections 111 and 129 for MWIs on August 15, 1997. When fully implemented, in 2002, EPA's final rule will reduce mercury emissions from MWIs by about 94% from 1990 emission levels.

- HWCs emitted about 2.5% of total national mercury emissions in 1990. In February 1999, EPA issued emission standards under Section 112 for these facilities, which include incinerators, cement kilns, and light weight aggregate kilns that burn hazardous waste. When fully implemented, these standards will reduce mercury emissions from HWCs by more than 50% from 1990 emission levels.

These promulgated regulations, when fully implemented and considered together with the actions discussed above that will reduce the mercury content of waste, are expected to reduce national mercury emissions caused by human activities by about 50% from 1990 levels.

In February 2002 President Bush announced the Clear Skies Initiative. This initiative proposed to reduce mercury emissions from power plants (electric utilities) by 69%. An intermediate cap of 26 tons of mercury per year was proposed for 2010. Current mercury emissions from power plants are 48 tons per year. EPA projections indicate that mercury emission from power plants in Region 6 will be reduced approximately 50%.

It is possible that the cumulative effect of additional standards and voluntary actions will reduce mercury emissions from human activities in the U.S. by more than 50% from 1990 levels. However, whether the overall, total percent reduction in national mercury emissions in the future will exceed 50% cannot be estimated at this time. EPA will continue to track emissions of mercury and evaluate additional approaches to reduce releases of mercury into the environment.

6.3 Mercury from Soils and Geologic Source

A large portion of the mercury load comes from erosion of soils and geologic sources. Implementing best management practices (BMPs) in the watershed to reduce erosion would be expected to reduce the mercury load to the system. Reductions in atmospheric mercury will also reduce the accumulation of mercury in soils from atmospheric deposition. This will further reduce the mercury load to the system from soil erosion.

6.4 Recovery of Impaired Fishable Use

Because of the persistence of mercury in tissue, it could take decades for mercury levels in predatory fish to drop as a result of reductions in mercury loading to the system. In addition, geology or other characteristics (such as DO levels) may cause some sites (such as Felsenthal NWR) to react more slowly to reductions in mercury loading. Therefore, an adaptive management approach is recommended for the portion of the Ouachita River system included in this TMDL study. This approach would include public education on the potential effects and sources of mercury, implementation of BMPs, and management of fisheries based on local characteristics. The goal should be to move toward use attainment while protecting human health.

Effectiveness of regulatory controls and BMPs can be evaluated through monitoring of wet deposition rates at the LA10 site and fish tissue mercury concentrations in the basin.

7.0 PUBLIC PARTICIPATION

When EPA establishes a TMDL, 40 CFR §130.7(d)(2) requires EPA to notify the public and seek comment concerning the TMDL. This TMDL was prepared under contract to EPA. After completion of the draft TMDL, EPA commenced preparation of a notice seeking comments, information and data from the general and affected public. No comments, data, or information were submitted during the public comment period. Therefore the TMDL was finalized without further revision. EPA has transmitted the TMDL to ADEQ for incorporation into the ADEQ current water quality management plans.

8.0 LITERATURE CITED

ADEQ. 2002. Arkansas Pollution Control and Ecology Commission Regulation 2; Regulation establishing water quality standards for surface waters of the state of Arkansas. Little Rock, AR., October 20, 2002

Armstrong, M.A., P. Burge, S. Evans, J. Giese, T. McChesney, J. Nix, A. Price, K. Thornton, and D. Turman. 1995. Arkansas Mercury Task Force. Report Submitted to the Governor, State of Arkansas. AR Dept. of Pollution Control and Ecology. Little Rock, AR.

BASINS Version 2.0. 1999. Region 6. EPA-823-C-98-008. USEPA Office of Science and Technology. Washington, DC.

Benoit, J.M., C.C. Gilmour, and R.P. Mason. 2000. The influence of sulfide on solid phase mercury bioavailability for methylation by pure cultures of Desulfobulbous proprionicus (1 PR 3). Submitted to Env. Sci. Technol.

Benoit, J.M. C.C. Gilmour, R.P. Mason, and A. Heyes. 1999. Sulfide controls on mercury speciation and bioavailability to methylating bacteria in sediment pore water. Env. Sci. Technol. 33:951-957.

Bloodworth, H. and J.L. Berc. 1998. Cropland acreage soil erosion and installation of conservation buffer strips: Preliminary estimates from the 1997 National Resource Inventory. USDA-NRCS. Washington, DC.

Brumbaugh, W.G., D.P. Krabbenhoft, D.R. Helsel, and J.G. Wiener. 2001. USGS National Pilot Study of Mercury Contamination of Aquatic Ecosystems along Multiple Gradients: Bioaccumulation in Fishes. (Abstract) Workshop on the Fate, Transport, and Transformation of Mercury in Aquatic and Terrestrial Environments, May 8-10, 2001. West Palm Beach, FL.

EPA. 2002. Hazardous Waste Combustion: FAQs. http://www.epa.gov/hwcmact/faqs.htm.

EPA. 2001. Total Maximum Daily Load (TMDL) Development for Total Mercury in the Middle/Lower Savannah River, GA. US Environmental Protection Agency Region 4. February 28, 2001.

EPA. 2000. Mercury TMDLs for Segments within Mermentau and Vermilion-Teche River Basins. US Environmental Protection Agency Region 6. February 29, 2000. Dallas, TX.

EPA. 1998. South Florida Ecosystem Assessment: Monitoring for Ecosystem Restoration. Final Technical Report - Phase I EPA 904-R-98-002. Region 4 Science and Ecosystem Support Division and Office of Research and Development. Athens, GA.

EPA. 1997. Mercury Study Report to Congress. EPA-452/R-97-003. Office of Air Quality Planning & Standards and Office of Research and Development. US Environmental Protection Agency. Washington, DC.

EPA. 1995. Monitoring Strategy. In Guidance for Assessing Chemical Containment Data for use in Fish Advisories Volume I: Fish Sampling and Analysis. Environmental Protection Agency. Washington, DC.

EPRI. 1994. Mercury Atmospheric Processes: A Synthesis Report. Electric Power Research Institute. EPRI/TR-104214. Palo Alto, CA.

Hydrosphre. 2000. Volume II. I NCDC Summary of the Day-Central. Data Products, Inc. 1002 Walnut Street, Suite 200, Boulder, CO 80302.

Kabata-Pendias, A. and Pendias. 1985. Trace elements in soils and plants. CRC Press, Inc.

Lin, H.S. and H.D. Scott. 1997. Spatial analysis of the cause of mercury contamination of fish in Arkansas. Publication No. MSC-196. Arkansas Water Resource Center. University of Arkansas, Fayetteville, AR.

Mason, R.P., W.F. Fitzgerald, and M.M. Morel. 1994. The Biogeochemical Cycling of Elemental Mercury: Anthropogenic Influences. Geochim. Cosmochim. Acta, 58 (15):3191-3198.

NADP. 2000. National Atmospheric Deposition Program/Mercury Deposition Network, NADP/MDN Monitoring Locations TX 21 and LA10. http:/nadp.sws.uiuc.edu/nadpdata/mdnsites.asp.

Neheus, Nat (ADEQ). Telephone conversation with Christina Laurin (FTN Associates, Ltd), August 29, 2003.

Novotny, V. and G. Chesters. 1981. “Handbook of Nonpoint Pollution Sources and Management.” Van Nostrand Reinhold Company. New York, NY.

Omernick, J.M. 1987. Ecoregions of the conterminous U.S. (map supplement). Ann. Assoc. Am. Geogr. 101(1):118-125.

Paquette, K. and G. Hely. 1995. Solubility of cinnabar (Red HgS) and implications for mercury speciation in sulfidic waters. Water, Air, Soil Pollut. 80:1053-1056.

Price, Allen (ADEQ). Telephone conversation with Christina Laurin (FTN Associates, Ltd.), October 6, 2003.

Rudd, J.W.M. 1995. Sources of methylmercury to freshwater ecosystems: A review. Water, Air, Soil Pollut. 80:697-713.

Scott, H.D., and J.M. McKimmey. 1997. Investigation of the statistical and spatial distributions of mercury contaminated fish, surface waters, and soils in Arkansas. Publication No. MSC-216. Arkansas Water Resources Center. University of Arkansas, Fayetteville, AR.

Shirley, K.E. 1992. Sportfish Contaminant Analysis Project. Arkansas Game and Fish Commission. Little Rock, AR.

Stone, C.G., J.F. Nix, and J.D. McFarland. 1995. A regional survey of the distribution of mercury in the rocks of the Ouachita Mountains of Arkansas. Arkansas Geological Commission. Information Circular 32. Little Rock, AR.

Trudel, M. and J.B. Rasmussen. 1997. Modeling the elimination of mercury in fish. Env. Sci. Technol. 31:1716-1722.

USDA Forest Service. 1999. Ozark-Ouachita Highland Assessment: Vol. 3-Aquatic Conditions. USDA Forest Service. Southern Research Station. Asheville, NC.

USDA Soil Conservation Service. 1958, 1967, 1968, 1972, 1973, 1976, 1979, 1980. County Soil Surveys. National Cooperative Soil Survey.

U.S. Geological Survey.1999. Water Data Records for Arkansas. http://waterdata.usgs.gov/nwis-w/AR.

Waring, R.H. and W.H. Schlesinger. 1985. Forest Ecosystems: Concepts and Management. Academic Press, Inc., Orlando, FL.

Winfrey, SS and J.W.M. Rudd. 1990. Review-Environmental Factors Affecting the Formation of Methylmercury in Low pH Lakes. Environ. Toxicol. Chem. 9:853-869.