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INVESTIGATION OF THE STATISTICAL AND SPATIAL DISTRIBUTIONS OF MERCURY CONTAMINATED FISH, SURFACE WATERS AND SOILS IN ARKANSAS

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INTRODUCTION

Mercury (Hg) contamination of fish is a widespread problem throughout much of the United States and the world (Louisiana WWW page, 1997). Levels of Hg in fish sufficient to exceed the FDA action level of 1 mg kg^{-1} have been found in many water bodies, including some in Arkansas and Louisiana. As a result of the serious public health ramifications for developing fetuses and for people that subsist on native fish, fish consumption advisories due to Hg contamination have been issued in 29 states. Contamination of surface water bodies by Hg results from deforestation, forest fires, fossil fuels, mining, natural emissions and commercial emissions (Armstrong, 1994). In addition, Hg has a high affinity for organic matter in soil and sediments, and therefore, long-term storage of Hg is an environmental problem. An excellent review of the integration and synthesis of recent work on Hg pollution is given in several papers edited by Watras and Huckabee (1994). The general consensus of the reports in this document seems to be that increases in Hg levels can be attributed to one or more of several mechanisms including atmospheric deposition, acidification of soils and lakes by sulfur deposition followed by an increased sulfate reduction, and transport from other source areas.

Transformation of Hg in the environment depends on natural variables that contribute to chemical and biochemical reactions. The key process in the cycling of Hg leading to its bio-accumulation in fish is the methylation of inorganic Hg (Hg^{2+}) to monomethyl Hg (CH_3Hg^+). Methyl-mercury was reportedly produced in the terrestrial environment, the water column, lake sediments and in the intestines and the slime layer of fish (Verta, et al. 1994). Both aerobic and anaerobic bacteria mediate the methylation process. Metallic Hg dumped in watercourses must be oxidized to be available for methylation. The Hg bio-geochemical cycle is complex and becomes even less clear when we consider that some bacterial strains can convert methyl Hg back to the metallic form. Sorption by soil components and sediments can also reduce the biological availability of oxidized forms to methylation.

When Hg contaminated fish were found in the Ouachita River in Louisiana, a group of Arkansas agencies were organized to investigate the magnitude and extent of any Hg contamination within Arkansas. These agencies included the Department of Health, Department of Pollution Control and Ecology, Game and Fish Commission and the Ouachita Baptist University. This coalition of state agencies is known as the Arkansas Mercury Task Force (AMTF). Initial investigations found various levels of Hg contamination in fish tissue throughout the state with excessive concentrations located in the Lower Ouachita and Saline Rivers in the southern portion of Arkansas. Of all sample locations within the state, these two rivers and associated drainage basins contained the majority of the locations where Hg contamination of fish tissue was above 1 mg kg^{-1}. These results initiated further investigations into potential Hg sources and processes involved in the bio-accumulation of Hg.

This work represents the second part of a research project examining the spatial distribution of mercury (Hg) in selected fish samples in Arkansas. The first portion, which was published previously (Lin and Scott, 1996), examined the spatial relationships between

the Hg-contaminated fish samples collected for the AMTF and several natural resource attributes. Maps were developed showing the sites in Arkansas where (1) contaminated large mouth bass fish were found, (2) various lake water quality parameters, (3) sediment Hg concentrations, (4) bedrock Hg contamination's and (5) oil fields. Vector maps were developed for the hydrologic units, perennial streams, major streams and lakes and ponds of Arkansas. Raster maps were developed for major land resource areas (MLRAs), hydrologic basins, soil associations, surficial geology, landuse-land cover, vegetation, elevation and slopes of Arkansas. Coincidence reports were constructed among the various maps and showed that the majority of the 27 Hg contamination sites were located in the Western Gulf Coastal Plains. The "hot" hydrologic basins were identified as the Lower Ouachita-Bayou De Loutre, Lower Ouachita-Smackover and the Lower Saline.

OBJECTIVES

The objectives of this work were to statistically characterize the (1) concentrations of Hg in the fish, and (2) physical and chemical characteristics of the lakes and reservoirs, and (3) to explore characteristics of the natural resources in the "hot" areas in southern Arkansas.

METHODS

The work was divided into three studies. In each study, the statistical characteristics of either the fish, water and soil attributes were related to the Hg contaminated fish. A description of each database is presented in greater detail in the sections that follow.

All statistical analyses were run in the SAS statistical software package known as JMP for PCs. Classical statistical analyses for all parameters included measures of central tendency, measures of dispersion, evaluations of normal probability distribution, scatter plots, by multivariate and non-parametric analyses. From the results, scatter plots and regression models were fit to those parameters determined to be significant to the spatial distribution of Hg concentration in fish in Arkansas.

The digital databases were developed and sorted with the geographic information systems (GIS) software known as Geographic Resources Analysis Support System or GRASS. This public domain computer software was run on a SPARC 10 in the UNIX environment.

Characteristics of the Fish Database

This database consisted of the characteristics of 834 fish taken from approximately 160 water bodies across Arkansas. The database, which was obtained from Alan Price of the Arkansas Department of Pollution Control and Ecology (ADPC&E), contains the following entries: water body name, longitude, latitude, fish Hg concentration, sample date, ADPC&E log number, fish common name, fish species, length and weight. The species of fish included bluegill, bowfin, buffalo catfish, crappie, drum, gar, large mouth bass, pickerel, red ear, red horse, small mouth bass, spotted bass, sucker, sunfish, trout and walleye. There are missing

data within some of the records. The minimum Hg detection level was 0.05 mg kg^{-1}. Any sample below this concentration was considered as zero.

Large Mouth Bass Database

The Fish database was sorted for the most common fish in the collection, i.e. large mouth bass. For the statistical analysis parameters in the original database such as longitude, latitude, sample date, log number and fish names were excluded. The large mouth bass database consisted of fish Hg concentration (mg kg^{-1}), water body name, fish length (mm), fish weight (g), and calculations of fish weight divided by length (g mm^{-1}) were generated. There were 470 entries in the large mouth bass database.

Statistical analyses performed on these four parameters included a test of fit to the normal probability distribution, a multivariate analysis, scatter plots of the correlation between each parameter, and non-parametric analysis. Regression models were used to determine the relationships between Hg concentration in large mouth bass and each of the three fish morphological parameters. Regression models and the associated statistical regression parameters presented included the following: linear, polynomial of degree 2, transform of the natural log of Y, transform of the natural log of X, and transform of the natural log of X and Y.

Characteristics of the Water Bodies

This database of Arkansas waterbodies also was obtained from Mr. Price at ADPC& E. The database consists of lake names, longitude, latitude, eco-region, lake type, lake area, mean depth, watershed area, year of dam construction, depth to the hypolimnion, Secchi dish depth, epilimnion chemical analyses, thermocline chemical analyses, hypolimnion chemical analyses, Hg in fish and length-adjusted Hg concentration in fish.

The Lake database was created from water samples taken from 84 surface water bodies within Arkansas. Portions of this database were extracted into smaller data sets based on vertical position in the lake. This database was grouped into four different databases of: (1) General Lake representing general characteristics of the lakes, (2) Lake Epilimnion representing the epilimnion chemical properties, (3) Lake Thermocline representing the thermocline chemical properties and (4) Lake Hypolimnion representing the hypolimnion chemical properties. Fish Hg concentration data were extracted with all four databases.

General Lake Database

This information includes general lake characteristics such as: lake name, longitude of the sample site, latitude of the sample site, lake area (h), mean lake depth (m), watershed area (km^2), dam construction year, depth to the hypolimnion (m), water clarity (in), and Hg concentration in fish (mg kg^{-1}). Of these data, longitude, latitude, and year of dam construction were omitted from computations of the probability distributions. Year of dam construction had several missing data points; while, distributions of longitude and latitude of the lakes were not of concern in this report. These three parameters were, however, used in the scatter plots. Fish Hg concentration were correlated pair wise with latitude, longitude,

lake area, mean lake depth, watershed area, dam construction year, depth to hypolimnion and water clarity. Additional correlations were made with eco-region and lake type.

Lake Epilimnion Database

This database contains a collection of mostly chemical parameters measured in the epilimnion layer of water bodies sampled in the Lake database. The parameters included in this database were: NH_3-N, NO_3-N, chloride, ortho phosphate (OP), total phosphorus (TP), sulfate (SO_4), water hardness, total organic carbon (TOC), dissolved oxygen (DO), pH, turbidity, total suspended solids (TSS), total dissolved solids (TDS), alkalinity, electrical conductivity (EC), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), calcium (Ca), fecal coliform, chlorophyll and Hg concentration in fish. Probability of normal distribution was estimated for these parameters using the complete database. Pair wise correlations were calculated between Fish Hg concentrations and all of the above parameters. Of the 84 entries in the lake database, only 40 entries from the Epilimnion database were used in multivariate correlations due to missing data. The number of parameters was also limited to the ones with the most complete data. These parameters were NH_3-N, NO_3-N, OP, TP, SO_4, Hardness, TOC, DO, pH, turbidity, TSS, TDS, alkalinity and EC.

Lake Thermocline Database

This database contained fewer data than the epilimnion database. For most parameters the number of determinations was 18. This database included NH_3-N, NO_3-N, OP, TP, SO_4, hardness, TOC, DO, pH, turbidity, TSS, TDS, alkalinity, EC, fecal coliform, chlorophyll and Fish Hg concentrations. Pair wise correlations between fish Hg concentrations and all other parameters were calculated. Multivariate correlations were not calculated due to insufficient data.

Lake Hypolimnion Database

This database is a collection of mostly chemical parameters measured in the hypolimnion layer of water bodies sampled in the lake database. The parameters included NH_3-N, NO_3-N, chloride, OP, TP, SO_4, hardness, TOC, DO, pH, turbidity, TSS, TDS, alkalinity, EC and Hg concentration in the fish. Probability of normal distribution was estimated for these parameters using the complete database. Pair wise correlations were calculated between Fish Hg concentrations and all of the above parameters. Of the 84 entries in the lake database, only 38 entries were used in multivariate correlations in the hypolimnion database due to missing data. The number of parameters was also limited to NH_3-N, NO_3-N, chloride, OP, TP, SO_4, hardness, TOC, DO, pH, turbidity, TSS, TDS, alkalinity, and EC.

Characteristics of the "Hot" Watershed

The watersheds draining into Lake Felsenthal were examined for characteristics that might suggest increased methylation of Hg. A mask defining the Felsenthal Lake Watershed was created in GIS from a map of 8-digit hydrologic units of Arkansas. All data extraction, table of coincidence generation and areal coverage reports were done in GIS using this mask. The land characteristics used in the spatial analysis included: hydrologic unit, elevation, slope,

aspect, vegetative cover, soil association, hydrology, locations of the contaminated large mouth bass, slopes of the Ouachita and Saline Rivers, and soil chemical analyses by soil association. Hydrologic units were obtained from the United States Geological Survey (USGS) in a Digital Line Graph (DLG) format mapped at a scale of 1:100,000. These were the data used to create the mask in GIS. Elevation used in this study were the Defense Mapping Agency's (DMA) Digital Terrain Models (DTM). The raster elevations were generated by the DMA at approximately 3 arc seconds resolution, equating to 80m x 80m in this study area, from digital hypsography mapped at a scale of 1:100,000. Slope and aspect maps were generated from this elevation map. The vegetative cover map of Arkansas was obtained from the Center for Advanced Spatial Technologies (CAST) and is a tassel cap analysis of 1992 LandSat Thematic Mapper imagery. The soil map used in this study was the State Soil Geographic Database (STATSGO) and was generated by the National Resources Conservation Service (NRCS) at a scale of 1:250,000. Raster hydrological data were generated at an 80m resolution from DLGs provided by USGS. These maps were developed at a scale of 1:100,000.

Distance Correlation Methods

Another aspect of Hg contamination of large mouth bass investigation was to determine the relationship between elevation and stream distance from the outflow of Felsenthal Dam to the headwaters of both the Ouachita and Saline rivers. Most sloughs, backwater areas, oxbow lakes and old river channels were eliminated from the DLGs so that the stream channel could be represented as a single line. The hydrological data were separated into three components: Ouachita River, Saline River and the Felsenthal Reservoir area. Stream channels were extracted from the latter file and incorporated with both the former resulting in stream channel raster data from the headwaters of both the Ouachita and Saline rivers to the outflow at Felsenthal Dam. The raster stream data were thinned to single pixel widths. An algorithm estimating approximate stream channel distance in meters per raster cell was run on the thinned stream data. Maps depicting stream channel distance from the outflow of Felsenthal Dam to the headwaters of both the Ouachita and Saline rivers were calculated for both streams. This cost surface reflected the cumulative ground distance per raster cell.

Statistical reports were run in GIS to generate coincidence tables of elevation and distance. Elevation by distance was graphed showing the relationship from the dam outflow to the headwaters for both stream channels. In both stream channels there were locations where the USGS DLG hydrological data did not match the DTMs. Although these areas were small they were excluded from the graphs.

The relationship between Hg concentration and distance from the dam was also investigated. As with the elevation data, Hg sample sites did not completely match the stream channel data. To correct for this, a 400m corridor was generated from the thinned stream channel data. Any Hg sampling site that fell within this zone was included in a coincidence table of Hg concentration and distance from Felsenthal outflow. It is possible that some of the Hg sample sites included in the analysis were not actually taken in the stream channels and

some of these sample sites could be located in features omitted from the stream channel data or have improper coordinates due to positioning errors. Many of the sites with Hg contaminated fish included multiple samplings. However, these were included to show the variations in Hg-contaminated Small Mouth Bass for each site.

Soils Database

The soil characteristics were examined further by obtaining the database from the Arkansas Soil Testing Laboratory at Marianna. This digital database is a collection of mostly chemical analyses of soil samples taken from across Arkansas between 1992 and early 1997. Each soil sample analysis is linked to a soil association within the states general soil map. This linkage allowed for statistical analyses of the soil database to be performed for each soil association. A table of coincidence was created showing soil associations by county within the "hot" watershed. Soil test data for the watershed were extracted from the database into individual soil association files. Each soil association file contained mostly chemical properties of the soils as well as the county from which each sample was taken.

The soils database fields used in this study included the following parameters: the county from which each sample was taken, soil association number (SAN), texture (TXT), pH, P, K, Ca, Mg, Na, S, Fe, Mn, Cu, Zn, boron (B), NO_3-N, percent organic matter (OM) and EC. Units of measurements for the elemental analysis were given as lb acre^{-1}. The units of EC were μmho cm^{-1}. Classical statistical analyses were generated for each soil property by soil association. Some of the parameters had obvious outliers and these were deleted from the analyses.

The soils database did not contain sufficient location information to reference the soil properties to the Lake and Fish databases. One solution was to create GIS maps for each soil property by classing the soil associations in the STATSGO digital map to the median for each soil property tested. Coincidence tables between each soil property and each Hg sample site were created, exported to JMP and tested for correlations and statistical significance.

RESULTS AND DISCUSSION

Locations of the Hg Contaminated Fish

The sample locations of Hg contaminated fish in Arkansas are shown in Figure 1. This map represents data in the Fish database and shows the degree of Hg contamination for various fish species. The map shows that Hg was found in fish tissue in all regions of the state. When Hg concentration in fish tissue is not considered there seems to be no particular direction or spatial pattern of contamination. The practically uniform distribution of Hg contaminated fish around the state can be attributed to multiple and dispersive sources of Hg and/or conditions favorable for Hg methylation.
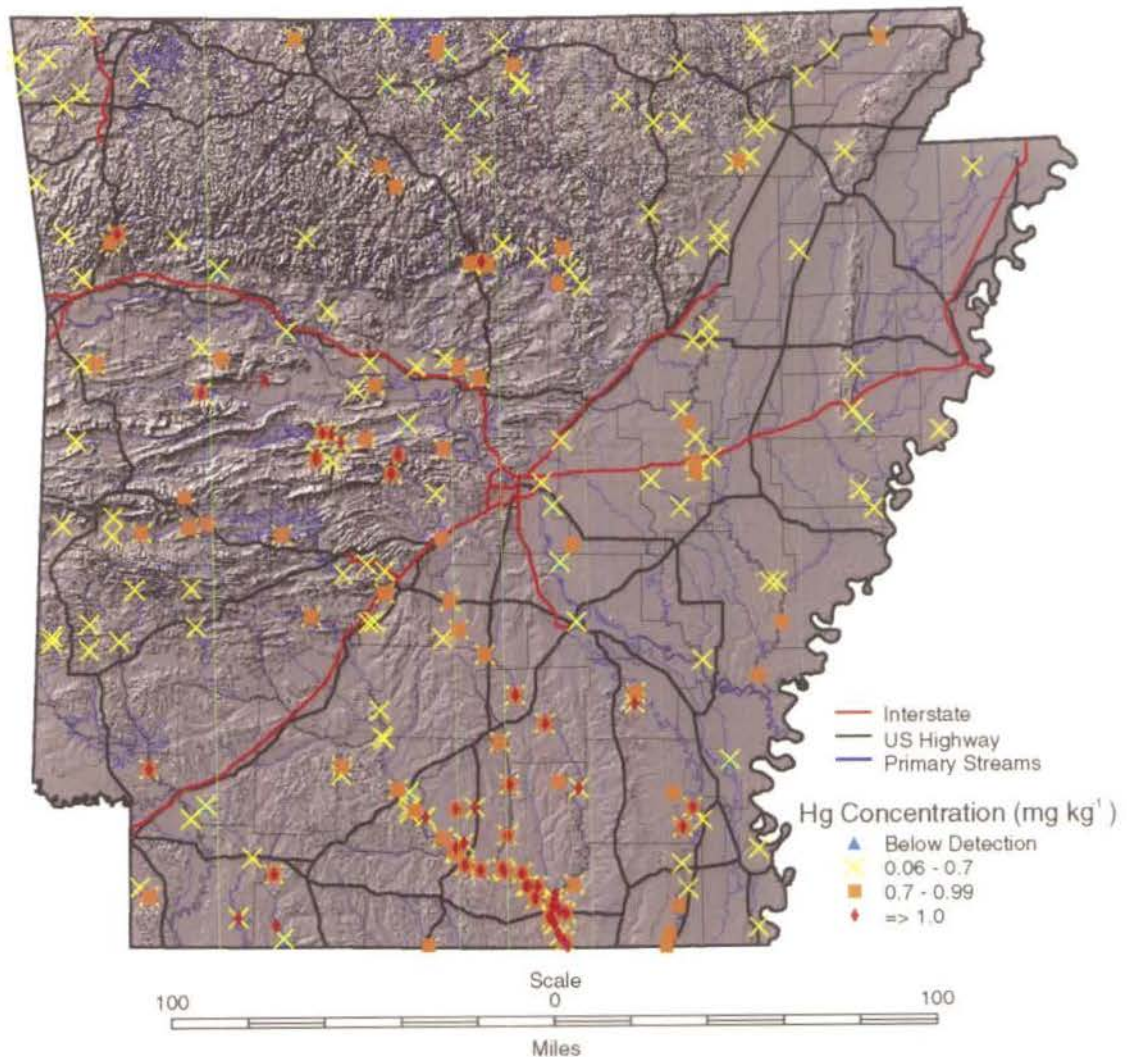
Figure 1. Spatial distribution of the Hg contaminated fish samples in Arkansas.

The Hg concentration of the fish at the sample locations was divided into four classes. Although found in all regions of the state there is a higher frequency of occurrence of the highest concentration class (> 1 mg kg^{-1}) in the Gulf Coastal Plains region and the Ouachita Mountains. The lack of higher Hg concentrations in fish tissue (0.70-0.99) in the Ozark Plateau could be attributed to higher flow rates in streams and higher alkali water conditions. However, the occurrence of Hg concentrations above 1mg kg^{-1} in the Ouachita Region would seemly reduce the influence of higher stream flow rates and put more influence on water pH and alkalinity.

Characteristics of the Large Mouth Bass

The spatial distribution of the Hg contaminated large mouth bass in Arkansas is shown in Figure 2. The large mouth bass data set was arbitrarily divided into three classes of Hg contamination: < 0.7, 0.7 to 0.99, and > 1.0 mg kg^{-1}. The map shows that the highest concentrations of Hg in the large mouth bass tend to occur in the northern

slopes of the Ouachita Region and the watersheds draining into Lake Felsenthal in the Gulf Coastal Plains in the south central portion of the state. The AMTF designated the Gulf Coastal Plains as the "hot" area for Hg-contamination of large mouth bass.
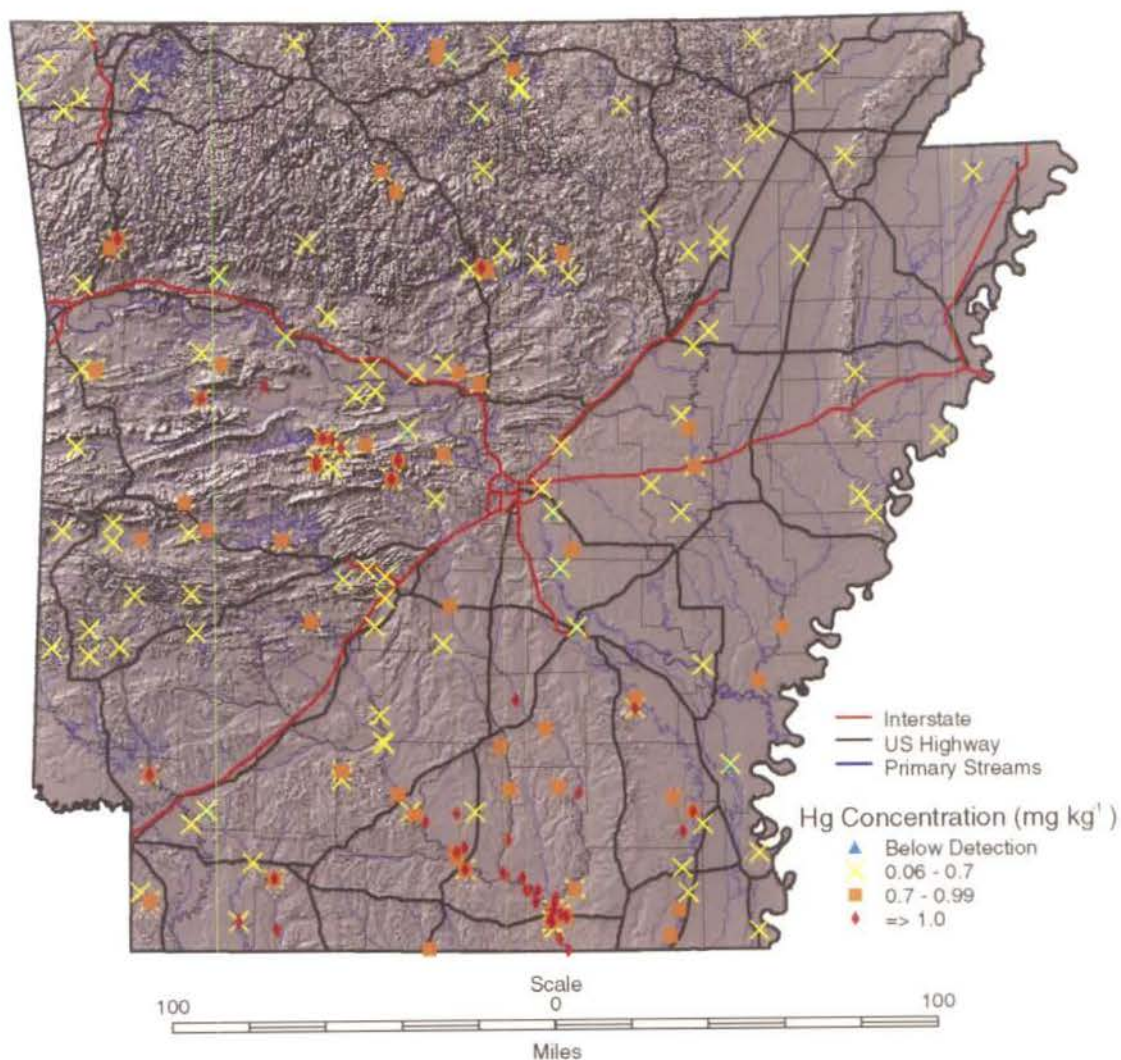
Figure 2. Spatial distribution of the Hg contaminated large mouth bass in Arkansas.

The differences in distribution of Hg contaminated fish between Figure 1 and Figure 2 show the influence of the large mouth bass on the fish database. The large mouth bass are primarily responsible for samples over $1 mg\ kg^{-1}$. The AMTF suggested that this distribution was due to the growth factors and feeding habits of the large mouth bass in that this species is a predator of other fish and that the predatory nature of large mouth bass begins at a very early age (AMTF 1995).

Statistical characteristics of Hg concentration and the morphometric measurements of length and weight of the large mouth bass are presented in Table 1. Non-normal

probability distributions were found for each of the parameters and the data are positively skewed. The median value of the large mouth bass was about 0.63 mg kg⁻¹ of Hg, 366mm length and 690g in weight. The average weight per unit length of fish was 1.89 g mm⁻¹. The %CV was relatively low for length but greater than 55% for Hg concentration and weight.

Table 1. Statistical characteristics of the concentration of Hg, length and weight of the fish in the large mouth bass database.

Statistical parameter	Hg conc.	Length	Weight
	$(mg\ kg^{-1})$	(mm)	(g)
Mean	0.727	382.2	850.8
Std. Deviation	0.476	67.4	470.3
Std. Error Mean	0.022	3.1	22.1
Upper 95% Mean	0.771	388.3	894.3
Lower 95% Mean	0.684	376.0	807.3
%CV	65.5	17.6	55.3
N	471	470	451
Skewness	1.58	1.4	1.2
Kurtosis	3.76	5.8	1.7
Median	0.630	366.0	690.0
Maximum	3.17	823	2900
Minimum	0.03	240	3

Linear correlations of the three parameters were examined. All three parameter correlations were significant ($\alpha > 0.01$). Only the length and weight were linearly correlated with each other having a Spearman Correlation Coefficient of 0.89. Linear correlations of Hg concentration with length and weight of the large mouth bass were less than 0.5 even though they were significant. This indicates that other factors were involved in determining the level of Hg in large mouth bass.

Characteristics of the General Lake Properties

The lake sampling locations and fish Hg concentrations are presented in Figure 3. These are the locations of the 84 different sampling sites in Arkansas. Many of these lakes are also represented in the fish data. There are several more lakes represented in this database that are not represented in the fish database. As noted with the large mouth bass database, the main concentration of "hot" areas is in the southern portion of Arkansas.

Statistical characteristics of the general lake properties are presented in Table 2. Non-normal, positively skewed populations were found with lake area, mean depth, watershed area, hypolimnion depth, clarity, fish Hg concentration and length-adjusted Hg concentration. The %CV for each of these parameters was about 75% or greater. The mean Hg concentration in the fish was 0.46 mg kg⁻¹ with a standard deviation of 0.37 mg kg⁻¹. The median Hg concentration was 0.44 mg kg⁻¹. Thus, the average Hg concentration of the fish in the lakes was less than the Health Advisory Level of 1.0 mg kg⁻¹.
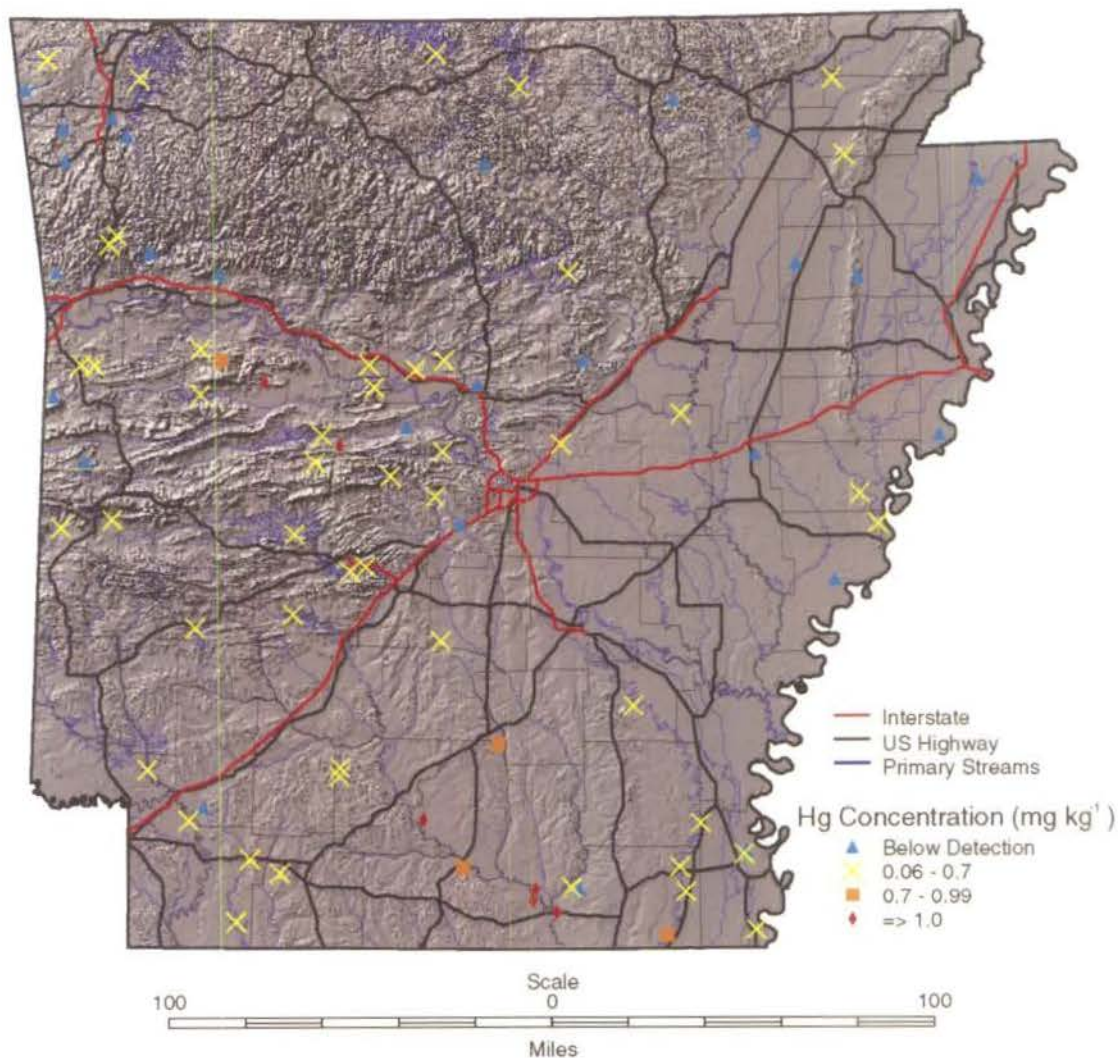
Figure 3. Spatial distribution of the lake database sample sites and associated fish Hg concentrations in Arkansas.

Of the pair wise correlations examined, both fish Hg concentrations and length-adjusted Hg concentration were negatively correlated with all parameters except watershed area. Latitude was the only significantly correlated parameter (Table 3). Depth to the hypolimnion had the next highest correlation to Hg concentration in fish, however, it was not significant and only had 20 data points.

The General Lake database was sorted by eco-region and lake type and the statistical characterizations are presented in Table 4. When examined by eco-region, the fish sampled in the Gulf Coastal Plains had the highest mean, medium and length-adjusted Hg concentrations. In terms of these parameters, the Arkansas River Valley and the Ouachita Region ranked similar. The lowest fish Hg concentrations were found in the lakes in the Ozark Plateau and Boston Mountains.

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Table 2. Statistical characteristics of the general lakes properties in the Lakes Database.

Statistical Property	Lake Area	Mean Depth	Basin Area	Hypol. Depth	Secchi Dish	Hg Conc.	Length Adjusted Hg
	(h)	(m)	(km^2)	(m)	(in)	$(mg\,kg^{-1})$	$(mg\,kg^{-1})$
Mean	1485	4.4	1043	14.1	52.8	0.46	0.52
Std. Dev.	3556	4.3	3717	9.7	40.2	0.37	0.39
Std. Error	388	0.5	406	2.2	4.4	0.05	0.05
Upper 95% Mean	2256	5.3	1850	18.7	61.6	0.56	0.62
Lower 95% Mean	713	3.4	237	9.6	44.1	0.37	0.42
N	84	83	84	20	83	65	63
Skewness	3.3	2.2	5.7	1.2	1.8	1.7	1.7
Kurtosis	10.7	4.3	36.9	0.4	3.8	3.7	3.8
%CV	239.5	98.8	356	68.3	76.1	80.8	74.5
Median	202	2.4	36	11.0	39.0	0.38	0.44
Maximum	18,389	20.4	28,107	36.7	206.7	1.75	1.96
Minimum	13	1.0	1.0	4.0	4.0	0.05	0.05

Table 3. Pair wise correlation between fish Hg concentrations and general lake properties.

Parameter	Spearman's Rho	Significance Of Probability	N
Latitude	**-0.3948**	**0.0016**	**61**
Longitude	-0.1421	0.2746	61
Lake Area (h)	-0.1195	0.3430	65
Lake Mean Depth (m)	-0.1307	0.3034	64
Watershed Area (km^2)	0.1594	0.2047	65
Dam Construction Year	-0.2552	0.1900	28
Depth of Hypolimnion (m)	-0.3837	0.0949	20
Secchi Dish (in)	-0.0944	0.4580	64

When examined by lake type, type D (small lakes) had the highest mean Hg concentration in fish and the highest variability in concentration of Hg in the fish. A general description of the lake types is given in Appendix I. Included are the locations of the lakes by region, approximation of the average depth and landuse in the watershed.

Characterization of the Epilimnion

This database was extracted from the Lake database and consists of a collection of chemical and physical parameters measured in the epilimnion layer of the lakes where the fish were sampled. The statistical characteristics of the epilimnion database are presented in Table 5. The Concentration of Hg in the water was omitted due to insufficient data points and low variability. With the exceptions of K all parameters were non-normally distributed and positively skewed with the exception of DO and TOC. When one data point was excluded (DO = 0.2) DO was normally distributed with a significance of 0.76. Percent CV was greater than 50 for all parameters with the exception of TOC (36.4%), pH (10.3%) and K (39.1%).

Table 4. Mean, standard deviation and standard errors of the mean of Hg concentrations in the fish sorted by region and lake type.

Region or Lake Type	N	Mean	Std. Dev.	Std. Err
		--- mg kg^{-1} ---		
Region				
AR River Valley	11	0.464	0.306	0.079
Boston Mountains	3	0.287	0.160	0.092
Mississippi Delta	14	0.337	0.224	0.060
Gulf Coastal Plains	18	0.674	0.563	0.133
Ouachita Mountains	10	0.436	0.120	0.038
Ozark Plateau	5	0.226	0.113	0.051
Lake Type				
A	11	0.347	0.119	0.036
B	15	0.477	0.306	0.079
C	15	0.405	0.248	0.064
D	13	0.648	0.631	0.175
E	11	0.427	0.354	0.107

The multivariate correlation is not presented due to numerous missing data points and thus, a low number of data points in the analysis. Pair wise correlations between fish Hg concentration and other lake parameters in the epilimnion are presented in Table 6. On initial analyses, the parameters hardness, pH, total dissolved solids, alkalinity and conductance were negatively correlated with fish Hg concentration. The highest correlation was with pH followed by alkalinity, hardness, conductance and total dissolved solids, respectively. After the omission of one data point from the analyses, DO and chlorophyll were also negatively correlated with fish Hg concentration. These points were outliers in a statistical sense and were mostly likely errors in data entry or analyses. All seven of these parameters were significantly correlated ($P < 0.05$). However, none of the seven elements were significantly correlated with fish Hg concentration.

Characterization of the Thermocline

This database provided did not have analyses of the seven elements unlike the epilimnion and the hypolimnion. There were also a limited number of observations. Statistical characteristics of the thermocline are presented in Table 7. Most parameters in the thermocline were non-normally distributed and positively skewed. The exceptions were TOC and pH which were normally distributed ($P > 0.05$). Percent CVs were greater than 50 for all parameters except for OP (7.5%), TOC (42.8%) and pH (11.1%).

Pair wise correlations were conducted between all thermocline parameters and fish Hg concentration. Results showed significant correlations ($P < 0.05$) between fish Hg concentration and TOC, DO and pH (Table 6). In addition, chloride was significantly correlated to Fish Hg concentration after omitting one data point. All correlations were negative with the exception of TOC.

Characterization of the Hypolimnion

The hypolimnion database was extracted from the lake database. There were no entries for fecal coliform and chlorophyll. All parameters were non-normally distributed with the exception of K. All were positively skewed and had percent CV greater than 50% with the exceptions of hardness, (47.1%), pH (9.0%) and K (48.1%).

Pair wise correlations between fish Hg concentrations and hypolimnion lake parameters responded differently than the epilimnion and thermocline correlations (Table 8). There were significant positive correlations ($P < 0.05$) with TOC and SO_4. When some of the outlier data points where omitted from analyses, additional positive correlations were noted with OP and turbidity. There were additional positive correlations with the elemental analyses that had not been noted with the epilimnion database. These included Mn, Hg concentration in the hypolimnion and Na. Negative but significant correlations were noted with pH and alkalinity.

Lake Database General Results

The important process of introducing bio-available Hg into the aquatic food chain is methylation of Hg, regardless of the Hg sources. Environmental conditions necessary for methylation are represented in the lake database by: low pH, low alkalinity, optimal sulfate concentration, high organic matter and low dissolved oxygen (Armstrong et al., 1995). These can be considered as the primary parameters. As noted by the AMTF, statistical relationships between these environmental conditions and fish Hg concentration are negative for pH, alkalinity and DO; while, TOC has a positive relationship with fish Hg concentrations. Most of these conditions can be noted by the correlations between fish Hg concentration and these primary parameters in the lake database. The relationship between the primary parameters and fish Hg concentrations in the epilimnion, thermocline and hypolimnion are shown in Figures 4, 5 and 6. In the epilimnion, pH, alkalinity, and DO were significantly negatively correlated with fish Hg concentration, while SO_4 and TOC were not. In the thermocline, pH, TOC and DO were significant, while alkalinity and SO_4 were not. Parameter TOC was the only one with a positive correlation with fish Hg concentrations in the thermocline. In the hypolimnion, all primary parameters were significantly correlated with fish Hg concentration, with the exception of DO. Figure 5B shows the lack of significance for DO in the thermocline. Parameters TOC and SO_4 were positively correlated.

In this study, limits were noted for pH (6.5 to 6.7) and alkalinity (0.4 to 0.7mg L^{-1}). The DO limit in the thermocline and the hypolimnion was 0.5mg L^{-1} while the epilimnion did not suggest any DO limits. The SO_4 data showed no tendencies in the epilimnion and thermocline while there was a relationship in the hypolimnion but with no limits. TOC showed no relationship with fish Hg concentration in the epilimnion, weak relationship in the thermocline and a strong relationship in the hypolimnion.

The additional parameters that showed correlations with fish Hg concentration in the epilimnion were significantly related to one or more of the five primary parameters. All of the

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additional parameters were significantly related to pH and all but chlorophyll was significantly related to alkalinity. Chlorophyll and TDS were also significantly related to TOC. Chloride in the thermocline was significantly related to SO_4. In the hypolimnion, all additional parameters were related to SO_4 with the exception of Hg, which was related to alkalinity. Turbidity, Mn and Na were also significantly related to TOC.

Table 5. Statistical characteristics of the epilimnion database.

Lake Parameter	Mean	Std. Dev.	Std. Err.	Upper 95% Mean	Lower 95% Mean	N	Skewness	Kurtosis	%CV	Median	Maximum	Minimum
NH$_3$-N (mg L^{-1})	0.076	0.068	0.007	0.090	0.061	84	2.9	10.6	90.0	0.056	0.406	0.025
NO$_3$-N (mg L^{-1})	0.029	0.043	0.005	0.038	0.019	80	4.5	24.4	148.9	0.020	0.310	0.010
Chloride (mg L^{-1})	4.375	4.399	0.489	5.348	3.403	81	3.9	18.4	100.5	3.050	30.400	1.310
Ortho P (mg L^{-1})	0.045	0.106	0.012	0.068	0.022	84	5.6	32.9	238.0	0.015	0.750	0.015
Total P (mg L^{-1})	0.103	0.164	0.018	0.139	0.068	84	5.1	28.7	158.2	0.068	1.140	0.015
SO$_4$ (mg L^{-1})	5.051	7.051	0.769	6.582	3.521	84	6.7	53.4	139.6	3.900	62.300	0.500
Hardness (mg L^{-1})	31.737	33.467	3.652	39.000	24.474	84	2.0	4.2	105.5	17.180	174.000	2.500
TOC (mg L^{-1})	7.508	2.732	0.322	8.150	6.866	72	0.0	-1.0	36.4	7.800	13.000	2.500
DO (mg L^{-1})	7.279	1.760	0.202	7.681	6.877	76	-0.9	3.1	24.2	7.425	11.000	0.200
pH	7.579	0.784	0.086	7.750	7.408	83	0.6	-0.4	10.3	7.420	9.500	6.000
Turbidity (mg L^{-1})	8.300	20.969	2.288	12.851	3.749	84	7.2	56.5	252.6	3.800	180.000	0.670
TSS (mg L^{-1})	5.831	7.108	0.776	7.374	4.289	84	3.1	13.2	121.9	3.000	47.000	0.500
TDS (mg L^{-1})	70.904	71.210	7.770	86.357	55.450	84	5.5	40.4	100.4	55.000	612.000	17.000
Alkalinity (mg L^{-1} as CaCO$_3$)	38.953	34.926	4.267	47.472	30.434	67	1.4	1.5	89.7	21.330	158.670	8.000
EC (μmho cm^{-1})	88.633	67.846	7.492	103.540	73.725	82	1.5	1.7	76.5	66.200	313.000	19.900
Fe (mg L^{-1})	0.142	0.199	0.048	0.245	0.040	17	2.0	3.4	139.9	0.054	0.690	0.002
K (mg L^{-1})	0.899	0.351	0.083	1.073	0.724	18	0.2	-1.3	39.1	0.841	1.500	0.430
Mg (mg L^{-1})	3.102	3.908	0.921	5.045	1.158	18	2.8	8.1	126.0	1.700	16.300	0.790
Mn (mg L^{-1})	0.031	0.065	0.016	0.064	-0.003	17	3.5	13.0	212.9	0.007	0.270	0.002
Na (mg L^{-1})	3.197	2.733	0.644	4.556	1.837	18	1.4	0.6	85.5	1.950	9.780	0.835
Ca (mg L^{-1})	7.360	8.447	2.049	11.703	3.017	17	1.7	1.5	114.8	3.900	27.033	1.300
Fecal Col. (col. 100ml^{-1})	4.222	2.465	0.636	5.587	2.857	15	1.2	1.8	58.4	4.000	10.000	1.000
Chlorophyll (mg L^{-1})	11.796	24.820	2.810	17.392	6.200	78	4.5	23.9	210.4	3.070	170.000	0.050
Fish Hg (mg kg^{-1})	0.464	0.375	0.047	0.557	0.371	65	1.8	3.7	80.8	0.380	1.750	0.050

Table 6. Fish Hg concentration and lake parameter pair wise correlations. Bold entries are significantly correlated. Blank entries were not provided with the database.

Lake Parameter	Epilimnion			Thermocline			Hypolimnion		
	Spearman's Rho	Sign. Prob.	N	Spearman's Rho	Sign. Prob.	N	Spearman's Rho	Sign. Prob.	N
NH3-N (mg L^{-1})	-0.0665	0.5988	65	-0.2160	0.3893	18	-0.0921	0.4694	64
NO3-N (mg L^{-1})	0.0850	0.5079	63	-0.2041	0.4166	18	-0.1013	0.4335	62
Chloride (mg L^{-1})	-0.0215	0.8680	62	*-0.5529	0.0403	14	-0.0158	0.9041	61
Ortho P (mg L^{-1})	-0.0767	0.5438	65	-0.1727	0.4931	18	**0.3240	0.0102	62
Total P (mg L^{-1})	-0.1367	0.2775	65	0.0247	0.9226	18	0.1152	0.3645	64
SO4 (mg L^{-1})	-0.1152	0.3608	65	-0.1330	0.5989	18	0.3114	0.0123	64
Hardness (mg L^{-1})	-0.3360	0.0062	65	-0.3039	0.2201	18	-0.1503	0.2395	63
TOC (mg l^{-1})	0.1286	0.3448	56	0.6003	0.0232	14	0.5314	0.0000	55
DO (mg l^{-1})	*-0.3725	0.0040	58	-0.5093	0.0308	18	-0.1827	0.1698	58
PH	-0.5725	0.0000	64	-0.4877	0.0401	18	-0.4786	0.0001	59
Turbidity (mg L^{-1})	-0.0139	0.9123	65	-0.1365	0.5890	18	**0.2976	0.0188	62
TSS (mg L^{-1})	-0.0496	0.6947	65	-0.0973	0.7010	18	0.1980	0.1167	64
TDS (mg L^{-1})	-0.2777	0.0251	65	-0.1897	0.4509	18	0.0550	0.6657	63
Alkalinity (mg L^{-1} as CaCO$_3$)	-0.4224	0.0020	51	-0.3950	0.1816	13	-0.3750	0.0073	50
EC (μmho cm^{-1})	-0.3090	0.0137	63	-0.1900	0.4502	18	0.0417	0.7477	62
Fe (mg L^{-1})	0.1826	0.4830	17	---------	---------	---	0.6936	0.0029	16
K (mg L^{-1})	-0.0889	0.7256	18	---------	---------	---	0.4041	0.1206	16
Mg (mg L^{-1})	-0.3013	0.2243	18	---------	---------	---	-0.2813	0.2912	16
Mn (mg L^{-1})	-0.0177	0.9461	17	---------	---------	---	0.8380	0.0001	16
Na (mg L^{-1})	0.2603	0.2968	18	---------	---------	---	0.5214	0.0384	16
Hg (mg L^{-1})	0.0000	1.0000	17	---------	---------	---	**0.6158	0.0250	13
Ca (mg L^{-1})	-0.2716	0.2917	17	---------	---------	---	-0.0282	0.9175	16
Fecal Coliform col. 100ml^{-1})	0.1023	0.7168	15	-0.1904	0.5143	14	---------	---------	---
Chlorophyll (mg L^{-1})	*-0.2601	0.0486	58	-0.2196	0.0977	58	---------	---------	---

* = one data point excluded ** = two data points excluded

Table 7. Statistical characteristics of the thermocline database.

Lake Parameter	Mean	Std. Dev.	Std. Err.	Upper 95% Mean	Lower 95% Mean	N	Skewness	Kurtosis	%CV	Median	Maximum	Minimum
NH_3-N (mg L^{-1})	0.072	0.035	0.008	0.090	0.055	18	2.0	4.3	47.8	0.053	0.178	0.050
NO_3-N (mg L^{-1})	0.042	0.060	0.014	0.072	0.012	18	3.3	11.1	144.2	0.020	0.259	0.020
Chloride (mg L^{-1})	8.890	22.701	5.861	21.461	-3.682	15	3.8	14.8	255.4	2.797	90.700	1.740
Ortho P (mg L^{-1})	0.031	0.002	0.001	0.032	0.030	18	2.1	2.7	7.5	0.030	0.037	0.030
Total P (mg L^{-1})	0.064	0.035	0.001	0.081	0.047	18	1.1	0.4	54.4	0.053	0.148	0.030
SO_4 (mg L^{-1})	6.093	8.532	2.011	10.335	1.850	18	3.9	16.1	140.0	4.000	39.500	1.200
Hardness (mg L^{-1})	38.007	52.873	12.462	64.300	11.714	18	1.9	2.4	139.1	14.660	177.000	5.000
TOC (mg L^{-1})	6.421	2.746	0.734	8.007	4.836	14	0.5	-0.9	42.8	6.100	11.400	3.067
DO (mg L^{-1})	2.553	2.371	0.559	3.732	1.374	18	1.4	2.2	92.9	1.965	9.160	0.070
pH	6.723	0.749	0.177	7.096	6.351	18	0.5	-0.9	11.1	6.700	8.100	5.650
Turbidity (mg L^{-1})	7.719	7.463	1.759	11.430	4.008	18	1.7	3.7	96.7	5.450	30.000	0.867
TSS (mg L^{-1})	5.432	4.436	1.046	7.639	3.227	18	0.7	-1.0	81.7	3.500	13.500	1.000
TDS (mg L^{-1})	74.273	70.246	16.557	109.206	39.341	18	2.5	6.9	94.6	50.000	307.000	16.000
Alkalinity (mg L^{-1} as $CaCO_3$)	36.150	51.051	14.159	67.000	5.300	13	2.2	3.6	141.2	17.000	164.670	8.000
EC (μmho cm^{-1})	124.370	140.314	33.072	194.147	54.594	18	2.3	5.7	112.8	73.000	572.000	24.000
Fecal Col. (col. $100ml^{-1}$)	34.786	72.678	19.424	76.749	-7.177	14	3.0	9.7	208.9	4.000	270.000	1.000
Chlorophyll (mg L^{-1})	17.460	41.929	4.778	26.976	7.943	77	5.8	39.7	240.2	5.720	325.290	0.050
Fish Hg (mg kg^{-1})	0.464	0.371	0.047	0.557	0.371	65	1.8	3.7	80.8	0.380	1.750	0.050

Table 8. Statistical characteristics of the hypolimnion database.

| Lake Parameter	Mean	Std. Dev.	Std. Err.	Upper 95% Mean	Lower 95% Mean	N	Skewness	Kurtosis	%CV	Median	Maximum	Minimum
NH$_3$-N (mg L^{-1})	0.434	0.694	0.076	0.585	0.282	83	3.2	13.1	160.0	0.153	4.280	0.025
NO$_3$-N (mg L^{-1})	0.054	0.090	0.010	0.074	0.034	79	3.0	9.3	166.8	0.020	0.450	0.010
Chloride (mg L^{-1})	4.495	4.569	0.511	5.512	3.478	80	3.7	16.4	101.7	3.160	30.700	1.460
Ortho P (mg L^{-1})	0.067	0.113	0.012	0.092	0.043	83	3.4	13.0	167.8	0.030	0.667	0.015
Total P (mg L^{-1})	0.148	0.192	0.021	0.189	0.106	83	3.2	12.3	129.9	0.087	1.090	0.015
SO$_4$ (mg L^{-1})	6.773	6.609	0.725	8.216	5.330	83	3.2	14.7	97.6	4.800	45.800	0.500
Hardness (mg L^{-1})	39.067	38.673	4.271	47.565	30.570	82	1.8	3.2	99.0	19.950	193.000	5.000
TOC (mg L^{-1})	8.423	3.964	0.470	9.361	7.485	71	0.9	2.0	47.1	8.000	22.600	1.800
DO (mg L^{-1})	1.441	2.137	0.247	1.933	0.949	75	1.3	0.3	148.3	0.200	6.900	0.000
pH	7.007	0.631	0.071	7.149	6.865	78	0.8	1.2	9.0	6.920	9.000	5.800
Turbidity (mg L^{-1})	12.795	21.856	2.399	17.568	8.023	83	6.2	44.3	170.8	8.200	180.000	0.800
TSS (mg L^{-1})	9.107	10.126	1.112	11.319	6.896	83	3.9	22.7	111.2	6.833	76.000	0.500
TDS (mg L^{-1})	84.301	72.280	7.934	100.084	68.519	83	5.0	35.3	85.7	63.000	615.000	25.000
Alkalinity (mg L^{-1} as CaCO$_3$)	48.338	41.457	5.103	58.530	38.147	66	1.2	0.4	85.8	28.500	170.330	6.100
EC (µmho cm^{-1})	116.234	84.388	9.377	134.894	97.574	81	1.2	0.5	72.6	80.000	368.000	24.000
Fe (mg L^{-1})	4.158	7.612	1.903	8.215	0.102	16	2.3	5.1	183.1	0.294	27.000	0.007
K (mg L^{-1})	1.059	0.509	0.127	1.330	0.788	16	0.3	-0.9	48.1	1.065	2.000	0.350
Mg (mg L^{-1})	3.258	3.872	0.968	5.322	1.195	16	2.6	7.0	118.8	1.800	15.567	0.935
Mn (mg L^{-1})	1.263	1.709	0.427	2.173	0.352	16	1.8	3.3	135.3	0.557	6.100	0.002
Na (mg L^{-1})	3.031	2.408	0.602	4.314	1.748	16	1.4	0.7	79.4	2.017	8.300	0.950
Hg (µg L^{-1})	0.114	0.193	0.050	0.221	0.007	15	2.4	4.3	169.3	0.030	0.610	0.030
Ca (mg L^{-1})	9.797	10.579	2.645	15.434	4.160	16	1.4	0.9	108.0	5.360	34.367	1.300
Fish Hg (mg kg^{-1})	0.464	0.375	0.047	0.557	0.371	65	1.8	3.7	80.8	0.380	1.750	0.050

pH
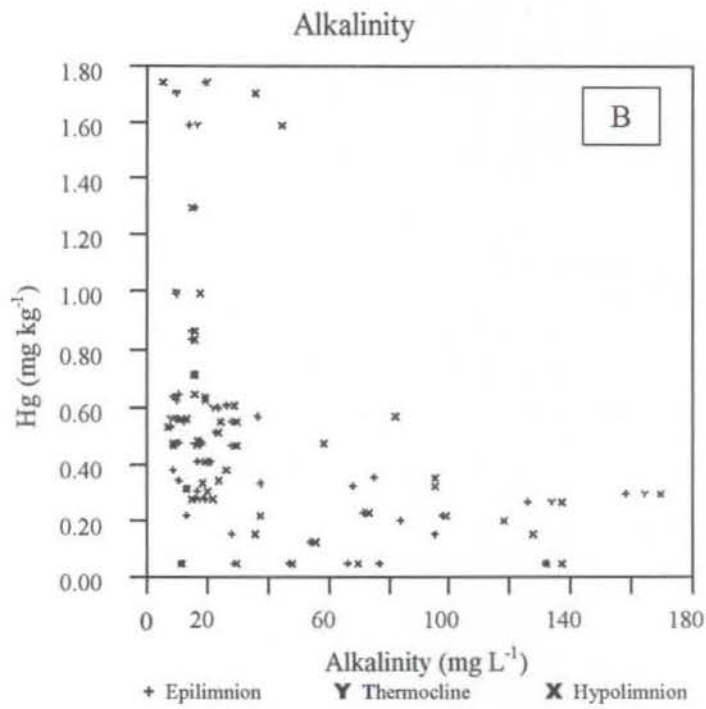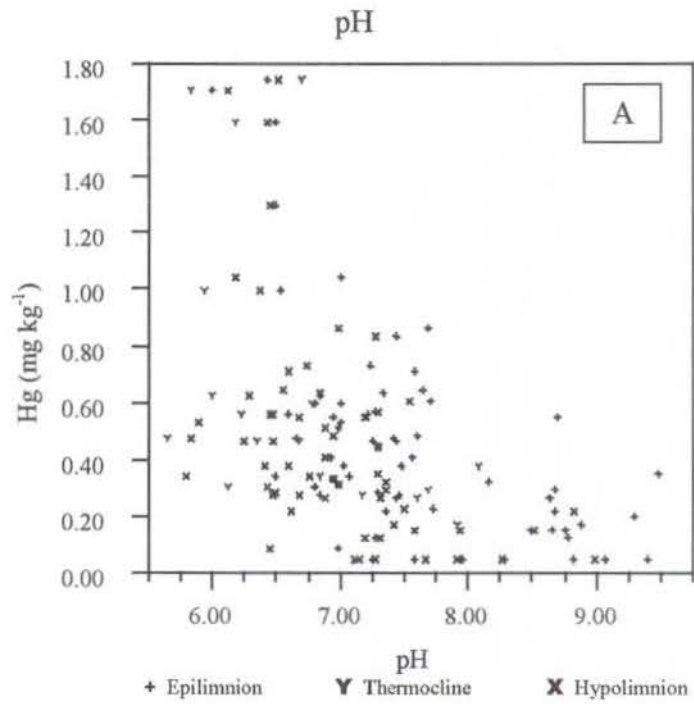
Alkalinity

Figure 4. Scatter plot of fish Hg concentration with pH (A) and alkalinity (B) for the epilimnion, thermocline and hypolimnion.
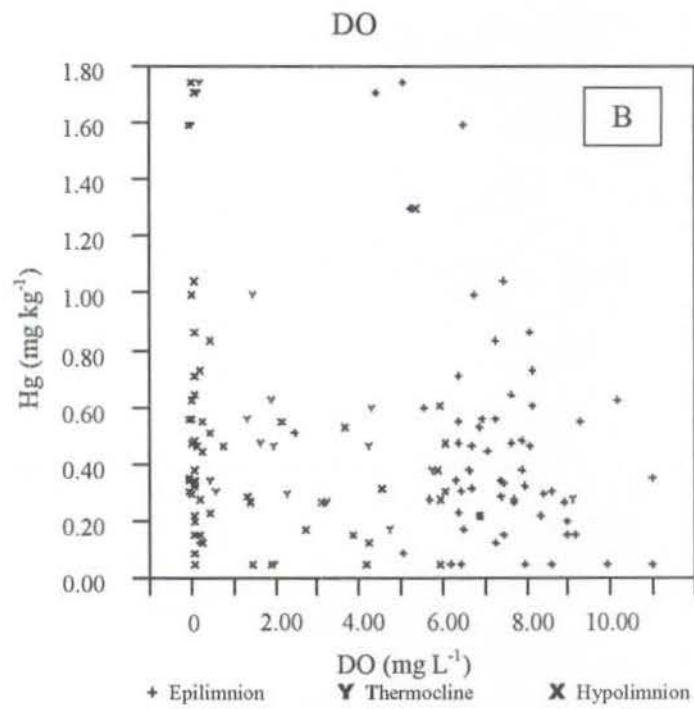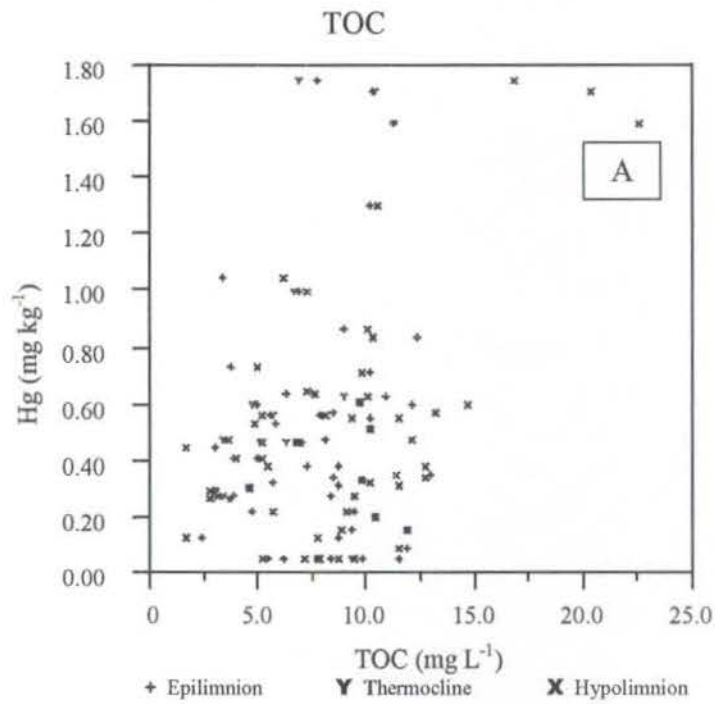
Figure 5. Scatter plot of fish Hg concentration with TOC (A) and DO (B) for the epilimnion, thermocline and hypolimnion.
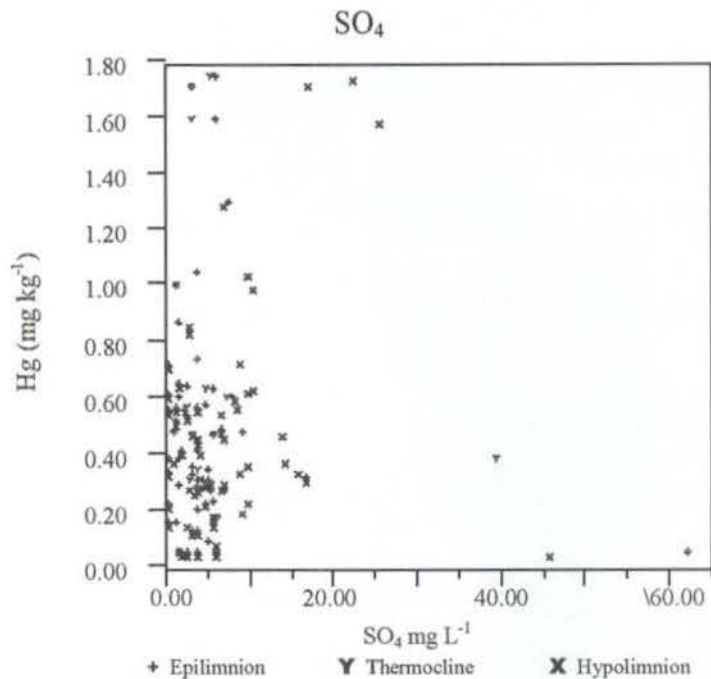
Figure 6. Scatter plot of fish Hg concentration with SO$_4$ for the epilimnion, thermocline and hypolimnion.

Characterization of the "Hot" Watershed

A close examination of the characteristics of the land area draining into Lake Felsenthal was made in order to have a greater understanding of the key edaphic factors causing the higher Hg concentrations in the large mouth bass in the lakes, streams and tributaries. In this work, we developed maps of several attributes of the watershed.

Watersheds

Five watersheds drain into Lake Felsenthal. The 8-digit hydrologic units and their areal extent are listed in Table 9 and the spatial distribution of each watershed is shown in Figure 7. The drainage area consists of over 4.765 million acres.

Table 9. Watersheds and aerial extent in the Lake Felsenthal area.

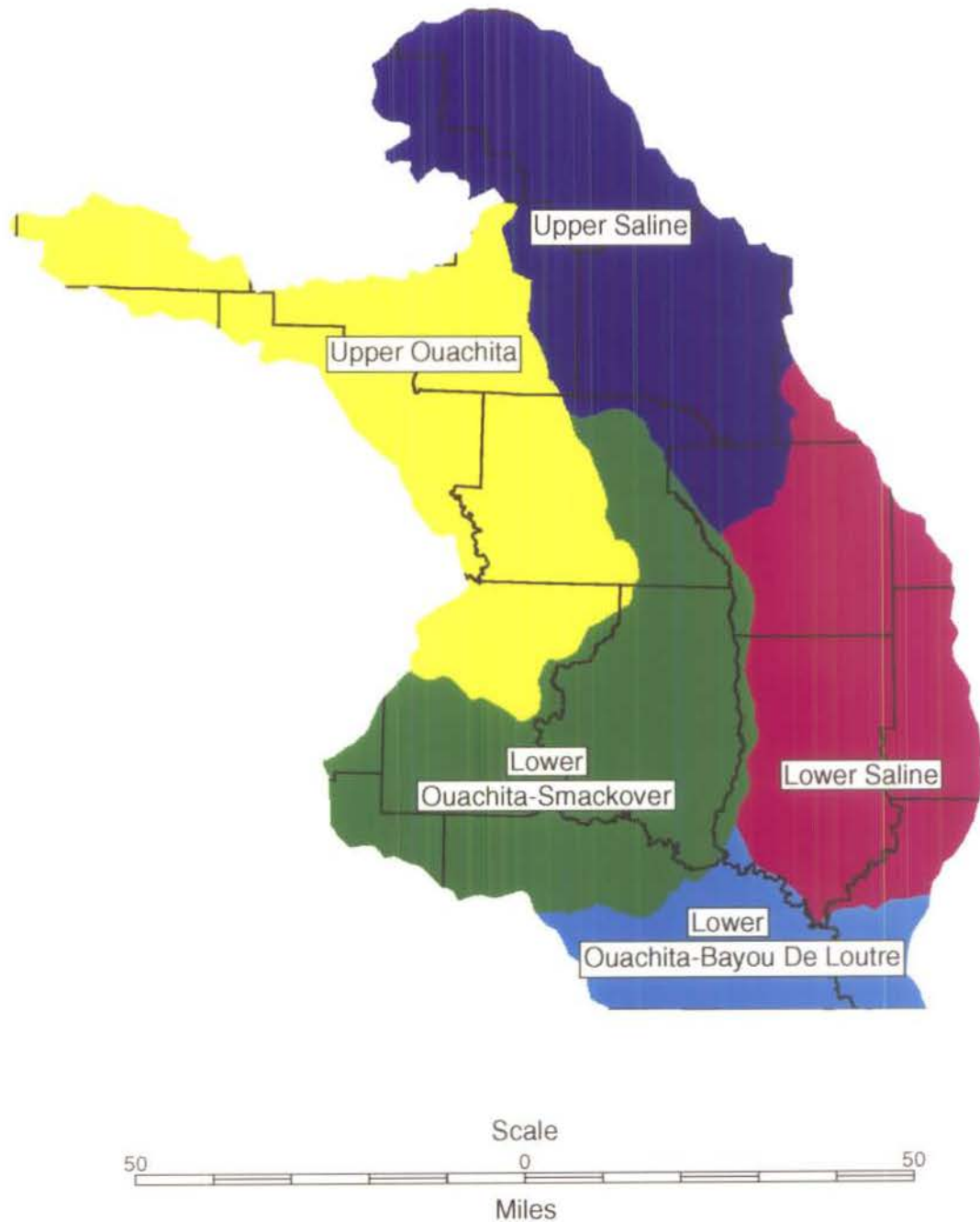| Watershed	Aerial extent (acres)	Cover %
Upper Ouachita	1,116,974	23.44
Lower Ouachita-Smackover	1,162,082	24.39
Lower Ouachita-Bayou De Loutre	422,712	8.87
Upper Saline	1,092,900	22.93
Lower Saline	970,773	20.37
Total	4,765,441	100.00

Figure 7. Hydrologic units draining into Lake Felsenthal.

The drainage basin occurs in 19 counties and their spatial distribution is shown in Figure 8. The drainage basin is bounded on the north by Saline County; on the west by Montgomery County; on the east by Drew County and on the south by the state line with Louisiana. Union County has the largest areal extent of 525,488 acres in the drainage basin and Nevada County has the lowest area of 22,570 acres.
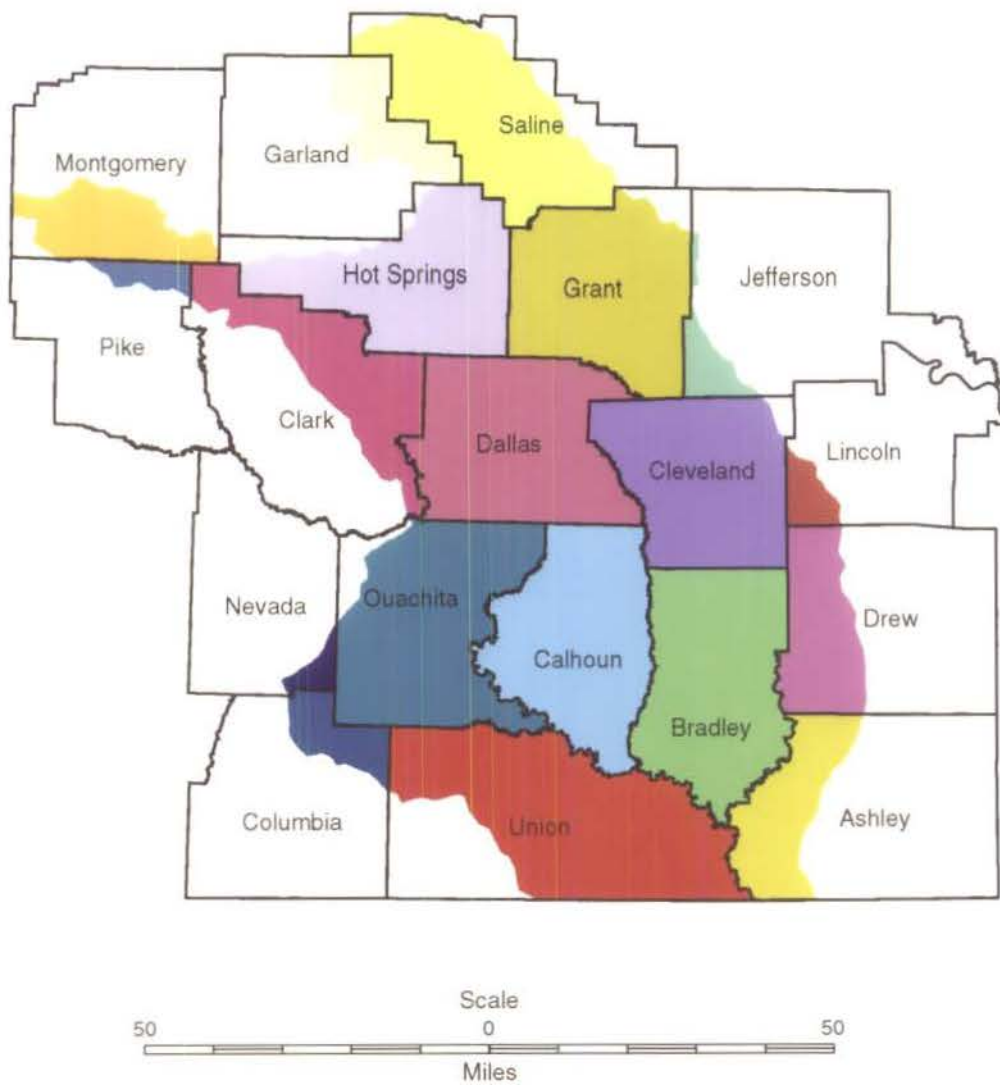
Figure 8. Counties in the watersheds draining into Lake Felsenthal.

Elevation, Slope and Aspect

The spatial distributions of the elevation, slopes and slope aspects are shown in Figures 9, 10 and 11, respectively. The highest elevations and greatest slopes are in the Ouachitas, the lowest are found in and around Lake Felsenthal. When considered as a percent of the drainage basin, 58.44 and 27.84% of the land area had a slope between 0 and 1 and between 1 and 2 degrees, respectively. Thus, almost 86.3% of the drainage basin had slopes less than 2 degrees indicating that low hydraulic gradient results in low water flow in most of the watershed.
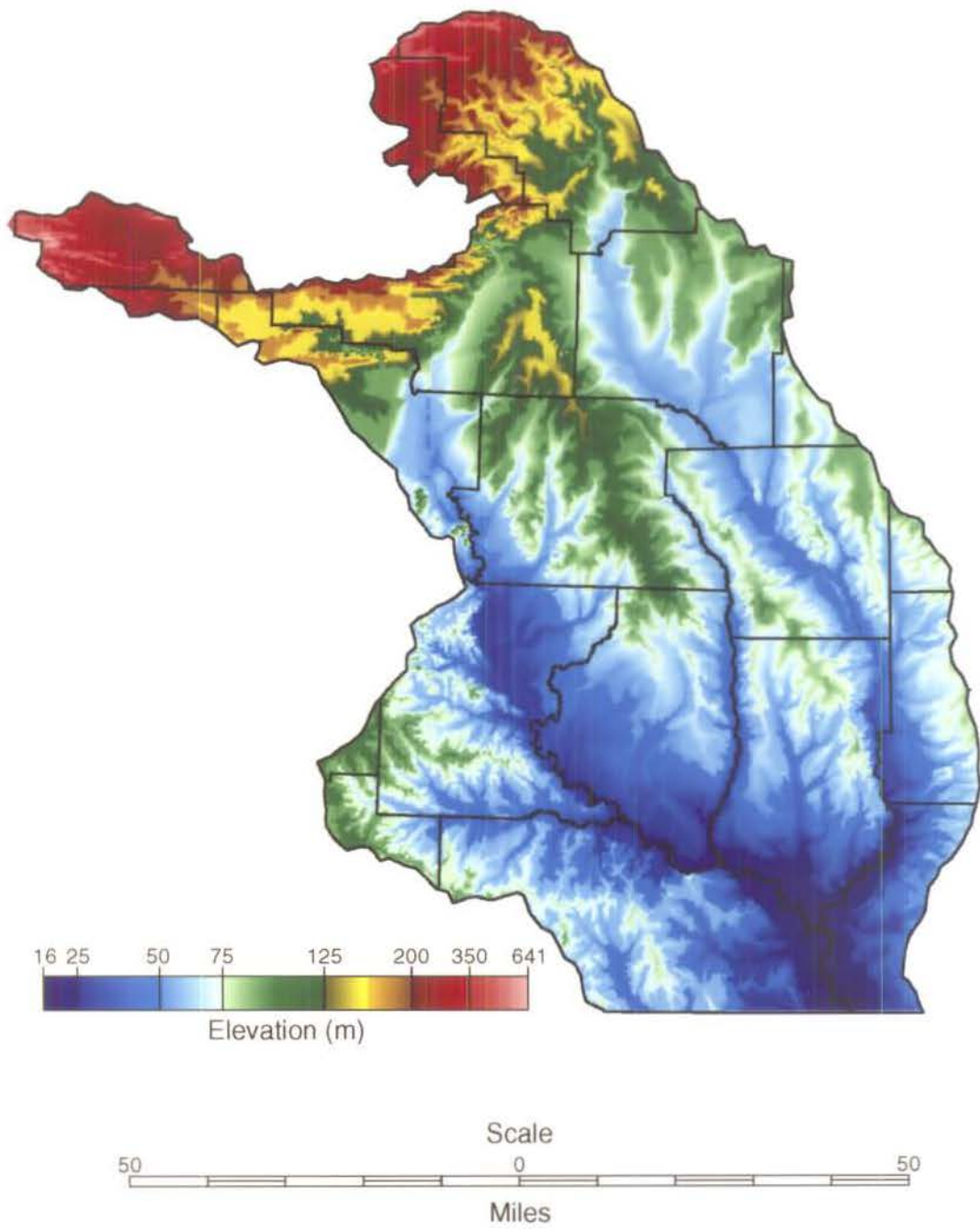
23

Figure 9. Elevations of the land surface draining into the Lake Felsenthal.
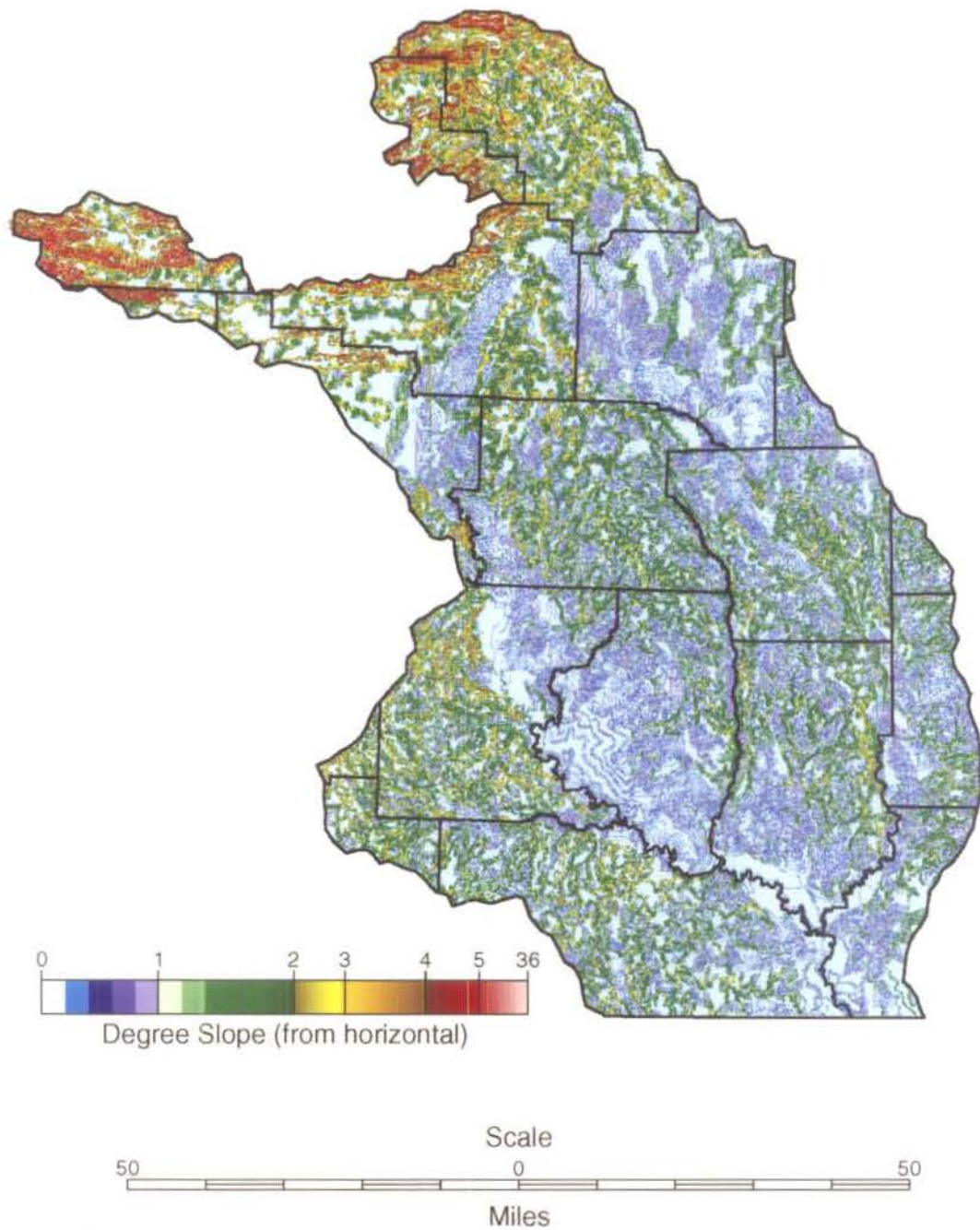
Figure 10. Slope of the land draining to Lake Felsenthal.

Hg Contaminated Large Mouth Bass

The spatial distribution of the Hg-contaminated large mouth bass is shown in Figure 11. The map shows that the highest concentration in the fish was found in Lake Felsenthal and in or around the Ouachita and Saline Rivers.
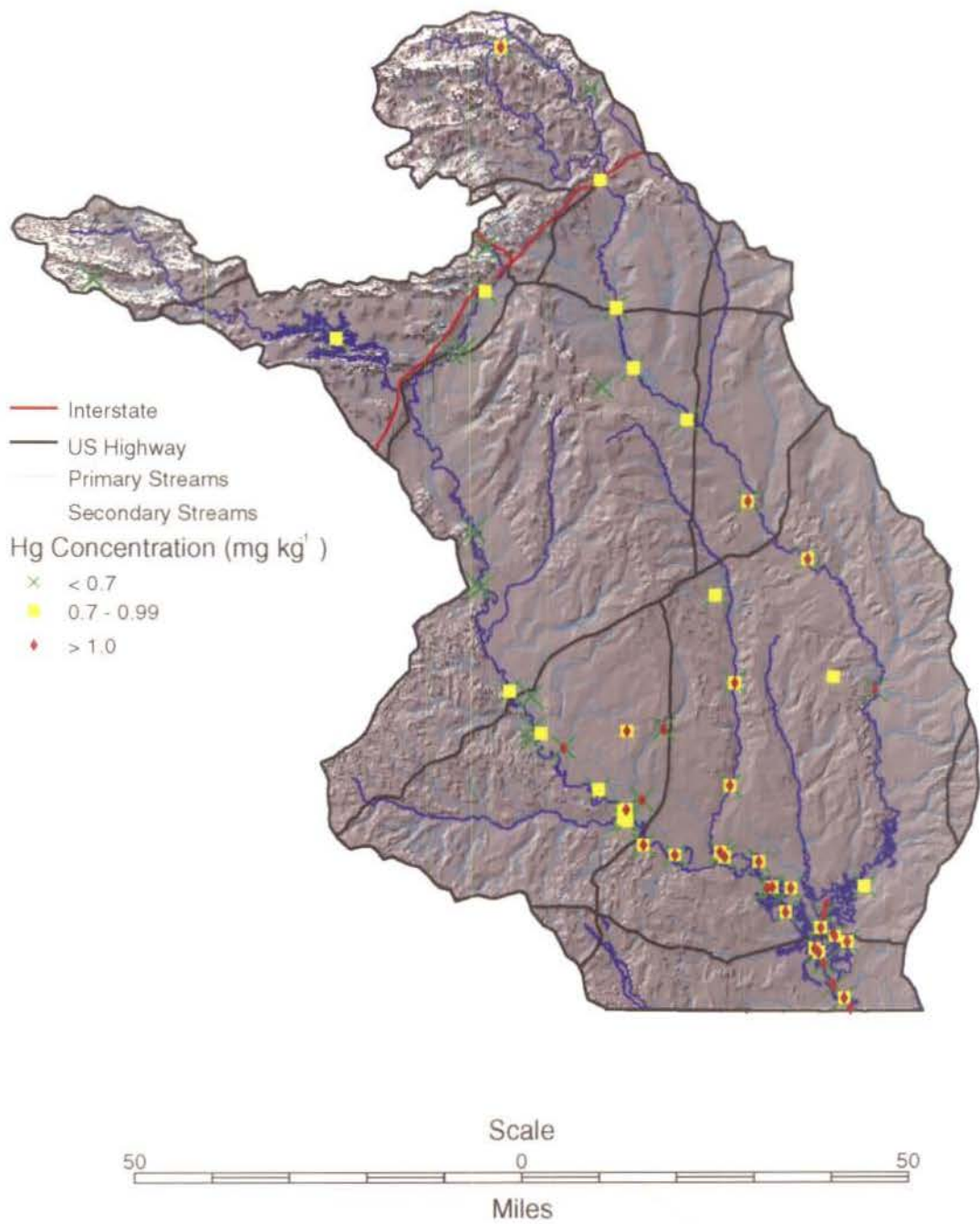
25

Figure 11. Locations of the large mouth bass by Hg concentration in the Felsenthal Lake area.

Distance Correlation Results

The relationships of the elevation and Hg concentration in large mouth bass as a function of distance from the outflow at the dam at Lake Felsenthal were plotted for the Ouachita River (Figure 12) and the Saline River (Figure 13). Changes in elevation with distance are an indication of the hydraulic gradient, or driving force for surface water. Hydraulic gradient also influences the degree of turbulence and oxidation in surface waters. The location for the starting point of the distance calculations was just below the Felsenthal Dam at the confluence of three stream channels. The distance calculations include locations just down stream from the starting point.
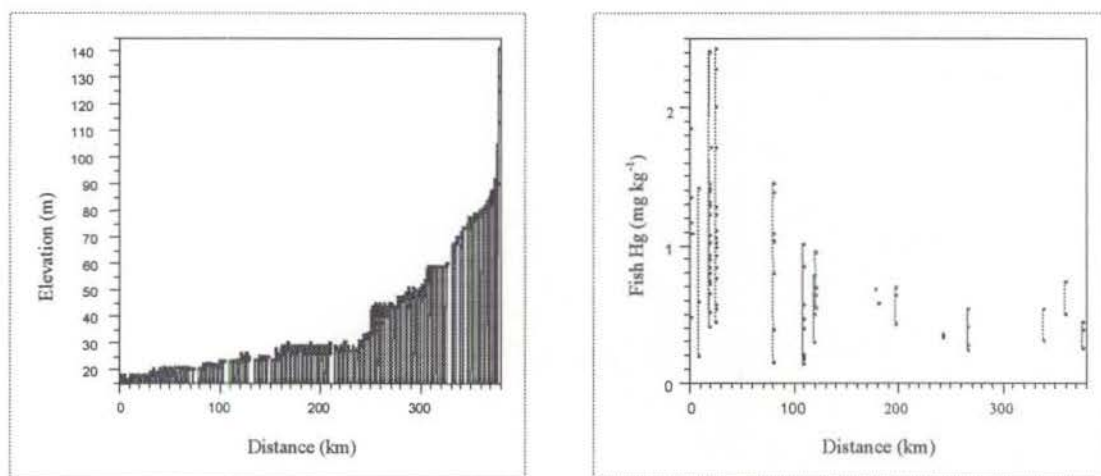

Figure 12. Elevations (left) and Hg concentrations in large mouth bass (right) of the Ouachita River as a function of distance from the outflow of Lake Felsenthal.

The elevation gain of both the Ouachita and the Saline rivers were similar when related to distance from the dam. However, where elevation gain on the Saline River seemed somewhat gradual, the Ouachita River consisted of a series of plateaus. These plateaus are locations where there is little elevation change, and thus, may reflect areas favorable for methylation. The Saline River also consists of a series of plateaus; however, these are smaller than those of the Ouachita River plateaus. Elevation changes for both rivers are gradual to a certain point. Saline River elevation changes are somewhat constant to nearly 325 km up stream where the change in elevation increases dramatically. This point coincides with the boundary between the Ouachita Mountains and the Gulf Coastal Plains. The same increase in elevation change was noted approximately 250 km up stream on the Ouachita River; however, the location of the point of change is at the confluence with the Little Missouri River, well within the Gulf Coastal Plains.
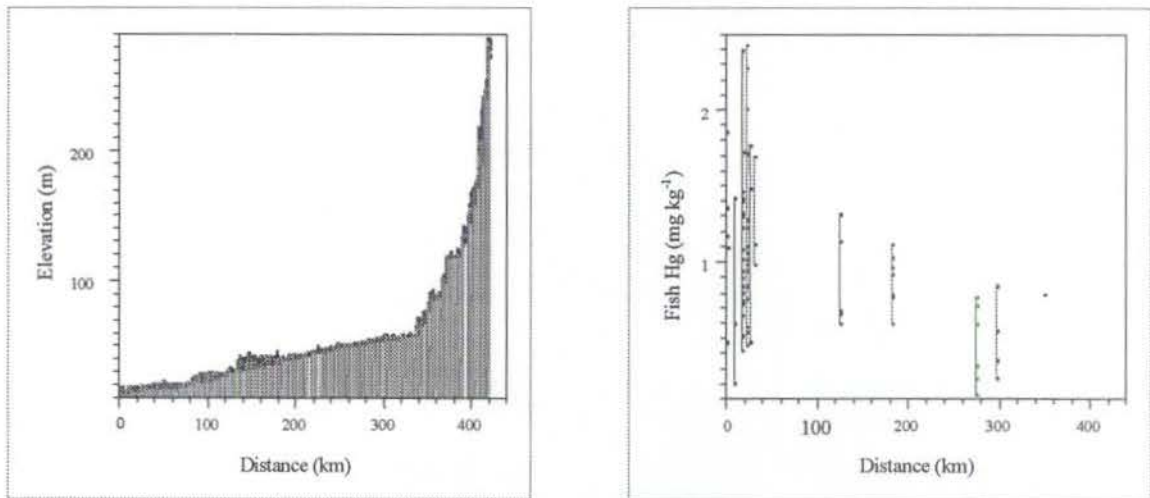
Figure 13. Elevations (left) and Hg concentrations in large mouth bass (right) of the Saline River as a function of distance from the outflow of Lake Felsenthal.

Large mouth bass Hg sample sites taken from Felsenthal Reservoir were the points where distances from the outflow of the Felsenthal Dam were greater than 10 and less than 30 km. The highest Hg concentrations in the fish generally decreased with distance from the outflow of the Felsenthal Dam. Exceptions to this are locations on the Ouachita River 360 km up stream west of Malvern and on the Saline River 300 km up stream from the dam at US Highway 270.

Variations in Hg concentrations of the large mouth bass from each sample site decreased with distance. Minimum concentrations of Hg in the fish did not show any trends with distance. Lower Hg concentrations nearest the point of origin on the graphs were sites located down stream from the dam, thus indicating more turbulent water flow and presumably more oxidation. However, even in these locations there were large mouth bass with Hg concentrations greater than 1.0 mg kg^{-1}. This may be due to the mobility of prey fish and the large mouth bass itself. Included in these areas are sample sites that were below the starting point of the distance calculations.

Correlation between fish tissue Hg concentration and elevation, distance, and stream gradient showed correlations of -0.54, -0.42 and -0.22, respectively. All correlations were significant ($P < 0.05$), although, gradient was less significant that elevation and distance.

Land Use and Land Cover

The map of the land use and land cover in the Lake Felsenthal watershed is shown in Figure 14. Nearly 82.8% of the drainage watershed is forested with 15.2% classified as agriculture and only 0.5% as urban (Table 10). The literature indicates that forests are important sources and sinks for Hg.

Legend:

- ☐ Out of Area
- ■ Pinus echinata
- ■ Pinus taeda
- ■ Quercus ssp.-Pinus echinata-Carya spp.
- ■ Pinus taeda-Pinus echinata-Quercus spp.
- ■ Quercus alba
- ■ Celtis laevigata
- ■ Quercus nuttallii
- ■ Quercus phellos
- ■ Liquidambar styraciflua
- ■ Taxodium distichum
- ■ Nyssa
- ■ Agriculture (dry crops)
- ☐ Agriculture (pasture)
- ■ Urban Commercial-Industrial
- ■ Urban Residential
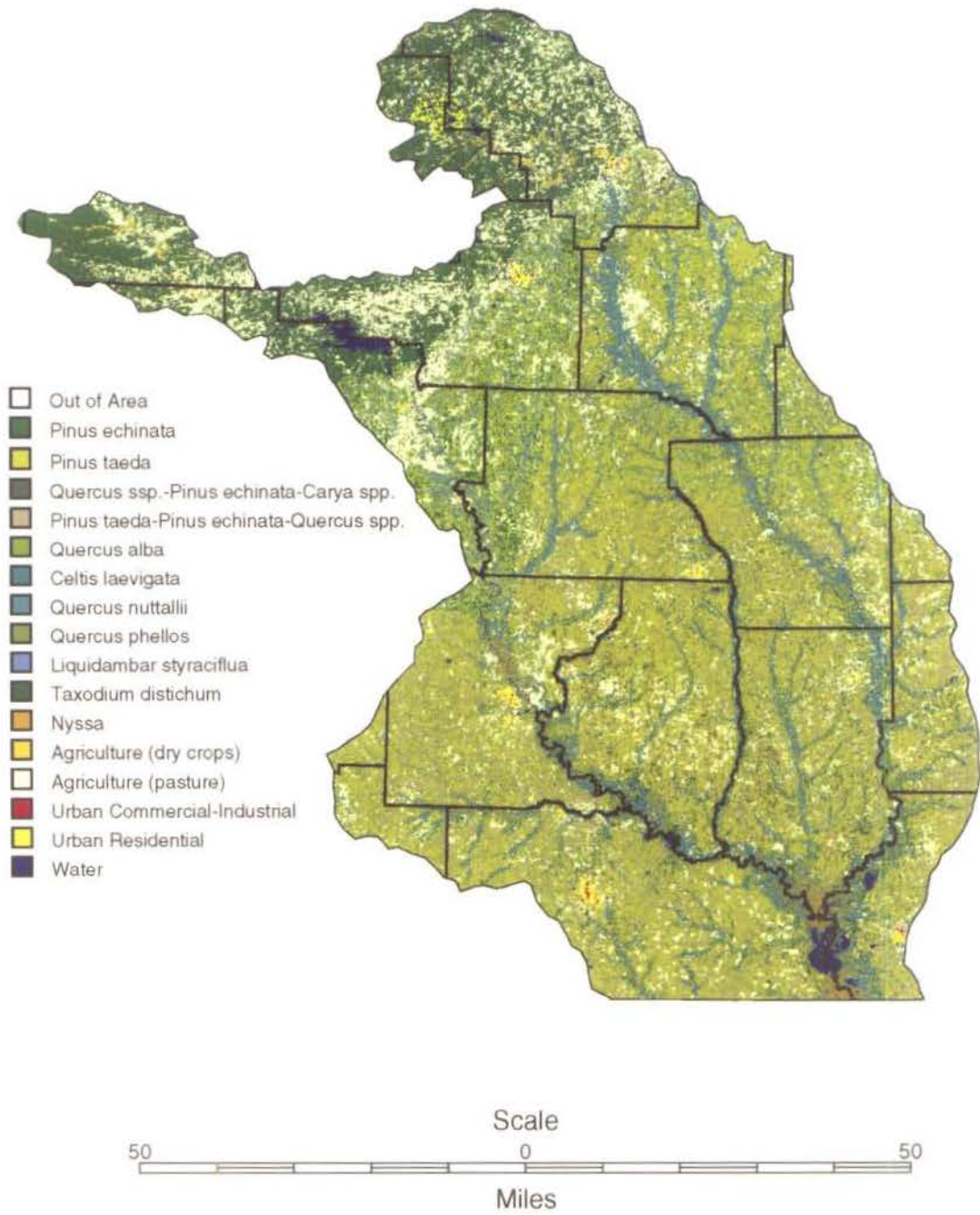- ■ Water

Scale

50   0   50

Miles

Figure 14. Vegetative cover of the watersheds draining into lake Felsenthal.

Table 10. Aerial extent of the land use and land cover in the watershed around Lake Felsenthal.

Genus Species	Common Name	Aerial extent		Cover
		acres	hectares	%
Pinus echinata	Shortleaf Pine	338,460	126,973	7.10
Pinus taeda	Loblolly Pine	1,332,817	539,384	27.97
Quercus stellata	Post Oak	222,803	90,167	4.68
Pinus taeda-Pinus echinata-Quercus sp.	Pine-Oak Mix	593,312	240,110	12.45
Celtis laevigata	Sugarberry-Hackberry	43,325	17,533	0.91
Quercus phellos	Willow Oak	212,381	85,949	4.46
Liquidambar styraciflua	Sweetgum	9,049	3,662	0.19
Taxodium distichum	Bald Cypress-Hardwoods	12,196	51,880	2.69
Nyssa	Tupelo-Gum	97,581	39,491	2.05
Water		71,528	28,947	1.50
Agriculture-dry crops		17,386	7,036	0.36
Agriculture-pasture		705,848	285,653	14.81
Urban-commercial-industrial		3,192	1,292	0.07
Urban-residential		22,506	9,108	0.47

Soils

The spatial distribution of the soil associations in the drainage basin is shown in Figure 15. Soils are important Hg sources in reservoirs and serve as storage compartments for atmospheric deposition of Hg. Changes in temperature, climate and landuse/landcover can affect the organic matter, nutrient accumulation and pH, all of which affect the methylation of Hg. Hg is strongly bound by organic matter and other soil surfaces and higher quantities of these soil components usually result in higher accumulations of Hg. Hg can also be transported via erosion to reservoirs and lakes from soils attached to dissolved humic material and particles. Erosion processes are primarily governed by hydrologic factors, vegetative cover, soil erodibility, slope and climate. Even a small percentage of Hg transported annually can result in a large accumulation of Hg in a water body over long periods of time. Studies have shown positive relationships between organic matter content and Hg accumulation. In addition, practices such as logging and urban growth provide transport of Hg via erosion of soil organic matter and sediments.

The soil associations, their aerial extent, drainage class and soil surface erodibility in the region surrounding Lake Felsenthal are given in Table 11. The largest areal extent is the Sacul-Savannah-Sawyer association, followed by the Guyton-Amy-Ouachita, the Smithdale-Savannah-Sacul and the Carnasaw-Clebit-Sherless association. The soils in the river bottoms tend to be in the Guyton-Amy-Ouachita Association in the Coastal Plains and in the Carnasaw-Clebit-Sherless Association in the Ouachitas. The Guyton-Amy-Ouachita soils tend to occur at lower elevations and are poorly drained near the streams with relatively high erodibility indices. In contrast, the Carnasaw-Clebit-Sherless soils tend to occur at the higher elevations and are well drained with moderate to low surface erodability indices.
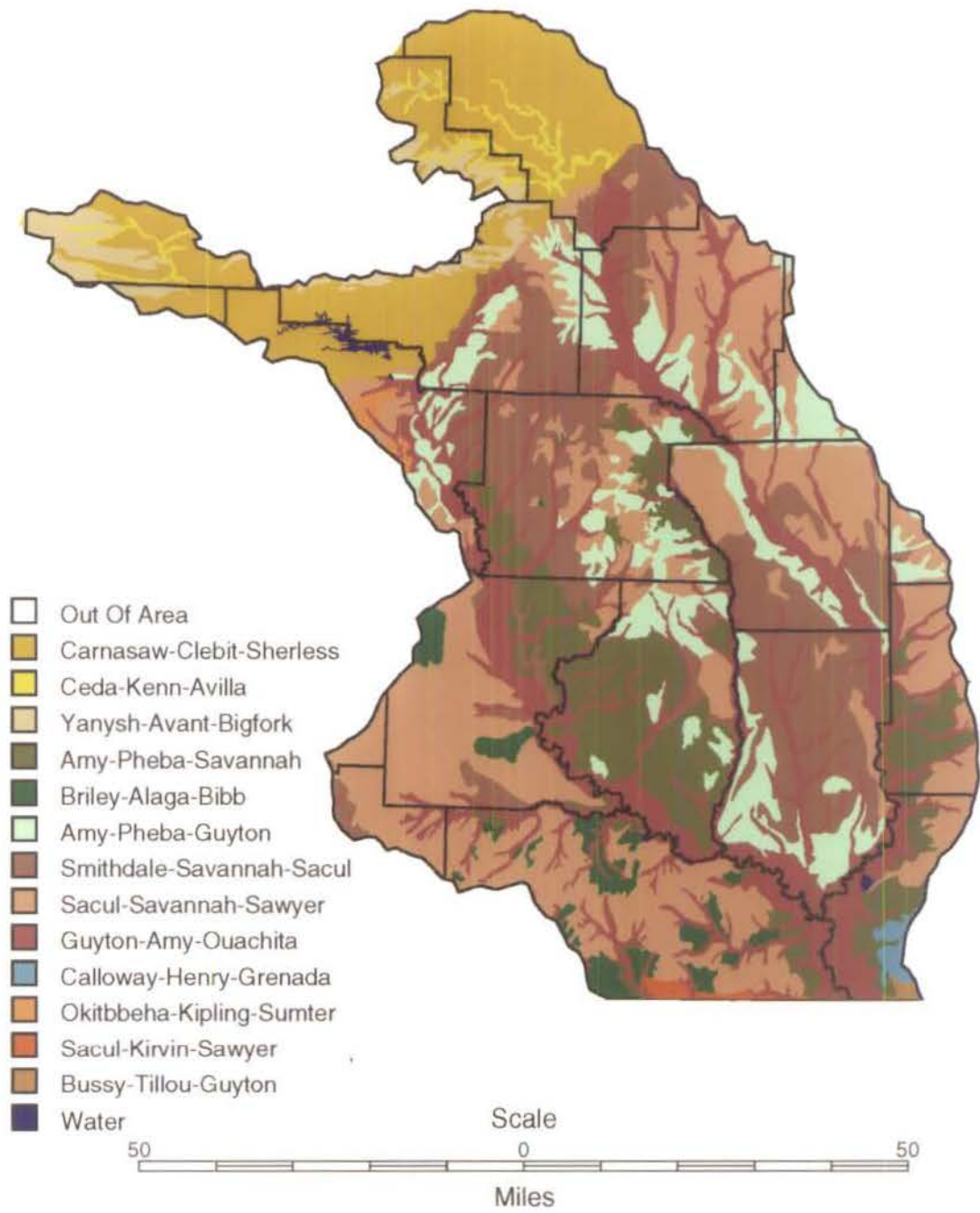
Figure 15. Soil associations of the Lake Felsenthal watershed.

Legend:

- Out Of Area
- Carnasaw-Clebit-Sherless
- Ceda-Kenn-Avilla
- Yanysh-Avant-Bigfork
- Amy-Pheba-Savannah
- Briley-Alaga-Bibb
- Amy-Pheba-Guyton
- Smithdale-Savannah-Sacul
- Sacul-Savannah-Sawyer
- Guyton-Amy-Ouachita
- Calloway-Henry-Grenada
- Okitbbeha-Kipling-Sumter
- Sacul-Kirvin-Sawyer
- Bussy-Tillou-Guyton
- Water

Scale

50   0   50

Miles

By combining the spatial distribution of the soil associations and the locations of the Hg-contaminated fish, the distribution of contaminated fish relative to soil associations was determined. Of the 137 Hg contaminated large mouth bass samples, 125 sample areas were occupied by the Guyton-Amy-Ouachita soil association, 11 samples areas were occupied by the Carnasaw-Clebit-Sherless association and one sample area was occupied by the Smithdale-Savannah-Sacul association. None of the other soil associations had Hg contaminated fish.

Table 11. Summary of the soil associations, aerial extent and characteristics in the "hot" watersheds.

Soil Association	Number	Acres	Drainage*	Surface erosion-k
Carnasaw-Clebit-Sherless	16	617,063	w-w-w	0.32-0.20-0.15
Ceda-Kenn-Avilla	17	57,878	w-w-w	0.24-0.17-0.32
Yanush-Avant-Bigfork	21	121,340	w-w-w	0.32-0.24-0.15
Amy-Pheba-Savannah	38	458,294	p-swp-mw	0.43-0.43-0.24
Briley-Alaga-Bibb	39	108,743	w-swe-p	0.20-0.10-0.37
Amy-Pheba-Guyton	40	443,022	p-swp-p	0.43-0.43-0.43
Smithdale-Savannah-Sacul	41	695,031	w-mw-mw	0.27-0.24-0.28
Sacul-Savannah-Sawyer	42	1,252,629	mw-mw-mw	0.28-0.24-0.28
Guyton-Amy-Ouachita	43	943,019	p-p-w	0.43-0.43-0.37
Oktibbeha-Kipling-Sumpter	49	15,674	mw-swp-w	0.32-0.32-0.37
Sacul-Kirvin-Sawyer	68	15,909	mw-w-mw	0.32-0.37-0.37
Bussy-Tillou-Guyton	69	5,871	mw-swp-p	0.43-0.43-0.43

* w=well p=poorly swp=somewhat poorly mw=moderately well swe=somewhat excessive

Median concentrations of the soil elements and attributes analyzed by the UA Soil Testing Laboratory were summarized by soil association and are presented in Table 12. The laboratory does not analyze for Hg concentrations in the soil but does provide a service for those interested in the concentrations of macro and several micro nutrient elements needed for plant growth. These data are presented to show the status of the soil chemical properties of the soils at or near the surface. It should be kept in mind that the soil samples were taken in the plow layer, i.e. the top 15 cm of the soil profile. The overwhelming majority of these soils have a sandy loam texture.

Considering the characteristics of the two soil associations that had the Hg contaminated large mouth bass, both the Guyton-Amy-Ouachita (Soil Association number 43) and Carnasaw-Clebit-Sherless (Soil Association number 16) tend to be moderately acid with no particularly high median elemental concentrations that make them stand out above the other soil associations with regard to those processes that might lead to methylation of Hg.

Correlations were determined between Hg concentrations in the large mouth bass and the median concentrations of the soil association at the sampling location. These results are

presented in Table 13. All of the linear correlation coefficients were low indicating that other factors were involved in determining the accumulation of Hg by the fish. However, significant correlations ($P < 0.05$) were found with the elements Ca, Mg, Na Fe, Cu and Zn and with EC. Large mouth bass Hg concentrations were negatively correlated with median soil concentrations of Ca, Mg, Cu, Zn, and with EC whereas there was a positive correlation between large mouth bass Hg concentrations and median soil concentrations of Na and Fe.

Table 12. Medians of soil elements and attributes summarized by soil association number. The name of the SAN is given in Table 11.

SAN	N	pH	NO₃	P	K	Ca	Mg	Na	SO₄	Fe	Mn	Cu	Zn	B	OM	EC
															%	µmho cm⁻¹
16	1787	5.6	10	112	186	1761	195	118	32	199	142	4	11	2	1.0	76
38	481	5.6	6	101	161	1067	111	127	27	222	109	2	8	2	1.0	60
40	2304	5.7	7	103	175	1375	142	124	29	245	103	3	9	2	1.0	65
41	3155	5.8	7	141	178	1160	117	125	28	221	95	3	11	2	1.0	64
42	3259	5.7	7	117	175	1235	133	125	28	262	84	3	10	2	1.0	62
43	347	5.5	7	80	179	1084	110	126	28	260	112	2	8	2	1.0	53
44	822	6.3	7	34	160	1617	198	147	26	286	181	2	7	2	1.0	67
49	337	5.8	5	70	177	1779	137	131	31	291	94	2	11	1	1.0	59

Attribute medians; -lb A⁻¹-

Table 13. Correlations between Hg concentrations in the large mouth bass and medians of the soil test chemical parameters at the location where the fish samples were taken.

Parameter	Correlation coefficient	Number	Significance level
pH	-0.24	49	0.11
N	-0.28	49	0.06
P	-0.28	49	0.06
K	-0.17	49	0.25
Ca	-0.30	49	0.05
Mg	-0.29	49	0.05
Na	+0.30	49	0.05
S	-0.28	49	0.06
Fe	+0.31	49	0.04
Mn	-0.20	49	0.18
Cu	-0.31	49	0.03
Zn	-0.32	49	0.03
EC	-0.32	49	0.03

CONCLUSIONS

Mercury contamination of at least 16 fish species has been found in 160 water bodies in Arkansas. The Hg contaminated fish were found in all regions of the state indicating multiple sources, mechanisms of transport and conditions that create methylation of Hg. This report emphasized the characterization of the data associated with the large mouth bass. While these fish were collected from all regions of the state, the highest Hg concentrations were found in fish from the Lake Felsenthal watershed, Ouachita Mountains and with lakes of type D. Statistically, all measured parameters with the exception of pH were non-normally distributed, positively skewed and with high %CV. The lake data were partitioned into four sections. The general lake properties database showed no correlations between fish Hg concentrations and any of the other parameters with the exception of latitude. In the epilimnion, the water parameters hardness, pH, total dissolved solids, alkalinity, and conductance were negatively correlated with fish Hg concentrations. In the thermocline, significant negative pair wise correlations were found with DO, pH and chloride. A positive correlation was found between TOC and fish Hg concentration. In the hypolimnion, positive correlations were found between TOC, SO_4, OP, turbidity, Mn and fish Hg concentrations. Some of these parameters were correlated with each other. A characterization of the natural resources in the Lake Felsenthal watershed show that the five watersheds draining into the lake occupied more than 4.76 million acres from 19 counties in southern Arkansas. The slopes tended to be less than 2 degrees in over 86 % of the watershed. Considering only the two major streams feeding the lake, the hydraulic gradients are relatively low for over 250 km from the dam on Lake Felsenthal. The gradients tended to be much higher in the Ouachita Mountains region. When plotted as a function of distance from the dam on Lake Felsenthal, the Hg concentration in large mouth bass decreased. Over 80% of the watershed was forested. Of the 12 soil associations in the watershed Hg contaminated fish tissue samples occurs on two soil associations that occur in the stream bottoms of the Ouachita and Saline Rivers. These soils tended to be poorly drained in the Gulf Coastal Plains and well drained in the Ouachita Mountains. Soil erodibility indices tended to be relatively high in the Gulf Coastal Plains and moderate to low in the Ouachita Mountains. When correlated with the locations of large mouth bass, the soils tended to be moderately acid with no particular median elemental concentration that could be attributed to methylation of Hg.

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Appendix I

A general description of the lake types. These descriptions were obtained from Alan Price of the Arkansas Department of Pollution Control and Ecology.

Lake type	General description
A	These are larger lakes, usually of several thousand acres in size. They have average depths normally of 30 to 60 feet and are located in the mountain areas of the Ozark Highlands, Ouachita Mountains and Boston Mountains. The watersheds are mostly forest dominated
B	These include the smaller lakes of the uplands or steeper terrain. Most are around 500 acres, but probably are the most heterogeneous group of lakes. Most are located in the Ozark Highlands, Ouachita Mountains and Boston Mountains; however, several are located in the more mountainous areas of he Arkansas River Valley. Average depths are relatively deep and range generally from 10 to 25 feet. Watersheds are normally dominated by forest lands.
C	This group is composed of the smaller lakes of the lowlands or flat terrain areas. Sizes generally range from 300 to 1000 acres with average depths of normally less than 10 feet. These lakes are located in the flatter terrain of the Arkansas River Valley, in the Gulf Coastal and in the Delta Eco-regions. The Delta lakes of this group are generally associated with the Crowley's Ridge region. Watersheds of these lakes include timberlands of both lowland hardwoods and pines, but some are broken by pasture land and small farms.
D	These are small impoundments of the Delta areas of the state, but include two similar type lakes from the large river alluvium of the Gulf Coastal Eco-region. The D type lakes are generally 200 to 500 acres in size with average depths of around 5 feet. This group includes several natural, oxbow-cutoff lakes which have been modified by a water control structure to increase their isolation from the parent stream and maintain higher dry-season water levels. These lakes are only occasionally flooded by the parent stream and generally have very small direct runoff watersheds. The other lakes of this type are man-made, but they are almost totally isolated from their watershed by levees. Water levels are maintained through occasional pumping from adjacent waterways. Where watersheds exist that discharge directly to the oxbow lakes in this group, the runoff is primarily from row crop agriculture.
E	These are large lowland lakes of the Delta, Gulf Coastal and the large alluvial areas of the Arkansas River Valley Eco-region. They range from several thousand to over 30,000 acres in size, but average depth is usually less than 10 feet. This group also includes four large, oxbow-cutoff lakes which have been substantially modified by construction of drainage ditches, levees and other water control structures. Watershed types include mixtures of intensive row crop agriculture, small farms and pastures with increasing amounts of confined animal production and timberlands