# Arkansas Water Resources Center

# 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.

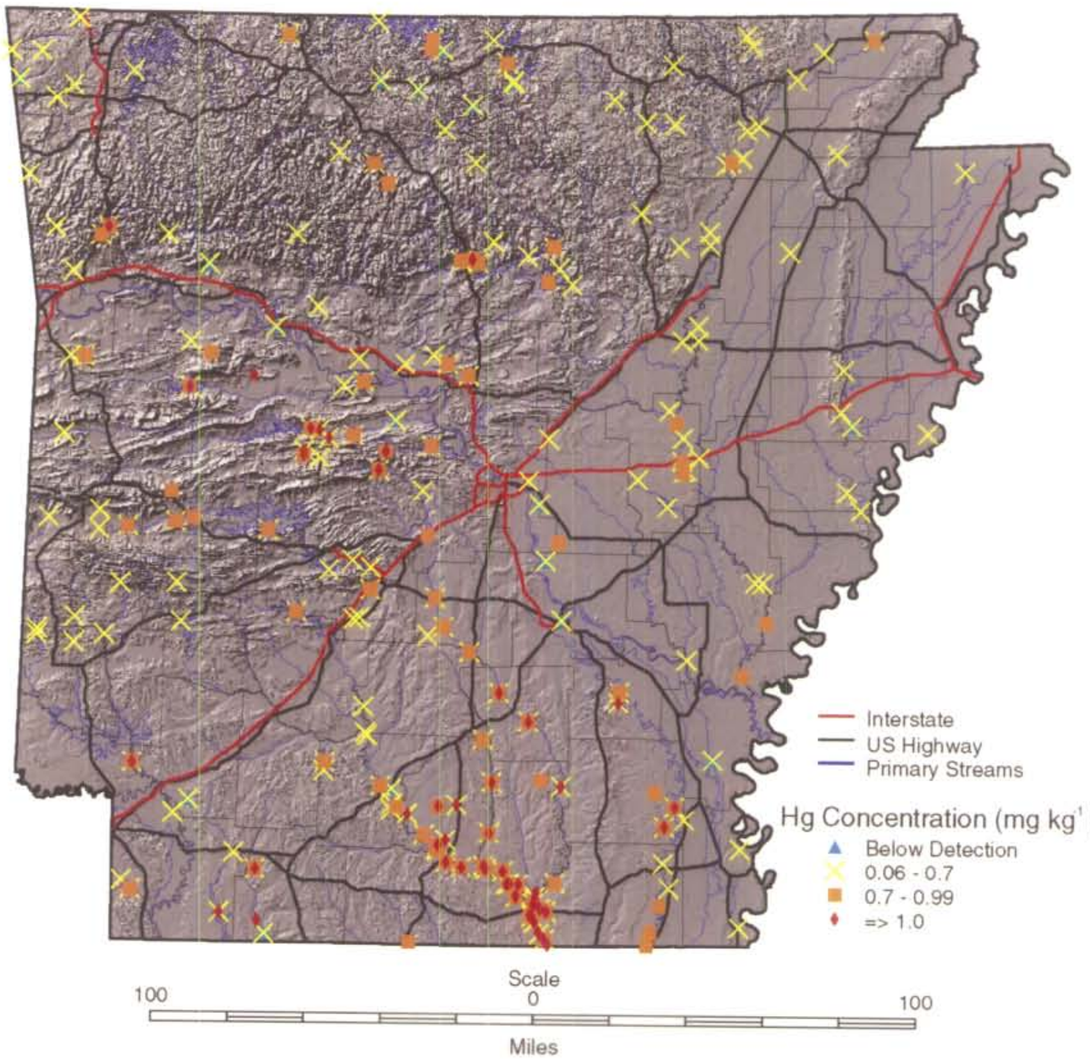



Figure 1. Spatial distribution of the Hg contaminated fish samples in Arkansas.

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.

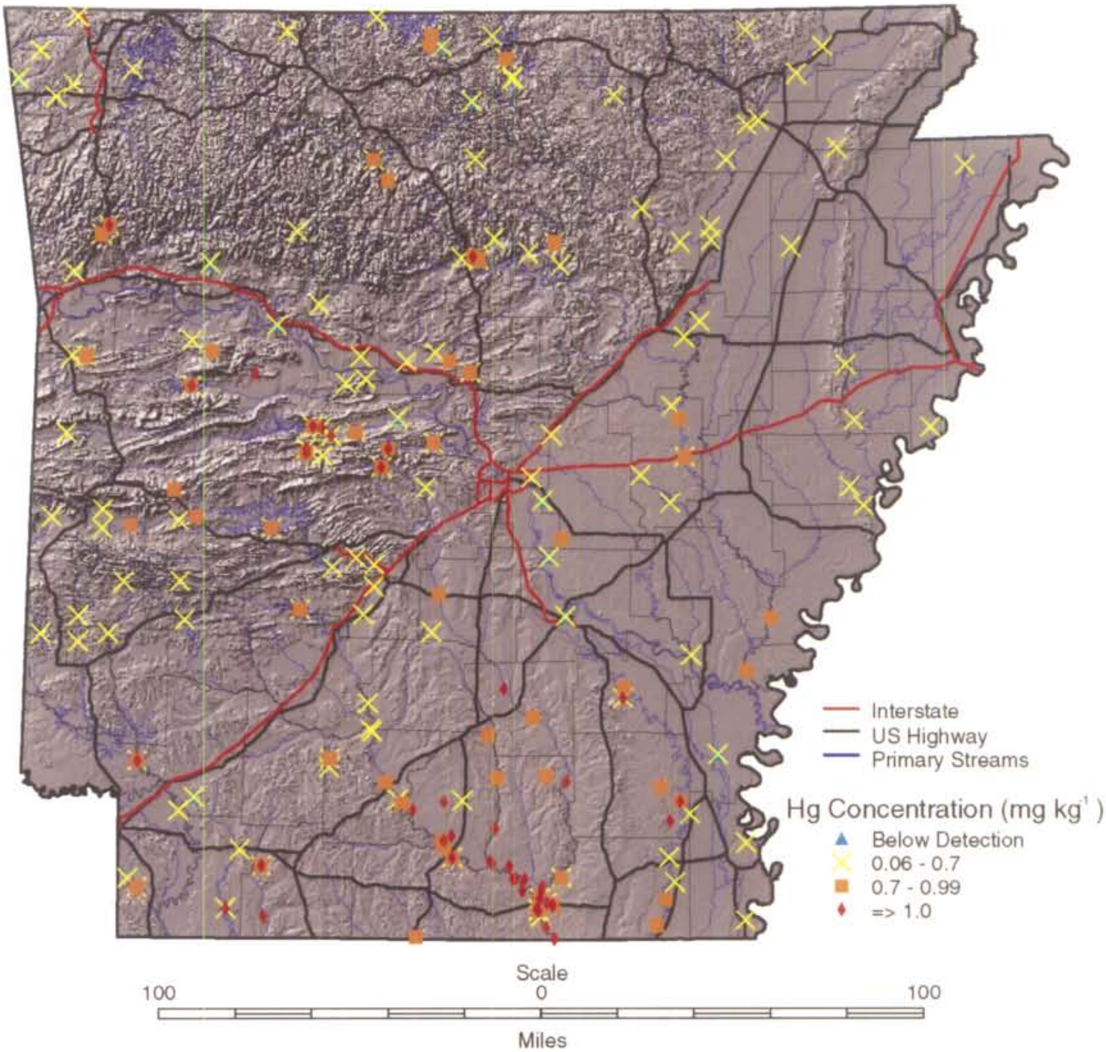



Figure 2. Spatial distribution of the Hg contaminated large mouth bass in Arkansas.

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 1mg $kg^{-1}$. 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. (mg $kg^{-1}$) | Length (mm) | Weight (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 $kg^{-1}$.

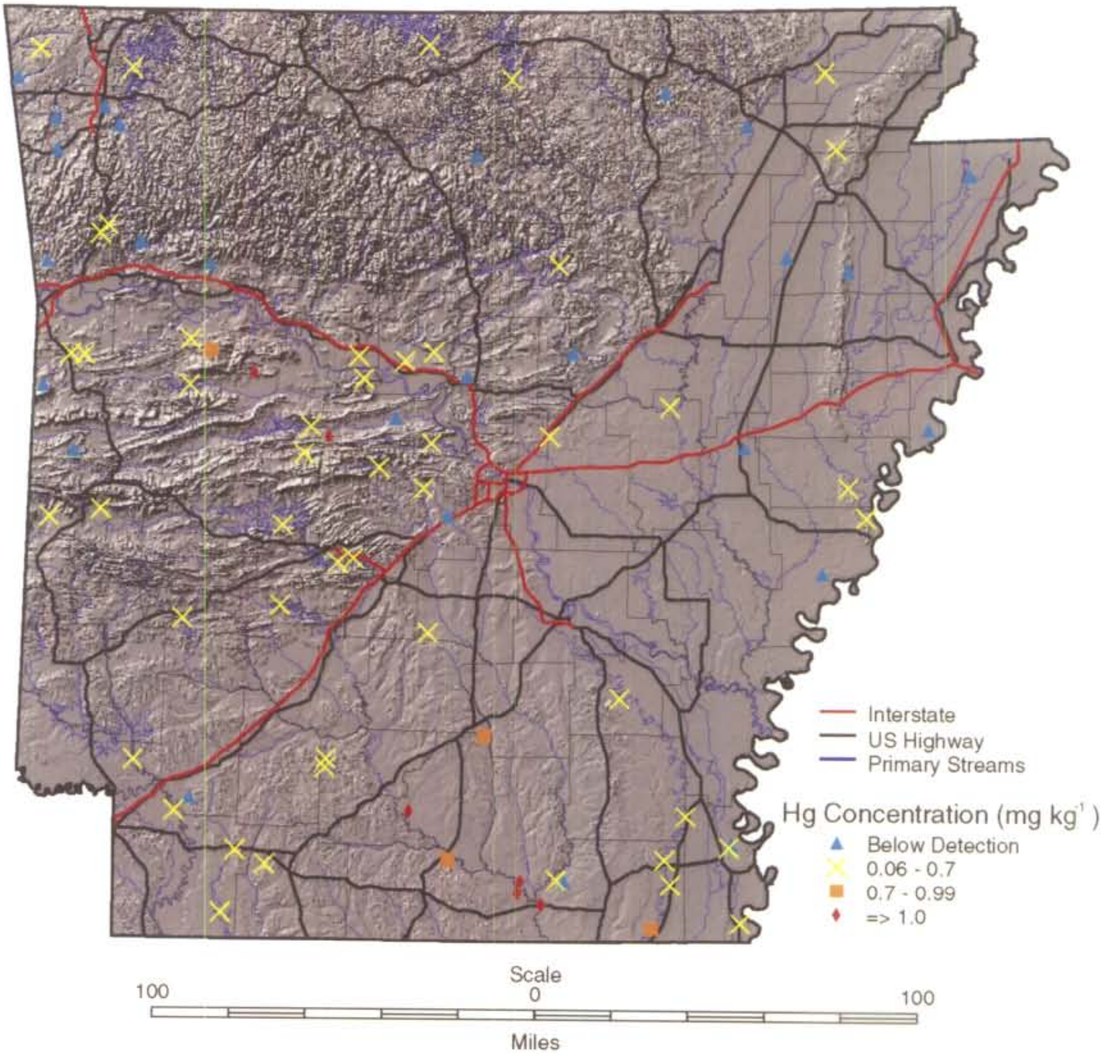



Figure 3. Spatial distribution of the lake database sample sites and associated fish Hg concentrations in Arkansas.

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.

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

| Statistical Property | Lake Area (h) | Mean Depth (m) | Basin Area ($km^2$) | Hypol. Depth (m) | Secchi Dish (in) | Hg Conc. (mg $kg^{-1}$) | Length Adjusted Hg (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 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 $CaC0_3$) | 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 |
| $NH_3$-N (mg $L^{-1}$) | -0.0665 | 0.5988 | 65 | -0.2160 | 0.3893 | 18 | -0.0921 | 0.4694 | 64 |
| $NO_3$-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 |
| $SO_4$ (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 | --------- | --------- | --- |

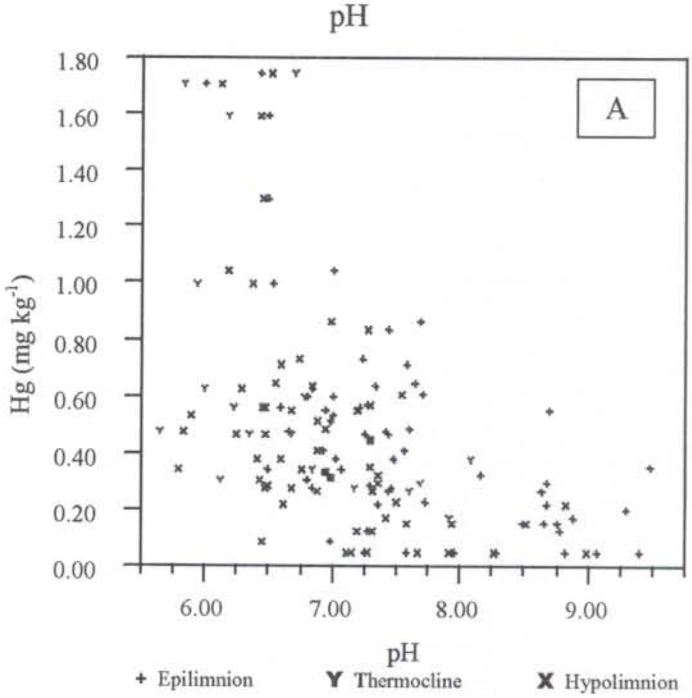
* = one data point excluded ** = two data points excluded

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 |



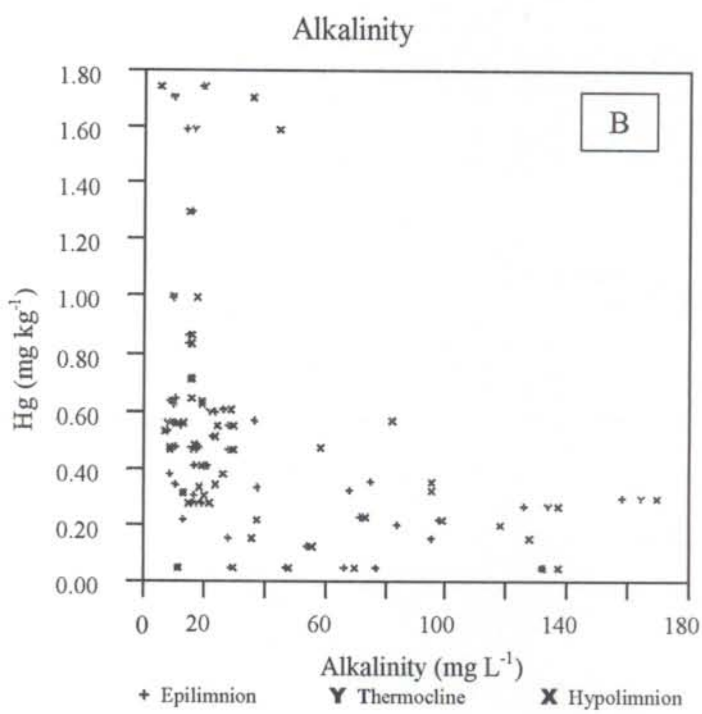




Figure 4. Scatter plot of fish Hg concentration with pH (A) and alkalinity (B) for the epilimnion, thermocline and hypolimnion.

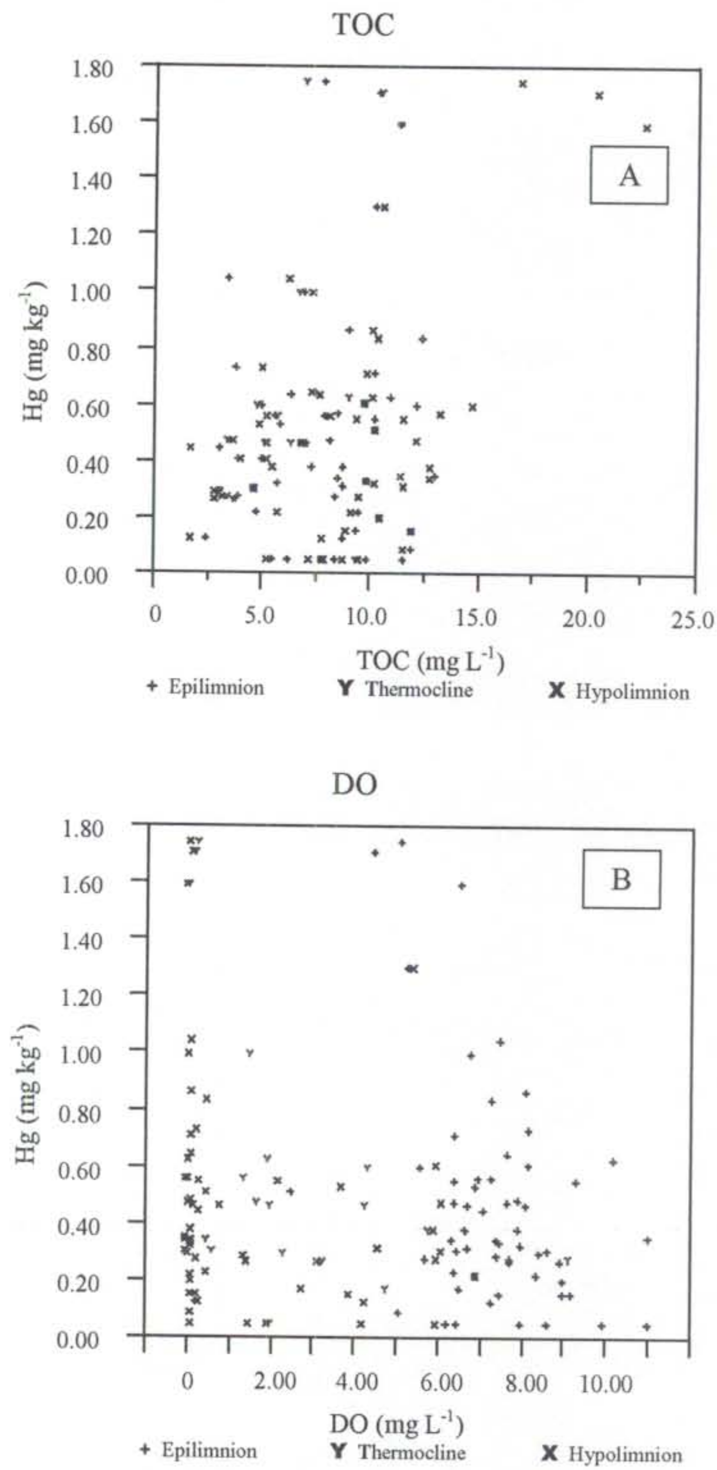



Figure 5. Scatter plot of fish Hg concentration with TOC (A) and DO (B) for the epilimnion, thermocline and hypolimnion.

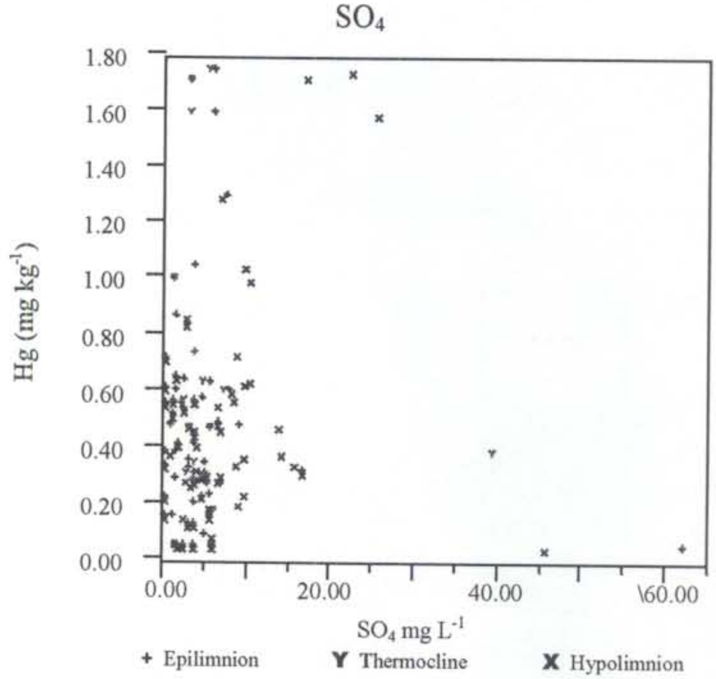



Figure 6. Scatter plot of fish Hg concentration with $SO_4$ for the epilimnion, thermocline and hypolimnion.

## 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 |

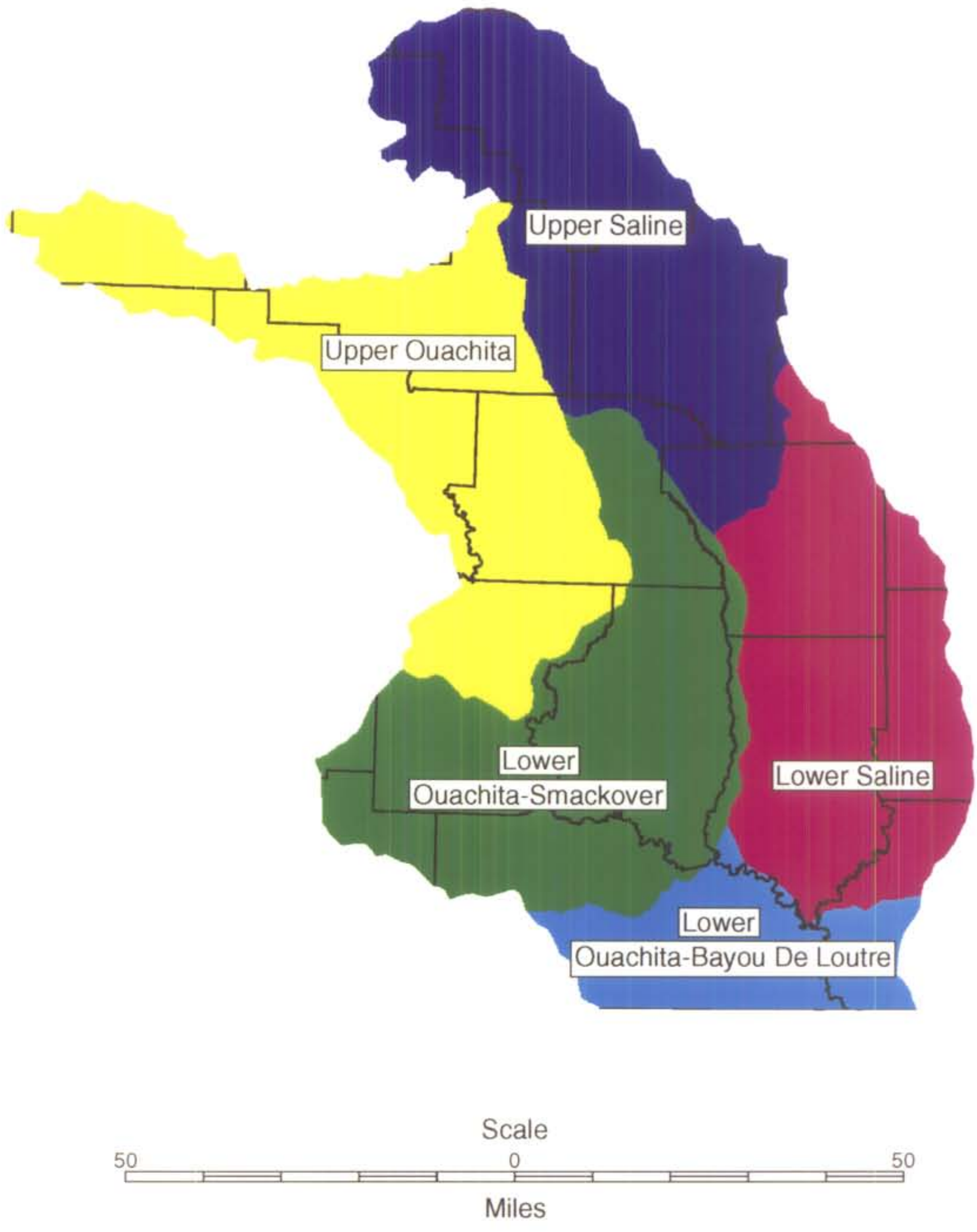



Figure 7. Hydrologic units draining into Lake Felsenthal.

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.

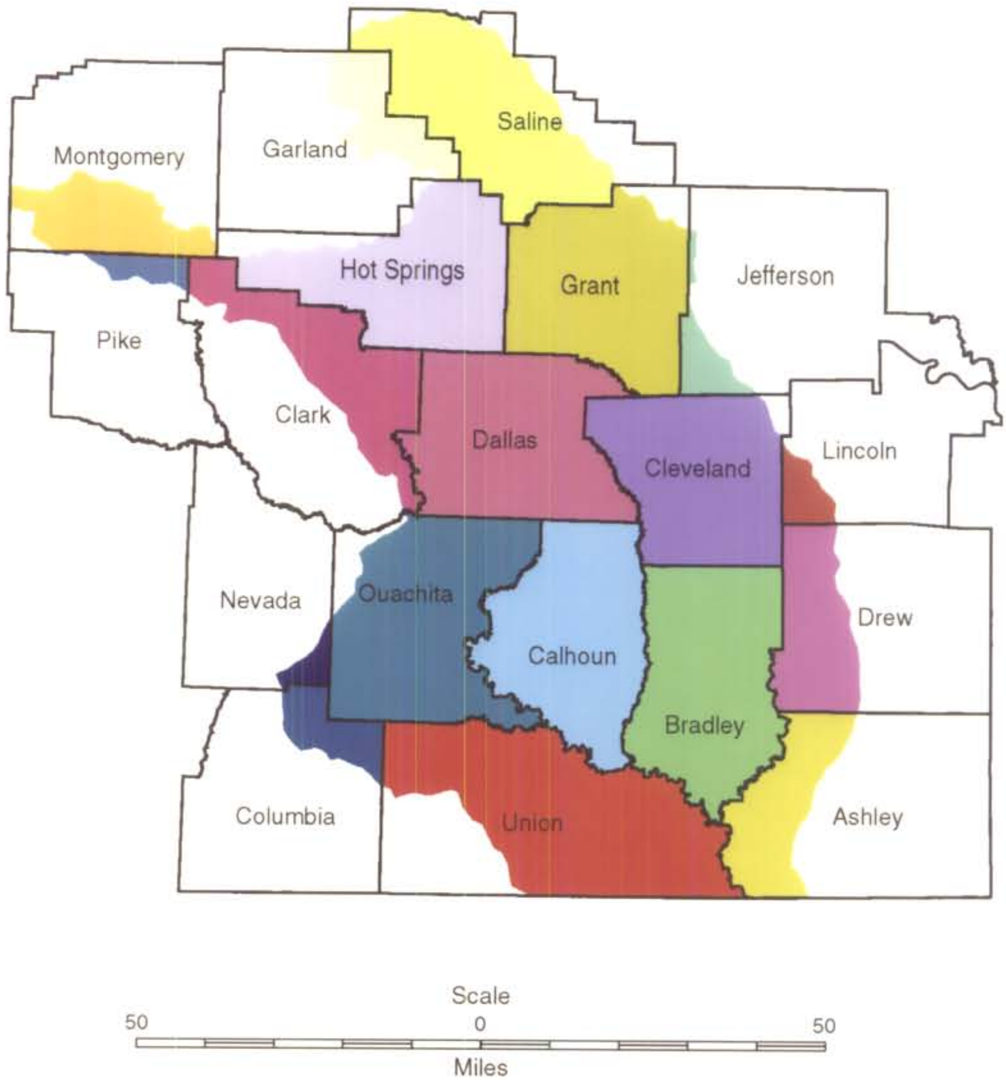



Figure 8. Counties in the watersheds draining into Lake Felsenthal.

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.

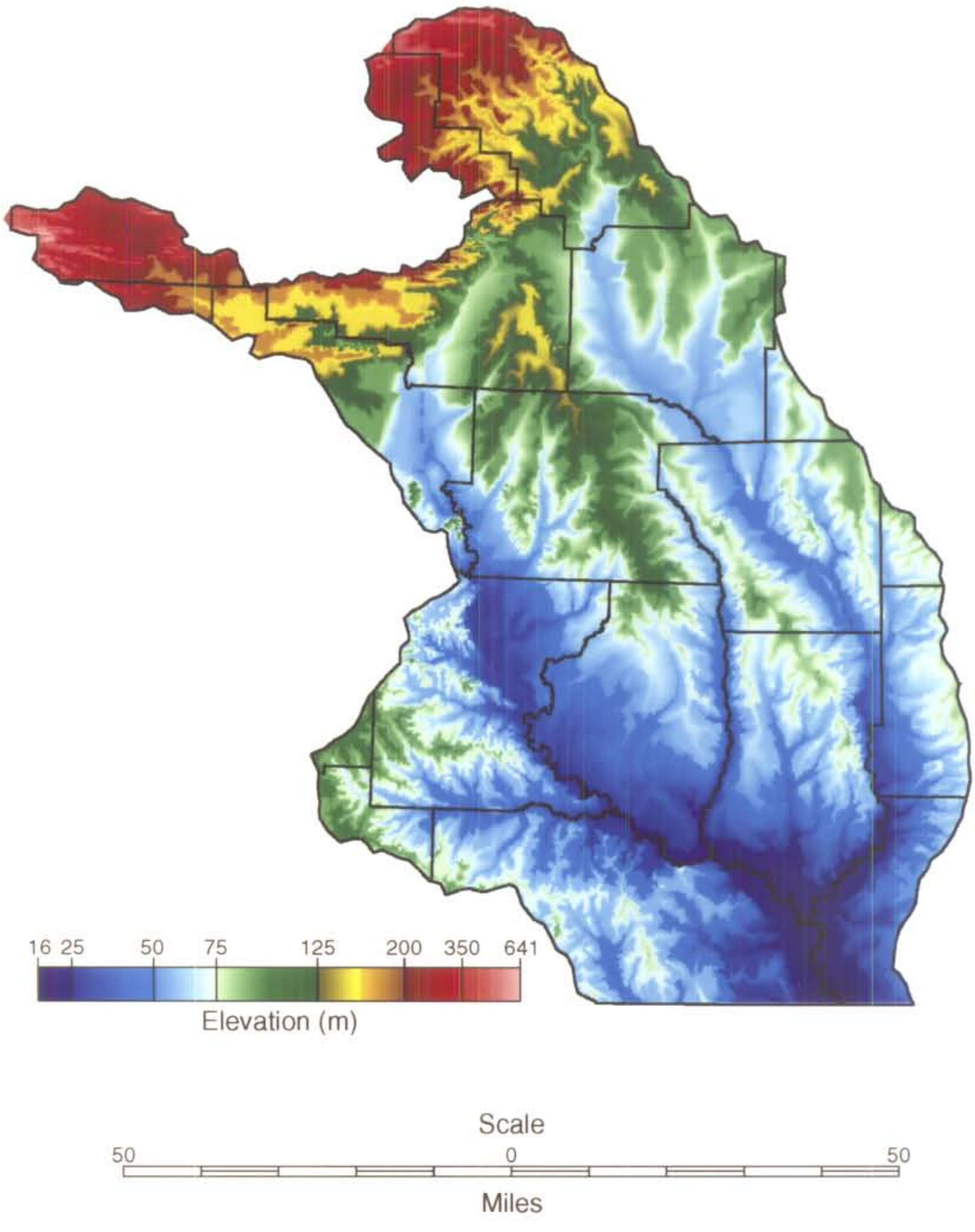



Figure 9. Elevations of the land surface draining into the Lake Felsenthal.

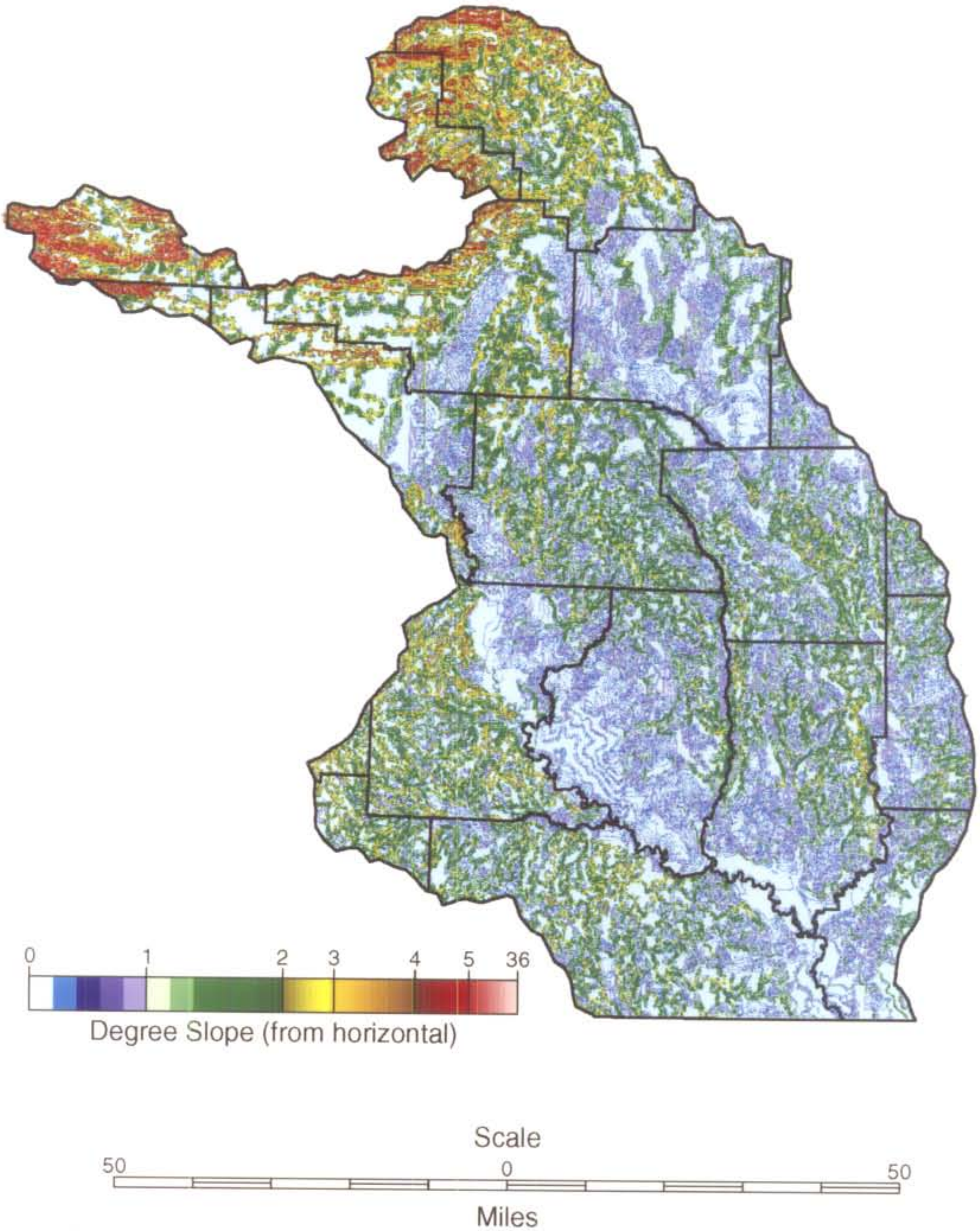



Figure 10. Slope of the land draining to Lake Felsenthal.

<u>Hg Contaminated Large Mouth Bass</u>

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.

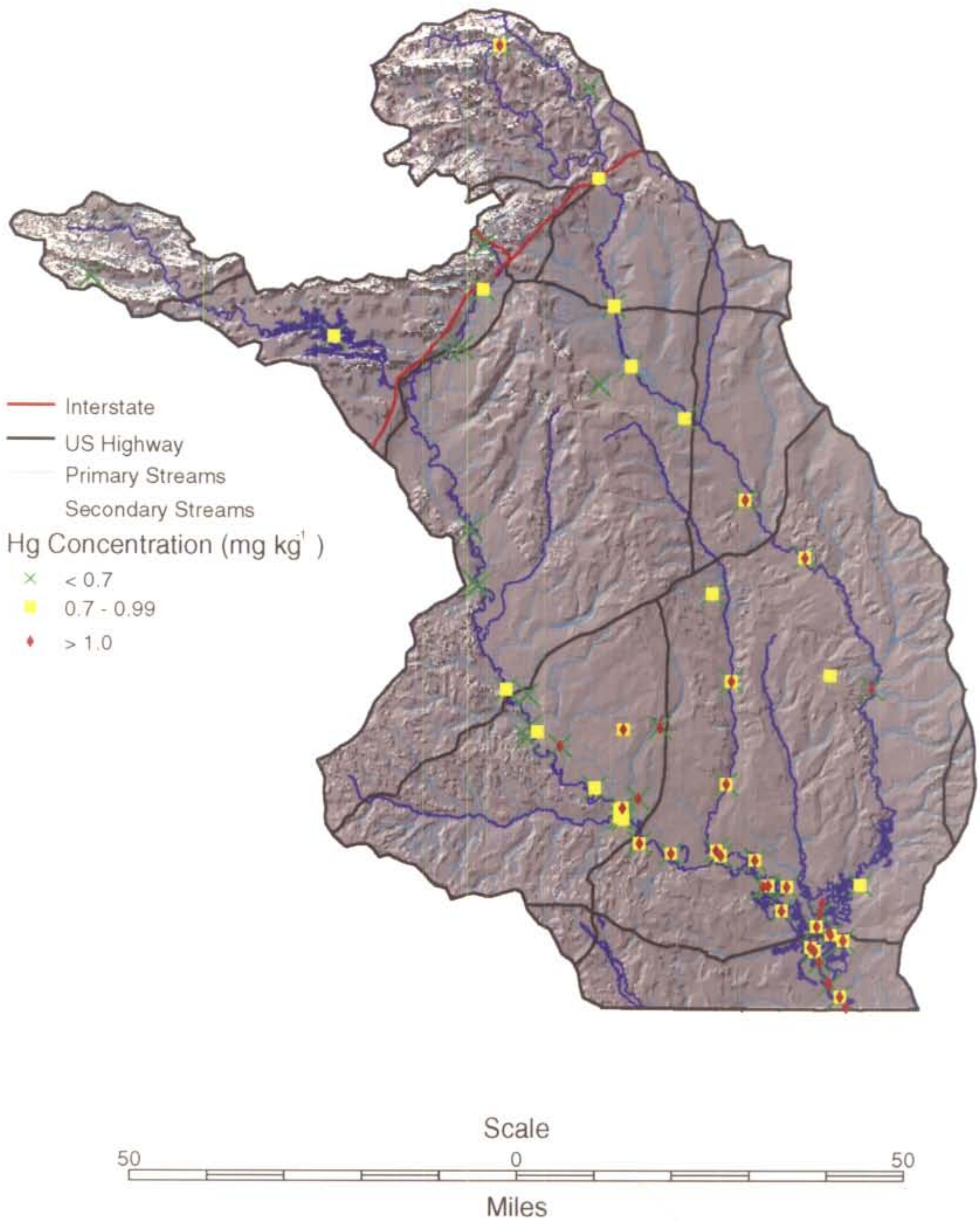



Figure 11. Locations of the large mouth bass by Hg concentration in the Felsenthal Lake area.

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.

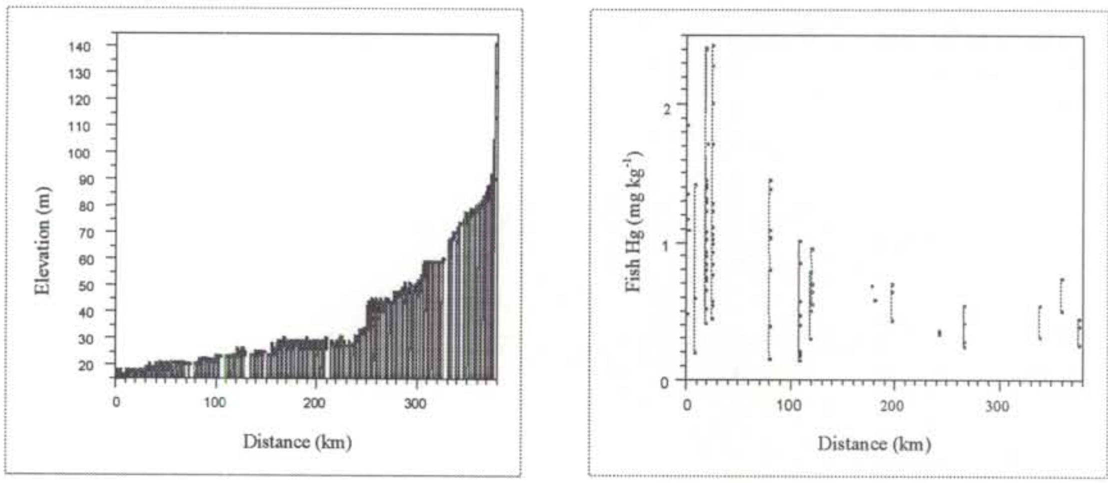



Figure 12. Elevations (left) and Hg concentrations in large mouth bass (right) of the Ouachita River as a function of distance from the outflow of Lake Felsenthal.

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.

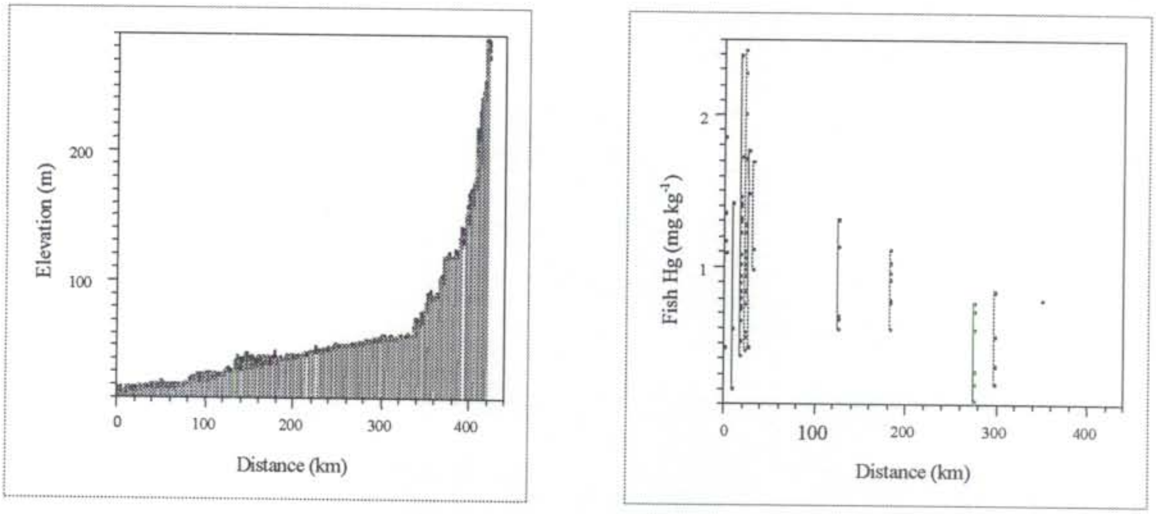



Figure 13. Elevations (left) and Hg concentrations in large mouth bass (right) of the Saline River as a function of distance from the outflow of Lake Felsenthal.

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.

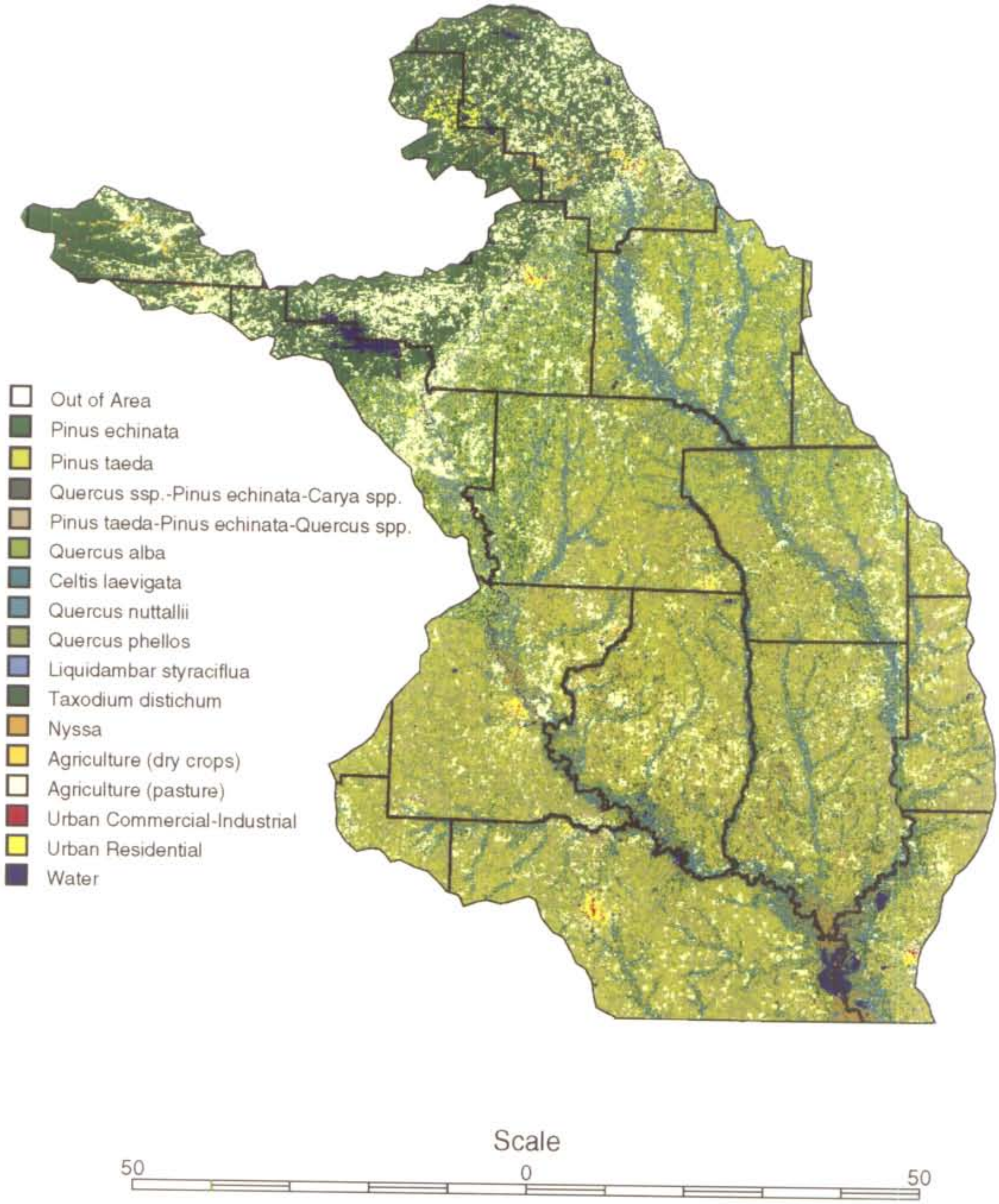



Figure 14. Vegetative cover of the watersheds draining into lake Felsenthal.

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.

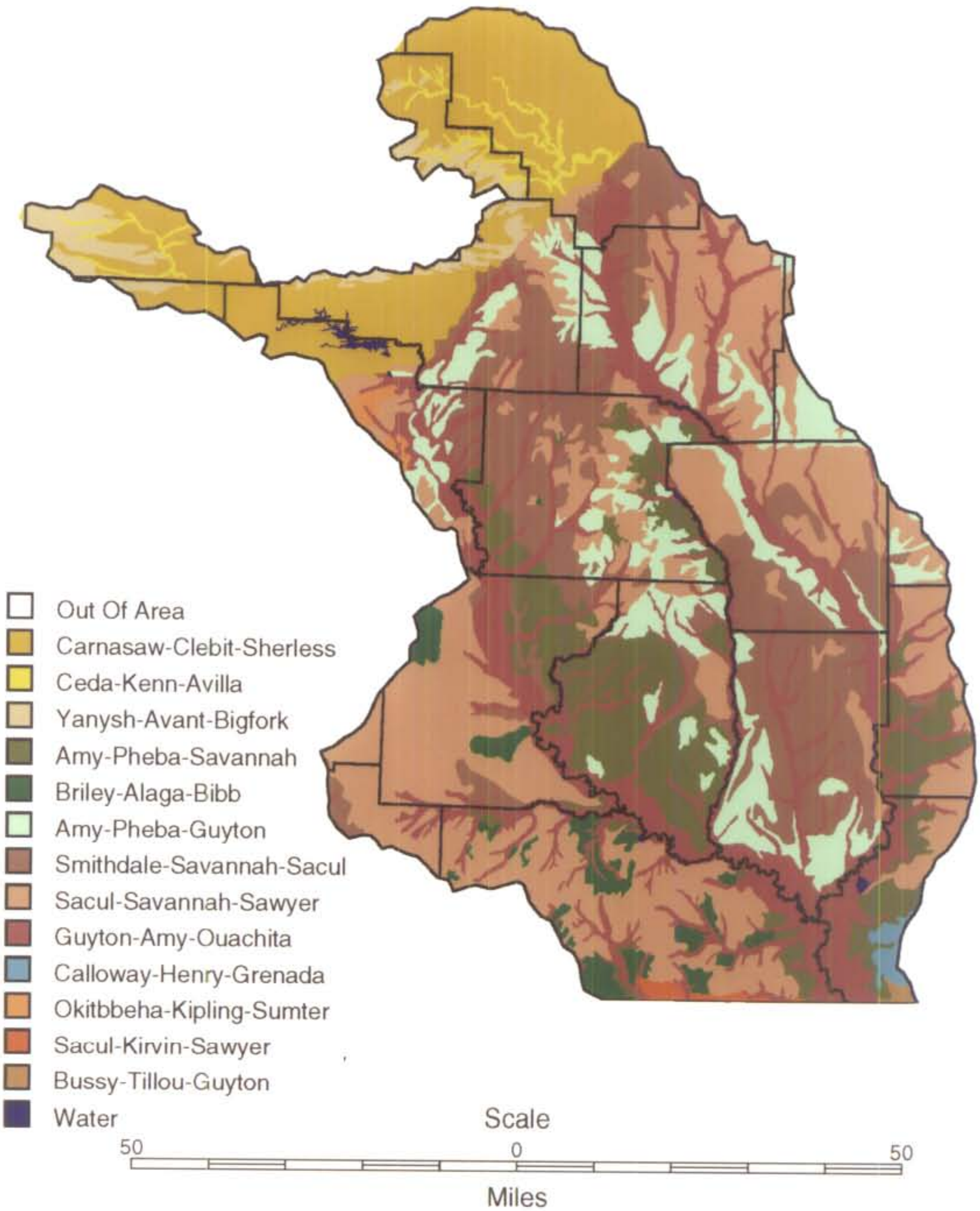



Figure 15. Soil associations of the Lake Felsenthal watershed.

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 | Attribute medians | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | pH | $NO_3$ | P | K | Ca | Mg | Na | $SO_4$ | Fe | Mn | Cu | Zn | B | OM | EC |
| | lb $A^{-1}$ | | | | | | | | | | | | | | % | 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 |

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 |