The Ozarks Environmental and Water Resources Institute (OEWRI)
Missouri State University (MSU)

Upper White River Basin Monitoring Program
Geomorphic Channel Assessment
Year 1 (2008-2009)

River Sediment Quality of the Upper White River Basin

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INTRODUCTION

The Upper White River Basin Foundation (UWRBF) implemented a water quality monitoring program in the Upper White River Basin in 2008 (www.whiteriverbasin.org). The goal of this program is to provide a long-term and consistent source of water quality and stream health information on the major rivers and tributaries draining into the upper portion of the White River including Beaver Lake, AR, Table Rock Lake, MO, and Bull Shoals Lake, MO/AR. It involves several partners including the United States Geological Survey (USGS), University of Arkansas-Fayetteville, Bull Shoals Field Station (BSFS) at Missouri State University-Springfield (MSU), and Ozarks Environmental and Water Resources Institute (OEWRI) at MSU.

The Ozarks Environmental and Water Resources Institute at Missouri State University (oewri.missouristate.edu) is responsible for protocol development, data collection, and trend analysis to support the geomorphology and watershed source monitoring components of the basin-wide stream monitoring program in the Upper White River Basin in Missouri and Arkansas (Figure 1). A final report detailing the methods and results of the geomorphic monitoring component was submitted to the UWRBF in October of2009. At the time of report submission, the results of the fine-grained sediment quality assessment were not complete. The purpose of this addendum report is to present the results and findings of the sediment quality study completed by OEWRI. The presence and size distribution of coarse and fine sediment at 10 UWRB monitoring sites has previously been evaluated in the Geomorphology Assessment Final Report submitted in October 2009. This report will evaluate fine-sediment quality at all thirty sites included in the monitoring program.

Sediment data is included in water resource assessments because excess sediment can impair aquatic habitat, interfere with water supply infrastructure, and cause channel instability (USEPA, 1999). In addition, fine-grained sediment particles can bind and accumulate contaminants such as heavy metal and phosphorus to higher concentrations than found in surrounding water (Horowitz, 1991). In order to address concerns about sediment affecting watersheds and surface waters, a wide range of methods have been developed to measure the abundance and quality of fine and coarse-grained sediment in rivers (Rosgen, 1996; Bunte and Abt, 2001; Kondolf et al. 2003). Federal agencies have incorporated sediment assessment procedures into their broader river bioassessment protocols (Fitzpatrick et al., 1998; Kaufmann and Robison, 1998; Kaufman et al., 1999). Rapid assessment methods used for screening purposes by water resources managers also evaluate sediment conditions in streams (Barbour et al. 1999; Sarver, 2003).

Fine-sediment is defined as active channel sediment that is <250 um in diameter. This size fraction is most geochemically active, easily transported downstream in the suspended sediment load, and can degree aquatic habitats in excessive amounts. Undisturbed fine-grained sediments within the river tend to contain the physical and chemical properties of natural bedrock and soil sources found in the upstream watershed. This natural source influence is termed the "background" source contribution, signal, or fingerprint. However, point and nonpoint source inputs can elevate contaminant concentrations such as copper, lead, zinc, and phosphorus above background levels in sediments. Thus, channel segments with higher than normal concentrations of sediment-associated metals or phosphorus indicate pollution inputs from upstream sources. Previous work in the basin has shown that river sediment geochemistry can be used to detect and track urban, industrial, and agricultural contaminant inputs in the James River (Fredrick, 2001), Wilson Creek (Rodgers, 2005), and Kings River (White, 2001).

METHODS

Sediment Sampling Sites

Active channel sediment samples were collected from 30 sampling sites or reaches in the Upper White River Basin (Figure 1). Samples were collected from recent fine-grained deposits that were deposited by floods occurring over the past year or two. Sampling occurred at location where fine-sediments are expected to be deposited in Ozark streams: (i) side pool areas or behind obstacles at or just below the water surface; (ii) tail or downstream end of bars just above the low-flow water surface; and (iii) top surface deposits on low bank or floodplain benches. At 10 sites, samples were collected near three different riffle crests (n=3 per site). Site duplicate samples for QA/QC purposes were collected during a second sampling visit at two sites: Swan Creek and lower Flat Creek. Four riffles were sampled at the lower Flat Creek site revisit n=4). At the remaining 20 sites, only one sample was collected at a single riffle location (n=1). Sediment sampling sites are located by GPS coordinates (Table 2) and on site maps in the Final Report submitted in October 2009. Samples were collected by trowel or shovel and put in labeled plastic 1-quart freezer bags.

Watershed Characteristics

Variations in sediment geochemistry and geomorphic indicators need to be evaluated based on the geology and land use characteristics of the watershed. A GIS database has been developed by OEWRI to organize sampling site information and evaluate watershed conditions. This data is used for interpreting the long-term trends and databases will be updated to reflect the most current conditions. The UWRB GIS database is maintained and available from the OEWRI server (see "Projects" at www.oewri.missouristate.edu). Geology and land use characteristics were compiled from the GIS database for all thirty sites (Table 3).

Sediment Analysis

A total of 57 samples were collected for this study (Table 1). Sample collection, sample preparation, and analytical methods are used in this study that have been previously tested and used to evaluate environmental quality trends in the James River (Fredrick, 2001), Wilson Creek (Rodgers, 2005), and Kings River (White, 2001). All samples are analyzed for physical properties and geochemical composition. After being delivered to the OEWRI laboratory, the samples were oven-dried at 60 degrees Celsius, disaggregated with mortar and pestal,

and put through a 2 mm sieve. Since the focus of this study was on the behavior and quality of finer sediment particles in the channel, the <250 um fraction was collected by additional sieving for further analysis. The size distribution of each sample was determined by hand sieving. Total and inorganic carbon, nitrogen, and sulfur content was determined using an Elementar C-N-S analyzer. Inorganic carbon was measured on a split sample combusted at 450 ^oC in a muffle furnace to drive off organic carbon as CO_2. Geochemical analysis of metals and phosphorus was completed using a hot nitric and hydrochloric acid (i.e. aqua regia) extraction and ICP-AES at ALS Chemex Laboratory, Nevada. Results for sediment geochemistry are presented for 13 elements: aluminum (Al), arsenic (As), cadmium (Cd), calcium (Ca), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), zinc (Zn), and phosphorus (P). The results of sediment analysis for all 57 samples are reported for texture, carbon, and nutrients (Table 4) and metals (Table 5).

Sediment Quality Criteria

Sediment quality criteria for metals were provided by MacDonald et al. (2000). These criteria are toxicity-based using experimental data from many studies. Sediment quality criteria for phosphorus were developed from the evaluation of field data previously collected in the basin (Fredrick, 2001; White, 2001, Rodgers, 2005). These criteria are field-based using apparent threshold values in statistical trends among P concentrations in sediments collected from sub-watersheds containing different land use types and pollution sources. Sediment P concentrations are usually highest immediately below wastewater treatment plants at >1,000 ppm P . Forested watersheds tend to have the lowest sediment P concentrations at 100 to 400 ppm P. Sediment samples from urban and agricultural areas tend to contain intermediate levels of P ranging from 300 to 600 ppm P. Confined animal feeding operations (CAFOs) can potentially increase sediment P concentrations in local streams to high levels exceeding 800 ppm P (White, 2001).

It is important to know the sediment size fraction used to determine sediment quality criteria. Small particles (i.e. clay, < 4 um diameter) tend to contain higher concentrations of metals and P compared to larger particles (i.e. sand, 100 um to 2000 um) due to greater surface area and number of geochemically reactive sites (Horowitz, 1991). Finer particles are both naturally elevated in metals and P and concentrate pollutants to higher levels than coarser particles. Typically, fine-grained sediment studies for risk assessment purposes are completed on sediments containing smaller particles <250 um in size in the fine sand, silt, and clay range (Mac Donald et al. 2000). This size fraction is most mobile in the water column and has the greater chances for uptake by aquatic biota. However, the <2 mm fraction of channel sediment is sometimes used in source monitoring studies since sand-sized particles can accumulate contaminants on reactive iron and manganese coatings on sand grains (Frederick, 2001; White, 2001). Moreover, the sand fraction in sediments affected by tailings inputs from Pb-Zn mining sources is often contaminated.

Rapid Assessment of Channel Condition

The USEPA's "Rapid Bioassessment Protocol" (RBP) is used in this monitoring program to visually evaluate and rank geomorphic and hydrological conditions at all 30 monitoring sites (Barbour et al., 1999). A copy of the form as used by the Missouri Department of Natural Resources is included in the appendix section of the final report submitted in October 2009 (Sarver, 2003). At 10 sites where more intensive geomorphic assessments were completed, three glide-riffle sub-reaches were evaluated by three different workers to produce nine separate

assessments per site. Workers were directed to stand in the vicinity of the riffle crest and rate channel conditions within an area of about two bankfull widths upstream and two widths downstream of the crest. The results of all nine evaluations were averaged to obtain one composite score for the reach. At the other 20 sites not selected for in-depth assessment, two workers evaluated one riffle site to yield two completed evaluation forms per site (composite scores for all sites are included in Table 14).

RESULTS

Geology and Land Use Trends

The first step in analysis of geochemical trends is to look for relationships among metal and P concentrations and geology and land use influence. Each site was classified according to dominant geology and land use characteristics (Table 6). The geology classification is based on the percentage of surficial bedrock units identified in the watershed area above each sampling site. The bedrock classification scheme used is as follows: "Limestone" for > or = 80% limestone, "Dolomite" for > or + 40% dolomite, and "Sandstone" for >45% sandstone and shale combined. The land use classification scheme used is as follows: "Urban" for >5% urban and barren area combined, "Agricultural/grass" for not urban and > or = 40% grass and cropland combined, and "Forest" for > or = 60% forest and new forest combined.

The watershed contributions to sediment geochemistry are being evaluated based on the median values and quartile ranges of all the samples collected in a specific class. Geology classification is being used to identify the background influence on geochemistry (Table 7). Land Use classification is being used to look for pollution source effects (Table 8). However, metal and P concentrations may vary independent of source due to natural variations in the composition of the sediment itself and its ability to bind and absorb pollutants from surrounding waters (e.g. clays, Fe-Mn oxides, organic matter) (Horowitz, 1991). Aluminum is often considered to be an element free of human influence, resistant to dissolution and weathering, and found in high concentrations in the finer sediment particles such as clay (Horowitz, 1991). Thus, ratios of the metal contaminant of interest to aluminum are often used to normalize geochemical data to account for sediment particle influence. The Al-ratios reported here are derived from median values (Tables 7 & 8). High Al-ratio values indicate that the sediment has a greater abundance or affinity for a specific element if sediment composition effects are held constant.

Broad relationships between metal and P concentrations and watershed geology are observed (Table 7). Watersheds draining sandstone and shale tend to have higher background levels of iron-associated elements such as As, Cr, and Ni, probably due to specific minerals in the sandstone or erosion contributions of shale sediment. Shale tends to be naturally enriched in some metals. The variability of concentrations in each class is quantified by the relative inter-quartile range calculated as: 100 x (R75% - R25% / median). As a rule of thumb, if you divide the inter-quartile range by 2, then this value approximates the standard deviation of the data set. Thus, the one standard deviation error as a percentage of the average value would generally range from 25% to 50% for limestone, 15% to 40% for dolomite, and 33% to 60% for sandstone watersheds (Table 7). This range in geochemical variability is reasonable given the nature of environmental data collected from such a large land area like the Upper White River Basin.

Land use intensity correlates to some degree with metal and P enrichment in fine-grained sediment samples in the UWRB. Urban land use is consistently associated with relatively high concentrations of metals and P in the basin, with the exception of As which is highest in sediments from forested watersheds located in sandstone/shale areas as described above (Table 8). Residential, commercial, and industrial areas are typically sources of metals to streams by point and non-point releases. Phosphorus is delivered to urban streams by nonpoint delivery of soil particles, animal wastes, and fertilizers in runoff and point source inputs from municipal wastewater plants. At the scale of study use here, the influence of waste water treatment plants on sediment quality is combined within the urban watershed classification (Frederick, 2001; Rodgers, 2005). The broader influence of CAFOs on sediment quality is probably mixed in with the agricultural land use class and with local effects of some operations in the forested areas (White, 2001). The range of geochemical variability (i.e. as used above: ½ the inter-quartile range %) by land use class is as follows: 20% to 65 % for urban, 14% to 35% for agricultural, and 35 % to 55% for forest. While these variations in geochemical concentrations are reasonable for this study, a more focused study of geochemical trends in the UWRB could develop an improved sampling plan and statistical relationships to reduce sampling error and improve trend precision.

Given the spatial distribution of the sampling sites used in this monitoring program, it is not possible to develop a geochemical matrix for a combined geology-land use classes since there are not enough samples/sites in all nine classes to derive meaningful statistics (Table 9). For example, there are no forested watersheds draining significant areas of limestone and few urban areas draining dolomite and sandstone/shale areas. Ultimately, this is the result of physical geography where limestone plateaus were settled extensively for farming and towns grew around them (e.g. City of Springfield and James River watershed). The Boston Mountains watersheds are primarily classified as sandstone/shale areas which are not as suitable for extensive farming and city expansion (e.g. Kings River watershed).

Sediment Quality Rankings

Sediment quality criteria are used to classify samples according to toxic limits for metals and field-based thresholds for P (Tables 10 & 11). Toxic criteria from MacDonald et al. (2000) are used to create the 1 to 5 class ranking for metals used in this report. Level 1 concentrations are less than ½ of the published Threshold Effect Concentration (TEC). The upper limit of level 2 concentrations is the TEC. Levels 3 and 4 are separated by ½ the difference between the TEC and Probable Effect Concentration (PEC). Level 5 concentrations are considered to be toxic to aquatic life and are greater than the PEC (Table 10). Sediment quality criteria for phosphorus were developed from the evaluation of field data previously collected in the basin (Fredrick, 2001; White, 2001). These criteria are field-based using operational threshold values in statistical trends among P concentrations in sediments collected below different land use types and pollution sources.

All 57 sediment samples were ranked according to the sediment quality criteria described above (Table 12). Overall, potentially toxic levels of metals (Levels 4 and 5) were found only in one sample at one site (Table 13). Potentially toxic concentrations of Zn and Cd were found at the James River near Springfield (site Jam2). This site is located below old mining areas along Pearson Creek where high sediment concentrations of Zn, Pb, and Cd were previously observed. Borderline concentrations (level 3) were measured for (i) As (5 samples) in the upper Kings River, upper Richland Creek, and White River/West and Middle Forks, (ii) Ni (1) in West Fork White River , and (iii) Zn (1) in upper Bull Creek (Table 12). Only Level 1 concentrations of Hg were found in the basin

by this study, however higher concentrations of Hg in the toxic range (>1.06 ppm) have been measured in channel and floodplain deposits along Wilson Creek near Springfield, Missouri (Rodgers, 2005). Phosphorus concentrations in fine-sediment samples were typically in the uncontaminated range (Levels 1 & 2). Four threshold (level 3) samples were collected at lower Flat Creek, Boaz and Galena on the James River, and upper Kings River (Table 12). The James River sample locations are notable because they receive P inputs from the southwest wastewater treatment plant at Springfield (Fredrick, 2001).

Basin-wide Evaluation

Table 14 contains a comprehensive summary of the results of this study and other monitoring program indicators (Table 14). Grouped by site in each sub-basin, the P rating and average metals rating (for all samples and metals at each site) is viewed against other independent channel assessments including the rapid channel assessment and fine sediment index described in the geomorphology final report, and the stream condition index related to aquatic life reported by the Bull Shoals Field Station at Missouri State University. Sites of concern requiring more focused study are described below:

<u>Beaver Lake Sub-Basin</u>

Kings River near Kingston (Kin1): relatively high rating for both P and metals, need more sampling.

Richland Creek at Goshen (Ric2): poor channel rating with moderate levels of both P and metals, need more sampling.

War Eagle Creek near Huntsville (War1): poor channel rating with moderate levels of both P and metals, need more sampling.

White River at Elkins (Whi3) and the middle and west Fork White River (Whi1m & Whi2w): all three of these sites have moderately high P and Metals ratings with low channel rating and, for Whi2w, a poor fine sediment index (i.e. excess fine sediment in the channel). HIGH PRORITY

<u>Bull Shoals Lake Sub-Basin</u>

Long Creek at Denver (Lon1): Low channel condition rating, need more sampling.

Bull Creek at Center Street (Bul1): Relatively high P and metals rating, need more sampling.

<u>James River Sub-Basin</u>

James River near Springfield (Jam2): High metal rating and toxic level of Zn in the one sediment sample collected from the site. This site is probably being affected by contaminated sediment released from abandoned mining areas on Pearson Creek, a mile upstream, need more sampling. HIGH PRIORITY

James River at Boaz (Jam3): Elevated P and metals ratings probably due to wastewater discharges and urban runoff from Springfield. MODERATE PRIORITY

James River at Galena (Jam4): Upstream urban influences decrease downstream, but this site has poor channel condition and fine sediment index. MODERATE PRIORITY

Flat River as a whole needs more study (Fla1 and Fla2): Both sites have elevated P and metals ratings, but little is known about the condition of this creek. MODERATE PRIORITY

CONCLUSIONS

This fine-grained sediment quality assessment evaluated metal and P concentrations in 57 samples from 30 sites throughout the Upper White River Basin (Figure 1). This is a screening-level evaluation, and further follow up monitoring may be needed to validate some of the present findings. Nevertheless, sediment monitoring is a valuable tool for identifying trends in the dispersal of sediment-associated contaminants such as P and metals in rivers. To improve its application for nonpoint and point-source assessments in the Ozarks and UWRB, more study is needed to determine the influence of background geochemistry and watershed conditions on sediment quality and concentrations of P and metals. This study found that watersheds draining the sandstone/shale bedrock of the Boston Mountains produced fine sediment with different geochemistry compared to the carbonate bedrock types of limestone and dolomite of the Springfield Plateau. Arsenic concentrations are elevated in sandstone watersheds, possibly due to contributions from erodible shale units to the sediment load that are naturally elevated in some metals.

Urban areas within the UWRB tend to be associated with elevated metals and P in rivers draining them. It is well known that residential, commercial, and industrial land use is associated with the release of metals and P to storm water runoff. In addition, waste water treatment plants are sources of P to streams and these facilities tend to cluster around population centers. Abandoned base-metal mining areas are also a source of metal contamination in the UWRB. A toxic level of Zn, and to a lesser degree Cd, was detected in one sample collected from the James River near Springfield (Jam2) which is located below the old mine workings along lower Pearson Creek.

<u>Continue to Monitor to Verify Trend</u>
Kings River near Kingston (Kin1)
Richland Creek at Goshen (Ric2)
War Eagle Creek near Huntsville (War1)
Long Creek at Denver (Lon1)
Bull Creek at Center Street (Bul1)

<u>Moderate Priority for Action</u>
Flat River (Fla1 and Fla2): need more information overall on the condition of the watershed
James River at Galena (Jam4): excess sediment and P may be a problem
James River at Boaz (Jam3): monitor middle James River for influence of urban runoff on channel conditions

High Priority for Action

James River near Springfield (Jam2): Need to determine extent of toxic sediment deposits.

White River at Elkins (Whi3) and the middle and west Fork White River (Whi1m & Whi2w): there appears to be a system wide problem with sediment excess and quality in this area. Need to monitor to verify trend and determine sources of impairment.

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Table 1: Sediment Sampling Sites and Dates

Lab No.		Monitoring Site	Site Code	Riffle (#)	Collection Date (m-d-yr)	Collection Worker (initials)	Verification Date (m-d-yr)	Verification Worker (initials)
WRB	1	Flat Creek below Jenkins, MO	Fla2	1	6/17/2009	JEE/MO	7/22/2009	WPD
WRB	2	Flat Creek below Jenkins, MO	Fla2	2	6/17/2009	JEE/MO	7/22/2009	WPD
WRB	3	Flat Creek below Jenkins, MO	Fla2	3	6/17/2009	JEE/MO	7/22/2009	WPD
WRB	4	Swan Creek near Swan, MO	Swa1	1	6/19/2009	JEE/MO	7/22/2009	WPD
WRB	5	Swan Creek near Swan, MO	Swa1	2	6/19/2009	JEE/MO	7/22/2009	WPD
WRB	6	Swan Creek near Swan, MO	Swa1	3	6/19/2009	JEE/MO	7/22/2009	WPD
WRB	7	Finley Creek below Riverdale, MO	Fin2	1	6/24/2009	JEE/MO	7/22/2009	WPD
WRB	8	Finley Creek below Riverdale, MO	Fin2	2	6/24/2009	JEE/MO	7/22/2009	WPD
WRB	9	Finley Creek below Riverdale, MO	Fin2	3	6/24/2009	JEE/MO	7/22/2009	WPD
WRB	10	James River near Boaz, MO	Jam3	1	6/25/2009	JEE/MO	7/22/2009	WPD
WRB	11	James River near Boaz, MO	Jam3	2	6/25/2009	JEE/MO	7/22/2009	WPD
WRB	12	James River near Boaz, MO	Jam3	3	6/25/2009	JEE/MO	7/22/2009	WPD
WRB	13	Kings River near Berryville, AR	Kin4	1	7/1/2009	JEE/PW	7/22/2009	WPD
WRB	14	Kings River near Berryville, AR	Kin4	2	7/1/2009	JEE/PW	7/22/2009	WPD
WRB	15	Kings River near Berryville, AR	Kin4	3	7/1/2009	JEE/PW	7/22/2009	WPD
WRB	16	Yocum Creek near Oak Grove, AR	Yoc1	1	7/2/2009	JEE/PW	7/22/2009	WPD
WRB	17	Yocum Creek near Oak Grove, AR	Yoc1	2	7/2/2009	JEE/PW	7/22/2009	WPD
WRB	18	Yocum Creek near Oak Grove, AR	Yoc1	3	7/2/2009	JEE/PW	7/22/2009	WPD
WRB	19	White River near Fayetteville, AR	Whi4	1	7/8/2009	JEE/PW	7/22/2009	WPD
WRB	20	White River near Fayetteville, AR	Whi4	2	7/8/2009	JEE/PW	7/22/2009	WPD
WRB	21	White River near Fayetteville, AR	Whi4	3	7/8/2009	JEE/PW	7/22/2009	WPD
WRB	22	West Fork White River east of Fayetteville, AR	Whi2w	1	7/8/2009	JEE/PW	7/22/2009	WPD
WRB	23	West Fork White River east of Fayetteville, AR	Whi2w	2	7/8/2009	JEE/PW	7/22/2009	WPD
WRB	24	West Fork White River east of Fayetteville, AR	Whi2w	3	7/8/2009	JEE/PW	7/22/2009	WPD
WRB	25	War Eagle Creek near Hindsville, AR	War2	1	7/9/2009	JEE/PW	7/22/2009	WPD
WRB	26	War Eagle Creek near Hindsville, AR	War2	2	7/9/2009	JEE/PW	7/22/2009	WPD
WRB	27	War Eagle Creek near Hindsville, AR	War2	3	7/9/2009	JEE/PW	7/22/2009	WPD
WRB	28	Swan Creek near Swan, MO Field Duplicate	Swa1-FD	1	8/5/2009	JEE/PW	9/23/2009	WPD
WRB	29	Swan Creek near Swan, MO Field Duplicate	Swa1-FD	2	8/5/2009	JEE/PW	9/23/2009	WPD
WRB	30	Swan Creek near Swan, MO Field Duplicate	Swa1-FD	3	8/5/2009	JEE/PW	9/23/2009	WPD
WRB	31	James River at Galena, MO	Jam4	1	8/17/2009	JEE/PD	9/23/2009	WPD
WRB	32	James River at Galena, MO	Jam4	2	8/17/2009	JEE/PD	9/23/2009	WPD
WRB	33	James River at Galena, MO	Jam4	3	8/17/2009	JEE/PD	9/23/2009	WPD
WRB	34	Flat Creek below Jenkins, MO Field Duplicate	Fla2-FD	0	7/23/2009	JEE/PD	9/23/2009	WPD
WRB	35	Flat Creek below Jenkins, MO Field Duplicate	Fla2-FD	1	7/23/2009	JEE/PD	9/23/2009	WPD
WRB	36	Flat Creek below Jenkins, MO Field Duplicate	Fla2-FD	2	7/23/2009	JEE/PD	9/23/2009	WPD
WRB	37	Flat Creek below Jenkins, MO Field Duplicate	Fla2-FD	3	7/23/2009	JEE/PD	9/23/2009	WPD
WRB	38	Flat Creek at Hwy C, MO	Fla1	1	8/28/2009	JEE/PD	9/23/2009	WPD

Table 1: Sediment Sampling Sites and Dates (con't)

Lab No.		Monitoring Site	Site Code	Riffle (#)	Collection Date (m-d-yr)	Collection Worker (initials)	Verification Date (m-d-yr)	Verification Worker (initials)
WRB	39	Bear Creek near Omaha AR	Ber1	1	8/28/2009	JEE/PD	9/23/2009	WPD
WRB	40	Beaver Creek at Bradleyville, MO	Bev1	1	8/28/2009	JEE/PD	9/23/2009	WPD
WRB	41	Bull Creek at Center St, MO	Bul1	1	8/28/2009	JEE/PD	9/23/2009	WPD
WRB	42	Bull Creek near Walnut Shade, MO	Bul2	1	8/28/2009	JEE/PD	9/23/2009	WPD
WRB	43	Finley Creek near Sparta, MO	Fin1	1	8/28/2009	JEE/PD	9/23/2009	WPD
WRB	44	James River near Springfield, MO	Jam2	1	8/28/2009	JEE/PD	9/23/2009	WPD
WRB	45	Pond Creek near Longrun, MO	Pon1	1	8/28/2009	JEE/PD	9/23/2009	WPD
WRB	46	Turkey Creek near Theodosia	Tur1	1	8/28/2009	JEE/PD	9/23/2009	WPD
WRB	47	James River at Hwy B, MO	Jam1	1	8/28/2009	JEE/PW	9/23/2009	WPD
WRB	48	Osage Creek southwest of Berryville, AR	Kin2O	1	8/28/2009	DM/EH	9/23/2009	WPD
WRB	49	War Eagle Creek near Huntsville, AR	War1	1	8/28/2009	DM/EH	9/23/2009	WPD
WRB	50	Long Creek at Denver, AR	Lon1	1	8/28/2009	DM/EH	9/23/2009	WPD
WRB	51	Kings River at Hwy 221, AR	Kin3	1	8/28/2009	DM/EH	9/23/2009	WPD
WRB	52	Crane Creek at Hwy AA, MO	Cra1	1	8/28/2009	DM/EH	9/23/2009	WPD
WRB	53	Middle Fork White River near Fayetteville, AR	Whi1m	1	8/28/2009	DM/EH	9/23/2009	WPD
WRB	54	Richland Creek at Hwy 303, AR	Ric1	1	8/28/2009	DM/EH	9/23/2009	WPD
WRB	55	Richland Creek at Goshen, AR	Ric2	1	8/28/2009	DM/EH	9/23/2009	WPD
WRB	56	White River at Elkins, AR	Whi3	1	8/28/2009	DM/EH	9/23/2009	WPD
WRB	57	Kings River near Kingston, AR	Kin1	1	8/28/2009	DM/EH	9/23/2009	WPD

Table 2: Sample Site Locations

Lab Code		Site	Riffle	Drainage Area (km2)	Elevation at Site (m asl)	Sub-Basin	Site Location *GPS Coordinates* Latitude	Longitude
WRB	1	Fla2	1	558	323	James	36.77164	-93.67811
WRB	2	Fla2	2	558	323	James	36.77067	-93.67717
WRB	3	Fla2	3	558	323	James	36.76983	-93.67650
WRB	4	Swa1	1	383	243	Bullshoals	36.78486	-93.05525
WRB	5	Swa1	2	383	243	Bullshoals	36.78569	-93.05794
WRB	6	Swa1	3	383	243	Bullshoals	36.78725	-93.05906
WRB	7	Fin2	1	666	317	James	36.97656	-93.31817
WRB	8	Fin2	2	666	317	James	36.97600	-93.31883
WRB	9	Fin2	3	666	317	James	36.97508	-93.32525
WRB	10	Jam3	1	1,192	317	James	37.01067	-93.35722
WRB	11	Jam3	2	1,192	317	James	37.00803	-93.36250
WRB	12	Jam3	3	1,192	317	James	37.00747	-93.36328
WRB	13	Kin4	1	1,363	298	Beaver	36.42181	-93.62594
WRB	14	Kin4	2	1,363	298	Beaver	36.42331	-93.62581
WRB	15	Kin4	3	1,363	298	Beaver	36.42450	-93.62578
WRB	16	Yoc1	1	136	298	Beaver	36.45431	-93.35964
WRB	17	Yoc1	2	136	298	Beaver	36.45467	-93.35872
WRB	18	Yoc1	3	136	298	Beaver	36.45483	-93.35819
WRB	19	Whi4	1	1,023	349	Beaver	36.07033	-94.07717
WRB	20	Whi4	2	1,023	349	Beaver	36.07086	-94.07869
WRB	21	Whi4	3	1,023	349	Beaver	36.07172	-94.07975
WRB	22	Whi2w	1	310	353	Beaver	36.05233	-94.08628
WRB	23	Whi2w	2	310	353	Beaver	36.05292	-94.08444
WRB	24	Whi2w	3	310	353	Beaver	36.05308	-94.08433
WRB	25	War2	1	684	355	Beaver	36.20403	-93.84817
WRB	26	War2	2	684	355	Beaver	36.19958	-93.85011
WRB	27	War2	3	684	355	Beaver	36.20133	-93.84873
WRB	28	Swa1-FD	1	383	243	Bullshoals	36.78486	-93.05525
WRB	29	Swa1-FD	2	383	243	Bullshoals	36.78569	-93.05794
WRB	30	Swa1-FD	3	383	243	Bullshoals	36.78725	-93.05906
WRB	31	Jam4	1	2,563	285	James	36.80931	-93.46289
WRB	32	Jam4	2	2,563	285	James	36.80983	-93.46272
WRB	33	Jam4	3	2,563	285	James	36.81069	-93.46336
WRB	34	Fla2-FD	0	558	323	James	36.77367	-93.68232
WRB	35	Fla2-FD	1	558	323	James	36.77321	-93.68000
WRB	36	Fla2-FD	2	558	323	James	36.77301	-93.67783
WRB	37	Fla2-FD	3	558	323	James	36.77211	-93.67710
WRB	38	Fla1	1	411	348	James	36.81883	-93.78753

Table 2: Sample Site Locations (con't)

Lab Code		Site	Riffle	Drainage Area (km2)	Elevation at Site (m asl)	Sub-Basin	Site Location *GPS Coordinates* Latitude	Longitude
WRB	39	Ber1	1	344	217	Bullshoals	36.44971	-93.07598
WRB	40	Bev1	1	773	250	Bullshoals	36.77969	-92.90728
WRB	41	Bul1	1	97	292	Bullshoals	36.90607	-93.13786
WRB	42	Bul2	1	507	220	Bullshoals	36.71789	-93.20692
WRB	43	Fin1	1	425	364	James	37.03704	-93.05566
WRB	44	Jam2	1	634	350	James	37.14961	-93.20326
WRB	45	Pon1	1	53	237	Beaver	36.66864	-92.69738
WRB	46	Tur1	1	93	218	Beaver	36.66918	-92.63275
WRB	47	Jam1	1	243	385	James	37.26276	-93.00315
WRB	48	Kin2O	1	387	327	Beaver	36.34776	-93.59134
WRB	49	War1	1	518	374	Beaver	36.04212	-93.70551
WRB	50	Lon1	1	266	304	Bullshoals	36.38974	-93.31712
WRB	51	Kin3	1	788	318	Beaver	36.31666	-93.66402
WRB	52	Cra1	1	399	298	James	36.85559	-93.45414
WRB	53	Whi1m	1	197	357	Beaver	36.04077	-94.05508
WRB	54	Ric1	1	223	378	Beaver	36.01040	-93.88836
WRB	55	Ric2	1	362	344	Beaver	36.10412	-94.00750
WRB	56	Whi3	1	465	363	Beaver	36.00167	-94.00355
WRB	57	Kin1	1	166	399	Beaver	36.08823	-93.54186

Table 3: Watershed Characteristics

Lab Code		Location		Drainage Area	Bedrock Geology			Land Use			Road Density
					Carbonate	Sandstone	Shale	Urb+Bar	Grass+Crop	Forest (all)	
		Site	Riffle	(Ad, km2)	(% of Ad)	(% of Ad)	(% of Ad)	(% of Ad)	(% of Ad)	(% of Ad)	(km/km2)
WRB	1	Fla2	1	558	99	1	0	3.1	64.9	31.9	1.43
WRB	2	Fla2	2	558	99	1	0	3.1	64.9	31.9	1.43
WRB	3	Fla2	3	558	99	1	0	3.1	64.9	31.9	1.43
WRB	4	Swa1	1	383	100	0	0	1.5	23.7	74.2	0.93
WRB	5	Swa1	2	383	100	0	0	1.5	23.7	74.2	0.93
WRB	6	Swa1	3	383	100	0	0	1.5	23.7	74.2	0.93
WRB	7	Fin2	1	666	100	0	0	5.5	63.7	30.3	1.9
WRB	8	Fin2	2	666	100	0	0	5.5	63.7	30.3	1.9
WRB	9	Fin2	3	666	100	0	0	5.5	63.7	30.3	1.9
WRB	10	Jam3	1	1,192	99	1	0	17	56.2	25.1	2.91
WRB	11	Jam3	2	1,192	99	1	0	17	56.2	25.1	2.91
WRB	12	Jam3	3	1,192	99	1	0	17	56.2	25.1	2.91
WRB	13	Kin4	1	1,363	51	45	4	2.2	22	75.7	1.15
WRB	14	Kin4	2	1,363	51	45	4	2.2	22	75.7	1.15
WRB	15	Kin4	3	1,363	51	45	4	2.2	22	75.7	1.15
WRB	16	Yoc1	1	136	80	17	2	4.7	68.1	27.2	1.19
WRB	17	Yoc1	2	136	80	17	2	4.7	68.1	27.2	1.19
WRB	18	Yoc1	3	136	80	17	2	4.7	68.1	27.2	1.19
WRB	19	Whi4	1	1,023	2	98	0	4.8	15	79.9	1.31
WRB	20	Whi4	2	1,023	2	98	0	4.8	15	79.9	1.31
WRB	21	Whi4	3	1,023	2	98	0	4.8	15	79.9	1.31
WRB	22	Whi2w	1	310	2	98	0	11.6	17	71.2	1.95
WRB	23	Whi2w	2	310	2	98	0	11.6	17	71.2	1.95
WRB	24	Whi2w	3	310	2	98	0	11.6	17	71.2	1.95
WRB	25	War2	1	684	27	73	0	2.9	27.6	69.6	1.12
WRB	26	War2	2	684	27	73	0	2.9	27.6	69.6	1.12
WRB	27	War2	3	684	27	73	0	2.9	27.6	69.6	1.12
WRB	28	Swa1-FD	1	383	100	0	0	1.5	23.7	74.2	0.93
WRB	29	Swa1-FD	2	383	100	0	0	1.5	23.7	74.2	0.93
WRB	30	Swa1-FD	3	383	100	0	0	1.5	23.7	74.2	0.93
WRB	31	Jam4	1	2,563	99	1	0	10.4	60.9	28.2	2.31
WRB	32	Jam4	2	2,563	99	1	0	10.4	60.9	28.2	2.31
WRB	33	Jam4	3	2,563	99	1	0	10.4	60.9	28.2	2.31
WRB	34	Fla2-FD	0	558	99	1	0	3.1	64.9	31.9	1.43
WRB	35	Fla2-FD	1	558	99	1	0	3.1	64.9	31.9	1.43
WRB	36	Fla2-FD	2	558	99	1	0	3.1	64.9	31.9	1.43
WRB	37	Fla2-FD	3	558	99	1	0	3.1	64.9	31.9	1.43
WRB	38	Fla1	1	411	99	1	0	3.6	72	24.2	1.62

Table 3: Watershed Characteristics (con't)

Lab Code		Location		Drainage Area	Bedrock Geology			Land Use			Road Density
		Site	Riffle	(Ad, km2)	Carbonate (% of Ad)	Sandstone (% of Ad)	Shale (% of Ad)	Urb+Bar (% of Ad)	Grass+Crop (% of Ad)	Forest (all) (% of Ad)	(km/km2)
WRB	39	Ber1	1	344	90	10	0	3.1	31.3	65.5	1.1
WRB	40	Bev1	1	773	93	7	0	2.4	47.7	49.5	1.13
WRB	41	Bul1	1	97	100	0	0	1.1	40	58.2	1.06
WRB	42	Bul2	1	507	100	0	0	2.9	24.2	72.4	1.06
WRB	43	Fin1	1	425	100	0	0	2.7	58.3	38.6	1.52
WRB	44	Jam2	1	634	100	0	0	5.5	59.6	34.3	1.87
WRB	45	Pon1	1	53	100	0	0	4.2	34.6	61	0.98
WRB	46	Tur1	1	93	100	0	0	1.5	58	40.3	1.03
WRB	47	Jam1	1	243	100	0	0	3.9	62.7	33	1.51
WRB	48	Kin2O	1	387	0	100	0	1.9	22.1	76	1.07
WRB	49	War1	1	518	8	92	0	2.6	21.8	75.5	1.11
WRB	50	Lon1	1	266	40	60	0	2.2	31.5	66.2	1.08
WRB	51	Kin3	1	788	47	51	2	1.4	20.5	78	1.1
WRB	52	Cra1	1	399	95	5	0	1.5	74.4	24.1	1.62
WRB	53	Whi1m	1	197	0	100	0	1.6	19.3	78.9	1.22
WRB	54	Ric1	1	223	0	100	0	0.9	18.1	80.9	1.07
WRB	55	Ric2	1	362	8	92	0	1.7	26.4	71.8	1.19
WRB	56	Whi3	1	465	1	99	0	0.7	10.1	89.1	0.87
WRB	57	Kin1	1	166	9	91	0	1.1	10.7	88.1	0.73

Table 4: Analytical Results: Texture, Carbon, and Nutrients

Lab Code		Site	Riffle	Bulk sample Gravel (% >2 mm)	<2mm fraction Fines (% <250 um)	C-N-S analysis on <250 um fraction Ctot (%)	Cin (%)	Corg (%)	N (%)	S (%)	ICP P (ppm)
WRB	1	Fla2	1	3.2	31.5	1.29	0.67	0.61	0.14	0.07	190
WRB	2	Fla2	2	31.3	8.8	1.26	0.51	0.76	0.12	0.04	220
WRB	3	Fla2	3	17.0	8.0	1.05	0.50	0.54	0.09	0.03	160
WRB	4	Swa1	1	6.3	36.6	3.24	1.37	1.87	0.21	0.04	240
WRB	5	Swa1	2	7.3	39.3	4.71	1.81	2.90	0.29	0.05	360
WRB	6	Swa1	3	44.5	7.3	1.28	0.32	0.96	0.07	0.02	70
WRB	7	Fin2	1	25.2	6.6	0.49	0.13	0.36	0.06	0.02	70
WRB	8	Fin2	2	9.8	16.3	0.60	0.28	0.31	0.06	0.02	110
WRB	9	Fin2	3	39.5	24.9	0.48	0.25	0.23	0.05	0.02	110
WRB	10	Jam3	1	26.1	23.6	0.96	0.26	0.70	0.10	0.02	230
WRB	11	Jam3	2	17.3	39.8	2.01	0.36	1.64	0.20	0.04	390
WRB	12	Jam3	3	34.7	32.0	2.58	0.72	1.86	0.21	0.05	510
WRB	13	Kin4	1	3.4	15.0	0.46	0.14	0.32	0.04	0.02	70
WRB	14	Kin4	2	0.4	55.3	0.76	0.09	0.67	0.08	0.02	190
WRB	15	Kin4	3	0.0	34.2	0.32	0.20	0.13	0.03	0.02	90
WRB	16	Yoc1	1	2.4	58.4	0.76	0.25	0.51	0.07	0.03	180
WRB	17	Yoc1	2	28.9	16.8	0.45	0.11	0.34	0.05	0.02	120
WRB	18	Yoc1	3	11.5	50.9	0.38	0.10	0.29	0.04	0.01	110
WRB	19	Whi4	1	31.1	12.9	*IS*	*IS*	*IS*	*IS*	*IS*	140
WRB	20	Whi4	2	6.2	40.1	1.20	0.12	1.08	0.13	0.02	370
WRB	21	Whi4	3	1.8	25.7	0.27	0.07	0.21	0.04	0.01	140
WRB	22	Whi2w	1	1.7	26.5	0.27	0.07	0.19	0.04	0.01	150
WRB	23	Whi2w	2	37.9	27.6	0.38	0.07	0.31	0.13	0.02	220
WRB	24	Whi2w	3	0.0	53.6	0.82	0.12	0.70	0.10	0.01	390
WRB	25	War2	1	0.0	28.3	0.61	0.08	0.53	0.06	0.01	160
WRB	26	War2	2	0.0	24.6	0.21	0.06	0.16	0.03	0.01	110
WRB	27	War2	3	4.8	68.4	0.32	0.07	0.26	0.08	0.06	160
WRB	28	Swa1-FD	1	81.2	11.0	*IS*	*IS*	*IS*	*IS*	*IS*	90
WRB	29	Swa1-FD	2	52.8	1.7	*IS*	*IS*	*IS*	*IS*	*IS*	170
WRB	30	Swa1-FD	3	34.0	4.8	*IS*	*IS*	*IS*	*IS*	*IS*	140
WRB	31	Jam4	1	0.0	30.7	1.93	0.45	1.47	0.15	0.04	250
WRB	32	Jam4	2	72.9	4.3	*IS*	*IS*	*IS*	*IS*	*IS*	430
WRB	33	Jam4	3	7.1	15.3	1.37	0.38	0.98	0.10	0.03	160
WRB	34	Fla2-FD	0	25.0	43.2	2.64	0.69	1.95	0.23	0.04	420
WRB	35	Fla2-FD	1	12.4	9.2	1.45	0.68	0.78	0.10	0.02	180
WRB	36	Fla2-FD	2	29.4	12.5	1.21	0.44	0.77	0.10	0.02	200
WRB	37	Fla2-FD	3	48.6	23.4	2.21	1.01	1.20	0.17	0.03	240
WRB	38	Fla1	1	10.4	21.8	1.34	0.30	1.04	0.13	0.03	320

Table 4: Analytical Results: Texture, Carbon, and Nutrients (con't)

Lab Code		Site	Riffle	Bulk sample Gravel (% >2 mm)	<2mm fraction Fines (% <250 um)	C-N-S analysis on <250 um fraction Ctot (%)	Cin (%)	Corg (%)	N (%)	S (%)	ICP P (ppm)
WRB	39	Ber1	1	15.7	30.0	1.97	1.30	0.67	0.09	0.02	140
WRB	40	Bev1	1	15.4	16.0	0.99	0.23	0.76	0.06	0.01	60
WRB	41	Bul1	1	34.3	39.0	3.77	1.54	2.23	0.23	0.04	340
WRB	42	Bul2	1	20.1	33.1	3.01	2.07	0.94	0.15	0.03	190
WRB	43	Fin1	1	65.5	6.8	*IS*	*IS*	*IS*	*IS*	*IS*	220
WRB	44	Jam2	1	6.4	24.8	1.04	0.15	0.88	0.07	0.04	120
WRB	45	Pon1	1	26.0	21.6	2.57	0.43	2.14	0.16	0.02	170
WRB	46	Tur1	1	46.0	48.1	4.15	1.56	2.59	0.20	0.02	220
WRB	47	Jam1	1	57.7	10.3	*IS*	*IS*	*IS*	*IS*	*IS*	80
WRB	48	Kin2O	1	1.3	58.9	1.74	0.75	0.99	0.05	0.03	100
WRB	49	War1	1	37.6	19.1	*IS*	*IS*	*IS*	*IS*	*IS*	220
WRB	50	Lon1	1	2.2	43.0	0.63	0.23	0.40	0.07	0.02	100
WRB	51	Kin3	1	0.3	72.4	0.30	0.07	0.23	0.04	0.01	80
WRB	52	Cra1	1	1.5	62.7	2.48	0.92	1.56	0.16	0.02	260
WRB	53	Whi1m	1	0.0	67.3	1.02	0.06	0.95	0.10	0.02	360
WRB	54	Ric1	1	2.9	2.0	*IS*	*IS*	*IS*	*IS*	*IS*	170
WRB	55	Ric2	1	1.1	14.5	0.78	0.11	0.67	0.09	0.02	220
WRB	56	Whi3	1	6.2	49.7	1.08	0.06	1.02	0.10	0.03	340
WRB	57	Kin1	1	9.4	28.9	3.90	0.25	3.65	0.37	0.05	590

Table 5: Analytical Results: Metals

Lab Code		Site	Riffle	Al (%)	Ca (%)	Fe (%)	Mn (ppm)	Pb (ppm)	Zn (ppm)	Cu (ppm)	Cr (ppm)	Ni (ppm)	As (ppm)	Cd (ppm)	Hg (ppm)
				Hot Strong Acid Extraction with ICP-AES analysis of the <250 um fraction											
WRB	1	Fla2	1	0.46	1.02	0.75	437	13	77	25	14	9	5	<0.5	0.02
WRB	2	Fla2	2	0.49	1.09	0.81	448	13	77	9	13	8	2	<0.5	0.02
WRB	3	Fla2	3	0.38	0.99	0.68	374	9	74	6	11	9	3	<0.5	0.02
WRB	4	Swa1	1	0.5	2.65	0.67	368	16	61	8	8	7	2	<0.5	0.02
WRB	5	Swa1	2	0.7	3.53	0.96	421	23	82	11	12	10	7	<0.5	0.03
WRB	6	Swa1	3	0.15	0.99	0.31	68	6	24	8	4	3	<2	<0.5	0.01
WRB	7	Fin2	1	0.13	0.22	0.29	176	4	18	3	7	2	2	<0.5	0.01
WRB	8	Fin2	2	0.24	0.5	0.42	227	6	26	3	9	3	2	<0.5	0.01
WRB	9	Fin2	3	0.17	0.49	0.35	127	6	24	6	9	3	<2	<0.5	0.01
WRB	10	Jam3	1	0.41	0.61	0.67	449	15	46	12	13	10	2	<0.5	0.03
WRB	11	Jam3	2	0.94	1.01	1.18	698	27	77	14	15	12	3	0.5	0.08
WRB	12	Jam3	3	0.8	1.98	1.04	765	26	97	21	17	12	4	0.6	0.08
WRB	13	Kin4	1	0.1	0.23	0.37	168	<2	8	2	6	3	2	<0.5	<0.01
WRB	14	Kin4	2	0.58	0.2	1.21	1,400	14	22	6	12	12	6	<0.5	0.02
WRB	15	Kin4	3	0.14	0.26	0.53	125	4	11	2	7	4	3	<0.5	<0.01
WRB	16	Yoc1	1	0.38	0.64	0.59	349	8	18	4	9	6	<2	<0.5	0.02
WRB	17	Yoc1	2	0.23	0.25	0.43	249	4	12	5	10	3	3	<0.5	0.01
WRB	18	Yoc1	3	0.21	0.27	0.42	255	5	11	3	9	3	4	<0.5	0.01
WRB	19	Whi4	1	0.19	0.04	0.92	479	4	21	4	11	9	3	<0.5	0.01
WRB	20	Whi4	2	0.74	0.19	2.21	1,090	19	57	11	23	19	11	<0.5	0.08
WRB	21	Whi4	3	0.22	0.05	0.91	579	5	24	3	11	9	3	<0.5	0.01
WRB	22	Whi2w	1	0.23	0.05	0.99	399	5	25	4	11	9	3	<0.5	0.01
WRB	23	Whi2w	2	0.29	0.09	1.27	892	7	34	7	14	13	5	<0.5	0.01
WRB	24	Whi2w	3	0.75	0.21	2.38	1,770	11	51	9	21	23	11	<0.5	0.02
WRB	25	War2	1	0.26	0.08	0.87	421	5	21	3	10	8	4	<0.5	0.01
WRB	26	War2	2	0.17	0.04	0.61	367	2	15	2	8	6	4	<0.5	<0.01
WRB	27	War2	3	0.27	0.07	0.95	406	5	23	3	11	9	5	<0.5	0.01
WRB	28	Swa1-FD	1	0.19	1.6	0.32	118	7	26	23	5	3	<2	<0.5	0.01
WRB	29	Swa1-FD	2	0.35	3.65	0.53	368	14	47	28	7	5	6	<0.5	0.01
WRB	30	Swa1-FD	3	0.29	1.89	0.47	162	10	38	14	12	5	2	<0.5	0.01
WRB	31	Jam4	1	0.41	1.71	0.63	301	10	34	6	12	5	2	<0.5	0.03
WRB	32	Jam4	2	0.57	10.6	0.66	463	14	52	15	10	7	<2	<0.5	0.04
WRB	33	Jam4	3	0.26	2.02	0.46	108	8	27	4	10	4	3	<0.5	0.02
WRB	34	Fla2-FD	0	0.79	1.67	0.96	324	16	116	9	12	10	5	0.8	0.05
WRB	35	Fla2-FD	1	0.41	1.4	0.7	399	11	55	5	11	7	5	<0.5	0.02
WRB	36	Fla2-FD	2	0.43	0.78	0.78	504	11	68	5	12	7	5	<0.5	0.02
WRB	37	Fla2-FD	3	0.49	2.41	0.69	332	10	74	14	11	7	6	0.6	0.02
WRB	38	Fla1	1	0.75	1.02	0.98	768	18	112	11	15	10	5	0.8	0.05

Table 5: Analytical Results: Metals (con't)

Lab Code		Site	Riffle	Hot Strong Acid Extraction with ICP-AES analysis of the <250 um fraction											
				Al	Ca	Fe	Mn	Pb	Zn	Cu	Cr	Ni	As	Cd	Hg
				(%)	(%)	(%)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
WRB	39	Ber1	1	0.29	2.75	0.55	329	6	17	6	8	6	4	<0.5	0.01
WRB	40	Bev1	1	0.12	0.7	0.19	92	5	20	5	3	4	2	<0.5	<0.01
WRB	41	Bul1	1	0.75	3.07	1.01	744	17	146	9	11	11	4	0.9	0.03
WRB	42	Bul2	1	0.45	3.61	0.59	205	7	26	6	7	5	4	<0.5	0.02
WRB	43	Fin1	1	0.44	0.34	0.67	452	9	26	8	10	5	3	<0.5	0.02
WRB	44	Jam2	1	0.17	0.61	0.43	168	9	642	3	9	2	3	4.4	0.02
WRB	45	Pon1	1	0.39	1.31	0.66	175	15	44	6	8	5	6	<0.5	0.02
WRB	46	Tur1	1	0.37	3.73	0.53	157	11	31	6	7	5	5	<0.5	0.01
WRB	47	Jam1	1	0.15	0.07	0.34	125	3	9	2	6	1	3	<0.5	0.01
WRB	48	Kin2O	1	0.15	1.52	0.62	106	3	11	2	8	4	3	<0.5	<0.01
WRB	49	War1	1	0.37	0.09	1.61	264	7	33	12	16	11	9	<0.5	0.01
WRB	50	Lon1	1	0.46	0.68	1.53	264	7	26	11	14	13	7	<0.5	0.01
WRB	51	Kin3	1	0.15	0.1	0.47	120	2	11	2	7	3	4	<0.5	<0.01
WRB	52	Cra1	1	0.44	2.77	0.56	218	6	28	4	10	4	4	<0.5	0.02
WRB	53	Whi1m	1	0.54	0.11	2.12	445	9	44	6	18	16	10	<0.5	0.02
WRB	54	Ric1	1	0.18	0.02	1.83	650	4	45	2	17	7	11	<0.5	0.01
WRB	55	Ric2	1	0.29	0.36	1.49	489	4	30	5	15	11	8	<0.5	0.01
WRB	56	Whi3	1	0.43	0.09	2.02	334	7	46	6	20	15	8	<0.5	0.01
WRB	57	Kin1	1	0.86	0.76	2.34	624	17	64	13	25	18	12	<0.5	0.04

Table 6: Watershed Classification by Geology and Land Use

Lab Code		Site Code	Riffle (#)	Drainage Area (Ad, km2)	*Watershed Classification* Geology	Land Use
WRB	1	Fla2	1	558	Limestone	Grass+Crops
WRB	2	Fla2	2	558	Limestone	Grass+Crops
WRB	3	Fla2	3	558	Limestone	Grass+Crops
WRB	4	Swa1	1	383	Dolomite	Forest
WRB	5	Swa1	2	383	Dolomite	Forest
WRB	6	Swa1	3	383	Dolomite	Forest
WRB	7	Fin2	1	666	Limestone	Urban+Barren
WRB	8	Fin2	2	666	Limestone	Urban+Barren
WRB	9	Fin2	3	666	Limestone	Urban+Barren
WRB	10	Jam3	1	1,192	Limestone	Urban+Barren
WRB	11	Jam3	2	1,192	Limestone	Urban+Barren
WRB	12	Jam3	3	1,192	Limestone	Urban+Barren
WRB	13	Kin4	1	1,363	Sandstone	Forest
WRB	14	Kin4	2	1,363	Sandstone	Forest
WRB	15	Kin4	3	1,363	Sandstone	Forest
WRB	16	Yoc1	1	136	Limestone	Grass+Crops
WRB	17	Yoc1	2	136	Limestone	Grass+Crops
WRB	18	Yoc1	3	136	Limestone	Grass+Crops
WRB	19	Whi4	1	1,023	Sandstone	Forest
WRB	20	Whi4	2	1,023	Sandstone	Forest
WRB	21	Whi4	3	1,023	Sandstone	Forest
WRB	22	Whi2w	1	310	Sandstone	Urban+Barren
WRB	23	Whi2w	2	310	Sandstone	Urban+Barren
WRB	24	Whi2w	3	310	Sandstone	Urban+Barren
WRB	25	War2	1	684	Sandstone	Forest
WRB	26	War2	2	684	Sandstone	Forest
WRB	27	War2	3	684	Sandstone	Forest
WRB	28	Swa1-FD	1	383	Dolomite	Forest
WRB	29	Swa1-FD	2	383	Dolomite	Forest
WRB	30	Swa1-FD	3	383	Dolomite	Forest
WRB	31	Jam4	1	2,563	Limestone	Urban+Barren
WRB	32	Jam4	2	2,563	Limestone	Urban+Barren
WRB	33	Jam4	3	2,563	Limestone	Urban+Barren
WRB	34	Fla2-FD	0	558	Limestone	Grass+Crops
WRB	35	Fla2-FD	1	558	Limestone	Grass+Crops
WRB	36	Fla2-FD	2	558	Limestone	Grass+Crops
WRB	37	Fla2-FD	3	558	Limestone	Grass+Crops

Table 6: Watershed Classification by Geology and Land Use (con't)

Lab Code		Site Code	Riffle (#)	Drainage Area (Ad, km2)	*Watershed Classification* Geology	Land Use
WRB	38	Fla1	1	411	Limestone	Grass+Crops
WRB	39	Ber1	1	344	Dolomite	Forest
WRB	40	Bev1	1	773	Dolomite	Grass+Crops
WRB	41	Bul1	1	97	Limestone	Grass+Crops
WRB	42	Bul2	1	507	Dolomite	Forest
WRB	43	Fin1	1	425	Limestone	Grass+Crops
WRB	44	Jam2	1	634	Limestone	Urban+Barren
WRB	45	Pon1	1	53	Dolomite	Forest
WRB	46	Tur1	1	93	Dolomite	Grass+Crops
WRB	47	Jam1	1	243	Limestone	Grass+Crops
WRB	48	Kin2O	1	387	Sandstone	Forest
WRB	49	War1	1	518	Sandstone	Forest
WRB	50	Lon1	1	266	Sandstone	Forest
WRB	51	Kin3	1	788	Sandstone	Forest
WRB	52	Cra1	1	399	Limestone	Grass+Crops
WRB	53	Whi1m	1	197	Sandstone	Forest
WRB	54	Ric1	1	223	Sandstone	Forest
WRB	55	Ric2	1	362	Sandstone	Forest
WRB	56	Whi3	1	465	Sandstone	Forest
WRB	57	Kin1	1	166	Sandstone	Forest

Table 7: Geochemical Trends by Geology

Class/Percentile		Al (%)	As ppm	Cd ppm	Cr ppm	Cu (ppm)	Hg (ppm)	Ni ppm	Pb (ppm)	Zn (ppm)	P (ppm)
Limestone	max	0.94	6	4.4	17	25	0.08	12	27	642	510
n=25	75%	0.49	5	0.5	12	11	0.03	9	14	77	260
(11 sites)	**Median**	**0.41**	**3**	**<0.5**	**11**	**6**	**0.02**	**7**	**10**	**52**	**200**
	25%	0.24	3	<0.5	9	4	0.02	3	6	26	120
	%Q-diff	*61*	*58*		*27*	*117*	*50*	*86*	*80*	*98*	*70*
Dolomite	max	0.70	7	<0.5	12	28	0.03	10	23	82	360
n=11	75%	0.42	6	<0.5	8	13	0.02	6	15	46	205
(6 sites)	**Median**	**0.35**	**4**	**<0.5**	**7**	**8**	**0.01**	**5**	**10**	**31**	**170**
	25%	0.24	2	<0.5	6	6	0.01	5	7	25	115
	%Q-diff	*51*	*100*		*29*	*81*	*100*	*20*	*80*	*66*	*53*
Sandstone	max	0.86	12	<0.5	25	13	0.08	23	19	64	590
n=21	75%	0.46	9	<0.5	17	7	0.01	13	7	44	220
(13 sites)	**Median**	**0.27**	**5**	**<0.5**	**12**	**4**	**0.01**	**9**	**5**	**25**	**160**
	25%	0.18	3	<0.5	10	2	0.01	7	4	21	110
	%Q-diff	*104*	*120*		*58*	*125*	*0*	*67*	*60*	*92*	*69*
M/Al ratio	Limestone	1	7		27	15	0.05	17	24	127	488
	Dolomite	1	11		20	23	0.03	14	29	89	486
	Sandstone	1	19		44	15	0.04	33	19	93	593

Table 8: Geochemical Trends by Land Use

Class/Percentile		Al (%)	As ppm	Cd ppm	Cr ppm	Cu (ppm)	Hg (ppm)	Ni ppm	Pb (ppm)	Zn (ppm)	P (ppm)
Urban	max	0.94	11	4.4	21	21	0.08	23	27	642	510
n=13	75%	0.57	4	<0.5	14	12	0.03	12	14	52	390
(13 sites)	**Median**	**0.29**	**3**	<0.5	**11**	**6**	**0.02**	**7**	**9**	**34**	**220**
	25%	0.21	3	<0.5	10	3	0.01	4	5	26	115
	%Q-diff	*126*	*17*		*41*	*150*	*100*	*114*	*100*	*78*	*125*
Ag/grass	max	0.79	6	0.90	15	25	0.05	11	18	146	420
n=17	75%	0.49	5	<0.5	12	9	0.02	9	13	77	240
(9 sites)	**Median**	**0.43**	**4**	**<0.5**	**11**	**6**	**0.02**	**7**	**10**	**55**	**200**
	25%	0.37	3	<0.5	9	5	0.01	4	6	20	160
	%Q-diff	*28*	*50*		*27*	*67*	*50*	*71*	*70*	*104*	*40*
Forest	max	0.86	12	<0.5	25	28	0.08	19	23	82	590
n=27	75%	0.46	8	<0.5	15	11	0.02	11	12	45	220
(16 sites)	**Median**	**0.29**	**5**	<0.5	**11**	**6**	**0.01**	**7**	**7**	**26**	**160**
	25%	0.19	3	<0.5	8	3	0.01	5	4	21	105
	%Q-diff	*93*	*100*		*64*	*133*	*100*	*86*	*114*	*90*	*72*
M/Al ratio	Urban	1	10		38	21	0.07	24	31	117	759
(median values)	Ag/grass	1	9		26	14	0.05	16	23	128	465
	Forest	1	17		38	21	0.03	24	24	90	552

Table 9: Distribution of Samples among Watershed Classes

Bedrock Class	*Land Use Class* Urban	Ag/grass	Forest
Limestone	10	15	**0**
Dolomite	**0**	2	9
Sandstone	3	**0**	18

Table 10. Sediment Quality Guidelines for Metals in Freshwater Ecosystems (mg/kg dry weight)*

Metal	Threshold Effect Concentration (TEC)#	Probable Effect Concentration (PEC)$
Arsenic	9.79	33.0
Cadmium	0.99	4.98
Chromium	43.4	111
Copper	31.6	149
Lead	35.8	128
Mercury	0.18	1.06
Nickel	22.7	48.6
Zinc	121	459

*MacDonald, D.D., C.G. Ingersoll, and T.A. Berger, 2000. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. Arch. Environ. Contam. Toxicol. 39:20-31.

TEC: Value below which harmful effects are unlikely to occur. These values were tested and generally 70-80% of samples were correctly classified as "nontoxic." Mercury showed 34% agreement suggesting that the limit for Hg should be lower. However, the test sample set for Hg was much lower than the other metals (347 vs. 79), thus further testing is needed to validate the Hg TEC.

$ PEC: Value above which harmful effects are likely to be observed. These values were tested and usually >90% of the samples were correctly classified as "toxic." Results were 100% for Hg.

Table 11: Sediment Quality Criteria used in this Study

A. Sediment Metals (ppm)

Metal	Uncontaminated		Borderline		Toxic
	1 1/2 TEC	2 TEC	3 1/2 TEC-PEC	4 PEC	5 >PEC
As	<5	5-9	10-20	21-33	>33
Cd	<0.5	0.5-0.9	1-3	3.1-5	>5
Cr	<22	22-42	43-77	77-111	>111
Cu	<16	16-31	32-89	90-149	>149
Hg	<0.09	0.09-0.17	0.18-0.61	0.62-1.06	>1.06
Ni	<11	11-22	23-35	36-49	>49
Pb	<18	18-35	36-81	82-128	>128
Zn	<61	61-120	121-289	300-459	>459

B. Sediment Phosphorus (ppm)

Nutrient	Uncontaminated		Threshold	Contaminated	
	1	2	3	4	5
P	<200	200-399	400-599	600-1,000	>1,000

Table 12: Sediment Quality Classification by Site

Lab Code		Site Code	Riffle	Drainage Area	Classification by Sediment Quality Guidelines								
			(#)	(Ad, km2)	As Rating	Cd Rating	Cr Rating	Cu Rating	Hg Rating	Ni Rating	Pb Rating	Zn Rating	P Rating
WRB	39	Ber1	1	344	1	1	1	1	1	1	1	1	1
WRB	40	Bev1	1	773	1	1	1	1	1	1	1	1	1
WRB	41	Bul1	1	97	1	2	1	1	1	2	1	3	2
WRB	42	Bul2	1	507	1	1	1	1	1	1	1	1	1
WRB	52	Cra1	1	399	1	1	1	1	1	1	1	1	2
WRB	43	Fin1	1	425	1	1	1	1	1	1	1	1	2
WRB	9	Fin2	3	666	1	1	1	1	1	1	1	1	1
WRB	7	Fin2	1	666	1	1	1	1	1	1	1	1	1
WRB	8	Fin2	2	666	1	1	1	1	1	1	1	1	1
WRB	38	Fla1	1	411	2	2	1	1	1	1	2	2	2
WRB	2	Fla2	2	558	1	1	1	1	1	1	1	2	2
WRB	3	Fla2	3	558	1	1	1	1	1	1	1	2	1
WRB	1	Fla2	1	558	2	1	1	2	1	1	1	2	1
WRB	34	Fla2-FD	0	558	2	2	1	1	1	1	1	2	3
WRB	35	Fla2-FD	1	558	2	1	1	1	1	1	1	1	1
WRB	36	Fla2-FD	2	558	2	1	1	1	1	1	1	2	2
WRB	37	Fla2-FD	3	558	2	2	1	1	1	1	1	2	2
WRB	47	Jam1	1	243	1	1	1	1	1	1	1	1	1
WRB	44	Jam2	1	634	1	4	1	1	1	1	1	5	1
WRB	10	Jam3	1	1,192	1	1	1	1	1	1	1	1	2
WRB	11	Jam3	2	1,192	1	2	1	1	1	2	2	2	2
WRB	12	Jam3	3	1,192	1	2	1	2	1	2	2	2	3
WRB	32	Jam4	2	2,563	1	1	1	1	1	1	1	1	3
WRB	31	Jam4	1	2,563	1	1	1	1	1	1	1	1	2
WRB	33	Jam4	3	2,563	1	1	1	1	1	1	1	1	1
WRB	57	Kin1	1	166	3	1	2	1	1	2	1	2	3
WRB	48	Kin2O	1	387	1	1	1	1	1	1	1	1	1
WRB	51	Kin3	1	788	1	1	1	1	1	1	1	1	1
WRB	13	Kin4	1	1,363	1	1	1	1	1	1	1	1	1
WRB	15	Kin4	3	1,363	1	1	1	1	1	1	1	1	1
WRB	14	Kin4	2	1,363	2	1	1	1	1	2	1	1	1
WRB	50	Lon1	1	266	2	1	1	1	1	2	1	1	1
WRB	45	Pon1	1	53	2	1	1	1	1	1	1	1	1
WRB	54	Ric1	1	223	3	1	1	1	1	1	1	1	1
WRB	55	Ric2	1	362	2	1	1	1	1	2	1	1	2
WRB	6	Swa1	3	383	1	1	1	1	1	1	1	1	1
WRB	4	Swa1	1	383	1	1	1	1	1	1	1	2	2
WRB	5	Swa1	2	383	2	1	1	1	1	1	2	2	2
WRB	28	Swa1-FD	1	383	1	1	1	2	1	1	1	1	1
WRB	30	Swa1-FD	3	383	1	1	1	1	1	1	1	1	1
WRB	29	Swa1-FD	2	383	2	1	1	2	1	1	1	1	1

Table 12: Table 12: Sediment Quality Classification by Site (con't)

Lab Code		Site Code	Riffle (#)	Drainage Area (Ad, km2)	As Rating	Cd Rating	Cr Rating	Cu Rating	Hg Rating	Ni Rating	Pb Rating	Zn Rating	P Rating
					Classification by Sediment Quality Guidelines								
WRB	46	Tur1	1	93	2	1	1	1	1	1	1	1	2
WRB	49	War1	1	518	2	1	1	1	1	2	1	1	2
WRB	26	War2	2	684	1	1	1	1	1	1	1	1	1
WRB	25	War2	1	684	1	1	1	1	1	1	1	1	1
WRB	27	War2	3	684	2	1	1	1	1	1	1	1	1
WRB	53	Whi1m	1	197	3	1	1	1	1	2	1	1	2
WRB	22	Whi2w	1	310	1	1	1	1	1	1	1	1	1
WRB	23	Whi2w	2	310	2	1	1	1	1	2	1	1	2
WRB	24	Whi2w	3	310	3	1	1	1	1	3	1	1	2
WRB	56	Whi3	1	465	2	1	1	1	1	2	1	1	2
WRB	21	Whi4	3	1,023	1	1	1	1	1	1	1	1	1
WRB	19	Whi4	1	1,023	1	1	1	1	1	1	1	1	1
WRB	20	Whi4	2	1,023	3	1	2	1	1	2	2	1	2
WRB	16	Yoc1	1	136	1	1	1	1	1	1	1	1	1
WRB	17	Yoc1	2	136	1	1	1	1	1	1	1	1	1
WRB	18	Yoc1	3	136	1	1	1	1	1	1	1	1	1

Table 13: Quality Classification Results

A. Sediment Metals (ppm)

Metal	Uncontaminated		Borderline		Toxic
	1 1/2 TEC	2 TEC	3 1/2 TEC-PEC	4 PEC	5 >PEC
As	35	17	5	0	0
Cd	50	6	0	1	0
Cr	55	2	0	0	0
Cu	53	4	0	0	0
Hg	57	0	0	0	0
Ni	44	12	1	0	0
Pb	52	5	0	0	0
Zn	43	12	1	0	1

B. Sediment Phosphorus (ppm)

Nutrient	Uncontaminated		Threshold	Contaminated	
	1	2	3	4	5
P	33	20	4	0	0

Table 14: Summary of Sediment Quality Assessment

Location Site	n	P Rating	Metals Rating	Channel Rating	Fine Sed Rating	SCI Index
Beaver Lake Sub-Basin						
Kin1	1	**3.0**	**1.6**	91		
Kin2O	1	1	1	81		
Kin3	1	1	1	92		
Kin4	3	1	1.1	89	85	**8**
Ric1	1	1	**1.3**	82		
Ric2	1	**2.0**	**1.3**	**56**		
War1	1	**2.0**	**1.3**	**67**		
War2	3	1	1	87	**65**	**12**
Whi1m	1	**2.0**	**1.4**	**37**		
Whi2w	3	**1.7**	**1.3**	**70**	**65**	**12**
Whi3	1	**2.0**	**1.3**	**75**		
Whi4	3	1.3	1.2	88	85	**12**
Pon1	1	1	1.1	**72**		
Tur1	1	**2.0**	1.1	88		
Yoc1	3	1	1	90	95	**12**
Bull Shoals Lake Sub-Basin						
Lon1	1	1	**1.3**	**74**		
Bul1	1	**2.0**	**1.5**	91		
Bul2	1	1	1	89		
Swa1	3	**1.7**	1.2	96	95	**14**
Swa1-FD	3	1.0	1.1	90	95	
Ber1	1	1	1	84		
Bev1	1	1	1	85		
James River Sub-Basin						
Jam1	1	1	1	83		
Jam2	1	1	**1.9**	**76**		
Jam3	3	**2.3**	**1.4**	94	95	**10**
Jam4	3	**1.7**	1	**78**	**65**	**12**
Fin1	1	**2.0**	1	86		
Fin2	3	1	1	90	85	**10**
Cra1	1	**2.0**	1	87		
Fla1	1	**2.0**	**1.5**	84		
Fla2	3	1.3	1.2	89	85	**12**
Fla2-FD	4	**2.0**	**1.3**	90	**75**	

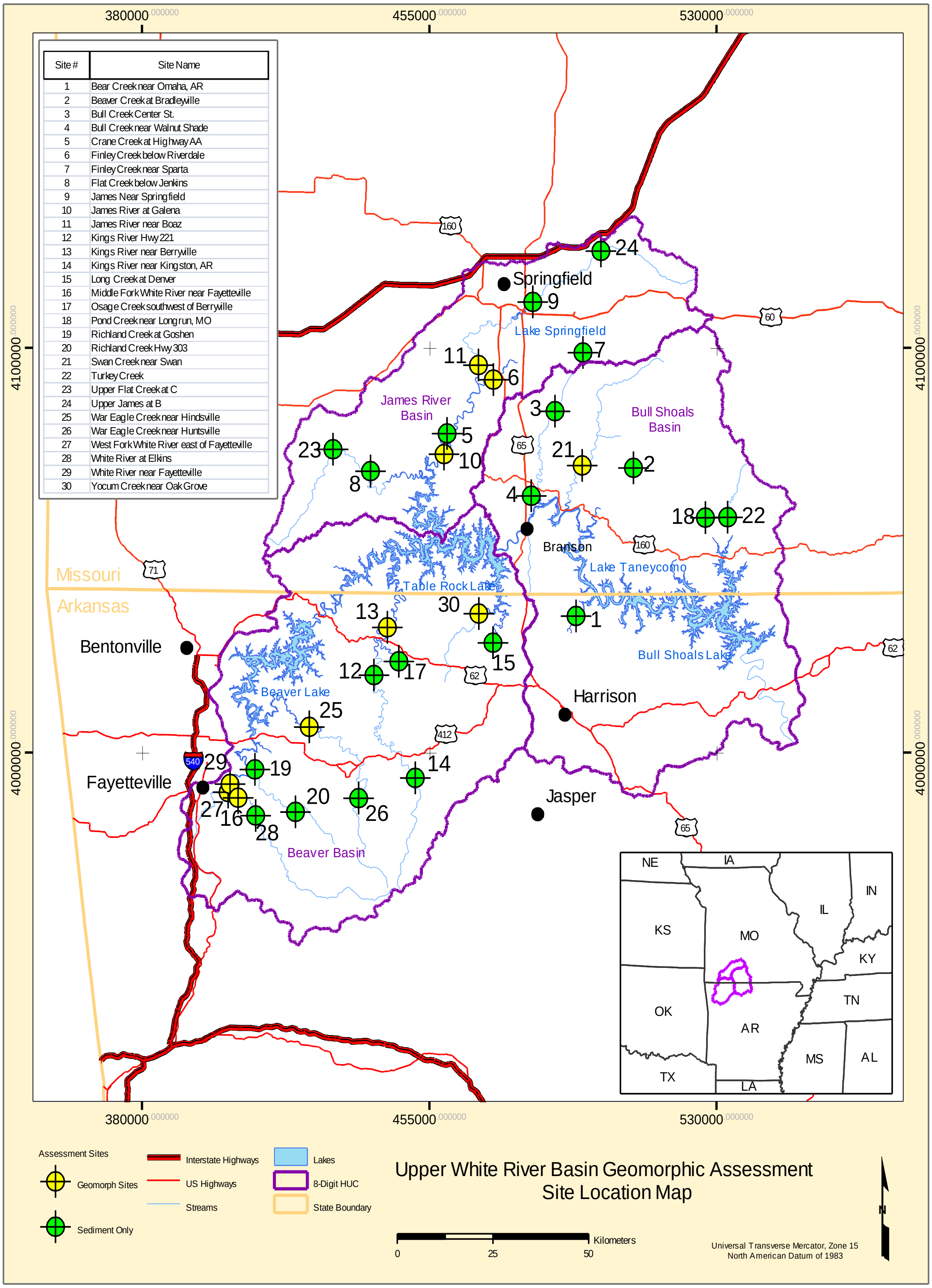

Figure 1: Study Area Map with Sampling Site Locations