

## **STATEMENT OF WORK**

# **Big River Mine Sediment Assessment Project (2008-2009)**

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## **INTRODUCTION**

The Old Lead Belt is a historic lead and zinc mining district within the Southeast Missouri Lead Mining District which was a leading producer of lead worldwide from 1869 to 1972. There are major concerns about the long-term stability and toxic risk of mill waste dumps and mining sediment in rivers draining the mining areas of the Old Lead Belt. As used here, mill tailings-derived materials released to the river that are transported and deposited downstream are generally referred to as mining sediment. Six major chat piles and tailings impoundments in the Old Lead Belt have been identified as major original source points of contaminated mining sediments within the Big River watershed. These abandoned dump sites are located in the towns of Leadwood, Desloge, Elvins/Rivermines, Park Hills/Federal, Flat River/National, and Bonne Terre. Historically, mine/mill wastes have been discharged directly into streams, gradually eroded into streams, and catastrophically released into streams en masse due to tailings dam failures.

Past and ongoing releases of tailings have contaminated channel sediment, and probably floodplain deposits, along 90 miles of the Big River and its tributaries (MDNR, 2007) with lead and zinc in excess of Probable Effects Concentrations (PEC) established by MacDonald et al. (2000). The Missouri 2004/2006 303(d) List identifies over 93 miles of the Big River as impaired due to tailings sediment and cadmium, lead, and zinc and another 10 miles along its tributaries. A TMDL has been approved for lead, zinc, and sediment for the Big River and Flat River Creek (MDNR, 2007). There are also documented ecological consequences of mining contamination in the Big River. Reduced mussel numbers and diversity have been documented in reaches below tailings input points (Buchanon et al., 1979; Schmitt et al., 1987; Roberts and Bruenderman, 2000). A 2007 screening level survey of mussel

populations and sediment metal concentrations in the Big River demonstrated that mussels are less abundant and less diverse in sampling locations below mining impacts where sediment concentrations exceed the PEC for Pb and/or Zn (Mosby et al, 2008). Moreover, elevated levels of metals have been found in aquatic plants and animals in contaminated segments of the Big River (Schmitt and Finger, 1982).

Presently, almost all of the tailings piles created during the mining period have been removed or are being stabilized. However, questions still remain about the fate of the chat and tailings materials released to the river in the past that are presently in transit in the channel system or stored in alluvial deposits. It is estimated that 39.3 million cubic yards of chat and tailings are presently stored at milling sites out of a total of about 170 million cubic yards of wastes produced (Newfields, 2006). A preliminary assessment of mining sediment storage in St. Francois County estimated that 1.1 million cubic yards is stored in Big River and 0.013 million cubic yards in Flat River Creek. These estimates were based on visual chat assessments and probe depths at 10 transects along 25 miles of the Big River and 10 transects along 5 miles of Flat River Creek (Newfields, 2007).

The dispersal patterns and environmental fate of mining sediment in the Big River is largely controlled by the original characteristics of the tailings supply. Chat and tailings are mill wastes produced during the separation of ore from host rock. They typically contain relatively high levels of residual metals since recoveries typically ranged from <80 to 95 percent (Wixson et al. 1983). Mining sediments in the Big River are mainly composed of fragments of dolomite, shale, quartz, and sulfide minerals including pyrite, galena, and sphalerite (Wronkiewicz et al. 2006). There are three types of mill wastes of interest to this study. "Chat" is 4 to 16 mm in diameter (fine gravel) and produced during the dry gravity separation of ore. Finer "tailings" are 0.06 mm to 0.20 mm in diameter (sand) and produced during wet separation by shaking tables or flotation. Finally, "slimes" are powdered rock fragments that are too small (<32 um) to separate and concentrate from the mill feed and so they were usually washed through the circuit and released directly to waste dumps or nearby streams even though they contained high levels of lead and other metals.

The mobility and rate of transport of mining sediment has not been studied. However, experience indicates that chat-sized materials are easily transported downstream as bed load by seasonal floods occurring in the Big River. During periods of low flow, mining sediment transport largely ceases and its load becomes deposited and stored on the channel bed and with bar deposits. Fine-grained mining sediment is transported as suspended load and deposited on floodplains and low terrace surfaces along the channel during flood stage. In general, sediments <2mm in diameter are the most mobile and contain metal concentrations that are potentially toxic to aquatic life (Schmitt and Finger, 1982; MDNR, 2001 & 2003; Mosby, 2008).

## **PURPOSE AND OBJECTIVES**

The purpose of this project is to improve our understanding of the physical mobility of mining sediment and metal contaminants in the river system and better quantify the locations of mining

sediment storages within channel and floodplain deposits that are available for future transport in the Big River and its affected tributaries. Several previous studies have found elevated lead and zinc concentrations in active channel sediments of Big River (Schmitt and Finger, 1982; Smith and Schumacher, 1993; Mosby, 2008). However, what is not well understood are the spatial and temporal patterns of the volume or mass storage of metals and mining sediment in the river along 95 miles of the Big River and its major tributaries in SE Missouri. The primary concerns of this study focus on understanding the spatial distribution of sediment contamination and volumes of stored mining sediment in the channel and on floodplains and long-term mobility of contaminated sediment. In this study, contaminated overbank and channel sediments are defined as containing >128 ppm Pb and/or >458 ppm Zn (MacDonald et al. 2000).

The objectives of this project are as follows:

- (1) Quantify the volume and downstream distribution of mining sediment storage in channel bed and bar deposits;
- (2) Quantify the volume and downstream distribution of contaminated sediment in overbank floodplain areas and
- (3) Determine the rates of mining sediment transport and probable residence times in the Big River Watershed.

## **METHODS**

### **Sampling Design**

Sample reaches will be located on the Big River at approximately 10 km intervals going downstream from Leadwood to the confluence with the Meramec River. Twenty or more sites are used to measure the spatial distribution of mining sediment characteristics and metal concentrations; 10 mainstem and 3 tributary reaches are used to quantify and calibrate mining sediment storage; and 5 sites are used to determine local variations in sediment depth and lateral distribution in bar and floodplain deposits using geophysical methods and coring methods. Sample reaches are located in two areas of the Big River watershed: on the main stem and major tributaries. Each site is classified as either affected by mining (i.e. contaminated) or affected only by background processes (i.e. unmined reference). The sampling reach locations and assessment schedule for this project are listed in Table 1.

## Field Methods

Field assessment activities will be divided into four components: (i) geomorphic analysis of the channel bed profile, cross-section, and depth of sediment storage, (ii) sediment sampling and characterization of bed, bar, and floodplain deposits, (iii) cross-valley coring of floodplain areas, and (iv) geophysical investigation of the subsurface features in floodplain and bar deposits. Initially, a “full” assessment including both geomorphic analysis and sediment characterization will be completed at 10 sample reaches along the main stem and 3 on tributaries (Table 1). In addition, sediment characterization (“sed”) will be completed at 5 background reference and 5-8 main stem contaminated sample reaches. After the initial evaluation of each sample reach is completed, 5 sites will be selected for geophysical investigation involving ground penetrating radar (GPR) and resistivity of floodplain and bar areas. Truck-mounted coring will be combined with geophysical methods where possible to determine the applicability of such methods for subsurface analysis under these conditions and the degree to which probing depths are representative of mining sediment volume estimates.

Geomorphic Analysis of Channel and Bar Areas. Longitudinal profiles and channel cross-sections are measured over a reach length of at least 8 active channel widths. If possible, the center of the sample reach is located at the glide-riffle crest transition zone. Topographic channel surveys are completed using a total station or auto-level with at least 3 GPS control points. Cross-sections are collected at 9 or more transects spaced out at 1 width intervals. A tile probe with extensions as needed is used to determine the refusal depth in bed or bar areas at 5 to 10 locations across the active channel to estimate the thickness of chat-sized sediment and scour depth in the channel. Permanent monuments are set at the end of each transect and located with total station and/or GPS coordinates and will allow for relatively precise repeat surveys in the future, if needed. Field data from channel surveys will be used to determine channel dimensions, size of channel bedforms, bank or floodplain heights, channel hydraulic parameters for bed load equations, and minimum/maximum depths of potential mining sediment.

Sediment Sampling and Characterization. Bed, bar, and floodplain sediment samples are collected and bagged for laboratory analysis in order to determine textural and geochemical properties.

1. *Bed sediment* samples are collected in glides or plane beds where chat-sized sediment is expected to accumulate. A small plastic bucket is used to collect a core of bed sediment to a depth of 15 to 20 centimeters. Up to three bed sites are sampled within each reach and sites tend to be along transects if possible. At each site, three samples are typically collected across the channel, dewatered by decantation, and placed in a 1-gallon plastic freezer bag. Each sample location is marked with GPS coordinates.

2. *Bar sediment* samples are collected shovel collection at a depth of 3x the maximum clast size in the immediate vicinity on the bar to exclude the influence of surface armoring on textural measurements. The composition of mine sediment inputs to the channel may not vary significantly at the scale of concern here. Chat and tailings pile coring studies indicated that the geochemical profile is random and relatively uniform over large areas in the dump piles (Wixson et al. 1983). Thus, if bar

deposits reflect tailings composition and are well mixed within a reach by seasonal or annual floods, then bar composition will be relatively uniform and surface sampling may reveal information about the deposit as a whole. Typically three samples are collected down the centerline of the bar at head, middle, and tail locations. Samples are stored in 1-quart plastic freezer bags. Each sample location is marked with GPS coordinates. At least two different bar features are sampled at each reach in this manner.

“Core sampling” involves the vertical collection of several samples with increasing depth into the bar deposit to test the assumption that surface samples can be used to determine the composition of the bar deposit as a whole. Core or pit excavation is completed with hand tools such as shovel or posthole digger to refusal or collapse. Samples will be collected at 1-foot (0.3 m) intervals and stored in 1-quart plastic freezer bags. Field logs of the stratigraphy of each pit will be collected as well. If needed, a Geoprobe will be used to collect cores to refusal depth through collaboration with John Schumacher at the USGS or possibly with MSU’s Giddings coring rig. Core sampling will be done at five different bar sites including the large accessible bar deposit on the Big River at St. Francois State Park. Two to three pits will be sampled from a single bar at 3 to 5 different reaches.

3. *Overbank sediment* samples are collected at exposed cut-bank locations where the stratigraphy is clearly shown and no slumping is indicated. The targeted deposits contain evidence of very little to no soil development indicating their relatively young age and formation during the historical or mining period. Field notes on the stratigraphy (color, texture, structure, artifacts) of the exposure will be collected at each core site. Usually 5 to 10 vertical “core” samples are collected down the cut at intervals based on observed stratigraphic units and obvious mining influence. At least two different floodplain units are sampled at each reach: high floodplain (older) and low floodplain (younger) as indicated in the field and located on soil maps (Brown, 1981). In some reaches, other locations in high and low floodplains are sampled if time permits. Samples are stored in 1-quart plastic freezer bags. Each core location is marked with GPS coordinates.

Cross-Valley Coring. A truck-mounted Giddings coring rig will be used to collect push cores along cross-valley transects to check for vertical and lateral variations in contaminated layer thickness, where needed. These sites will probably be combined with geophysical survey lines and/or at areas where the contaminated floodplain is relatively wide such as along the lower section of the Big River. Field descriptions of each core will be collected. A portable X-ray fluorescence spectrometer (XRF) will be used in the field to measure lead and zinc concentrations in the sediment (USEPA, 1998). Selected samples maybe collected and brought back to the laboratory for further textural and geochemical analysis.

Geophysical Subsurface Investigations. Ground penetrating radar (GPR) and direct current electrical resistivity will be used to examine the subsurface composition of bar features and overbank deposits at up to five different locations. The data will help us describe the uniformity of sediment deposits at depth to validate volume calculations.

1. *Ground Penetrating Radar.* We plan to use is a Mala-Ramac system with shielded antennae. Antennae with frequencies- 100 MHz, 250 MHz and 500 MHz will be used along each profile, this will allow for both high depth penetration (100 MHz) and high resolution (500 MHz) investigations. The depth of penetration will depend on the clay and water content of the sediments, but may be as great as 10 meters. The antennae will be dragged along the profiles with the antenna attached to a

computer collecting the data carried by the operator. Each profile will be flagged and the endpoints will be located with GPS. The data will be then be transferred to a computer to be processed and interpreted. Processing includes background noise removal, band-pass filtering, amplitude corrections and possibly deconvolution.

*2. Direct Current Electrical Resistivity.* Soundings will be made across specific profiles. An L and R Mini-Res 4 electrode system will be used and the data will be collected in the Schlumberger sounding mode. At each station, the current spacing will be multiples of three meters starting at 3 meters and going to a maximum of 30 meters. Station spacing will vary between 3 and 5 meters. The data will be analyzed for the Earth's electrical resistivity structure using two-dimensional inversion methods.

## **Laboratory Methods**

Laboratory methods involve the preparation, physical analysis, and geochemical analysis of bed, bar, and overbank samples. All laboratory work is carried out by the Ozarks Environmental and Water Resources Institute at Missouri State University.

Sample Preparation. All sediment samples are stored in labeled plastic bags in the field with sample number, location, and field description verified according to field notes upon receipt by the laboratory. All samples are dried in an oven at 60° Celsius, disaggregated with mortar and pestle (if needed), and put through a sieve set to isolate mining-related size-fractions for gravimetric and physical/chemical analysis.

Sediment Texture. Mining sediment texture is controlled by the milling process, subsequent weathering during fluvial transport, fluvial sorting/selective transport, and degree of mixing with background sediment.

*1. Channel bed and bar samples* are processed similarly to quantify the size distribution and obtain selected size fractions for further analysis. Sieving is accomplished by manual methods for diameters of 2mm or larger and mechanical methods using mechanical sieving for sand- and silt-sized materials. Size fractions will be quantified as percent of total mass of the bulk sample passing through a 32 mm sieve. Sieve stacks are set up as follows to fractionate bulk sediment samples:

64 mm- initial screening of any cobble-sized material, if present

32 mm- maximum size of mine feed into circuit

16 mm- typical maximum size of chat

4 mm- typical minimum size of chat

2 mm- maximum sand size

1 mm- coarse sand break

250 um- maximum flotation tailings size

63 um- approximate minimum flotation tailings size

<63/<32 um- slime particles

2. *Overbank floodplain samples* are prepared and processed in the same manner as channel sediments. However, the size fractionation scheme is as follows:

- 32 mm- initial screening sieve, usually no material in this range
- 16 mm- typical maximum size of chat
- 2 mm- maximum sand size
- 1 mm- coarse sand break
- 250 um- maximum flotation tailings size
- 63 um- approximate minimum flotation tailings size
- <63/<32 um- slime particles

Geochemical Analysis. The geochemistry of selected sediment fractions is used to determine the contamination level of the sediment, indicate the influence of mining source inputs on sediment composition, and evaluate the chemical conditions prevalent within the deposit. The following geochemical data is collected for this study:

1. *Munsell Color and pH.* Color and pH will be determined for the <2 mm fraction of the overbank floodplain samples. Color can indicate stratigraphic units, source/provenance, and redox environment. The pH of the fine-grained portion of the sediment can indicate the potential chemical mobility of metals in the pore water/soil environment.
2. *Total and inorganic carbon analysis.* A CNS analyzer will be used to determine the carbon content of selected samples and distinguish between the carbon in organic matter and mineral grains. "Total carbon" is determined on an untreated sample and "inorganic carbon" is determined after burning off the organic carbon as CO<sub>2</sub> in a muffle furnace at 400° Celsius. Since the primary host rock of the mineralization in the district is dolomite, it is anticipated that mining sediment will have higher inorganic carbon content as carbonate (Ca-Mg CO<sub>3</sub>) than background sediment. Ratios of mining sediment C to background sediment C will be used as an indicator of mining sediment contribution in the sample.
3. *Elemental and metal analysis.* Levels of lead, zinc, cadmium, and barium found in the samples indicate the level mining pollution in relation to contamination thresholds. The content of mining-related metals and pathfinder elements in selected sediment samples and their specific size fractions will be used to calculate the mining contribution using a mixing model comparing contaminated and background samples in much the same way as the carbonate testing described above. Two methods are used for geochemical analysis: XRF analysis in the field or laboratory and/or hot strong acid extraction (aqua regia) with ICP-AES analysis in the laboratory. For bed and bar sediment, three size fraction are evaluated: (i) chat-size, 4 mm to 16 mm; (ii) flotation tailings-size, 63 um to 250 mm; and (iii) slime-size, <63 um. For overbank sediment, two size fractions are evaluated: (i) the entire sand, silt, and clay fraction, <2mm; and (ii) silt and clay fraction, <63 um. Chat-sized samples will first be powdered in a ball mill in preparation for geochemical analysis. High resolution XRF instrumentation may be used for cadmium and barium analysis in collaboration with the USFWS.

## Geospatial Data and Analysis

A geospatial data base and GIS analysis is used to organize and analyze all the field and laboratory data evaluated in this study. High resolution 2007 aerial photographs are used as a base map for this study. Geospatial technologies and analysis are used in this study to evaluate sample reach characteristics, channel storage of mining sediment, floodplain contamination, historical records of channel change, and serial mapping borrow pit volume.

Sample Reach Location and Mapping. All channel survey data and GPS points will be stored in a GIS and displayed on the 2007 base map. This includes channel bed and bar features, sediment sampling points, geophysical transects, and probing locations. High-resolution GPS is used to determine an accurate true elevation for each channel survey. Laser total-station equipment is used to complete the longitudinal survey and some of the cross-channel transect lines. The total station is also used to tie-in the transect surveys and monuments completed by auto-level to the GIS. Within the sample reach, several GPS control points are used to accurately locate the survey in the GIS.

Channel Storage Mapping. Reach-scale measurements of mine sediment storage will be modeled and spatially applied to the entire Big River. A continuous data set of active channel bed width, vegetated bars, recent high bars, and low bars has been created by digitizing of the 2007 photographs. Bed and bar areas can be calculated from these maps and combined with elevation or depth information from the reach surveys to determine volume of bed and bar sediment in the river.

Floodplain Mapping. All the counties in the Big River watershed have published soil surveys available along with GIS data layers of the soil series maps and soil attributes (e.g. Brown, 1981). These soil maps are used to identify floodprone soils adjacent to the Big River. Published soil descriptions and field evaluations by MSU are used to interpret the elevation and age of floodplain units that can be expected to contain historical mining sediment. Field sampling and assessment of metal contaminate profiles are used to verify floodplain interpretations.

Historical Channel Changes along the Big River. In a parallel project, the USGS is rectifying and overlaying historical series of aerial photographs to map out channel changes of the Big River since the 1940s or so. If available, this study will use this information to determine the location of river segments that are storing and releasing bar and floodplain sediment. The amounts of erosion and deposition indicated on the USGS maps can be compared to sediment transport rates to calculate and refine mining sediment residence times and locate the present-day sinks of contaminated sediment for further investigation.



## **Sediment Transport**

Sediment transport rates need to be evaluated to understand the residence time of mining sediment in the Big River and to estimate the rate of contaminated sediment delivery to downstream areas. Three different methods may be used to determine the temporal patterns of mining sediment transport in the Big River: Bedload transport equations, channel borrow pit monitoring, and interpretation of long-term sediment “wave” patterns.

Bedload Transport Equations. Popular bed load transport equations will be used to provide a range of estimates of bed load transport rates for each of the 13 fully assessed sample reaches. These equations include: (i) Shields equation for bed mobility; (ii) Ackers-White equation for total bed-material load ; (iii) Bagnold stream power equation; and (iv) Meyer-Peter-Muller equation (Ward and Trimble, 2004; Rosgen, 2006). These equation will use input parameters based on local channel and sediment texture data collected for this study.

Discharge. Flow magnitude and frequency data required to understand sediment transport is available for three USGS continually recording gages located at Irondale (#07017200), Richwoods (#7018100), and Byrnesville (#07018500). These stations are included in the on-line “real-time” data network.

Borrow pit repeat surveys. Two mill dam sites along the Big River will be used as pilot projects to determine the feasibility of remediation through mine sediment excavation. MSU will perform high resolution total-station surveys of the area before and after sediment removal to monitor sediment trapping rates within channel borrow pits in the channel bed. Repeat surveys will be performed after floods or as needed to document the filling rate of the borrow pit to estimate mining sediment transport rates. GPS control point and survey monuments will be set at each site and a contouring software program used to calculate volume changes of the reach through time.

Long-term “sediment wave” analysis. After analysis of sediment storage volumes and metal concentrations in sediment along the Big River, it may be possible to estimate the long-term rates of transport downstream through the system. An assumed attenuated sediment wave model may be used to describe sediment translation downstream based on the spatial analysis of observed mining sediment volumes and metal concentrations in deposits of different ages.

## **DATA ANALYSIS**

### **Channel volume of mining sediment**

Potential mining sediment storage is calculated for each sample reach based on channel surveys and probe depth measurements. Potential storage will be partitioned according to high bar, low bar, and bed volumes and related to depth or height above the bed. Carbonate and metal ratios based on comparisons of contaminated sediment to background sediment are used to refine the actual mining

contribution as equal to or less than the total volume of sediment in the reach. Geomorphic and storage trends for each sample reach will be analyzed spatially using regression analysis to identify distance or drainage area relationships that model the downstream changes in mining sediment storage. Local storage calculations, either through the model or by reach up-scaling, will be applied to the entire river based on the GIS map of the channel bed and bar locations. Mining sediment volumes outputted from this process will be mapped and summed for the entire river. Geophysical data will be used to verify bar storage volume estimates.

### **Floodplain volume of contaminated sediment**

The depth of mining sediment and concentrations of metals deposited on floodplains of two different ages will be related to location in the drainage network using the soils database and modeled using a regression equation of concentration and depth over distance or drainage area. The resulting model will be applied to the entire Big River floodplain soil map in the GIS to sum the volume and metal mass stored in floodplain locations. Geophysical data will be used to verify floodplain storage volume estimates.

### **Mine Sediment Transport Rates**

As described above, mine sediment transport rates will be evaluated at two and maybe three temporal scales: (i) bed transport equation, (ii) channel borrow pit infilling rates (maybe), and (iii) analysis of watershed-scale patterns of channel and floodplain storage in different ages of deposits. These transport rates will be compared with storage estimates in the river and remobilization/deposition rates determine from USGS historical channel change assessment to determine residence times of mining sediments. Results from elevation pit morphology changes will be compared to current and historic hydrographs and discharge data from relevant stream segment(s). This comparison will give some information on periodicity and magnitude of transport events necessary to move a discreet sediment volume. Also, the time period for contaminated sediment to reach sensitive downstream areas will be evaluated.

### **PRODUCTS AND TIMELINE**

This is a one year project from September 1, 2008 to August 31, 2009. Field work will commence as soon as possible and will be on-going through the Spring semester 2009 and possibly Summer 2009. Given the short timeline for this project, the products of this study are staged as follows:

February 15, 2009 Draft report/data presentation on channel storage for Big River and tributary sites.

March 1, 2009 Draft report/data presentation on floodplain storage for Big River and tributary sites.

April 1, 2009 Draft report/data presentation on geophysical investigation of bar and floodplain deposits.

April 1, 2009 Draft report on mining sediment transport and residence times.

April 7, 2009- Final report on channel storage for the Big River and tributary sites.

April 30, 2009- Final report on floodplain storage for the Big River and tributary sites.

May 31, 2009- Final report on geophysical investigation of bar and floodplain deposits.

June 31, 2009- Final report on mining sediment transport and residence times.

July 31, 2009- Update or addendum on channel and floodplain volumes and presentation of watershed-scale mining sediment budget.

## **BUDGET**

This project has a proposed total budget of \$92,000. Salary includes faculty, staff, graduate assistant, and undergraduate worker. Faculty summer salaries include 1.5 months for Pavlowsky, 1 month for Lecce, and 0.5 months for Mickus. Other salaries include 3 month of staff time, 1 semester graduate assistant, and 200 hours of undergraduate worker time. Travel costs include lodging and meals for a crew of 4 for 25 nights, flight travel for Lecce from North Carolina, and mileage. Supplies costs include field supplies for surveying, sample collection, and data collection and laboratory supplies for sediment sample prep and analysis, and mapping. Per CESU requirements, indirect costs are calculated at 17.5% of the total direct costs. The distribution of the funds requested for this project is as follows:

Salary:	\$38,642
Fringe:	\$9,266
Travel:	\$12,389
Supplies:	\$18,000
Indirect:	\$13,702
TOTAL	<u>\$92,000</u>

## Literature Cited:

Brown, B.L., 1981. Soil Survey of St. Francois County, Missouri. United States Department of Agriculture, Soil Conservation Service and Forest Service in cooperation with the Missouri Agricultural Experiment Station.

Buchanan, A.C. 1979. Mussels (Naiades) of the Meramec River Basin, Missouri. Final report prepared for U. S. Army Corps of Engineers, St. Louis District.

Buckley, E.R., 1908. Geology of the disseminated lead deposits of St. Francois and Washington Counties, Missouri Bureau of Geology and Mines (Missouri Geological Survey): Hugh Stephens Printing Company: Jefferson City, Missouri.

MDNR, 2001. Biological assessment and fine sediment study: Flat River (Flat River Creek), St. Francois County, Missouri. Prepared by the Water Quality Monitoring Section, Environmental Services Program, Air and Land Protection Division of the Missouri Department of Natural Resources.

MDNR, 2003. Biological assessment and fine sediment study: Big River (lower): Irondale to Washington State Park, St. Francois, Washington, and Jefferson Counties, Missouri. Prepared by the Water Quality Monitoring Section, Environmental Services Program, Air and Land Protection Division of the Missouri Department of Natural Resources.

MDNR, 2007. Total Maximum Daily Load Information Sheet: Big River and Flat River Creek. <http://www.dnr.mo.gov/env/wpp/tmdl/info/2074-2080-2168-big-r-info.pdf>

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.

Mosby, D.E., Weber, J.S., and Roberts, A.D., 2008. 2007 Big River Sediment Sampling Executive Summary and Report, Memorandum to File, May 9, 2008. Report prepared for U.S. Department of the Interior, Washington D.C.

Newfields, 2006. Hydrogeology and groundwater quality of mill waste piles: St. Francois County, Missouri. Report submitted on November 30, 2006 as an addendum to the March 2006 "Focused Remedial Investigation of Mined Areas in St. Francois County, Missouri" by Newfields, 730 17<sup>th</sup> Street, Suite 925, Denver, CO 80202.

Newfields, 2007. Volume of sediment in Big River, Flat River Creek, and Owl Creek-St. Francois County mined Areas, Missouri. Report submitted on June 29, 2007 as an addendum to the March 2006 "Focused Remedial Investigation of Mined Areas in St. Francois County, Missouri" by Newfields, 730 17<sup>th</sup> Street, Suite 925, Denver, CO 80202.

Roberts, A.D. and S. Bruenderman. 2000. A reassessment of the status of freshwater mussels in the Meramec River Basin, Missouri. Report prepared for the U.S. Fish and Wildlife Service, Whipple Federal Building, 1 Federal Drive, Fort Snelling, Minnesota 55111-4056. 141 pp.

Rosgen, D., 2006. Watershed assessment of river stability and sediment supply (WARSSS). Wildland Hydrology, Fort Collins, Colorado.

Schmidt, C.J., and S.J. Finger, 1982. The dynamics of metals from past and present mining activities in the Big and Black River watersheds, southeastern Missouri. Final report to the U.S. Army Corps of Engineers, St. Louis District, project No. DACW43-80-A-0109.

Schmitt, C.J., Finger, S.E., May, T.W., Kaiser, M.S., 1987, Bioavailability of lead and cadmium from mine tailings to the pocketbook mussel (*Lampsilis ventricosa*), in Neves, R.J., ed., Proceedings of the Workshop on Die-offs of Freshwater Mussels in the United States: Rock Island, Illinois, U.S. Fish and Wildlife Service and Upper Mississippi River Conservation Committee, p. 115–142.

Smith, B.J., and J.G. Schumacher, 1993. Surface-water and sediment quality in the Old Lead Belt, southeastern Missouri—1988-89. USGS Water-Resources Investigations Report 93-4012.

Ward, D., and S.W. Trimble, 2004. Environmental Hydrology, 2<sup>nd</sup> Ed., CRC Press, Boca Raton, Florida.

Wixson, B.G., N.L. Gale, and B.E. Davies, 1983. A study on the possible use of chat and tailings from the Old Lead Belt of Missouri for agricultural limestone. A research report completed by the University of Missouri-Rolla and submitted to the Missouri Department of Natural Resources in December 1883.

Wronkiewicz, D.J., C.D. Adams, and C. Mendosa, 2006. Transport processes of mining related metals in the Black River of Missouri's New Lead Belt. In the "Center for the Study of Metals in the Environment: Final Report" submitted to USEPA and project officer Iris Goodman by the University of Delaware.

USEPA, 1998. Field Portable X-Ray Fluorescence Spectrometry for the Determination of Elemental Concentrations in Soil and Sediment. EPA-SW-846-6200. Washington, DC: USEPA. 32pp.

**Table 1: Sampling Reaches**

<b>Location</b>	<b>Assessment</b>	<b>River mile</b>
<u>Main Stem-affected by mining</u>		
Leadwood MDC Access	<u>Full</u>	-5
Bonehole	Sed	
Hwy 67 above Flat/Bonne Terre (S)	<u>Full</u>	3
Hwy K below Flat/Bonne Terre (E)	Sed	6
Hwy 67 Campground/Bonne Terre (N)	<u>Full</u>	14
At St. Francois State Park (BAR)	Sed	
Hwy E below St. Francois State Park	Sed	16
Above Mill Creek	Sed	26
Hwy CC at Blackwell below Mill Creek	<u>Full</u>	27
Washington State Park-above Mineral Fork (BAR)	Sed	33
Mammoth MDC Access	<u>Full</u>	38
Brown's Ford MDC Access	<u>Full</u>	49
Above Morse Mill	<u>Full</u>	61
Above Cedar Hill Mill dam	<u>Full</u>	74
Byrnesville above or below mill dam	Sed	80
Above House Spring's Mill Dam/Rockford Beach	<u>Full</u>	84
Hwy W/1/4 mi above confluence w/ Meramec	<u>Full</u>	94/95
<u>Main Stem-background reference</u>		
Irondale	Sed	-21
Below Hwy 8-Leadwood	Sed	-15
<u>Tributary-affected by mining</u>		
Flat River	<u>Full</u>	
Mill Creek	<u>Full</u>	
Mineral Fork	<u>Full</u>	
<u>Tributary- background reference</u>		
Flat River	Sed	
Mill Creek	Sed	
Mineral Fork	Sed	