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

Big River Mining Sediment Assessment Project

Distribution, Geochemistry, and Storage of Mining Sediment in Channel and Floodplain Deposits of the Big River System in St. Francois, Washington, and Jefferson Counties, Missouri

Field work completed Fall 2008 to Spring 2009

FINAL REPORT

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ABSTRACT

The Old Lead Belt is a historic lead (Pb) and zinc (Zn) mining sub-district within the Southeast Missouri Lead Mining District which was a global producer of Pb worldwide from 1869 to 1972. Past and ongoing releases of chat, tailings, and other mining wastes to the Big River have resulted in the contamination of channel sediment and floodplain deposits with toxic levels of Pb along 170 river kilometers of the Big River from Leadwood to its confluence with the Meramec River. Previous studies by the USGS and USFWS identified elevated Pb concentrations in the active channel sediments of Big River. However, what is not well understood are the spatial and temporal patterns of the volume or mass storage of mining sediment in channel and floodplain deposits of the Big River and its major tributaries.

The magnitude and impact of mining operations on the sediment load and geochemistry of the Big River has been significant. Active channel bed and bar deposits are contaminated above the aquatic sediment PEC with >128 ppm Pb from Leadwood (R-km 171) to the confluence with the Meramec River (R-km 0). In channel sediments, the highest Pb concentrations (>1,000 ppm Pb) occur from Desloge (R-km 158.1) to St. Francois State Park (R-km 140.3). Similarly, overbank floodplain deposits are contaminated above the residential soil threshold limit of 400 ppm Pb along the entire length of the river below Leadwood to a depth of 1 to 4 meters or more. In floodplain deposits, the highest concentrations (>2,000 ppm) tend to occur between the Bonehole (R-km 165.3) and Browns Ford (R-km 79.5).

Both fine-grained and coarse sediments are contaminated with Pb and other metals in the Big River. XRF Pb analyses for <2 mm fraction of channel sediment typically approach 2,500 ppm in St. Francois County, while larger chat (4-8 mm) fractions can contain over 5,000 ppm Pb. Mill slimes (<63 um) were released directly to the river during mining operations and contained concentrations of Pb typically >10,000 ppm.

The occurrence of mining chat (2-16 mm) deposits is largely limited to channel segments in St. Francois County between Leadwood and Bonne Terre. Dolomite tailings fragments were only detected in the channel from below the Desloge pile (R-km 158.1) to Highway E (R-km 132.9). Calcium analyses (tailings tracer) suggest that the downstream extent of transport for mining chat is probably about 10 km upstream of the Jefferson County line. However, finer tailings sediment fractions (<2 mm) are present further downstream to Browns Ford (R-km 79). Tile probe depths in bar and bed locations of the channel are used to estimate the storage of contaminated sediment. Average unit storage rates are 2,570 +/- 14% (1s) m^3/100 m from R-km 171 to 90 and 1,580 +/- 12% from R-km 90 to 15.

The storage budget for contaminated sediment and Pb focuses attention on the role of floodplains as sources and sinks of contaminants in mined watersheds. There is about 3,700,000 m^3 of contaminated sediment stored in the channel and 86,800,000 m^3 stored in floodplains. Following, there is 3,800 Mg Pb stored in the channel and 226,000 Mg Pb stored in floodplain deposits in along the Big River. About 63% of the contaminated sediment is stored in Jefferson County, but 73% of the Pb is stored in St. Francois County. Of the total metallic Pb contained in the 227 million Mg of tailings produced during the mining period, 23% still remains stored in tailings piles and 32% is stored in channel sediments and floodplain deposits of the Big River.

INTRODUCTION

The Old Lead Belt is a historic lead (Pb) and zinc (Zn) mining sub-district within the Southeast Missouri Lead Mining District which was a leading producer of Pb worldwide from 1869 to 1972. During the century-long mining period, large volumes of metaliferous wastes were produced during ore processing and stored in piles and slurry ponds near the mill. Generally referred to as tailings, these mining wastes are composed of sand- and fine gravel-sized particles of crushed rock and ore that contain relatively high concentrations of Pb, Zn, and other heavy metals such as copper and cadmium. Presently, six large abandoned tailings piles are located in the towns of Leadwood, Desloge, Elvins/Rivermines, Park Hills/Federal, Flat River/National, and Bonne Terre. The footprints of several piles cover over a square mile each (Figure 1). From about 1850 to World War II, mining wastes were released unabated to the surrounding landscape and nearby streams. After World War II, mining wastes were generally confined to on-site piles and impoundments. However, even after mine closure, tailings materials were still able to enter waterways due to ongoing erosion, slope failures, and dam breaches--such as occurred in 1977 at the Desloge pile (Newfields, 2007). All major tailings piles in St. Francois County have been stabilized or are undergoing construction for stabilization under the regulatory framework of the Comprehensive Environmental Response Compensation Liability Act, commonly known as "Superfund."

There have been concerns for some time about the geochemistry of, and toxic effects posed by, mining sediment in rivers draining the Old Lead Belt (Smith and Schumacher, 1991, 1993; Gale et al., 2004, 2002). Mining-related sediment contamination generally occurs via three mechanisms: (i) direct discharge of ore processing effluents and mine water during active mining periods; (ii) mechanical erosion of metal-laden particles from tailings piles from both active and abandoned mine sites; and (ii) leaching of dissolved weathering products from tailings piles by surface runoff or groundwater over long time periods (Ritcey, 1989; Moore and Luoma, 1990). Relatively low levels of mining-related pollution can cause measureable sediment contamination, since metal concentrations in tailings tend to be 10 to 100 times greater than natural or background concentrations. For example, tailings piles in the Old Lead Belt typically average 2,000 to 4,000 ppm Pb (Wixson, et al., 1983), while similarly fine-grained sediments from background control sites typically contain <100 ppm Pb (Smith and Schumacher, 1991, 1993). Mine tailings can be classified into three different types based on the diameter of the particles produced for specific milling purposes: chat (4-16 mm) for gravity separation; fine tailings (0.06 mm to 0.20 mm) for flotation; and slimes (<32 um) released in mill effluents. In most tailings piles, varying mixtures of all three sizes of materials are present.

"Mining sediment" refers to any channel deposit or floodplain soil along the Big River that was in some part formed by or contaminated with wastes released from mining operations in the Old Lead Belt. It commonly is composed of a mixture of natural watershed-derived minerals (e.g. quartz and feldspar) and contaminated mine tailings (e.g. dolomite and primary sulfides) (Smith and Schumacher, 1991, 1993). In addition, metals sorbed from solution to particle surfaces can also contaminate mining sediment. Mining sediment deposits usually have different textural and mineralogical properties compared to uncontaminated deposits and so can appear visually as a distinct unit or feature.

There is an extensive literature focusing on understanding the physical and geochemical processes in controlling mining sediment transport. It is well known that fluvial processes can effectively disperse contaminated mining sediments far downstream (James 1989, 1991; Knighton, 1989). Indeed, detrital sulfide ore grains about 20 um in diameter from tailings sources were found in reservoir sediments 500 km downstream (Horowitz et al. 1988; Horowitz et al. 1990). Metal concentrations in fluvial sediments generally decrease exponentially downstream from mine source points due to the influence of both physical and chemical processes (Wolfenden and Lewin, 1978; Axtmann and Luoma, 1991). This longitudinal trend of decreasing sediment-metal concentrations from source is caused by the influence of one or more of the following factors: (i) mixing and dilution with tributary sediment inputs (Marcus, 1987; Marron, 1989); (ii) release of metals from the particle surface to the water column by weathering and solution of primary sulfides (Reece et al., 1978; Mann and Lintern, 1983); (iii) selective deposition of higher density, metal-rich sulfide grains along the channel bed close to the source (Best and Brayshaw, 1985; Day and Fletcher, 1991); and (iv) removal from transport by deposition of mining sediment in channel bars and overbank floodplain deposits (Bradley, 1989; Pavlowsky, 1996; Lecce and Pavlowsky, 2001). Indeed, floodplains can act as both source and sink for mining contaminants (Moore and Luoma, 1990). During the period of mining, greater than 40% of the tailings introduced into a river system may go into storage in floodplain deposits (Jeffery et al. 1988; Marron, 1989, 1992). However, after mine closure, subsequent remobilization of stored mining sediment by bank erosion and weathering can continue to contaminate the river for centuries (Ongley, 1987; Leenaers, 1989; Lecce et al., 2008).

Previous studies identified elevated Pb and Zn concentrations as a potential environmental problem in present-day channel sediments of Big River (Schmitt and Finger, 1982; Smith and Schumacher, 1993; Roberts et al., 2009). However, what is not well understood are the spatial and temporal patterns of the volume or mass storage of mining sediment in channel and floodplain deposits of the Big River and its major tributaries. This information is needed to understand the long-term fate of Pb contamination, predict the recovery period, and develop mitigation plans for the Big River. The magnitude of mining sediment and Pb storage in the Big River watershed is only generally understood. It is estimated that out of a total of about 227 million megagrams (Mg) of tailings produced during the mining period, 57 million Mg of tailings (i.e. about 23%) still remain within tailings confinement areas today (Newfields, 2006) (Table 1). Tailings piles contain Pb concentrations ranging from about 600 to 12,000 ppm (Table 2). The mass of Pb storage in the tailings piles (Table 1) is calculated by multiplying three values: (i) volume of tailings in each pile (Table 1); (ii) average Pb concentration in each pile (Table 2); and (iii) specific gravity for tailings piles of 1.9 (lab measurement). Following, about 166,000 Mg Pb is stored in the six major tailings piles and this amount is roughly similar to St. Francois County's peak annual lead production of 179,000 Mg in 1942 (Newfields, 2006). While the majority of these piles have had some level of stabilization which has reduced or contained erosion, questions still remain about the fate of the materials presently in transit in the channel system or temporarily stored in floodplain deposits. A preliminary assessment of the storage of mining chat and tailings in St. Francois County estimated that 840,000 m^3 is stored in channel deposits of the Big River and 9,900 m^3 in Flat River Creek. These estimates were based on visual chat deposit estimates and probe depth surveys at 10 transects along 25 miles of the Big River and 10 transects along 5 miles of Flat River Creek (Newfields, 2007).

The purpose of this project is to improve our understanding of the physical mobility and geochemistry of mining sediment and Pb, Zn, and other metals in the Big River and its affected tributaries in southeast Missouri. In addition, this study aims to reliably quantify the amounts and locations of mining sediment storages within channel and floodplain deposits that are available for future transport. Specifically, it addresses the following objectives and research questions:

(1) Perform a field study to determine the concentrations, geochemical associations, and spatial distribution of Pb and Zn contamination in the channel and floodplain sediments of the Big River;

   a. What are the textural and geochemical characteristics of contaminated mining sediment?

   b. What is the longitudinal pattern of Pb contamination in channel and floodplain deposits?

   c. How far downstream below the St. Francois County mines are mining chat and fine-tailings detectable in channel sediment?

(2) Quantify the volume of potentially toxic sediment stored in channel bed and bar deposits and floodplains;

   a. What is the volume and spatial pattern of contaminated sediment stored in channel and floodplain deposits?

   b. What is the mass and spatial pattern of Pb stored in channel and floodplain deposits?

(3) Evaluate the spatial contamination trends observed to describe present-day source areas and transport processes of mining sediment and Pb and Zn in the Big River Basin.

   a. What is the relative importance of the Washington County mining areas to extent of contamination along the lower segment of the Big River in Jefferson County?

   b. What are the present-day sources of sediment Pb contamination?

   c. To what degree are contaminated floodplains contributing to present-day contamination by bank erosion?

BACKGROUND

The Big River drains the majority of the mining areas in the Old Lead Belt. Past and ongoing releases of chat and fine tailings to the river have resulted in the large-scale contamination of channel sediment and floodplain deposits with toxic levels of Pb along 90 miles of the Big River from Leadwood to its confluence with the Meramec River (MDNR, 2007a; Roberts et al., 2009). Toxic criteria used in this study are metal concentrations found in excess of the Probable Effects Concentrations (PEC) for aquatic sediments established by MacDonald et al. (2000). The PEC is the expected concentration above which harmful effects to aquatic organisms are likely to be observed. In this study, the PEC threshold value for aquatic or channel sediments is 128 ppm Pb and 459 ppm Zn (MacDonald et al. 2000). For floodplain deposits, the threshold limit of 400 ppm Pb was used for residential soil in accordance with U.S.E.P.A. Region 9 "Regional Screening Levels (RSL) for Chemical Contaminants at Superfund Sites" reported at http://www.epa.gov/region09/superfund/prg/index.html. This threshold limit is also being used by U.S.E.P.A. Region 7 for soil contamination projects in Missouri.

The Missouri 2008 303(d) List identifies over 55 miles of the Big River and 10 miles along its tributaries as impaired due to mining sediment, Pb, Zn, and cadmium (Cd). A Total Maximum Daily Load has been approved for Pb, Zn, and sediment for the Big River and Flat River Creek (MDNR, 2007b). Ecological consequences of mining contamination have been documented in the Big River. Reduced freshwater mussel density and diversity have been reported in stream 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 either the Pb or Zn PEC (Roberts et al, 2009). Moreover, elevated levels of metals have been found in aquatic plants and animals in contaminated segments of the Big River (Schmitt and Finger, 1982; Gale et al., 2002, 2004).

The transport and environmental fate of tailings materials and mining sediment in the Big River is largely controlled by the physical characteristics of mill wastes. Tailings are produced by crushing during the separation of ore from host rock. They contain high levels of residual metals since recoveries typically ranged from <80 to 95 percent during the mining period (Taggart, 1945; 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). Channel bed sediments in tributaries draining tailings piles contain abundant dolomite while sediment further downstream in the main channel is dominated by quartz (Smith and Schumacher, 1991, 1993; Wronkiewicz et al. 2006). Mill wastes in the Old Lead Belt are generally referred to as tailings, however, they can be further classified into three different types based on the milling process and texture or grain-size of the material produced. **Chat** is 4 to 16 mm in diameter (i.e. fine gravel) and was produced during the dry gravity separation of ore. **Fine tailings** are 0.06 mm to 0.20 mm in diameter (sand) and were produced during wet separation by shaking tables or flotation. **Slimes** were comprised of powdered rock fragments that are too small (<32 um) to separate and concentrate from the mill feed (Taggart, 1945). These small particles were usually washed through the circuit and released directly to tailings impoundments or nearby streams even though they contained high levels of Pb and other heavy metals (Taggart, 1945; Somasundaran, 1986).

The mobility and rate of transport of mining sediment in Big River has not yet been studied. However, experience indicates that chat-sized and smaller materials can be transported downstream by seasonal floods. Finer-grained mining sediment is transported as suspended load and deposited along channel margins on floodplains and low terrace surfaces during floods. During periods of low flow, chat- and sand-sized particles settle out on the channel bed and form bar deposits. Typically, sediments <2 mm in diameter are the most mobile and contain metal concentrations that are potentially toxic to aquatic life (Schmitt and Finger, 1982; MDNR, 2001 and 2003; Roberts et al., 2009). In addition, small sulfide grains containing high concentrations of Pb and Zn have been detected in channel bed sediments up to 12 km downstream of tailings piles in St. Francois County (Wronkiewicz et al. 2006) and at Richwoods on the Big River (R-km 88) in Jefferson County below Mill and Mineral Fork Creeks (Smith and Schumacher, 1991, 1993). Resistance to mechanical and chemical weathering of the sulfide minerals in the Big River decreases in the order: galena (Pb sulfide), sphalerite (Zn sulfide), and pyrite (iron (Fe) sulfide) (Wronkiewicz et al. 2006).

STUDY AREA

A brief study area description is provided here, but more in-depth information can be found in Brown (1981), Smith and Schumacher (1993), and Meneau (1997).

Geology and Soils

The Old Lead Belt and Big River are primarily located on the Salem Plateau of the Ozarks Highlands. The Big River drains about 2,500 km^2 before it flows into the Meramec River near Eureka, Missouri. Land elevations range from 700 to 1,000 ft above sea level. The rugged terrain is well-dissected with narrow divides. The headwaters of the river are in the St. Francois Mountains which are composed of igneous rocks (Table 3; Figure 2). However, most of the drainage area of the Big River is underlain by dolomite with some limestone and shale units. Sandstones outcrop locally in the southern and northern portions of the basin. The chief host-rock of Pb and Zn mineralization is the Bonne Terre Dolomite of Cambrian age which outcrops at the surface in the southern and eastern portions of the basin (Table 3; Figure 2) . The main ore minerals are galena (Pb-sulfide), sphalerite (Zn-sulfide), and some smithsonite (Zn-carbonate). Other sulfides are also found in association with Pb-sulfide including pyrite (Fe-sulfide, gangue) and various copper sulfides (Smith and Schumacher, 1993). The richest deposits are found in association with shale layers and breccias in the lower third of the formation. In the area, the Bonne Terre Dolomite is typically from 375 to 400 ft thick and typically 200 to 1000 ft deep, but it is exposed at the surface in some places. Upland soils in the area are typically formed in a thin layer of silty Pleistocene loess overlying cherty or non-cherty residuum formed in dolomite, limestone, and shale (Brown, 1981).

Mining History

The Old Lead Belt Mining Sub-district is located in St. Francois County, about 110 km south of St. Louis (Figure 1). Lead was first mined in the region between 1742 and 1762. Early mining involved the extraction of relatively large galena crystals from shallow pits until the middle 1800s. Around 1864 the first organized mining operations began in Bonne Terre and large-scale mining began in the Old Lead Belt from around 1904. Initially, gravity milling produced coarse chat wastes until the 1930s. Froth flotation was introduced in 1917 and produced fine-grained tailings. Annual metallic lead production peaked in 1942 and the last mine closed in 1972.

About 227 million Mg of tailings were produced during the mining period with coarse chat wastes stored in large piles (Table 1). Fine tailings were slurried and transported by pipe to impoundments, called slime ponds, into dammed valleys (Newfield, 2006). Presently, mine wastes of both types cover over 11 km^2 of land in St. Francois County with 12 % of the area as chat piles (Table 1). The Hayden Creek pile is small and, as shown later, does not appear to affect Pb concentrations in main channel sediments of the Big River. The Leadwood pile covers 2.3 km^2 and drains to the Big River by Eaton Creek (R-km 172). The Desloge pile covers 1.5 km^2 in the middle of a large bend of the Big River between R-km 165 and R-km 160. The Federal (4.7 km^2), Elvins/Rivermines (0.6 km^2), and National (0.6 km^2) piles drain into Flat River Creek which flows into the Big River at R-km 155. The Bonne Terre pile covers 1.4 km^2 and drains into the Big River at several points between R-km 145 and Turkey Creek (R-km 136).

Climate and Hydrology

Southeastern Missouri is in a moist continental climate region. The average annual temperature is about 55 ^oF ranging from an average of 32 ^oF in January to 77 ^oF in July. The annual rainfall in the region averages about 40 inches with the wettest period in the spring months. There are three U.S. Geological Survey discharge gaging stations on the Big River located at the following locations:

(1) Irondale (07017200), draining 453 km^2 with a mean flow of 5.2 m^3/s since 1965;

(2) Richwoods (07018100), draining 1,904 km^2 with a mean flow of 20 m^3/s since 1942; and

(3) Byrnesville (07018500), draining 2,375 km^2 with a mean flow of 25 m^3/s since 1921.

County Boundaries

The Big River first flows into St. Francois County from Washington County at R-km 182 at the Hwy 8 Bridge. It then leaves St. Francois County in a progressive manner where it first forms the boundary between St. Francois County (west bank) and Jefferson County (east bank) at R-km 121 at Dickinson Road. The Big River exits St. Francois County completely at R-km 110, about 8 km upstream of

Washington State Park, where it flows between Washington County (west bank) and Jefferson County (east bank). The Big River enters Jefferson County entirely at R-km 99 and remains in the county until its confluence with the Meramec River at R-km 0.

The appendix contains a reference table of important locations by river-kilometer along the Big River including sampling sites, tributary confluences, and road crossings.

METHODS

Sampling Design

To identify watershed-scale patterns in tailings dispersal, mining sediment storage, and Pb and Zn contamination, sampling sites were distributed along river segments affected by mining and along major tributaries. In general, sampling sites were located at bridge crossings or public access areas on the Big River at intervals of approximately 10 km or less, from Leadwood to the confluence with the Meramec River. Twenty five sites were sampled on the main stem of the Big River, including 2 control sites above mining areas and 23 sites near to or downstream of mining areas (Table 4; Figure 3). In addition, seven sites were sampled on major tributaries. Two sites were sampled on Flat River Creek, including one site located downstream of three major piles and one upstream control site. Three sites were sampled on Mill Creek: (i) at the confluence with the Big River, (ii) near the town of Tiff, and (iii) below the town of Mineral Point. Two sites were sampled in Mineral Fork Creek: (i) a downstream site within a few kilometers of the Big River; and (ii) a control site upstream of known mining at County Highway F. Samples of chat and tailing materials were also collected from the piles at Leadwood, St. Joe State Park (Federal), and Park Hill (National).

Field Methods

Field assessment activities for the project were divided into two components: (i) geomorphic analyses of the channel bed profile, cross-section, and depth of sediment storage; and (ii) sediment and soil sampling and characterization of bed, bar, and floodplain deposits. A storage volume assessment including both geomorphic analyses and sediment characterization was completed at 10 sample sites along the main stem of the Big River and three of its tributaries ("data collection" column in Table 4). The other sites were sampled for physical and geochemical properties of channel and floodplain deposits (i.e. bar and glide designations, Table 4). Subsurface sampling of contaminated and undisturbed floodplain soils was completed during this study. Core samples were collected at cut-bank exposures and through the use of a truck-mounted Giddings rig. In addition, the truck-mounted coring rig was also used to collect core samples of bar deposits at an easily accessible location about 2 km downstream of the Bonehole site, upstream of the Desloge tailings pile (R-km 163.4). A separate appendix volume contains detailed maps of each sampling site and the types of information collected. One example is included in the appendix of this report.

Geomorphic Analyses of Channel and Bar Areas.

The center of each sample reach was located within a glide channel unit just above a riffle crest except where low water bridges or dams affect the character of the river (i.e. at Leadwood, Cedar Hill, and Rockford Beach). For each site where the sediment storage volume of the channel was determined, three types of geomorphic data were collected. First, a longitudinal profile along the thalweg or deepest thread of the channel was used to determine bed form and location of riffle and pool areas. Second, nine or ten channel cross-sections--spaced at one channel width intervals--were used to measure channel capacity and locations of channel bar and bed deposits. Third, in order to estimate the thickness of chat-sized sediment and scour depth in the channel, refusal depth in bed or bar areas was determined with a tile probe at 5 to 10 locations across the active channel (similar to Newfields, 2007).

Channel Surveys

Topographic channel surveys were used to determine channel dimensions, size of channel bedforms, height of banks or floodplain surfaces, channel hydraulic parameters for bed load equations, and minimum/maximum depths of potential mining sediment. Surveys were performed with either a Topcon GTS electronic total station, a Topcon GPT-7500 electronic total station, or--at sites not conducive to total station use--a Topcon Autolevel. Survey data were geo-referenced with at least two Global Positioning System (GPS) points collected along the survey with Trimble GeoXH GPS receivers fitted with a Zephyr antenna. At a majority of the sites, surveys were converted to true elevations using high accuracy GPS base station coordinates.

For each survey, a longitudinal profile and several cross-sectional transects were completed to determine channel topography. At each site, 10 channel cross-sections were measured, evenly spaced one channel width apart. Permanent monuments were set at the end of each cross-section and located with total station and/or GPS coordinates so that repeat sampling, if needed, could be conducted more easily. Each cross-section survey included, at a minimum, the following points: the permanent survey monument, floodplain elevation, top of the bank edge, water edge, bank toe, deepest point in the channel (thalweg), opposite bank toe, water edge, top of bank, and floodplain on the opposite bank. To create a longitudinal profile, points were surveyed at the thalweg starting one channel width upstream of the first cross-section and ending one channel width downstream of the last cross-section. Thalweg points were surveyed at each cross-section with at least one additional point in between each cross-sectional transect.

All photographs included in the report were taken by the lead author or OEWRI staff during field work for this study. A record of these photographs is stored by OEWRI at Missouri State University.

Sediment Sampling and Characterization

Two types of in-channel deposits were evaluated for texture and geochemistry in this study. Glides are channel units located along the bed where flow shallows and spreads out at the tail-end of a pool prior to crossing a riffle crest or along a relatively featureless plane bed with shallow flow depth (Figure 4). Bars are depositional features that are exposed above the water line during low flow conditions (Figure 5). To document locations, GPS coordinates were recorded for all sediment sampling sites.

GLIDE SEDIMENT. A small plastic bucket was used to collect a subaqueous core of bed sediment to a depth of 15 to 20 centimeters. Up to three glide samples were collected within each glide channel unit and often two to three glides were sampled per reach site. Multiple samples from a glide were collected along a transect perpendicular to flow at even spacing. After collecting the sample from the bed and placing it in a small plastic bucket, the sample was dewatered by decantation, and placed in a 1-gallon plastic freezer bag labeled with sample location.

BAR SEDIMENT. Bar sediment samples were collected by shovel at a depth of approximately three times the maximum clast size observed on the bar surface to exclude the influence of surface armoring on sediment measurements (Rosgen, 1996, 2006). Bar samples were usually collected at a depth of 10 to 20 cm below the surface. Typically three samples were collected down the centerline of each bar at the head, middle, and tail locations. Where possible, at least two different bar deposits were sampled within each reach. Samples were stored in labeled 1-quart plastic freezer bags.

BAR CORE SAMPLES. A critical assumption of the study is that Pb concentrations in shallow bar and glide grab samples were representative of the average concentration over the entire depth of the deposit. To verify this assumption, a truck-mounted Giddings coring rig was used to collect bar cores to check for vertical and lateral variations in contaminated layer thickness (Figure 6). A 4" diameter and 36" long universal bucket auger was used to extract bar core samples up to 180 cm in depth. Field descriptions of each core were recorded and a portable X-ray fluorescence (XRF) analyzer was used in the field to measure Pb and Zn concentrations in the sediment (USEPA, 1998). GPS coordinates were recorded at each core location.

FLOODPLAIN DEPOSITS. Overbank floodplain samples were collected at cutbank exposures and with the use of a coring truck. Cutbank exposures (referred to as a "pit" in the sample log) were sampled vertically where the stratigraphy was clearly shown and no slumping was indicated (Figure 7). The targeted deposits contained evidence of very little to no soil development indicating their relatively young age and formation during the historical mining period. Field notes on the stratigraphy of the exposure including color, texture, structure, and artifacts were collected at each core site. Usually 5 to 10 vertical "core" samples were collected down the cut at intervals based on observed stratigraphic units and apparent mining influence. An attempt was made to sample at least two different floodplain units at each reach: high floodplain (older) and low floodplain (younger) deposits as determined in the field or located on soil maps (Brown, 1981). In some reaches, additional locations on high and low floodplains were sampled if time permitted. Samples were stored in 1-quart plastic freezer bags. All core locations were located with GPS coordinates.

Push cores were collected with a truck-mounted Giddings coring rig along cross-valley transects to check for vertical and lateral variations in contaminated layer thickness (see locations on Table 4). Field descriptions of each core were recorded and a portable X-ray fluorescence (XRF) analyzer was used in the field to measure lead and zinc concentrations in the sediment (USEPA, 1998).

Laboratory Methods

Laboratory methods involved the preparation, physical analysis, and geochemical analysis of bed, bar, and overbank samples. All laboratory work was carried out by Ozarks Environmental and Water Resources Institute staff at Missouri State University. Standard operating procedures (SOPs) can be found at http://oewri.missouristate.edu/.

Sample Preparation

All sediment samples analyzed at the laboratory were stored in new plastic freezer bags labeled with the sample number, location, and field description. Upon receipt, the laboratory verified the information on the bag with corresponding field notes. Samples were dried in an oven at 60 ^{o}C, disaggregated with mortar and pestle (if needed), and put through a sieve set to isolate mining-related size-fractions for gravimetric, physical, and 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. Textural information is important for interpreting the source and mobility of sediment in a river channel.

Channel bed/glide and bar samples were hand sieved to determine particle size distribution and isolate size fractions for further analysis. Specific size fractions are reported as a percentage of total mass of the bulk sample passing through a 64 mm sieve. Larger clasts (>64 mm) were excluded from sampling because they were too large for the sampling procedures being used, represent a relatively small fraction of the glide, bar, and bank deposits sampled for this study, and rarely originate from mining sources. Sieving was conducted manually on dry samples. Dry sieving saves time and involves less particle disturbance during sample preparation. Moreover, no significant differences in geochemistry were detected in samples derived from dry sieving and wet sieving in a recent study of Big River sediment contamination (MDNRa, 2007).

In this study, "bulk" samples are defined as the as the <64 mm sediment fraction. This distinction is important because some other studies of Big River sediments define bulk samples differently. Roberts et al. (2009) describe the < 2 mm size fraction as a bulk sample. MDNR (2007a) describe a "bulk composite" sample that represents the average geochemistry of several different size fractions analyzed separately including fine gravel (>2 mm) or chat. The selection of a larger range of particle sizes for bulk analysis in the present study is justified because it includes the entire size range of mining inputs (i.e. chat) and bed and bar deposits of the Big River in St. Francois County (Taggart, 1945; MDNRa, 2007; Newfields, 2007).

Sieve stacks were set up to fractionate bulk sediment samples according to the following rationale (mill screen information from Taggart, 1945; size classes after Rosgen, 1996, 2006):

>64 mm- initial screening out of any cobble-sized material, if present
32 mm- maximum diameter of ore feed into the mill circuit; coarse/very coarse gravel break
16 mm- typical maximum diameter of chat; medium/coarse gravel break
4 mm- typical minimum diameter of chat; very fine/fine gravel break
2 mm- maximum sand size; sand/very fine gravel break
1 mm- coarse/very coarse sand break
<250 um- flotation tailings size range; fine/medium sand break
<32-63 um- slime particles size range; silt and clay fraction

In this study, the <2 mm fraction of the sample was routinely analyzed for particle size and geochemistry for all samples. Other size factions, both finer and coarser than <2 mm, were analyzed for selected bar and glide samples.

Chat Grain Counts

Field observations and laboratory tests indicated that angular dolomite fragments typically compose almost 100% of the fine-gravel or chat-sized fraction in tailings piles. This mineral type and shape seemed to be lacking in fine gravel fractions collected from control or uncontaminated river segments. Thus, visual grain counts were used in this study to quantify the direct mining origin of chat-sized particles in the 4-8 mm sediment fraction of glide and bar deposits. Chat-sized grains were classified into five groups: (i) dolomite chips related to tailings inputs; (ii) natural weathered chert and other grains indicative of non-mining sources; (iii) quartz grains also from natural sources; (iv) shale grains from tailings inputs; and (v) slag or coal fragments from industrial sources such as mining, smelters, foundries, or steam engines (Figure 8). Results were tabulated as percent of total number of 50 to 100 grains counted.

Geochemical Analysis

Geochemical analysis is used on Big River sediments to (i) measure the level of contamination, (i) identify the source fingerprint from mining inputs, and (iii) determine the chemical conditions within different fluvial deposits. Geochemical procedures are aimed to evaluate both the mining and natural or background source fingerprints in river sediments (Horowitz, 1991). In Madison County, located just south of the present study area, the geochemistry of mining-contaminated soil samples was found to be controlled by three source factors listed in the order of decreasing significance: (i) inputs from mining wastes; (ii) secondary minerals formed from the long-term supply by natural weathering; and (iii) local bedrock composition (Davies and Wixson, 1987). In addition, the importance of specific geochemical substrates for the transport of mining contaminants such as sulfides, carbonates, and secondary iron-manganese oxides has been previously documented in Big River channel sediments from St. Francois County (Schmitt and Finger, 1982; Smith and Schumacher, 1981, 1983; Wronkiewicz et al. 2006). In order to investigate the geochemical and transport processes affecting contaminant transport in the Big River, the following analytical procedures were selected for geochemical analysis.

INORGANIC CARBON ANALYSIS. It is expected that mining sediment will be enriched in Ca and Mg carbonate grains from dolomite and calcite inputs compared to samples from control sites located outside of mining influence. Thus, relatively high concentrations of inorganic C were assumed to be a specific indicator of the presence of tailings particles in fluvial deposits. An Elementar Vario EL CNHS Elemental Analyzer was used to determine the carbon content of Big River sediment samples. Total carbon was determined for an untreated sample and inorganic carbon was determined after burning off the organic carbon as carbon dioxide (CO_2) in a muffle furnace at 450 ^{o}C.

The SOP for use of the CNHS Elemental Analyzer in the OEWRI laboratory can be found at http://oewri.missouristate.edu/. Standard checks and duplicate analyses are routinely used every 10 to 20 samples. For total carbon analysis on 7 batches of Big River sediment samples, accuracy errors typically ranged from -2 to 1 RD% and precision errors from -5 to 4 RD% (relative difference). For inorganic carbon analysis on 6 batches of Big River sediment samples, accuracy errors typically ranged from -1 to 1 RD% and precision errors from -3 to 13 RD%.

ELEMENTAL AND METAL ANALYSIS. High Pb and Zn concentrations in channel sediment samples from the Big River tend to be positively related to the degree of mining influence (Schmitt and Finger, 1982; Smith and Schumacher, 1993; Roberts et al., 2009). Hence, the concentrations of mining-related metals in sediment samples will be used to quantify mining contribution by comparing contaminated and control samples in the same way as the carbonate testing described above. X-ray Fluorescence (XRF) analysis was used in the field and OEWRI laboratory to determine the geochemistry of mining and background sediment samples. Several other studies have also used similar analytical technology to determine levels of sediment contaminants in the Big River (MDNR, 2001, 2003, 2007a; Roberts et al. 2009). In the present study, an Oxford Instruments X-MET 3000 TXS+ was used to determine the concentrations of Pb, Zn, Fe, Mn, and Ca in tailings, channel, floodplain, and control site sediment samples.

The SOP for using the XRF in the OEWRI laboratory can be found at http://oewri.missouristate.edu/. Standard checks and duplicate analyses were routinely used every 10 to 20 samples. The following error summaries correspond to 22 batches of Big River channel sediment samples for laboratory use of the XRF. For Pb, accuracy errors typically ranged from -6 to 1 RD% and precision errors from -3 to 2 RD%. For Zn, accuracy errors typically ranged from -6 to -1 RD% and precision errors from -3 to 4 RD%. For Fe, accuracy errors typically ranged from -4 to 2 RD% and precision errors from -2 to 3 RD%. For Mn, accuracy errors typically ranged from -22 to 19 RD% and precision errors from -4 to 4 RD%. Finally, for Ca, accuracy errors typically ranged from 1 to 9 RD% and precision errors from -7 to 1 RD%. However, field use of the XRF on untreated floodplain samples over varying weather conditions typically yields poorer levels of accuracy and precision, with errors in the range of 10 to 20 RD%. The wide range of accuracy errors for Mn relates to the relatively low content of the metal in the check standard. However, the median accuracy error for Mn is reasonable at 3 RD%.

PARTICLE SIZE FRACTIONATION. Geochemical properties were compared among three different size fractions to evaluate the effects of selective transport, fluvial sorting, and physical dilution on downstream contamination trends in channel sediment samples. The size fractions are indicative of mining source contributions as follows: (i) chat, 4 mm to 8 mm; (ii) chat-tailings transition, 1 mm to 2 mm; and (iii) fine tailings and slimes, <250 mm. Chat-sized and chat-tailings transition fractions were powdered in a ball mill prior to geochemical analysis to improve analytical accuracy and precision.

GEOCHEMICAL INDICATORS AND TRACERS. Three types of geochemical indicators were evaluated in this study: toxic metals, secondary geochemical substrates, and carbonate tracers.

Toxic metals include both Pb and Zn concentrations. Metal toxicity is evaluated based on published PECs above which ecological effects are expected for contaminated aquatic sediments. The PECs used here are 128 ppm Pb and 459 ppm Zn (MacDonald et al. 2000). The toxic threshold for floodplain soils as prescribed by USEPA Region 9 for residential soils is 400 ppm Pb (http://www.epa.gov/region09/superfund/prg/index.html).

Lead:Zinc ratios are used to isolate subtle changes in source and transport of the contaminated sediments in the Big River. Control sites tend to have very low Pb:Zn ratios compared to contaminated sediments. However, there were variations in the composition of mineral deposits and milling procedures among the major mining areas. Thus, distinct geochemical signatures related to variations in Pb:Zn ratios may be used to track the source contributions of individual tailings piles to channel and floodplain deposits. The Pb:Zn ratios in tailings piles tend to decrease in the following order: (i) >4, Bonne Terre and National; (ii) >1 to 4, Desloge and Federal; and (iii) <1, Elvins/Rivermines and Leadwood (Newfields, 2006) (Table 1).

Secondary geochemical substrates include mineral coatings and organic matter particles that have the capacity to bind metals to relative high concentrations in uncontaminated sediments (Horowitz, 1991). In this study, Fe and Mn concentrations are used to evaluate the potential influence of secondary oxides on contamination trends in Big River sediments. Organic C concentrations are used to evaluate the role of organic matter particles as binding agents of mining-related metals. Hypothetically, as unaltered mining sediment is affected by weathering over time and redox processes release sediment contaminants to pore water periodically, there may be a shift of Pb and Zn from sulfide and silicate minerals to more mobile secondary substrates (Horowitz, 1991; Pavlowsky, 1996; Wronkiewicz et al. 2006). Fe-Mn oxides have been found in sediments from both contaminated and control sites (Smith and Schumacher, 1991, 1993). Moreover, Fe and Mn concentrations also correlate with mining source inputs and are elevated to moderate levels in channel sediments below tailings piles. Following, it may be hard to resolve secondary contamination effects in the Big River since the mining signal may overwhelm more subtle secondary geochemical trends (Schmitt and Finger, 1982; Smith and Schumacher, 1993).

Carbonate tracers indicate source inputs of excess dolomite and calcite fragments introduced to the channel by mill discharges and tailings piles. In this study, inorganic C by elemental analysis and Ca by XRF are used as indicators of tailings particle inputs. Dolomite (Ca Mg $(CO_3)^2$) forms the majority of underlying bedrock of the Big River basin and is the primary host rock of the Pb-Zn mineralization in the Old Lead Belt (Smith and Schumacher, 1993). In addition, calcite (Ca CO_3) is a common gangue mineral associated with Pb and Zn sulfide ores and is the primary mineral found in scattered limestone formations in the region. Tailings particles of all sizes are typically composed of dolomite with lesser amounts of primary Pb, Zn, Fe, and Cu sulfides (Smith and Schumacher, 1991, 1993). Pure dolomite with a Ca:Mg molar ratio of 1 is composed of 21.7% Ca and 13.0% C. Pure calcite is composed of 40.1% Ca and 12.0% C. Thus, a sample composed of 100% tailings would be expected to contain about 21% Ca and the concentration of Ca would increase slightly in proportion to the amount of calcite in the sample.

Carbonate mineral tracers are expected to be a conservative indicator of mining sediment in the Big River. Tailings materials that end up in channel deposits are mainly composed of relatively unaltered dolomitic grains in the very fine sand to fine gravel size range. Since tailings materials were artificially created by the crushing and grinding of uniformly selected ore, gross mineralogy can vary little among different particle size fractions (Taggart, 1945; Wixson et al., 1983). This homogenizing effect is often inherited by mining sediment deposited in the main channel and tributaries of the Big River (Smith and Schumacher, 1991, 1993; MDNR, 2007a; Roberts, et al., 2009). Carbonate tracers will also likely be a robust indicator of tailings inputs with maximum effect concentrations ranging from 10 to 20 times background levels. The term "background" is commonly used to describe the natural or uncontaminated geochemistry and supply characteristics of river sediment. While carbonate bedrock outcrops frequently in bluffs along the Big River and beds of its tributaries, these formations do not apparently produce measureable amounts of carbonate-containing sediment for fluvial transport. Channel sediments from a control site on the Big River at Irondale, far above mining areas, contained no dolomite and only 0.8 to 1.2 % Ca (Smith and Schumacher, 1991, 1993). However, sediments from "tunnel seep" which drains the Desloge pile contain >90% dolomite and from 15 to 20% Ca. Similarly, sediments collected downstream of the seep in the Big River below the Desloge pile contain 85 to 88 % dolomite and 8 to 13% Ca (Smith and Schumacher, 1991, 1993).

Geospatial Data and Analysis

A geospatial data base and Geographic Information System (GIS) were used to organize and analyze field and laboratory data. A series of 2007 aerial photographs with 2-foot resolution were used as a base map. Geospatial technologies and analysis were used to evaluate sample reach characteristics and channel sediment storage capacity of mining sediment.

GIS Data Sources

The Big River geospatial data base is composed of spatial data from multiple sources. Data were either readily available in ArcGIS®, or collected in the field with survey equipment and geo-referenced. Much of the base data were available through the OEWRI Ozarks GIS database. Base data that were not available in-house were downloaded from the Missouri Spatial Data Information Service (MSDIS). The data used for spatial analysis (i.e. channel areas, floodplain areas, river kilometers, in-channel bar areas, etc.) were created in ArcGIS® through a variety of feature editing procedures, both automated and manual. Data were also extracted from 2-foot resolution, leaf-off aerial photographs, (also available from MSDIS). The development of spatial data files involves the creation of vast amounts of subsequent files. Table 5 lists the files and file sources used for this project.

Channel and Floodplain Feature Classification

Channel features were classified based on the interpretation of the 2-foot resolution aerial photographs in the GIS. All features of interest were easily recognizable given the resolution of the photographs and the low flow conditions that existed at the time the photo was taken. In this study, channel features were classified as low flow channel, high bar, low bar, vegetated bar, or delta bar. The low flow channel is delineated by the two sides of the wetted channel that are adjacent to either channel bars or banks. A high bar is the exposed gravel bar surface above the waterline. A low bar is a submerged gravel bar that is visible below the water surface. A vegetated bar is a sub-aerial bar that has been stabilized by vegetation. Finally, a delta bar is defined by accumulations of gravel immediately downstream of a tributary confluence with the Big River. The entire channel length was divided into one kilometer long channel cells along the centerline of the channel and included all channel and bar areas. This GIS layer was used to divide the channel into channel segments for channel sediment and Pb storage calculations.

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 were used to identify flood prone soils adjacent to the Big River. Published soil descriptions and field evaluations by OEWRI staff were used to interpret the elevation and age of floodplain units that could be expected to contain historical mining sediment. Field sampling and assessment of metal contaminated profiles were used to verify floodplain interpretations.

Floodplain areas were delineated using a combination of the digital elevation model (DEM), the alluvial soils layer, and the aerial photographs. First, the 100-year floodplain coverage was evaluated to determine the boundaries of the floodplains on the valley floor of the Big River. However, the boundaries of the 100-year floodplain proved to be too erratic and hard to relate to soil survey data. Therefore, floodplains along the Big River were delineated by best professional judgement (i.e., heads up method). Differences in resolution between the soils layer and the DEM produced slight inconsistencies when viewed simultaneously. These were evaluated separately for each channel-floodplain segment. In order to smooth out differences in floodplain boundaries between contrasting DEM elevations and soil survey units, elevations were extracted from the DEM at the soil type boundaries to identify breaks in the various depositional surfaces. In many cases the surface breaks could be confirmed through various features on the aerial photograph. To facilitate the calculation of floodplain storage for contaminated sediment and Pb, the floodplain was also divided into two kilometer long cells based on the valley centerline. Only floodplain soil areas within the delineated floodplain boundaries were included in the analysis.

In this study, individual floodplain units were designated by the distribution of mapped alluvial soil series as described in USDA soil surveys (e.g., Brown, 1981). Only those floodplain features that were formed or received sediment since the beginning of the mining period to present were included in this analysis. Floodplain areas in soil surveys generally include both active floodplain areas and older terraces of different heights. Floodplains were classified as areas that flood once or more every two years (frequent) and terraces as areas that flood once or more every 20 years (occasional). High terraces were classified as areas that flood once every 100 years (rarely). Additional soil series were mapped on higher/older alluvial terrace surfaces in the Big River valley. However, since the elevations of these surfaces were beyond the range of present day flooding and therefore sediment contamination, they were omitted from this analysis. Floodplain areas for storage calculations were based only on the distribution of high and low floodplain soil series as mapped by the soil surveys.

Four floodplain classes composed of eight soil series were used to describe historical alluvial deposits and older terraces in this study (Brown, 1981):

1. Low Floodplain (LP) with frequent flooding:
75398-Kaintuck series (A/C soil profile; youngest deposit);

2. High Floodplain (HP) with frequent flooding:
66014-Haymond series (A/Bw)- well drained,
66024-Wilbur series (A/Bw)- low-lying areas;

3. Low Terrace (LT) with frequent to occasional flooding:
75453-Sturkie series (A/Bw); and

4. High Terrace (HT) with occasional to rare flooding:
64007-Freeburg series (A/E/Bt/Btg),
66000-Moniteau series (A/E/Btg),
75375-Horsecreek series (A/Bt),
75385-Gabriel (A/Bt).

River Kilometer Scale

Locations along the length of the Big River are referenced by river kilometer (R-km) with R-km 0 at the confluence with the Meramec River (mouth of the Big River). The appendix contains a reference table that relates river kilometer to study reach locations, road crossings, and tributary confluences. The scaling of the R-km system used in this report is based on the center line of the river as determined by Missouri State University staff using a recent aerial photograph geo-referenced in a GIS.

Background Information and Appendices

A complete appendix volume will be provided as a companion volume to this report. However, an abbreviated appendix is included in this report and it contains the following information:

1) River Kilometer and Mile Reference Tables

2) Channel sediment sample locations

3) Channel sediment sample geochemistry

4) Channel sediment sample particle size distributions

5) Floodplain core sample locations

6) Floodplain pit sample locations

7) Floodplain sediment sample geochemistry

RESULTS AND DISCUSSION

Tailings Input Geochemistry

Historical inputs of tailings from the St. Francois County mines were responsible for the large-scale contamination of the Big River system. Therefore, the first step in understanding the spatial patterns of sediment contamination involves obtaining information about the physical and chemical characteristics of tailings piles. The location, size, and geochemistry of the remaining tailings piles in St. Francois County have been previously studied (Tables 1 and 2; Figure 1). Further, the physical and mineralogical characteristics of tailings materials have already been reviewed in this report in the background section of the introduction.

Assessments of the Pb and Zn concentrations in indvidual tailings piles were completed by previous studies (Wixson et al., 1983; Table 2). Variations in tailing composition reflect both the characteristics of the mineralization and the milling process. Tailings sources to the Big River above the Flat River Creek confluence (Leadwood and Desloge) tend to average between 1,800 to 2,000 ppm Pb, while the piles along and below Flat River Creek (Federal, Elvins, National, Bonne Terre) have higher Pb concentrations ranging from 3,000 to 4,000 ppm (Table 3). Average zinc concentrations at in the Leadwood and Elvin piles were typically >3,900 ppm. The National and Bonne Terre tailings piles contain relatively lower Zn concentrations at <500 ppm. Differences in Pb:Zn ratios of tailing source materials should imprint on the mining sediment and may be used to identify source influence of particular tailings piles. Typical Pb:Zn ratios ranged from 0.4 to 0.7 at the Leadwood pile to 7.7 to 13.7 at the National pile (Wixson et al., 1983; Table 1).

Analysis of the data in Wixson et al., (1983) revealed that Pb and Zn concentrations in tailings are log-normally distributed and the geometric-mean is a relatively precise measure of central tendency. The coefficient of variation (Cv%) or relative standard deviation can be used to evaluate the variability or error associated with set of values such as geochemical data. It is calculated as the standard deviation divided by the mean in percent. Arithmetic coefficients of variation in percent (Cv%) ranged from 43%

to 100% for Pb and 36% to 153% for Zn. However, analyzing the log-10 values of the data set normalized the geochemical data and reduced the Cv% to <10%. Geochemical data for soils and sediments are typically distributed in a log-normal manner (Horowitz, 1991). The reduction in the Cv% values by using a logarithmic transformation supports the assumption of log-normality for tailings materials and this aspect may be transferred to contaminants in mining sediment too.

The geochemistry of several different size fractions of tailings was compared for this study (Table 6). In Table 6, the "cr" suffix attached to the sample label indicates that ball mill crushing was used to prepare the sample for XRF analysis. In the Leadwood and National piles, the highest Pb concentrations were found in both the finest (<63 um) and coarsest (4-8 mm) fractions examined. This trend is caused by the tendency of the milling process to be more efficient in recovering Pb and Zn from the middle range of the crushed and ground ore feed (Taggart, 1945). For the 1-2 mm fraction, ball mill crushing prior to XRF analysis resulted in higher metal concentrations in some cases (Table 6), however crushed and uncrushed samples generally yielded similar results as found in another recent study of Big River channel deposits (MDNR, 2007a). As expected, chat and tailings materials contain relatively high Ca concentrations ranging from 21.1 % to 24.2 % (Table 6). Given that the theoretical composition of Ca in pure dolomite is 21.7% and pure calcite is 40%, tailings materials are almost entirely composed of carbonate minerals and generally >98% dolomite. In comparison, the ore mineral galena contains 87% Pb and it would take about 0.35% galena mineral to yield a Pb concentration of 3,000 ppm in a typical tailings sample.

In most cases, the "routine" sediment analysis of the <2 mm fraction yielded results that were in the same range as the concentrations reported for the <250 um and 1-2 mm fractions. Indeed, while finer particles in mining-contaminated sediment in the Big River has been previously reported to contain slightly higher metal concentrations (Roberts et al., 2009), metal concentration ratios between the <63um and <2 mm fractions in tailings and channel sediments tend toward unity suggesting a common geochemical origin and similar composition (Table 7). The 4-8 mm chat-size fraction contains relatively high levels of both metals in the tailings samples tested. The fact that high concentrations of metals were found in the chat-sized fraction underscores the importance of the coarse fraction for metal contamination and long-term storage in streams in mined regions.

Channel Sediment Geochemistry and Particle Size Trends

<u>Comparison of Glide and Bar Geochemistry</u>

Lead concentrations in channel bar samples show similar trends to glide samples suggesting a well mixed sediment load on the bed as well as mixing to depth at the reach-scale (Figure 9). Previous studies on the Big River also found that there was very little within-reach contrast in sediment geochemistry between riffle and pool channel units (Schmidt and Finger, 1982) and bar and bed areas (MDNR, 2007a). At the basin-scale, Pb concentrations in channel sediments follow a distance decay trend from the source to the mouth. Concentrations range from 2,500 ppm at Desloge (R-km 158.1) to near 100 ppm near the mouth (R-km 1.8). Lead concentrations begin to increase at Leadwood and then peak in St. Francois County between the Bonehole (R-km 165.3) and Cherokee Landing (R-km 136.7). Bar and glide samples yield concentrations of concern (above the PEC of 128 ppm) along the entire 171 km distance of the river to its confluence with the Meramec River. From Leadwood to Morse Mill (R-km 170.7 to 49.8) only 3 out of 111 bar and glide samples (<3%) collected contained Pb concentrations below the PEC. However, in the lower portion of the Big River, Pb concentrations were below the PEC in 11 of the 22 samples (50%) collected between Cedar Hill and the mouth (below R-km 40). Channel sediment Pb concentrations along the Big River have remained relatively consistent over the past three years (2007 to 2009). Similar Pb trends were found in both this study and a previous screening-level study by the U.S. Fish and Wildlife Service, even though different depositional features were sampled in the two studies (Roberts et al., 2009) (Figure 9).

Within-Site Geochemical Variability

Since “at-a-site” geochemistry of glide and bar deposits were comparable and produced identical downstream trends (Figure 9), geochemical data were pooled and averaged for each site (Table 8). It is important to understand the variability of such estimates of metal contamination to evaluate them properly. To determine the statistical precision associated with mean values, Cv% values were compared among sites. As with the tailings samples (Table 3), the data appear to be log-normally distributed as Cv% values of logged data are typically 5 to 10 times lower than arithmetic values. Arithmetic Cv% values typically range from 30% to 60% for both Pb and Zn. In comparison, geometric Cv% values are typically <10% for both metals. For environmental data, averages with Cv% values less than 20% are considered reliable.

Site-averaged Pb concentrations rise rapidly below Leadwood (R-km 170.7) from <50 ppm at upstream control sites to peak levels of almost 2,500 ppm between Desloge (R-km 158.1) and St. Francois State Park (R-km 140.3) (Figure 10). After peaking, Pb concentrations decrease exponentially downstream to the Meramec River. While the geometric site means have lower errors compared to the arithmetic means, there is little difference between Pb decay trends as they plot very close to one another (Figure 10). Comparison of geometric site means from this study with Pb data from previous studies show fairly good agreement given that the sampling period for these different studies extends for almost 30 years and includes different types of sediment samples and analytical methods (Figure 11). As expected, earlier samples collected closer to the active mining period and finer-grained sediment fractions tend to yield higher Pb concentrations compared to the present study. The other metals included in this study show similar decay trends as observed for Pb (Figure 12 A-D). With the exception of very high concentrations > 4,000 ppm near Leadwood and Desloge, Zn concentrations are lower than those for Pb (Figure 12-A). Iron concentrations tend to be about 10 times larger than Mn concentration in Big River channel sediments (Figures 12-B & C). The response of Ca to tailings inputs is striking and concentrations drop by over 100,000 times from its peak below Flat River Creek (R-km 147.1) to near background at Cedar Hill (R-km 32.7) (Figure 12-D).

Particle Size of Channel Glide and Bar Deposits

The percent of bulk sediment <2 mm is an indicator of the abundance of fine-grained sediment on the bed. Increases in the fine sediment deposition in the channel near mining areas may be caused by local inputs of sand-sized tailings. Upstream control sites show a similar percentage of fine-grained sediment in glides and bars, ranging from 20% to 35% (Figure 13). Tailings inputs may be responsible for the increasing abundance of sandy sediment in channel bar and glide sediments in St. Francois County below Leadwood (R-km 170.7). In mining affected segments, between 20% and 40% in bar deposits and 10% and 50% in glides is composed of fine-grained sediment (Figure 13). Bar sediments tend to be finer than glide sediments because they were formed and sampled at higher elevations in the channel and the size of sediment in transport tends to decrease with height above the bed (Bridge, 2003). While relatively fine bar deposits are found in the mining areas in St. Francois County, there may be a natural sandstone source responsible for sandy bar deposits in the lower Big River (below R-km 15) (Table 3; Figure 2). Coarse gravel-sized sediments (>32mm) make up less than 20% of bar and glide deposits with the exception of two sites where gravel content is greater than 20% by mass of the sediment found in glides (Figure 14).

Channel sediment in the size range for mining chat of 2 mm to 32 mm is considered "chat-sized." Chat-sized sediment percentages in bar deposits vary widely ranging between 10% and 80% of the sediment by mass (Figure 15). Glides contain chat percentages ranging from 50% to 80%. No downstream trend in chat-sized material is observed. Deposits rich in sand (i.e. a high percentage <2 mm) correspondingly show a relative depletion in chat-sized materials. The relatively high variability of chat-sized material in channel deposits may be due to supply variations from both natural and mining inputs. Control sites (above R-km 171) have relatively high proportions of chat-sized sediments ranging from 50% to 75% and indicate a natural fine gravel source to the Big River (Figure 15). Nevertheless, control reaches tend to have coarser glides and bars overall compared to the mining areas since they are not affected significantly by natural sandstone or sandy tailings source inputs. Therefore, the occurrence of chat-sized material in the channel is not a precise indicator of mining inputs since there is apparently a sufficient supply from other natural sources. However, the mineralogy and geochemistry of chat-sized sediment in mining-affected river segments is different compared to control sites and these trends are discussed below.

Chat Grain Mineralogy

Given that the quantity of chat-sized material in the channel is affected by both natural and artificial inputs, the characteristics of chat-sized grains can be used to determine mining influence. Grain counts based on the shape and mineralogy of the 4-8 mm fraction use dolomite chips as an indicator of chat input from mining areas. Laboratory tests of tailings from the Leadwood, Federal, and National Piles indicated that chat is composed of 100 percent dolomite chips. Conversely, control site sediments typically contain >95% weathered chert and feldspar grains from natural sources, but no dolomite chips. Chert grains from natural sources tend to contain <500 ppm Pb and <1% Ca, while dolomite chips contain more than 5,000 ppm Pb and >20% Ca (Table 9). Slightly elevated Pb and Zn levels in the natural chert and feldspar fraction may be caused by surface sorption of metals from surrounding contaminated deposits and waters, possibly by iron-manganese oxides or contaminated silt coatings (Schmidt and Finger, 1982; Smith and Schumacher, 1991, 1993; Wronkiewicz et al. 2006).

The highest concentrations of dolomite chips in the Big River are found in bar and glide deposits in the segment from a location beginning below the Desloge pile (R-km 158.1) and extending to Highway E (R-km 132.9) in St. Francois County. Farther downstream, reaches below Dickenson Road bridge and the Mill Creek confluence (approximately R-km 120) typically contain 0 percent dolomite chips in the 4-8 mm sediment fraction (Figure 16). Flat River Creek contains high percentages of dolomite chips because it was affected by tailings inputs from several nearby mining operations (Table 1; Figure 1). Conversely, Mill and Mineral Fork Creeks do not contain dolomite chips suggesting that milling operations in these tributary watersheds did not produce chat at levels high enough to be measured in stream sediments. Mining along these tributaries in Washington County primarily involved shallow pit Pb and barite mining which did not, and still does not, involve large-scale milling of Pb ores and creation of large tailings piles like in St. Francois County. However, Washington County mining activities may have released eroded soil and clayey wash water to streams (Figure 1), but not tailings or chat materials in amounts large enough to affect the carbonate mineralogy of sediment loads (Smith and Schumacher, 1991, 1993). In another recent study, relatively high barium (Ba) concentrations (>2,000 ppm) were found in channel sediments of the two major tributaries that drain Washington County mining areas (i.e. Mill Creek and Mineral Fork Creek) (Roberts et al., 2009). Barium concentrations also increased in channel sediments of the Big River below these tributaries and then gradually decreased downstream from there indicating a geochemical source of Ba in Washington and Jefferson Counties that is not present in St. Francois County. However, Washington County was not found to be a significant source of Pb and Zn contamination to the Big River (Roberts et al., 2009). These trends suggest that chat sources were primarily located in St. Francois County and that chat deposits barely extend to the Jefferson County line in the channel of the Big River.

Downstream changes in Sediment Geochemistry

Systematic variations in geochemical trends downstream of mining sources of metals can provide evidence for specific source characteristics and transport processes (Wolfenden and Lewin, 1978; Marcus, 1987). In order to evaluate the effect of particle-size on transport patterns, three size fractions (i.e. <250 um, 1-2 mm, and 4-8 mm) from selected samples were analyzed for inorganic C, Ca, Fe, Mn, Pb, and Zn (Figure 17). High concentrations of inorganic C and Ca in channel sediments indicate a tailings source due to the presence of calcium carbonate minerals from crushed dolomite, limestone, or calcite (Smith and Schumacher, 1991, 1993; Wronkiewicz et al. 2006). In contrast, natural soils in the region are usually weathered and depleted in calcium carbonate (Brown, 1981). The highest concentrations of Ca and C in each size fraction tend to be found in locations expected to receive heavy tailings loads such as below the Desloge pile (R-km 158.1) and confluence of Flat River Creek (R-km 155) (Figure 17-A & B). The lowest concentrations of Ca and C are found in <250 um fraction, suggesting that this fraction either contained lower proportions of carbonate minerals initially or that contributions of fine soil particles from soil and bank erosion are diluting the finer carbonate sediment fraction at a relatively high rate compared to the larger grains studied.

CALCIUM AND INORGANIC CARBON. As expected, the distance of downstream dispersal of each size fraction appears to be negatively related to particle size (Figure 17-A & B). The smallest and most mobile fraction (<250 um) has been transported the furthest downstream to below Mineral Fork Creek (R-km 99). The intermediate-sized, coarse sand fraction has been transported as far as Mill Creek (R-km 115). The largest sediment fraction representing the chat-size fraction has moved the shortest distance downstream with Ca and C enrichment only extending to Cherokee Landing (R-km 137), about

16 km from the Jefferson County line at R-km 121. This dispersal pattern shows that tailings particles are selectively transported by size and sorted longitudinally over a channel distance of 40 km—finer particles are dispersed furthest downstream because they are easier to erode and transport by fluvial processes (Bridge, 2003). It may be possible that this trend is the result of recent transport of the material released by the tailings dam breach at the Desloge pile about 30 years ago. However, C and Ca concentrations tend to peak farther downstream below the Flat River Creek confluence and not immediately below the Desloge tailings dam. This pattern suggests a more cumulative source of the sorted material and not a single pulse-release from a dam break. In addition, as will be made evident by the discussion of mining sediment storage below, the volume of the tailings released by the breach (about 50,000 cubic yards) is relatively insignificant compared to the total mining sediment stored in the channel system.

IRON AND MANGANESE. Iron and manganese are important metals in mining-affected rivers since their distribution in sediments can reflect the influences of both the tailings source of primary mineral particles and the precipitation of dissolved metals released by weathering as oxide coatings on sediment particles (Horowitz, 1991) In general, the dispersal trends for Fe and Mn show similar patterns compared to Ca and inorganic C, but peak concentrations have shifted downstream about 20 km from the Flat River Creek confluence (R-km 155) to Cherokee Landing below Bonne Terre (R-km 137) (Figure 17 C & D). The coarse sand fraction again contains the highest concentrations of both metals due to either primary tailings source contributions or formation of secondary Fe-Mn oxides coatings on sand grains (Horowitz et al., 1993; Evans and Davies, 1994). However, the influence of selective transport by size (i.e. physical sorting) is not as clear for Mn and Fe as it is for Ca. Secondary Fe-Mn oxides have previously been identified in contaminated sediments in the Big River (Schmitt and Finger, 1982; Smith and Schumacher, 1991, 1993; Wronkiewicz et al. 2006). Further, groundwater seepage into the channel from underground mines can be a source of dissolved Fe and Mn that forms oxide coatings shortly after entering surface waters (Smith and Schumacher, 1993; Newfields, 2006; Wronkiewicz et al. 2006). Thus, Fe and Mn dispersal trends may partially reflect the influence of geochemical redistribution causing geochemical peaks to shift downstream and cloud grain-size relationships.

LEAD AND ZINC. The longitudinal patterns of Pb and Zn in bar and glide sediments clearly show the influence of tailing pile sources (Figure 17 E & F). Peak concentrations of both metals occur just below the Desloge pile, Flat River Creek confluence, and Bonne Terre pile where the coarse sand fraction contains the highest concentrations of Pb (5,000 ppm). In St. Francois County, the highest Pb concentrations are associated with the coarsest sediment fractions. However, in the lower segments of the river in Jefferson County, this trend reverses and the <250um fraction becomes the most contaminated albeit at a lower concentration. Zinc trends are a bit different with the <250 um fraction most contaminated at 3,000 ppm at Desloge and below Flat River Creek but then moderates downtream (Figure 17 F). Concentrations of both metals seem to decrease to steady levels below Mineral Fork Creek (R-km 99). Downstream trends in Pb:Zn ratios show the influence of the Leadwood tailings inputs (i.e. relatively high Zn content) on sediment geochemistry above Flat River Creek (Figure 17 G). The Big River below R-km 125 and in Jefferson County contains a relatively high Pb:Zn ratio in the <250um fraction. This trend may be explained by several factors: (i) selective transport of fine-grained sediment far downstream from high ratio tailings piles (i.e. Federal, National, Bonne Terre), (ii) bank erosion inputs of contaminated sediment stored in overbank floodplain deposits; and (iii) low-level contamination from Washington County mines and related soil erosion inputs.

Tributary Channel Sediment Contamination

Channel sediments were sampled and evaluated for texture and geochemistry at seven tributary sites and two control sites along the upper Big River (Table 10). Channel sediments from unmined drainages tend to have Pb concentrations <100 ppm with normal range between 10 and 60 ppm. Zinc concentrations in unmined areas are typically similar or up to twice the Pb concentrations. Ratios of Pb:Zn are usually <0.8 in background channel sediments. One exception is in the upper Flat River Creek at Davis Crossing Road where Pb:Zn ratios are near 1.7 (Table 10). This geochemical effect may be related to the different sediment supply from weathered igneous bedrock in the St. Francois Mountains (Table 3; Figure 3). Indeed, Smith and Schumacher (1991,1993) found an igneous fingerprint in the mineralogy of channel sediments in the upper Flat River Creek. Contaminated channel sediments are obviously found in the lower Flat River Creek at St. Joe Bridge, Pb concentrations are >2,000 ppm with Pb:Zn ratios >2. In Mill Creek, there appears to be slightly elevated Pb concentrations in sediments at Tiff, but well within the regional influence of elevated sediment background levels. However, Zn concentrations seem to be elevated above what would be normally expected. Maybe this is the result of the early Pb mining history and intense Ba mining operations in the Mill Creek watershed. Samples from the lower Mill Creek contain high Pb levels, but the source is probably related to local supply from eroding banks formed within contaminated floodplain deposits along the Big River. The Mineral Point sample was collected on a tributary below an old Pb mining area far from the Big River confluence.

Bar Core Analysis

If surface sediment contamination is an adequate indicator of deeper contamination trends within the larger deposit, then a better case can be made for a surface sediment monitoring program in the Big River. Coring in sand and gravel bars above and below the water table is difficult because most economical coring methods are not suited for this type of sampling and access to bar sites is often limited. In all, eight individual bar cores were evaluated for this study. Three were collected during a previous study at St. Francois State Park by the Missouri Department of Natural Resources (MDNR, 2007a) and five were collected during this study by MSU from a large, accessible bar above Desloge (R-km 163.4) (Table 11). The DNR cores ranged from 70 to 100 cm in depth and the MSU cores ranged from 100 to 180 cm in depth.

MSU bar coring activities yielded three cores at the head of the bar and two at the tail end (Figure 18). Averages of single cores tend to be relatively representative of the surface and uniform with depth. The Cv% values for core means were typically <30% for Pb and Zn (Figure 18). Surface sample variability was evaluated in two ways: (i) arithmetic average of four samples collected in a routine manner; and (ii) arithmetic average of the surface samples from each core. The results showed similar variability as compared to the deeper cores. As shown, the mean concentrations of each core were not identical, but the variability with the core and among surface samples was within limits for a precise analysis. In addition, the grand mean of all four core averages had a Cv% of <30% for Pb.

The next step was to relate surface sample geochemistry to mean core chemistry (Table 11, Figure 19). The relative percent difference between the surface sample Pb concentration and mean core Pb concentration was calculated for each core. At core depths of 1 meter or less, the surface sample concentration was nearly equal to the core mean (Figure 19 A). However, as cores get deeper, mean core values increased to up to 40% of the surface sample value. Given this analysis, surface samples under-predict the mean concentration of deeper cores. For bar depths greater than 1 meter, surface sample data could be multiplied by a factor of 1.2 to 1.4 to correct for depth variations.

Another way to evaluate this relationship is to compare the surface concentration to mean core concentration by direct correlation (Figure 19 B). A regression equation was used to predict the average core Pb concentration given the surface concentration value. A 1:1 line shows that the surface and core mean concentrations are fairly consistent. The values for shallow cores (1 meter or less) plot close to the 1:1 line. The other cores all plot about 400 to 500 ppm Pb above or below the 1:1 line. The conclusion of this analysis is that surface samples are relatively good predictors of deeper core mean concentrations. For bar deposits deeper than 1 meter, surface sample values should be multiplied by 1.2 to correct for depth variations (Figure 19).

The analysis above supports the assumption that the bulk geochemistry of glide and bar surface samples is a good estimate of the composition of deeper materials, at least to the refusal depth of the tile probe (which usually ranges from 0.10 to 2 meters). There are other reasons that justify the homogenous deposit assumption and these are described below.

1. Glide and bar deposits are well-mixed within a reach due to source characteristics. Mining sediment is generally composed of fine-gravel and sand with varying amounts of silt and clay. Sediment in this size range is relatively mobile and can be mixed by floods and re-deposited in bar and bed areas until stabilized by geomorphic conditions or vegetation (Bridge, 2003). In addition, relatively high rates of tailings inputs entered the river system from the same source points for more than 70 years. This is probably enough time for distance-decay relationships between source and sediment geochemistry to balance out and remain relatively stable over time (Marcus, 1987; Ongley, 1987).

2. A recent study of bar deposits in St.Francois State Park indicates homogenous deposit to a depth of about 1 meter (Lister et al., 2009). Several pits were excavated in active bar deposits along the river and both grain-size and Pb concentration were found to not vary significantly with depth.

3. The main stem of the Big River channel is typically bedrock or bluff confined and thusly limited in ability to erode and develop laterally. Therefore, most of the bars along the Big River are of the center or longitudinal types (Rosgen, 1996). When they change location, these bar types tend to erode as a unit and shift randomly across the channel with some downstream translocation of

sediment (Bridge, 2003). Typically, they will not build across the valley floor and gradually bury older deposits with younger materials, at least over timescales of 10 years or so. Given this geomorphic evolution, they may tend to be well mixed over the time of interest to this study. Nevertheless, there is always the chance that more or less contaminated sediments can be buried at depth compared to surface materials in the bar deposits along the Big River due to local variations in bar sedimentation and time of mining sediment inputs..

4. In some places, the depth of floodplain contamination extends below the present-day bed elevation suggesting that the bar deposits in that reach are relatively young and of similar age.

Thus, it is suggested that most of the channel bar deposits containing mining sediment are composed of sedimentary bodies that are of similar age and are generally homogenous. Bar and bed deposits are not time-transgressive in form and so do not usually yield systematic age and compositional changes vertically or laterally. This conclusion is supported by the findings that within-reach geochemistry (e.g. Pb concentration) does not vary much among glide, bar, and riffle tail deposits (Table 8; Figure 9) and between riffle and pool sediments (Schmidt and Finger, 1982) in the Big River.

Lead Concentrations in the <2 mm and Chat Fractions of Channel Sediment

The <2 mm fraction was routinely analyzed by XRF for metal content for all sediment samples evaluated for this study. Accordingly, the assumption is made that the <2 mm fraction is an accurate indicator of the Pb concentrations in mining sediment as a whole including contributions from the chat fraction. For floodplain deposits, this assumption is reasonable since almost all overbank sediment is <2 mm in size. However, a significant fraction of the channel sediment is coarser than 2 mm (Figure 13). Indeed, the abundance of the >2 mm or gravel fraction in contaminated bar and glide samples averages 52% and 69% in St. Francois County and 47% and 73% in Jefferson County, respectively. In order to evaluate the validity of storage estimates based on the geochemistry of the <2 mm fraction, Pb concentrations were compared between the <2 mm and chat-sized (4-8 mm) fractions from the same sample in a subset of bar and glide samples (n=29). While not a perfect correlation, the relationship between the two fractions is linear and very close to 1:1 (slope=0.97 and r^2=0.76). While the geochemical mobility of the Pb in the two different fractions may be different, the total lead concentration is similar. Thus, Pb concentrations derived from the analysis of the <2 mm fraction can be applied to the bulk sediment (including chat) in storage calculations for channel sediment.

Contamination Trends in Floodplain Deposits

In all, 512 samples of floodplain deposits from 71 cores or pits were evaluated for this study (see appendix). The 25%-tile, median, and 75%-tile concentrations were 96 ppm, 902 ppm, and 1,798 ppm for Pb and 110 ppm, 212 ppm, and 483 ppm for Zn, respectively. Sixty-four percent of the samples exceeded the PEC threshold of 400 ppm Pb. Background Pb concentrations in uncontaminated basal layers from 44 floodplain cores at 14 sites along the main stem of the Big River had a geometric mean of

45 ppm with a high range value of 70 ppm. The geometric mean of background Zn concentrations is 90 ppm with an upper limit of 146 ppm. Typical Pb-Zn ratios in background floodplain sediments are approximately 0.5.

Depth of Contaminated Floodplain Deposits

In order to calculate the volume of contaminated soil and mass of Pb stored in floodplain deposits, the depth of contamination was determined at the core depth where Pb concentrations fall below the residential soil threshold of 400 ppm. The contaminated depth varies downstream ranging from <1 meter to as high as 5 meters (Figure 20). A step model was used to estimate contaminated soil depths in floodplain areas along the Big River from Leadwood to the confluence with the Meramec River (Table 13). In the step model, average contaminated depths along segments of the Big River ranged from 1.8 m to 3.1 meters. The Cv% for depth estimates typically ranged from 30 % to 63 %. More study of floodplain contamination trends at the reach-scale must be completed to improve on this depth model.

Maximum Floodplain Contamination

Maximum Pb concentrations in floodplain deposits were high (>2,000 ppm) from Leadwood all the way to the mouth and did not show the expected trend of decreasing Pb concentration with distance due to dilution (Figure 21). The highest Pb concentrations (>8,000 ppm) measured during the study were in cores collected in Jefferson County at Washington State Park (R-km 101.7) and Browns Ford (R-km 79.5). Moreover, peak Pb concentrations >6,000 ppm were found far downstream near Meramec River confluence at Highway W (R-km 1.8 and 2.8). The most contaminated floodplain deposits typically occur in brown to light brown layers that range from 0.2 to 0.6 m thick and have a silt loam texture. Occasionally, heavily contaminated gray or mottled-brown fine sand layers <0.2 m thick are found in floodplain deposits that occur closer to mining source areas in St. Francois County. In general, the most heavily contaminated floodplain layers are found in association with higher relief areas of frequently flooded floodplains at soil depths ranging from 1 to 3 m. More moderately contaminated floodplain deposits occur across a variety of floodplain locations and range of soil depths.

Surface Floodplain Contamination

Downstream contamination patterns of floodplain surface deposits (i.e. within 0.3 m of surface) show a different pattern compared to peak Pb concentrations (Figure 22). Lead concentrations in surface soils are about one-third those of the maximum levels and show longitudinal decay trends similar to that of active channel sediments (Figure 9). The surface deposits are relatively recent, probably less than 30-50 years old, and reflect a record of mining contamination related to a period of decreasing ore production, mine closure, and in-transit sediment delivery with little new tailings sediment creation. It is possible that the main supply of the contaminated sediment and Pb to the surface soil is related to the weathering of in-channel deposits (Wronkiewicz et al., 2006) and the downstream dilution of this source during floods. Nevertheless, surface soils of low and high floodplains contain from 1,500 to 3,000 ppm Pb between Leadwood and Browns Ford (R-km 79.7) and from 500 to 1,500 ppm Pb from below Browns Ford to Hwy W (R-km 1.8) (Figure 22).

Floodplain Contamination Processes

Typically, concentrations of mining-contaminants in sediments tend to decrease noticeably over long transport distances from source points (Wolfenden and Lewin, 1978; Axtmann and Luoma, 1991). Thus, the occurrence of high Pb concentrations (>6,000 ppm) in floodplain soil layers near the mouth about 135 km downstream of the Bonne Terre pile (last tailings source) is striking because of the lack of sedimentary dilution effects (Figure 21). Interestingly, a downstream decay trend is shown by surface floodplain soil Pb concentrations indicating a sedimentary dilution effect on recently contaminated floodplain deposits (Figure 22). The maximum trend (little/no dilution) was deposited during the period of peak mining when the mills were running nonstop and few pollution controls were in place. Field evaluations of floodplain stratigraphy suggest that the most heavily contaminated floodplain units were probably deposited after the onset of large-scale mining around 1900 and prior to the widespread implementation of managed tailings ponds in the late 1930s. In contrast, the surface floodplain trend (strong dilution) reflects contaminated sediment transport during the post-mining period after 1972 when mines were closed and the primary source of contamination was the erosion of tailings pile and remobilization of previously contaminated mining sediment. While more studies are needed to confirm the stratigraphic relationships described above, errors are probably on the order of decades at most and do not negate the results described in this section.

Interpretation of the contrasting sediment contamination trends present in floodplain layers from the two different times periods requires an understanding of both the mining history in the Old Lead Belt and the sedimentation processes during the mining period. Floodplain contamination in mined watersheds generally involves three processes: (i) delivery of excessive supply of tailings to the channel; (ii) transport and deposition of contaminated sediment by overbank floods; and (iii) downstream decrease in metal-sediment concentrations due to sediment dilution from tributary/stream bank inputs and alluvial storage by channel and floodplain deposition (Bradley, 1989). Floods capable of inundating floodplains along the middle and lower segments of the river would be caused by regional storm systems. Under these storm conditions, tributaries would supply watershed contributions of suspended sediment and bed load to the main stem of the Big River from upland soil, gully, and channel bank erosion sources. Thus, dilution of the mining sediment load should occur downstream. This scenario explains the recent trend of floodplain contamination as shown in surface soils (Figure 22). However, there is little evidence for peak Pb dilution in floodplain layers deposited during the mining period. Thus, the explanation for peak Pb transport must involve mining-related source and transport factors (numbers i and ii above), and not upland sediment supply (number iii).

It is hypothesized that the highest Pb concentrations in floodplain layers deposited along the lower segments of the Big River in Jefferson County (as well as St. Francois County) were probably caused by the release of very fine tailings particles or “slimes” from mining operations in St. Francois County. Slimes are composed of powdered rock particles too small to allow metal recovery that were usually washed through mill circuits with little control (Taggart, 1945; Somasundaran, 1986). Given that the mills operated continuously, there would be a constant supply of slimes being produced and dumped into Big River and Flat River Creek. During low flow periods, loose deposits or suspensions of these small particles probably accumulated below mill input points in pools and other low energy areas within the channel. When floods occurred, slimes were scoured from fair-weather storage areas in the channel and then flushed *en masse* down the length of the Big River in an episodic sediment pulse or slug. Assuming an excessive and readily mobile supply of cohesive and muddy slime sediment already in the channel, entrainment would occur almost instantaneously and transport would occur in the form of a relatively concentrated and dense flow that could partially resist turbulent mixing and in-channel dispersal. Overbank floods would spread out from the channel and deposit contaminated sediment over adjacent floodplains one event at a time during the period of highest rates of slime delivery to the river (probably between 1910 and 1930). It may be possible that a catastrophic tailings dam break could also deliver high loads of tailings to the channel in an episodic manner. A tailings dam break would release chat and fine sand tailings as well a slime material, but there is no chat and little tailings sand associated with peak Pb contamination layers below St. Francois State Park at R-km 140. Typically, maximum Pb concentrations in floodplain soils are usually associated with finer material in the silt and clay size range.

Indirect evidence in support of the slime hypothesis was observed during field work for this study. Two slime deposits were sampled during this study and the geochemical results lend support to the slug transport hypothesis described above. The first sample was collected at the Desloge site (R-km 158.1) from the channel bed where the slime deposit was partially exposed from underneath chat-sized gravel. The geochemistry of sample #1 is as follows: 13,706 ppm Pb, 1,676 ppm Zn, and 10.3% Ca. The second sample was collected at the Bone Hole site (R-km 165.3) where cohesive blocks of the material had been ripped up by an excavator during sediment removal for a borrow pit mitigation project. The geochemistry of sample #2 is as follows: 20,695 ppm Pb, 3,755 ppm Zn, and 14.6 % Ca. These Pb levels were some of the highest concentrations measured in this study and clearly support the hypothesis that slime particles, as well as other mining sediments, from St. Francois County mines were responsible for historical floodplain contamination along the middle and lower sections of the Big River.

The in-channel slime deposits described above indicate that not all slime materials were mobilized by floods and that buried slime deposits may represent a potential source of mobile Pb and Zn in other locations in the Big River. The preservation of these distinct tailings deposits is explained as follows. Typically, floods will transport recent slime sediments downstream. However, if enough time passes between floods, slime deposits will compress under gravity, expel pore water, and form very cohesive layers that are relatively resistant to erosion. If conditions are right, other channel sediments will bury these deposits and preserve them as a distinct unit in the sub-stratum of the channel bed. The lead author (Pavlowsky) has seen similar channel deposits in another carbonate-hosted Pb-Zn District in Wisconsin. In the Old Lead Belt, these slime deposits are reduced, bluish green, and very cohesive.

<u>Average Floodplain Contamination</u>

Average floodplain contamination trends represent the cumulative influence of mining sediment deposited during the entire history of active mining and post-mining contamination. The average Pb concentration for the contaminated portion of each core ranges from 1,000 ppm to 4,000 ppm between Leadwood and Browns Ford (R-km 79.7) and 500 ppm to 3,000 ppm from below Browns Ford to Hwy W (R-km 1.8) (Figure 23). Only the sample values from the length of the core that contained Pb concentrations above the residential soil limit of 400 ppm were included in the mean calculation (Figure 20). A polynomial regression curve has been fitted to the data. The equation for the curve was used to predict Pb concentrations in floodplain deposits for the Big River (Figure 23). While the average Pb concentrations for contaminated cores shows a decay trend downstream from source, this trend is attenuated somewhat due to the probable influence of slug-like transport of very contaminated slime sediments downstream, as described above. A comparison between the Pb trend and the trends for other mining-associated metal underscores this effect on Pb transport and floodplain deposition. Both Zn and Ca are found in relatively high concentrations in St. Francois County but their levels drop off rapidly downstream in Jefferson County in contrast to the Pb trend (Figure 24). A similar pattern is shown for average core Fe and Mn concentrations (Figure 25).

Spatial Variability of Floodplain Geochemistry

Floodplain deposition and contamination is not uniform across the valley floor. Sediment depth and Pb profiles vary longitudinally, vertically, and laterally within floodplain deposits.

Vertical variations in geochemistry indicate temporal changes in both sediment deposition and metal contamination rates at a floodplain core location. High concentrations of Pb can be found in floodplain deposits from Leadwood to the confluence with Meramec River, with peak Pb concentrations ranging from 1 to 4 m in depth (Figure 26). In core sediment layers deposited during the mining period on relatively flat floodplain surfaces, Pb peaks are clearly shown in core profiles. However, where deposition occurs on channel margins or after mine closure, peak Pb core profiles are not as heavily contaminated or clearly delineated. Indeed, near channel cores in the low floodplain (i.e. Kaintuck soil series) show relatively deep contamination, but at a lesser concentration than older historical high floodplain deposits formed during the period of maximum tailings supply (i.e. Haymond soil series) (Brown, 1981) (see “near channel cores” in Figure 26). Near-channel deposits are significant because there is potential of remobilization where the river has been actively migrating over recent time. Vertical profiles in concentrations of Zn show similar trends as for Pb (Figure 27). Calcium concentrations in contaminated floodplain deposits range from 14 to 19 % in St. Francois County to <2% along the lower segment in Jefferson County (Figure 28). The occurrence of higher Ca concentrations in contaminated floodplains in St. Francois County is probably related to the presence of higher percentages of dolomitic fine tailings (fine sand grains) in floodplain deposits. Decreasing content of sandy tailings in downstream floodplain deposits may be related to: (i) high sand supply rate due to close proximity to mining sources; (ii) lack of tributary inputs to dilute tailings loads; (iii) higher fluvial energy available to transport sand up on floodplains due to geomorphic conditions; and/or (iv) dilution of tailings sand signal by sediment inputs from Mill Creek and Mineral Fork Creek.

Contaminated floodplain deposits usually extend laterally across the entire valley floor where floodplain soils have been mapped as being frequently or frequently to occasionally flooded (Brown, 1981). A good example of the range of lateral core variations in contaminated floodplain deposit thickness and peak Pb contamination is shown for Washington State Park (R-km 101.7, transect #1) (Figure 29). The depth of contaminated soil in the floodplain ranges from 1 m near the valley wall to as high as >4 m close to the present channel. Concentrations at the surface are elevated, but relatively consistent across the valley floor at or just below 2,000 ppm Pb. Maximum Pb concentrations found in individual cores near the surface range from 2,000 ppm in cores #2, #3, #7, and #8 to as high as 12,000 ppm in core #6 (Figure 29). Notice that contaminated sediment is found below the present channel bed elevation at core #8. This cross-valley Pb trend also indicates that since the most contaminated deposits occur in cores #4, #5, and #6, the channel location was about 50 to 100 meters further to the south (in the vicinity of the most contaminated cores) during the peak mining period. Core profiles along three other cross-valley transects show similar trends for Pb at St. Francois State Park (R-km 140.3), Washington State Park (R-km 101.7, Transect #3), and Morse Mill (R-km 49.6) (Figures 30, 31, & 32).

Tributary Floodplain Contamination

Floodplain cores were collected for geochemical analysis at three tributary sites: Flat River Creek, Mill Creek, and Mineral Fork Creek (Table 13). As expected, floodplain deposits are heavily contaminated along Flat River Creek below the old tailings piles to concentrations of up to 4,000 ppm Pb and 1,000 ppm Zn. Floodplain deposits along both Mill Creek and Mineral Fork Creek contain low to moderate levels of Pb contamination with one core sample in Mill Creek exceeding the soil threshold level (>400 ppm Pb). Zinc concentrations are also elevated to relatively high levels in floodplain deposits (Table 13). Since large-scale Pb and Zn mining operations and tailings production did not occur in Mill Creek and Mineral Fork Creek watersheds to near the extent as in St. Francois County, the low levels of Pb contamination present are probably related to nonpoint influence of various past and present soil disturbance, mining, and other industrial activities. In small drainage basins containing widespread mineralization, natural weathering and erosion processes can transport relatively high concentrations of metals downstream to become enriched in channel and floodplain sediments (Rose et al., 1970; Hawkes, 1976; Ottesen et al., 1989). The degree of influence, if any, of this potential natural contamination source on Pb and Zn concentrations in tributary floodplain soil geochemistry is not clear at present. However, the relatively low background levels of Pb and Zn measured in uncontaminated basal units of floodplain cores along the Big River in Jefferson County suggests little effect on main stem metal trends.

Pb:Zn Ratios of Floodplain Deposits

Examination of the spatial patterns of the Pb:Zn ratios and their variations with sediment size can yield clues to identify the sources of channel contamination in Jefferson County. The Pb:Zn ratios in contaminated floodplain deposits tend to increase downstream from <2 at Leadwood and Desloge , 4 to 8 at the Jefferson County line, and up to 10 along the lower Big River (Figure 33). The high-ratio floodplain deposits in Jefferson County do not reflect local source influence, but rather transport of mining sediment contaminated from tailings released from tailing piles in St. Francois County (Tables 1 & 6). Local sediment supply from natural sources and tributary inputs in Jefferson County is largely a low-ratio source. Uncontaminated floodplain sediments along the Big River and both channel and floodplain sediments from Mill and Mineral Fork Creek tributaries tend to have Pb:Zn ratios <1 (Tables 10 & 13; Figure 33). However, as discussed earlier, Pb:Zn ratios tend to be much higher in samples from the Federal, National, and Bonne Terre piles (i.e. >10) (Tables 1 & 6). Moreover, the two slime samples collected in this study have Pb:Zn ratios of 6 at the Bone Hole and 8 at Desloge in a river segment affected by tailings inputs with low ratios (i.e. <2 at the Leadwood and Desloge piles (Table 1).

It is probable that the slime fraction from in samples of higher ratio tailings at Bonne Terre and Flat River would have supplied even higher-ratio particles to the channel. These results indicate that the high Pb:Zn ratios in the floodplain deposits of Jefferson County were caused by tailings inputs from St. Francois County. Thus, mining activities in Washington County seem to have little effect on the regional trends of Pb and Zn contamination in the Big River (see also Roberts et al., 2009).

Comparisons of spatial patterns of Pb:Zn ratios between channel sediments and floodplain deposits can help identify contamination sources to the Big River in Jefferson County. The <2 mm fraction of channel sediments in the Big River tends to have Pb:Zn ratios that increase from 1 at Leadwood to 2 to 4 at the county line. From that point, ratios decrease to 1 to 2 at the mouth (Figure 34). The ratio pattern of the <2 mm fraction tends to follow the trend of high Pb:Zn ratio values in the <250 um fraction of about 3 in Jefferson County (Figure 17 G). Further, the <250 um fraction is the most contaminated of the fractions evaluated here, suggesting that it is strongly influencing the overall ratio trend of the <2 m fraction (Figure 16). The source of high ratio sediment in the <250 um channel fraction may be the contemporary delivery of suspended sediment load from St. Francois County. However, the relatively higher ratios in the <250 um channel sediment fraction (i.e. fine tailings- and slime-sized fractions) may also be related to river bank erosion and the remobilization stored high ratio sediment (possibly of slime origin during the first half of the mining period) (Figure 33). Thus, present-day contamination of channel sediments in the lower Big River in Jefferson County is probably related to varying contributions of at least two sources of contaminated fine-grained sediment: (i) on-going weathering and remobilization of stored mining sediment in St. Francois County (distant source); and (ii) river bank erosion in Jefferson County (local source).

Storage of Contaminated Sediment and Lead

Channel Sediment and Lead Storage

MODELLING APPROACH. The volume of in-channel glide and bar sediment storage was estimated using field survey data from reaches at 10 sites on the main stem of the river. Contaminated channel storage volume in cubic meters was calculated as: reach length (m) multiplied by mean channel width (m) multiplied by mean probe depth (m). Probe depth transects used to calculate storage cross-section areas were divided into glide and bar areas to better understand the distribution of contaminated sediment on the channel. Contaminated sediment was identified by a step model where sample average concentrations were applied to discrete river segments (Table 14; Figure 35). Total contaminated depth was operationally approximated by the probe refusal depth since surface samples were contaminated to concentrations above the PEC by the step model all the way to Cedar Hill (R-km 32.7) (Table 11). In the Big River below Cedar Hill, Pb concentrations in about half of the channel sediment samples collected fell below the PEC with a mean value of 122 ppm and a standard deviation of 58 ppm (n=8) (Table 14). Therefore, a conservative approach was taken and sediment volumes below Cedar Hill were not considered for inclusion in contaminated volume estimates. However, correlation analysis of surface and core samples suggests that Pb concentrations may increase with deposit depth (Figure 19). Because of potentially slightly higher concentrations at depth as well as sampling error, future sediment surveys might be expected to sometimes identify this segment as “contaminated” although just above the PEC.

CHANNEL CHARACTERISTICS. Sample reach lengths (or longitudinal profiles) on the main stem ranged in length from 305 m at Cherokee Landing to 771 m at Hwy W (i.e. 11 to 18 bankfull widths) (Table 15). Mean active channel width ranged from 31 m at Hwy 67 above Flat River Creek to 53 m at Rockford Beach MDC Access (Figure 36). If these two extremes are removed from consideration, channel width only increases downstream by <5 m over a distance of 171 km (Figure 19). A regression equation relating distance (in "R-km") to channel width (m) was used to calculate the reach width of channel cells for sediment storage calculations (Figure 37).

Mean probe depth ranged between 0.37 to 0.80 m at 9 out of 10 sites (Table 15; top of blue bar, Figure 38). The furthest downstream site at Highway W (R-km 1.8) near the confluence with the Meramec River had a mean sediment depth of 0.09 m. This reach has bedrock exposed along the bed in several places and also has a cobble bed with little fine sediment accumulation. Thalweg probe depths averaged from 0.2 to almost 1 m (top of red bar, Figure 38). Assuming that the thalweg should normally be at bedrock or on cobble where probe depths would be <0.2 m (see site M-24), some of these channels are in a slightly aggraded condition where bed elevation may have risen over time, but we have no reference stream data for comparison. The mean probe depth of the deepest point on each transect ranged from 1.2 m to almost 2 m (top of green bar, Figure 38). The deepest probe refusal depths measured in this study were 3.2 m at Blackwell and 3.3 m at Rockford Beach. At some locations along the Big River in Jefferson County, average probe depths may not indicate just the depth of "chat" deposits, but also fine-grained sediment layers (cohesive gray to light brown) composed of material from bank failure, back-water deposition, and older alluvium. A regression equation relating distance (in "R-km") to mean probe depth (m) was used to calculate the reach sediment depth in channel cells for sediment storage calculations (Figure 39).

UNIT VOLUME SEDIMENT STORAGE. Unit volume storage per 100 meters of channel length decreased downstream, excluding Rockford Beach (Table 15). Volume estimates from Leadwood (R-km 171) to Blackwell and the Mill Creek Confluence (R-km 115) are slightly higher, but comparable with the recent Newfields report (Newfields, 2007) (Figure 40). Average unit storage rates are 2,570 +/- 14% (1s) m^3/100 m from R-km 171 to 90 and 1,580 +/- 12% from R-km 90 to 15 (Figure 41). Storage rates can be locally high behind low water bridges or old mill dams such as found at Leadwood and Rockford Beach sites. Bar deposits typically contain about 10% of the total contaminated sediment in the reaches studied, but may range from 0% to 35% (Table 15; Figure 42). This proportion is roughly equivalent to the bar areas shown on 2007 aerial photography (Figure 43). To estimate depth errors caused by probe limitations due to armoring or pavement layers buried in bar deposits, sediment depths were recalculated for the deepest probe depth at each cross-section (in contrast to the average probe depth across each transect). Reach sediment depths increased to a maximum of 1.5 m and unit storage volumes increased by 1.4 to 2.7 times (Table 15). It is probable that the actual sediment depth is somewhere between the mean and maximum depths reported here (Table 10).

SEDIMENT VOLUME. A distance-storage regression equation was used to predict the contaminated sediment storage for 1 km channel increments from Leadwood (R-km 171) to the Meramec River (R-km

0) (Figure 40). The total volume of contaminated sediment stored in the channel of the Big River from R-km 171 to the mouth is 3,669,000 m^3 or 4,828,000 yd^3 (Table 16). The storage in St. Francois County (R-km 171 to R-km 121) is 1,357,000 m^3 or 37% of the total. In Jefferson County from R-km 121 to the mouth there is an estimated 2,311,000 m^3 or 63% of total of channel sediment stored in the Big River.

LEAD MASS. It is possible that the spatial distribution of contaminated sediment volume and stored Pb metal may differ enough to affect management decisions for remediation plans. Lead mass storage was calculated by multiplying sediment volume by a bulk density value of 2 g/cm^3 and Pb concentrations from the step model for a given river segment (Table 14). In addition, metal concentrations in the step model were reduced by the Pb PEC limit of 128 ppm to calculate only the potentially toxic sediment mass. This background correction value is conservative and probably underestimates the actual mass of mining-contaminated sediment by up to 5 percent since the actual background level appears to be <50 ppm Pb. Nevertheless, there is about 6,600,000 Mg of contaminated sediment and 3,800 Mg Pb stored in the channel bed and bar deposits of the Big River (Table 16). Recall, Pb mass calculations assume that there is no contaminated sediment below Cedar Hill (R-km 32) even though half of the samples in that river segment contained concentrations above the PEC limit.

Lead mass storage in channel sediment is highest in St. Francois County and declines is an exponential trend in Jefferson County (Figure 44). Maximum Pb storage occurs in the channel segment from Leadwood (R-km 171) to Cherokee Landing (R-km 137), moderate levels of Pb storage occur from Cherokee Landing (R-km 137) to the Mineral Fork confluence (R-km 99), and progressively lower levels of Pb storage occur from Mineral Fork to Cedar Hill (Figure 25). The mass of Pb stored in channel deposits represents about 2.2 percent of the total amount of lead still stored in present-day tailings and chat piles in the Old Lead Belt (Tables 1 & 16).

Floodplain Soil and Lead Storage

CONTAMINATED SOIL VOLUME. To calculate the volume of contaminated soil, the average depth of Pb contamination in each 2 km long floodplain valley cell (Table 12) is multiplied by the floodplain surface area within each cell (Figure 39). Again, the depth of contamination is determined at the point in the lower core where Pb concentrations drop below the residential soil threshold of 400 ppm. The individual volumes for each cell area are then summed by segment or entire river length to determine the amount and distribution of basin-scale storage (Table 16). About 86,800,000 m^3 or 114,200,000 yd^3 of contaminated floodplain material is currently stored along the main stem of the Big River valley.

About 21% of the contaminated floodplain volume is stored in St. Francois County. Jefferson County contains most of the contaminated floodplain sediment because of three reasons. First, there is more linear length of river in Jefferson County (121 km of channel and 94 km of valley) compared to St. Francois County (50 km of channel and 40 km of valley). Second, floodplains within Jefferson County are almost two times wider on average and therefore offer more area for sediment deposition and storage (Figure 45). The average floodplain width in St. Francois County is 189 m (+/- 53 Cv%) compared to 342 m (+/- 47 Cv%) in Jefferson County. Finally, there is only a moderate degree of distance decay of Pb by dilution or deposition in floodplain deposits downstream from the tailings pile sources in St.

Francois County (Figure 23). The depth of floodplain contamination varies within a site, but in general does not change significantly downstream at 2 to 3 meters (Figure 20). Relatively high concentrations of Pb in the floodplains extend all the way from Leadwood (R-km 171) to the Meramec River (R-km 0) (Figure 21). While Pb concentrations in floodplain soils were highest during the mining period at >4,000 ppm, floodplain deposits formed over the past decade still typically contain between 1,000 to 2,000 ppm Pb.

LEAD MASS. The spatial distribution of contaminated soil storage primarily depends on the area of the valley floor available for overbank flooding and sedimentation since contaminated depth does vary greatly downstream (Figure 20). However, if the mass of lead storage is desired, then the concentration of Pb in the floodplain soil also becomes an important variable in determining the final pattern of storage. To calculate the mass of contaminated Pb storage in the floodplain, the volume of contaminated floodplain storage is multiplied by both the predicted Pb concentration using a distance-concentration regression equation (Figure 23) and the bulk density of the floodplain soil estimated to be 1.5 g/cm^3 (Brown, 1981). The results of mass distribution show a slightly different pattern compared to volume-based storage (Figure 46). While the mass of contaminated sediment storage is still controlled by valley morphology, the distribution of Pb mass storage shifts upstream toward St. Francois County (Figure 46). Even so, out of the total floodplain storage of 226,000 Mg Pb only 27% of the floodplain Pb mass is stored in St. Francois County, with more than 72% is stored in Jefferson County (Table 16).

Total Storage in Channel and Floodplain Deposits

The total contaminated storage volume for the entire river system is 90,500,000 m^3 (119,100,000 yd^3) sediment and 230,000 Mg Pb (Tables 16 and 17). The relative importance of individual storages by county in the Big River valley is as follows: (i) Jefferson Co. channel sediment, 2.6%; (ii) St. Francois Co. channel sediment, 1.5%; (iii) Jefferson Co. floodplain deposits, 76.2%; and (iv) St. Francois Co. floodplain deposits, 19.7%. The distribution of Pb mass storage is as follows: (i) Jefferson Co. channel sediment, 0.6%; (ii) St. Francois Co. channel sediment, 1.2%; (iii) Jefferson Co. floodplain deposits, 71.8%; and (iv) St. Francois Co. floodplain deposits, 26.4%. Most of the contaminated sediment and Pb storage is presently in Jefferson County even though the primary source of the contamination was in St. Francois County.

Spatial Patterns of Mining Sediment Storage in the Big River

Contaminated sediment and Pb storage is evaluated for six river segments delineated according to source area, county boundaries, and network location as follows:

1) Upper Mining area: R-km 171 to 155: Leadwood to Flat River Creek Confluence;

2) Lower Mining area: R-km 154 to 136: Below Flat River Creek to Cherokee Landing;

3) Southern St. Francis County segment: R-km 135 to 118: Cherokee Landing to Mill Creek/Jefferson County Line;

4) Southern Jefferson County segment: R-km 117 to 71: County Line to below Browns Ford MDC Access;

5) Middle Jefferson County segment: R-km 70 to 31: From above Morse Mill Park to Cedar Hill Park; and

6) Northern Jefferson County segment: R-km 31 to 0: From below Cedar Hill to the Meramec River.

Storage is evaluated in two ways: (i) relative contribution to total storage in each segment (in %) (Figures 47 A & B), and (ii) unit volume of segment storage (storage/km river length) (Figures C & D). "Relative" storage describes the amount of storage in a segment and "unit" storage describes the intensity of storage in a segment adjusted for differences in segment length. Channel storage trends are affected by the variable lengths of each segment and downstream bed and bar sediment depth relationships. Lead metal storage tends to decrease downstream with more than half of the Pb stored in the channel in the upper two segments in the mining areas (Figure 47 A). Floodplain storage is more controlled by valley form and the amount of floodplain area available for sediment deposition. About 20% of the contaminated sediment volume and 30% of the Pb is stored in floodplains within St. Francois County (Figure 48 B).

Unit storage of channel sediment decreases gradually downstream from 25,000 to 28,000 m^3/km in St. Francois County, to 23,000 m^3/km in southern Jefferson County, and finally to 10,000 m^3/km in northern Jefferson County (Figure 47 C). As expected, channel Pb unit storage is highest in the upper two segments near the mining areas at 50 to 60 Mg/km (Figure 47 C). Unit Pb storage in channel sediments drops dramatically from 30 Mg/km in southern St. Francois County to <2 Mg/km in northern Jefferson County. Efforts to mitigate contaminated sediment and reduce channel sources to downstream segments should focus on channel areas extending from Leadwood to Cherokee Landing, R-km 171 to136 (Figure 47 A & C).

Unit storage of floodplain sediment increases by four times from the upper most segment to the lower segment since contaminated floodplains become wider and slightly deeper downstream (Figure 47 D). Storage volumes range from 200,000 to 400,000 Mg/km in St. Francois County to almost 800,000 Mg/km in northern Jefferson County. Interestingly, the unit storage trend for floodplain Pb is rather uniform in the downstream direction, with the exception of the Leadwood segment where unit storage is about half that of the rest of the river system (700 Mg/km). The rest of the segments have unit Pb storage values ranging from 1,200 to 1,500 Mg/km (Figure 47 D).

The mining sediment and Pb storage budget in the Big River system focuses attention on the role of floodplains as sources and sinks of contaminants in mined watersheds. In the Big River, downstream variations in storage of contaminated mining sediment and Pb are primarily controlled by valley form and available floodplain depositional area as well as soil Pb content (Figure 39). In addition, lateral variations in Pb concentration and contaminated depth in floodplain soils are also affected by the age of the deposit relative to the mining period and the elevation of the floodplain surface relative to expected flood stages (Figure 45). These relationships need to be investigated further to better understand reach-scale variations in floodplain contamination. In addition, more information is needed that describe bank erosion rates along the Big River to better understand the locations and rates of contaminated sediment remobilization and long-term contamination risk to the Big River. Two types of information are required to better evaluate potential bank erosion risk to channel contamination: (i) locations of major disturbance zones along the Big River using historical aerial photograph analysis; and (ii) locations and patterns of Pb concentrations in near-channel deposits most available for erosion and channel contamination.

CONCLUSIONS

There are eleven main conclusions in this report:

1. The magnitude and impact of mining operations on the sediment load and geochemistry of the Big River has been significant. Active channel glide and bar deposits are contaminated above the PEC with >128 ppm Pb from Leadwood (R-km 171) to the confluence with the Meramec River (R-km 0). However, below R-km 30 at Cedar Hill, Pb concentrations in the channel occur at levels both above and below the PEC value. The river segment with the highest Pb concentrations of five-times the PEC value extends from the Bone Hole (R-km 165.3) to Hwy E (132.9).

2. Both fine and coarse sediment fractions are contaminated in channel deposits of the Big River. In St. Francois County near mining areas, XRF Pb analyses for <2 mm fraction of in-channel sediment typically approach 2,500 ppm. The coarse sand (1-2 mm) and chat (4-8 mm) fractions typically contain 3,000 ppm Pb or more. While finer sediment fractions (<63 um and <250 um) may contain the highest Pb concentrations in some samples, mining sediment typically contains similar Pb concentrations across a range of size fractions.

3. Overbank floodplain deposits are contaminated above the residential threshold level of 400 ppm Pb from Leadwood to the confluence with the Meramec River to a depth of 1 to 4 meters or more. While there is significant variability in the vertical and lateral trends of Pb profiles in floodplain cores, contaminated deposits occur across valley floor areas generally ranging in width from 200 m to 800 m in soil series mapped as floodplains in NRCS soil surveys. These soil series are: (i) 75398-Kaintuck series, low floodplain with frequent flooding; (ii) 66014-Haymond and 66024-Wilbur series, high floodplain with frequent flooding; and (iii) 75453-Sturkie series, low terrace with frequent to occasional flooding.

4. Calcium analysis is an excellent tool to use as a tracer of tailings transport in channel and floodplain sediments in the Big River. Tailings from gravity (chat inputs) and flotation mills (sand inputs) located in St. Francois County were composed almost entirely of dolomite (and some calcite) fragments of various sizes ranging from fine silt and clay to medium gravel (<16 mm). These minerals are common in the bedrock and ore deposits in the District. Calcium is

found in similar concentrations in both dolomite and in tailings piles (around 22 %), but is not common in the sediment load of undisturbed rivers (<2% Ca). Calcium concentrations are highest in channel sediments located between Leadwood and Bonne Terre and then decrease in an exponential trend downstream to near undisturbed levels in Jefferson County.

5. Mine tailings from St. Francois County have been selectively transported downstream in association with channel sediment according to size. In general, Ca concentrations indicating tailings inputs remain elevated in finer channel sediment fractions (<2 mm) downstream to between Browns Ford (R-km 79) and Morse Mill (R-km 50). Selected samples were sieved and analyzed to compare the relative mobility of different size fractions. In this subsample, no evidence was found for the transport of mining chat by the Big River into Jefferson County. Chat (4-8 mm diameter), sand tailings (1-2 mm), and slimes (<63 um) have been gradationally sorted by size for over a 40 km segment of the Big River. Chat was only detected as far downstream to Cherokee Landing (R-km 137). Following, the historical chat supply to the Big River must be stored in bed, bar, or young floodplain deposits in St. Francois County, probably within 20 km or less of input points. As expected, coarse sand tailings have been transported about 22 km farther downstream to Mill Creek (R-km 115) and the <250 um fraction even farther to below Mineral Fork Creek (R-km 99). Some floodplain layers composed of silt and clay material are contaminated the entire length of the river with Ca concentrations about 2 to 3 times those in the channel suggesting that the tailings signal presently extends further downstream in floodplain soils compared to active channel sediments. However, floodplain soils were most heavily contaminated during the active mining period and so present-day floodplain trends have been inherited from historical contamination events to a large extent.

6. There is about 3,700,000 m^3 of contaminated sediment and 3,000 Mg of Pb stored in channel bed and bar deposits of the Big River. About 63% of the contaminated sediment is stored in Jefferson County, but 73% of the mining sediment Pb is stored in St. Francois County.

7. The spatial distribution of contaminated sediment storage in the channel has been quantified for the Big River. Average unit storage rates are 2,570 +/- 14% (1s) m^3/100 m from R-km 171 to 90 and 1,580 +/- 12% from R-km 90 to 15. Storage rates may be locally high behind low water bridges or old mill dams such as those found at Leadwood and Rockford Beach. Bar deposits typically contain about 10% of the total contaminated sediment in the reaches studied.

8. The storage budget for contaminated sediment and Pb focuses attention on the role of floodplains as sources and sinks of contaminants in mined watersheds. The distribution of contaminated sediment volume storage in the Big River valley is as follows: (i) Jefferson Co. channel sediment, 2.6%; (ii) St. Francois Co. channel sediment, 1.5%; (iii) Jefferson Co. floodplain deposits, 76.2%; and (iv) St. Francois Co. floodplain deposits, 19.7%. The distribution of Pb mass storage in the Big River valley is as follows: (i) Jefferson Co. channel sediment, 0.6%; (ii) St. Francois Co. channel sediment, 1.2%; (iii) Jefferson Co. floodplain deposits, 71.8%; and (iv) St. Francois Co. floodplain deposits, 26.4%. Almost all of the contaminated sediment and Pb

storage in Jefferson County today originally came from the historical mining operations in St. Francois County.

9. Floodplain contamination is generally more severe and extends further downstream compared to channel sediments. The depth of contamination (>400 ppm Pb) in floodplain soils typically extends to 2 to 3 meters with some reaching >4 m. Maximum Pb concentrations in floodplain soils typically occur in a 0.1 to 0.4 m layer at a depth of 1 to 3 m and show little influence of downstream dilution. Lead concentrations >6,000 ppm have been measured in floodplain soils located near R-km 0 at the mouth. The hypothesized cause of this pattern resulted from the episodic "slug-like" transport of slimes (<63 um) released into the river by mill discharges and then scoured by floods from temporary pool storage areas during the active mining period. Slime tailings contain very high concentrations of Pb typically >10,000 ppm. Floodplain surface soils less than two decades old contain between 1,000 and 2,000 ppm Pb. In these layers, Pb concentrations decrease downstream from the mining areas in St. Francois County due to the influence of dilution and upstream deposition.

10. Tributary inputs can be a source of mining contamination to the Big River in some instances. Flat River Creek still represents an important source of mining-related contamination to the Big River. Both channel and floodplain deposits are contaminated to moderate or high levels. Mill Creek and Mineral Fork Creek both contain elevated Pb and Zn concentrations in channel sediments, but these are usually below the PEC. Floodplain deposits in these creeks tend to also be elevated in both Pb (near toxic levels) and Zn concentrations. The source of contamination from Washington County along the lower Big River is probably related to the release of metals to the stream from past and present mining activities and other industries. Nevertheless, the release of contaminated sediment from Mill Creek and Mineral Fork Creek to the Big River does not appear to influence the regional trend of mining-related sediment contamination along the main stem of the Big River. The pollution signal from St. Francois County mines overwhelms any tributary influence, at least at the scale of this study. There may be localized contamination problems that can have significant effect on the environment, but these still need to be investigated.

11. Floodplain soil and bank erosion represent a significant potential Pb source to the Big River. Lead concentrations in floodplain deposits are typically 10 times greater than that in channel sediments in the lower segments of the Big River. Present-day sources of mining sediment contamination to the channel in St. Francois County include the remobilization of stored mining sediment in channel and floodplain deposits, in-transit mining sediment temporarily stored in tributaries, and localized releases from remaining unstabilized tailings piles. Sources of contamination to the lower Big River in Jefferson County include the release of contaminated fine particles by winnowing or weathering of channel deposits in St. Francois County, the local reworking of older channel deposits, and erosion of previously contaminated floodplain deposits.

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TABLES

Table 1: Location and Size of Tailings Piles

Tailings Pile	*Big River Input Point*	*Land Area** Total	Chat	*Chat + Tailings* Volume	Mass	*Pb* Mass	Pb:Zn
	R-km	km^2	%	m^3	Mg	Mg	Ratio
Big River above Flat River Creek							
Hayden Creek	177	0.03	0.0	NA	NA	NA	NA
Leadwood	172	2.3	6.2	3,896,000	7,403,000	17,630	0.5
Desloge	165-160	1.5	26	4,966,000	9,435,000	19,860	1.7
Flat River Creek							
Federal	155	4.7	2.8	3,973,000	7,548,000	6,680	3.0
Elvins/Rivermines	155	0.6	48	7,946,000	15,097,000	67,030	0.8
National	155	0.6	29	4,890,000	9,290,000	34,010	8.8
Big River below Flat River Creek							
Bonne Terre	145-136	1.4	11	4,355,000	8,274,000	20,640	5.5
TOTAL		11.13	12	30,026,000	57,047,000	165,850	1.2

* All tailings data from PAS, 2008 after Newfields 2006 and USFWS and MDNR 2007

Table 2: Lead and Zinc in Tailings Piles

Tailings Pile	*n*[#] Pb/Zn count	Lead min ppm	Lead max ppm	Lead mean ppm	Zinc min ppm	Zinc max ppm	Zinc mean ppm
Big River above Flat River Creek							
Leadwood	108/107	597	17,000	2,382	400	25,800	4,691
Desloge	74/74	826	6,200	2,105	233	3,990	1,243
Flat River Creek							
Federal	69/69	349	4,638	885	43	1,057	293
Elvins/Rivermines	92/93	851	11,600	4,440	108	11,900	5,541
National	96/96	1,100	9,283	3,661	34	5,055	417
Big River below Flat River Creek							
Bonne Terre	88/88	660	7,610	2,495	51	1,470	457

[#] From PAS, 2008 after Newfields 2006 and USFWS and MDNR 2007

Table 3: Explanation of Geologic Map Units

Geologic Map Symbol	Period	Series	Description
Pu	Pennsylvanian		Uncertain Pennsylvanian
D	Devonian		Upper Series Shale, Middle Series Limestone
Omk	Ordovician	Cincinattian	Limestone
Ojc	Ordovician	Ibexian	Dolomite
Or	Ordovician	Ibexian	Roubidoux Sandstone
Og	Ordovician	Ibexian	Gasconade Dolomite
Ojd	Ordovician	Mohawkian	Joachim Dolomite, Dutchtown Formation
Odp	Ordovician	Mohawkian	Decorah Group Shale, Plattin Group Limestone
Mo	Ordovician	Osagean	Limestone
Ospe	Ordovician	Whiterockian	Everton Formation
Clm	Cambrian	Croixian	Lamotte Sandstone
Ceb	Cambrian	Croixian	Bonne Terre Dolomite
Cep	Cambrian	Croixian	Potosi Dolomite
i	Pre-Cambrian		Alkali Granite, St. Francois Intrusive Suite
v	Pre-Cambrian		Alkali Rhyolite, St. Francois Mtn. Volcanic Supergroup
d	Pre-Cambrian		Diabase Dikes and Sills

Table 4: Sample Site Descriptions

Code	Location	County	MO East State Plane Coordinates		River	Ad	Elev	Valley	Valley	Data Collection
			X	Y	Km	(km^2)	(m)	Slope	Sinuosity	
C-1	Irondale at Hwy U-control	Washington	764,939.995407	727,063.045679	191.7	457	233	0.0025	1.05	Bar/Glide
C-2	Highway 8 above Leadwood-control	St. Francois	779,836.775276	740,704.092372	181.2	572	223	0.009	1.02	Bar/Glide
M-1	Leadwood MDC Access	St. Francois	795,438.829942	741,478.174467	170.7	638	214	0.003	1.18	Volume/Core
M-2	Bone Hole at BS-#1	St. Francois	805,450.291702	743,473.586089	165.3	659	210	0.0135	1.42	Bar/Glide/Pit
M-3	Above Desloge at BS-#2	St. Francois	802,834.056000	748,278.405000	163.4	661	205	0.0005	1.56	Bar
M-4	Desloge above Old BT Rd.	St. Francois	812,245.012312	748,255.693252	158.1	675	204	0.0005	1.15	Bar/Glide/Pit
M-5	Highway 67 above Flat R. Cr.	St. Francois	815,943.404543	748,857.757104	156.5	678	202	0.002	1.04	Volume
M-6	Highway K below Flat R. Cr.	St. Francois	820,501.887990	761,810.730824	147.1	821	195	0.006	1.31	Bar/Glide/Pit
M-7	St. Francois State Park (upper)	St. Francois	808,839.051095	772,269.440016	140.8	1007	191	0.007	1.1	Bar/Glide/Core
M-8	St. Francois State Park (lower)	St. Francois	808,391.803662	773,765.998733	140.3	1008	191	0.007	1.1	Bar/Glide/Pit/Core
M-9	Hwy 67 at Cherokee Landing	St. Francois	805,312.677107	772,441.458259	136.7	1021	187	0.0005	1.05	Volume
M-10	Hwy E below Bonne Terre	St. Francois	798,517.956497	777,068.749004	132.9	1050	187	0.0005	1.14	Bar/Glide/Pit
M-11	Dickenson Rd.	Jefferson	784,859.707980	791,329.061373	121.1	1139	180	0.0005	1.14	Bar
M-12	US of Mill Cr.	Jefferson	786,872.321426	793,857.729549	118.9	1142	180	0.001	1.18	Bar/Glide
M-13	CC Bridge at Blackwell	Jefferson	785,306.955412	804,006.805903	115.5	1282	179	0.0005	1.05	Volume
M-14	Washington Park	Jefferson	767,864.305543	820,675.373678	101.7	1363	169	0.0035	1.46	Bar/Core
M-15	Mammoth MDC Access	Jefferson	769,412.469732	831,392.110235	97.0	1861	168	0.0025	1.12	Volume/Core
M-16	Merrill Horse MDC Access	Jefferson	760,484.722905	847,647.834227	87.3	1906	163	0.0035	1.03	Core
M-17	Browns Ford MDC Access	Jefferson	760,587.933851	865,434.520583	79.5	1959	156	0.0015	1.01	Volume/Core
M-18	Morse Mill Park	Jefferson	776,379.208586	888,708.588900	49.8	2165	144	0.005	1.04	Volume/Core
M-19	Cedar Hill Park	Jefferson	779,681.958857	915,698.251273	32.7	2296	138	0.0065	1.08	Volume/Core
M-20	Byrnes Mill at Byrnesville Rd.	Jefferson	781,006.499330	932,005.580737	23.4	2367	133	0.0085	1.2	Bar
M-21	Rockford Beach MDC Access	Jefferson	794,234.702239	941,569.795064	16.9	2386	132	0.0025	1.02	Volume/Core
M-22	Twin River Road	Jefferson	788,024.843657	956,621.391352	4.9	2493	130	0.0055	1.01	Bar
M-23	Hwy W (upper)	Jefferson	785,891.817440	954,660.383379	2.8	2492	130	0.0195	1.04	Bar/Core
M-24	Hwy W (lower)	Jefferson	784,154.433182	955,933.318379	1.8	2499	130	0.0195	1.04	Volume
FRC-1	Flat R. Cr. at Davis	St. Francois	794,659.244580	721,559.489904	14.8	22.8	262	0.011	1.27	Bar/Glide
FRC-2	Flat R. Cr. at St. Joe Bridge	St. Francois	818,742.614971	740,865.275547	3.4	79.5	211	0.011	1.11	Volume
Mill-1	Tributary to Mill Ck at Min Pt	Washington	756,595.087808	770,696.293456	21.1	20.7	255	0.022	1.04	Bar
Mill-2	Mill Creek at Tiff	Washington	776,879.745660	794,892.342732	5.2	96.3	189	0.01	1.47	Volume
Mill-3	Mill Creek near Confluence	St. Francois	785,430.229239	801,926.783123	0.2	133	180	0.006	1.07	Bar/Glide/Pit
MF-1	Mineral Fork at Hwy F-Cntrl	Washington	722,294.815556	802,966.297060	24.2	300	204	0.004	1.69	Bar
MF-2	Mineral Fork near Mouth	Washington	758,966.671043	823,228.828877	4.4	485	173	0.001	1.15	Volume

Table 5: Geospatial Data Sources

	Spatial Data File	File Type	Source
Available Data	Roads	shapefile	OEWRI GDB
	Mines	shapefile	MSDIS
	Streams	shapefile	OEWRI GDB
	Towns	shapefile	ESRI
	States	shapefile	ESRI
	Counties	shapefile	ESRI
	2007 Leaf-off Aerial Photos	Raster	MSDIS
	Alluvial Soils	shapefile	SSURGO
	Digital Elevation Model (30m)	Raster	MSDIS
	100 Year Floodplain	shapefile	City of Springfield
Created Data	Big River Watershed	shapefile	DEM
	Subwatersheds	shapefile	DEM
	Active Channel	shapefile	Aerial Photograph
	Channel Centerline	shapefile	Channel Shapefile
	Alluvial Valley	shapefile	Floodplain/Soils
	Valley Centerline	shapefile	Valley Shapefile
	Alluvial Features	shapefile	Aerial Photograph
	Sampling Sites	shapefile	GPS
	Site Surveys	shapefile	Field Survey
	GPS Points	shapefile	GPS

MSDIS - Missouri Spatial Data Information Service
SSURGO - Soil Survey Geographic Database
ESRI - Environmental Systems Research Institute
DEM - Digital Elevation Model
OEWRI GDB - OEWRI geodatabase

Table 6: Size Fractionation of Metals in Tailings Materials

Size Fraction	Pb (ppm)	Zn (ppm)	Fe (%)	Mn (ppm)	Ca (%)	Cin (%)	Pb:Zn (ratio)
LEADWOOD PILE							
<63 um	5,380	9,720	2.4	3,508	21.8		0.6
<250 um	1,291	4,210	2.1	3,762	22.3		0.3
1-2 mm	1,556	1,687	2.2	3,625	21.6		0.9
1-2 mm cr	4,191	3,560	2.0	3,474	21.5	11.7	1.2
4-8 mm cr	3,362	1,178	1.9	3,466	21.1	11.3	2.9
<2 mm	*1,329*	*5,164*	*2.0*	*3,433*	*21.8*		*0.3*
NATIONAL PILE							
<63 um	5,156	676	4.3	4,945	21.7		7.6
<250 um	1,452	287	3.9	5,050	22.7		5.1
1-2 mm	2,193	162	3.8	4,692	21.7		13.5
1-2 mm cr	2,224	185	4.0	5,251	22.9	11.3	12.0
4-8 mm cr	9,902	307	5.7	6,318	25.2	11.6	32.3
<2 mm	*1,385*	*275*	*4.1*	*5,423*	*24.1*		*5.0*

Table 7: Geochemical Differentiation by Size Fraction

Description	Fraction (& ratio)	Pb ppm	Zn ppm	Fe %	Mn ppm	Ca %	Pb:Zn ratio
National	<2mm	4,783	689	4.3	4,778	21.8	6.9
Tailings	<63um	5,156	676	4.3	4,945	21.7	7.6
	63:2	*1.1*	*1.0*	*1.0*	*1.0*	*1.0*	*1.1*
Federal	<2mm	3,072	452	3.9	4,813	21.4	6.8
Tailings	<63um	3,435	471	4.2	4,940	22.1	7.3
	63:2	*1.1*	*1.0*	*1.1*	*1.0*	*1.0*	*1.1*
Leadwood	<2mm	3,413	8,417	2.2	3,403	22.0	0.4
Tailings	<63um	5,380	9,720	2.4	3,508	21.8	0.6
	63:2	***1.6***	***1.2***	*1.1*	*1.0*	*1.0*	***1.4***
M-2 Bonehole	<2mm	5,513	3,380	2.8	5,359	3.6	1.6
R-km 165.3	<63um	5,868	3,571	2.8	5,153	3.0	1.6
	63:2	*1.1*	*1.1*	*1.0*	*1.0*	***0.8***	*1.0*
M-7 ST. Fran SP	<2mm	2,560	1,090	4.8	7,906	14.3	2.3
R-km 140.81	<63um	3,495	1,529	6.3	10,229	16.4	2.3
	63:2	***1.4***	***1.4***	***1.3***	***1.3***	*1.1*	*1.0*
M-7 ST. Fran SP	<2mm	1,377	667	2.4	2,883	10.3	2.1
R-km 140.92	<63um	2,528	1,094	2.5	2,790	7.1	2.3
	63:2	***1.8***	***1.6***	*1.0*	*1.0*	***0.7***	*1.1*
M-10 Hwy E	<2mm	1,800	974	2.6	2,837	6.0	1.8
R-km 132.86	<63um	2,428	1,298	3.0	3,185	6.0	1.9
	63:2	***1.3***	***1.3***	*1.1*	*1.1*	*1.0*	*1.0*
M-24 Hwy W	<2mm	351	138	1.6	901	1.2	2.5
R-km 1.7	63:2	384	155	1.7	794	1.3	2.5
		1.1	*1.1*	*1.1*	*0.9*	*1.1*	*1.0*

Table 8a: Channel Sediment Geochemistry (Arithmetic)

Code	Site	R-km	n	Arith. Mean					Arith. cv%				
				Pb (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)
C1	Irondale at Hwy U-control	191.7	4	15	21	11,528	597	3,565	0.0	17.8	17.7	25.2	83.3
C2	Hwy 8 above Leadwood-control	181.2	2	15	43	13,541	534	6,410	0.0	13.2	1.1	85.2	36.3
M1	Leadwood MDC Access	170.7	7	287	284	15,480	619	8,430	109.5	93.3	19.2	86.1	74.4
M2	Bone Hole at BS-#1	165.3	3	1,766	2,663	22,199	2,620	101,218	41.7	119.7	42.7	45.4	40.8
M3	Above Desloge at BS-#2	163.4	4	1,043	1,837	25,521	1,791	108,905	17.9	102.2	31.9	10.1	11.6
M4	Desloge above Old Bonne Terre Rd	158.1	5	1,143	1,415	21,522	2,127	110,224	27.0	32.6	7.9	9.4	13.9
M5	Hwy 67 above Flat River Ck	156.5	14	1,211	1,424	25,084	2,587	139,577	26.8	49.4	29.8	13.0	13.3
M6	Hwy K below Flat River Ck	147.1	6	1,440	673	32,414	3,516	148,068	35.2	22.5	26.6	27.6	15.5
M7	St. Francois State Park (upper)	140.8	8	1,209	497	34,164	3,753	114,647	58.4	43.1	40.9	45.3	17.2
M8	St. Francois State Park (lower)	140.3	5	1,331	647	33,655	3,891	112,625	28.4	61.1	28.3	30.0	18.6
M9	Hwy 67 at Cherokee Landing	136.7	8	601	327	21,406	2,132	100,286	36.1	27.1	23.1	23.0	13.2
M10	Hwy E below Bonne Terre	132.9	5	785	394	24,152	2,314	88,744	25.2	27.3	21.8	23.6	27.7
M11	Dickinson Rd	121.1	3	475	230	20,088	1,344	53,452	10.7	41.9	27.7	30.3	52.2
M12	US of Mill Cr.	118.9	4	633	298	19,797	1,857	73,350	55.2	53.3	12.9	16.0	15.0
M13	CC Bridge at Blackwell	115.5	10	449	199	14,419	986	46,279	53.2	65.7	39.8	51.2	59.7
M14	Washington Park	101.7	3	329	109	12,139	690	35,070	18.9	8.4	6.9	47.8	45.4
M15	Mammoth MDC Access	97.0	11	353	121	10,560	458	18,447	36.4	25.8	21.2	56.9	59.0
M17	Browns Ford MDC Access	79.5	8	245	141	8,358	320	7,821	49.0	35.8	31.1	83.8	112.2
M18	Morse Mill Park	49.8	7	273	120	11,679	572	6,119	32.9	35.3	34.2	76.9	43.4
M19	Cedar Hill Park	32.7	5	242	91	8,507	213	4,224	56.2	47.8	33.7	79.6	70.6
M20	Byrnes Mill at Byrnesville Rd	23.4	3	119	94	9,498	293	2,266	77.0	108.6	72.8	95.4	60.3
M21	Rockford Beach MDC Access	16.9	5	93	61	8,160	424	4,154	59.4	67.5	41.5	76.5	75.3
M22	Twin River Road	4.9	2	102	71	8,305	189	945	30.5	2.0	11.9	82.2	21.6
M23	Hwy W (upper)	2.8	3	48	39	4,835	282	800	36.1	38.2	37.0	127.3	0.0
M24	Hwy W (lower)	1.8	4	170	95	11,349	551	6,393	39.9	39.3	43.2	46.1	68.5
FRC1	Flat River Creek at Davis- control	14.8	3	54	31	22,539	2,307	16,068	40.0	39.4	14.3	3.3	96.5
FRC2	Flat River Creek at St. Joe Rd Bridge	3.4	4	2,289	1,161	35,760	3,969	151,707	24.6	49.2	9.0	12.2	4.3
Mill1	Tributary to Mill Ck at Min Pt	21.1	1	306	1,338	74,787	1,267	12,899					
Mill2	Mill at Tiff	5.2	4	67	303	21,526	256	12,098	56.9	21.2	26.7	39.9	92.9
Mill3	Mill Creek near confluence	0.2	5	251	320	20,100	535	11,403	20.6	19.1	21.8	26.4	31.5
MF1	Mineral Fork at Hwy F- control	24.2	1	46	131	10,129	85	5,838					
MF2	Mineral Fork near mouth	4.4	4	82	132	14,240	342	6,298	39.0	25.1	35.1	50.2	85.1

Table 8b: Channel Sediment Geochemistry (Logarithmic)

Code	Site	R-km	n	Geomean					Geo-cv%				
				Pb (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)	Pb (%)	Zn (%)	Fe (%)	Mn (%)	Ca (%)
C1	Irondale at Hwy U-control	191.7	4	15	21	11,385	581	2,910	0.0	5.8	2.0	4.3	8.5
C2	Hwy 8 above Leadwood-control	181.2	2	15	43	13,540	426	6,195	0.0	3.5	0.1	16.3	4.2
M1	Leadwood MDC Access	170.7	7	145	187	15,218	494	5,788	28.6	19.3	2.1	10.7	12.2
M2	Bone Hole at BS-#1	165.3	3	1,638	1,622	20,726	2,425	94,575	6.8	16.0	4.7	6.4	4.1
M3	Above Desloge at BS-#2	163.4	4	1,030	1,355	24,561	1,784	108,344	2.6	11.4	3.2	1.3	1.0
M4	Desloge above Old Bonne Terre Rd	158.1	5	1,111	1,353	21,468	2,119	109,344	3.8	4.7	0.8	1.2	1.2
M5	Hwy 67 above Flat River Ck	156.5	14	1,177	1,310	24,232	2,566	138,329	3.4	5.5	2.6	1.7	1.2
M6	Hwy K below Flat River Ck	147.1	6	1,365	657	31,393	3,402	146,535	5.1	3.7	2.7	3.5	1.3
M7	St. Francois State Park (upper)	140.8	8	1,062	462	32,348	3,441	113,159	7.6	6.5	3.2	5.4	1.5
M8	St. Francois State Park (lower)	140.3	5	1,291	579	32,551	3,768	111,035	3.8	7.7	2.8	3.4	1.6
M9	Hwy 67 at Cherokee Landing	136.7	8	562	316	20,821	2,079	99,509	6.5	5.0	2.7	3.2	1.2
M10	Hwy E below Bonne Terre	132.9	5	766	382	23,716	2,264	86,223	3.8	4.6	2.1	3.0	2.3
M11	Dickinson Rd	121.1	3	473	217	19,564	1,304	49,089	1.7	7.8	2.9	4.2	4.6
M12	US of Mill Cr.	118.9	4	568	273	19,672	1,838	72,709	8.4	8.1	1.3	2.2	1.4
M13	CC Bridge at Blackwell	115.5	10	365	157	12,722	745	29,135	13.7	16.0	6.6	15.4	14.0
M14	Washington Park	101.7	3	326	109	12,120	640	32,677	3.1	1.8	0.7	7.3	4.5
M15	Mammoth MDC Access	97.0	11	329	118	10,349	378	14,870	7.2	5.7	2.3	12.2	7.8
M17	Browns Ford MDC Access	79.5	8	223	133	8,026	235	4,175	8.2	7.3	3.4	15.3	14.9
M18	Morse Mill Park	49.8	7	261	114	11,121	458	5,423	5.7	7.5	3.6	11.4	6.9
M19	Cedar Hill Park	32.7	5	207	81	8,009	126	3,257	12.7	12.9	4.6	30.2	10.6
M20	Byrnes Mill at Byrnesville Rd	23.4	3	99	62	8,056	201	2,011	15.9	27.4	7.6	21.2	7.8
M21	Rockford Beach MDC Access	16.9	5	80	51	7,571	309	3,426	14.8	16.2	5.0	17.0	8.3
M22	Twin River Road	4.9	2	100	71	8,276	153	933	6.7	0.5	1.3	18.7	3.2
M23	Hwy W (upper)	2.8	3	45	37	4,572	138	800	11.0	12.5	5.1	31.6	0.0
M24	Hwy W (lower)	1.8	4	159	90	10,600	494	5,028	8.7	8.6	4.6	9.5	10.1
FRC1	Flat River Creek at Davis- control	14.8	3	50	29	22,379	2,306	11,890	12.1	13.7	1.5	0.4	9.8
FRC2	Flat River Creek at St. Joe Rd Bridge	3.4	4	2,240	1,059	35,649	3,946	151,604	3.1	7.1	0.9	1.5	0.4
Mill1	Tributary to Mill Ck at Min Pt	21.1	1	306	1,338	74,787	1,267	12,899					
Mill2	Mill at Tiff	5.2	4	54	297	21,002	238	9,003	21.9	4.1	2.5	8.6	9.6
Mill3	Mill Creek near confluence	0.2	5	247	315	19,741	521	10,957	3.9	3.4	2.1	4.2	3.4
MF1	Mineral Fork at Hwy F- control	24.2	1	46	131	10,129	85	5,838					
MF2	Mineral Fork near mouth	4.4	4	76	129	13,637	296	4,343	11.1	5.6	3.5	12.1	13.3

Table 9: Geochemistry of Chat Grains from Different Sources

Sample Site	Code	R km	Pb (ppm)	Zn (ppm)	Fe (%)	Mn (ppm)	Ca (%)	*Pb:Zn*
Weathered Grains (natural source)								
M-5	B-5	156.9	574	719	1.68	667	0.29	*0.8*
	G-7	156.5	542	731	3.05	1,167	3.74	*0.7*
M-8	G-33	140.3	452	296	1.89	696	0.26	*1.5*
M-10	B-40	132.9	513	373	2.30	1,362	0.64	*1.4*
	G-34	132.8	220	347	2.19	1,933	0.71	*0.6*
M-14	B-95	101.7	311	193	1.93	288	0.05	*1.6*
Dolomite Chips (mining source)								
M-5	B-5	156.9	3,869	512	2.32	4,175	23.2	*7.6*
	G-7	156.5	5,406	1,265	2.91	4,825	21.2	*4.3*
M-8	G-33	140.3	2,411	1,827	3.78	5,518	22.5	*1.3*
M-10	B-40	132.9	838	154	3.75	5,936	22.4	*5.4*
	G-34	132.8	2,564	305	3.38	4,946	22.3	*8.4*
M-14	B-95	101.7	*No dolomite chips observed in the sample*					

Table 10: Channel sediment geochemistry at Tributaries and Control Sites

Site Location	Texture		Geochemistry					
	<2 mm	4-8 mm	Ca	Fe	Mn	Pb	Zn	Pb:Zn
(data value)	% fines	% chat	%	%	ppm	ppm	ppm	Ratio
Flat River Creek (confluence with Big River at R-km 155)								
Davis Crossing Bridge at 15 km above the Big River (n=3)								
Geometric mean	11	17	1	2	2,306	50	29	1.7
Minimum value	3	13	1	2	2,226	29	17	1.7
Maximum value	21	24	3	3	2,379	68	40	1.8
St. Joe Bridge at 3.5 km about the Big River (n=4)								
Geometric mean	37	9	15	4	3,946	2,240	1,059	2.1
Minimum value	30	6	15	3	3,322	1,777	689	1.3
Maximum value	46	11	16	4	4,443	3,046	1,874	2.8
Mill Creek (confluence with Big River at R-km 116)								
Mineral Point, MO at 21 km above the Big River (n=1)								
Single value	20	30	1	7	1,267	306	1,338	0.2
Tiff, MO at 5.2 km above the Big River (n=4)								
Geometric mean	25	17	1	2	238	54	297	0.2
Minimum value	19	14	0	2	123	15	214	0.1
Maximum value	49	19	3	3	358	105	368	0.3
Near confluence at 0.2 km above the Big River (n=5)								
Geometric mean	23	15	1	2	521	247	315	0.8
Minimum value	8	4	1	2	380	182	245	0.6
Maximum value	56	26	2	3	743	306	393	1.0
Mineral Fork Creek (confluence with Big River at R-km 99)								
Highway F at 24 km above the Big River (n=1)								
Single value	35	14	1	1	85	46	131	0.4
NW of Washington State Park at 4.4 km above the Big River (n=3)								
Geometric mean	20	16	0	1	296	76	129	0.6
Minimum value	7	9	0	1	109	38	88	0.4
Maximum value	51	22	1	2	513	106	168	0.8
Upper Big River Control Sites above Leadwood								
Irondale, MO at R-km 192 (n=4)								
Geometric mean	25	20	0	1	581	<15	21	<0.7
Minimum value	21	15	0	1	400	<15	17	<0.8
Maximum value	31	23	1	1	730	<15	26	<0.9
Highway 8 Bridge at R-km 181 (n=2)								
Geometric mean	32	18	1	1	426	<15	43	<0.4
Minimum value	30	12	0	1	212	<15	39	<0.3
Maximum value	34	26	1	1	855	<15	47	<0.4

Table 11: Comparison of Surface and Core Metal Content in Bar Deposits

Core Description				*Metal Concentration (ppm)*		**Relative**
Source & Date	Label	Depth Max cm	Samples n	Surface Grab	Core Average	**Difference %**
Lead						
DNR 2007	1-29	70	3	875	868	1
DNR 2007	10-44	100	4	647	657	-2
DNR 2007	7-12	100	4	732	803	-9
MSU-2009	Head-A	100	4	1,558	1,494	4
MSU-2009	Tail-E	112	4	2,853	2,427	16
MSU-2009	Head-C	140	6	1,427	1,749	-20
MSU-2009	Tail-D	150	5	1,827	2,268	-22
MSU-2009	Head-B	180	5	973	1,489	-42
Zinc						
DNR 2007	1-29	70	3	460	504	-9
DNR 2007	10-44	100	4	381	376	1
DNR 2007	7-12	100	4	262	422	-47
MSU-2009	Head-A	100	4	6,321	5,335	17
MSU-2009	Tail-E	112	4	3,722	3,257	13
MSU-2009	Head-C	140	6	3,033	5,415	-56
MSU-2009	Tail-D	150	5	3,165	3,083	3
MSU-2009	Head-B	180	5	3,339	2,960	12

Table 12: Step Model for Depth of Floodplain Contamination

River KM		**n**	**Mean Depth (m)**	**St. Dev**	**Cv%**
171	160	5	1.8	0.9	49
160	150	5	2.8	0.8	30
150	140	7	3.1	1.4	47
140	130	4	2.3	1.5	66
130	120	0	2.7		
120	110	4	3.1	0.5	16
110	80	15	2.3	1.4	63
80	50	0	2.0		
50	30	12	1.8	0.8	48
30	0	6	2.6	0.7	26

Table 13: Floodplain Sediment Geochemistry at Tributaries and Control Sites

Pit	Distance to confluence	Depth	n	Value	Ca	Fe	Mn	Pb	Zn	Pb:Zn
#	km	max, cm	count		%	%	ppm	ppm	ppm	ratio
Flat River Creek (confluence with Big River at R-km 155)										
37	3.5	120	4	Geomean	15.5	3.58	3,749	2,916	760	3.8
				Min	13.3	3.17	3,096	2,025	685	2.8
				Max	18.3	3.89	4,250	4,002	926	5.5
38	3.4	110	3	Geomean	15.1	3.59	3,829	2,985	1,095	2.7
				Min	13.8	3.27	3,499	2,704	1,017	2.6
				Max	16.8	3.80	4,137	3,579	1,263	2.8
Mill Creek (confluence with Big River at R-km 116)										
41	5.3	240	4	Geomean	0.73	2.12	345	148	445	0.3
				Min	0.31	1.59	73	79	231	0.2
				Max	1.53	3.78	1,410	411	780	0.5
Mineral Fork Creek (confluence with Big River at R-km 99)										
39	4.3	220	8	Geomean	0.64	1.71	680	169	220	0.8
				Min	0.35	1.28	380	107	164	0.7
				Max	1.03	2.37	1,406	308	343	1.0

Table 14: Step Model for In-Channel Pb Concentrations.

River KM		n	Mean Pb (ppm)	St. Dev	Cv%
171	160	4	922	896	97
160	150	4	1,154	143	12
150	140	6	1,404	278	20
140	130	4	768	141	18
130	120	0	646		
120	110	5	524	195	37
110	100	0	417		
100	30	8	311	67	22
30	0	8	122	58	47

Table 15: Channel Dimensions and Unit Storage

Reach		Reach Length (m)	Width mean (m)	Probe Depth mean (m)	Probe Depth max (m)	Unit Volume Mean (m3/100m)	Unit Volume Max (m3/100m)	Ratio (Max/ Mean)	Bar % mean
	Mainstem								
M-1	Leadwood	515	40.3	0.7	1.1	2,963	4,485	1.5	9.3
M-5	Hwy 67 ab Flat River Ck	484	31.0	0.8	1.1	2,470	3,356	1.4	25.5
M-9	Cherokee Landing	395	33.6	0.6	1.3	2,035	4,295	2.1	9.5
M-13	CC Bridge at Blackwell	516	41.2	0.6	1.2	2,508	4,737	1.9	34.5
M-15	Mammoth Access	520	35.7	0.8	1.5	2,852	5,327	1.9	2.8
M-17	Browns Ford Access	428	38.0	0.4	1.1	1,591	4,298	2.7	1.8
M-18	Morse Mill Park	534	42.4	0.4	1.1	1,776	4,504	2.5	12.3
M-19	Cedar Hill Park	512	37.8	0.4	0.7	1,385	2,644	1.9	0.0
M-21	Rockford Beach Access	660	52.6	0.7	1.3	3,764	6,685	1.8	0.0
M-24	Downstream of Hwy W	771	41.8	0.1	0.2	364	847	2.3	1.3
	Tributaries								
FRC-2	Flat R Ck at St. Joe Bridge	157	17.9	0.3	0.6	590	1,142	1.9	16.5
Mill-3	Mill Ck Near Confluence	123	12.1	0.1	0.2	100	243	2.4	8.6
MF-2	Mineral Fork Ck	195	21.8	0.4	0.8	885	1,687	1.9	16.0

Table 16: Channel and Floodplain Storage Volume by County

Location	In-Channel	Floodplain	Total	
	Volume (m^3)	Volume (m^3)	Volume (m^3)	%
St. Francois County	1,357,370	17,854,091	19,211,461	21
Jefferson County	2,311,174	68,938,738	71,249,911	79
Total	3,668,543	86,792,829	90,461,372	100
	Pb (Mg)	Pb (Mg)	Pb (Mg)	%
St. Francois County	2,562	61,350	63,912	28
Jefferson County	1,248	164,469	165,717	72
Total	3,810	225,819	229,629	100

Table 17. Sediment Volume and Pb Mass as a Percent of Total by County

A.

Location	**Sediment Volume (%)**	
County	In-Channel	Floodplain
St. Francois	1.5%	19.7%
Jefferson	2.6%	76.2%
Total Sediment Volume = 90,461,000 m^3		

B.

Location	**Pb Mass (%)**	
County	In-Channel	Floodplain
St. Francois	1.1%	26.7%
Jefferson	0.6%	71.6%
Total Pb Mass = 230,000 Mg		

FIGURES

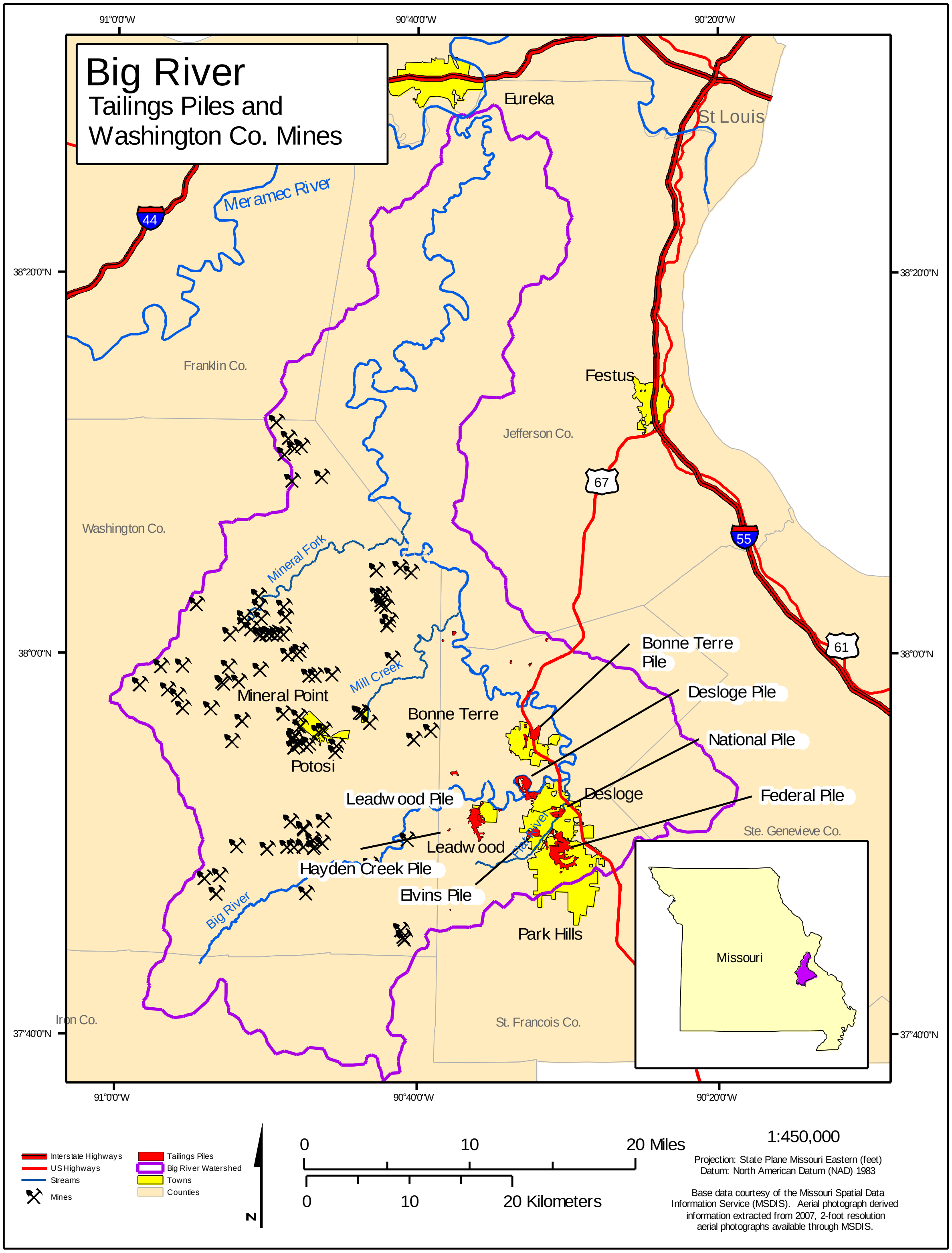


Figure 1: Mining areas in the Big River watershed
Yellow areas mark tailings piles of large-scale mining operations at the Leadwood, Desloge, Flat River, and Bonne Terre mining sites. Red symbols mark the locations of smaller shallow Pb mines.

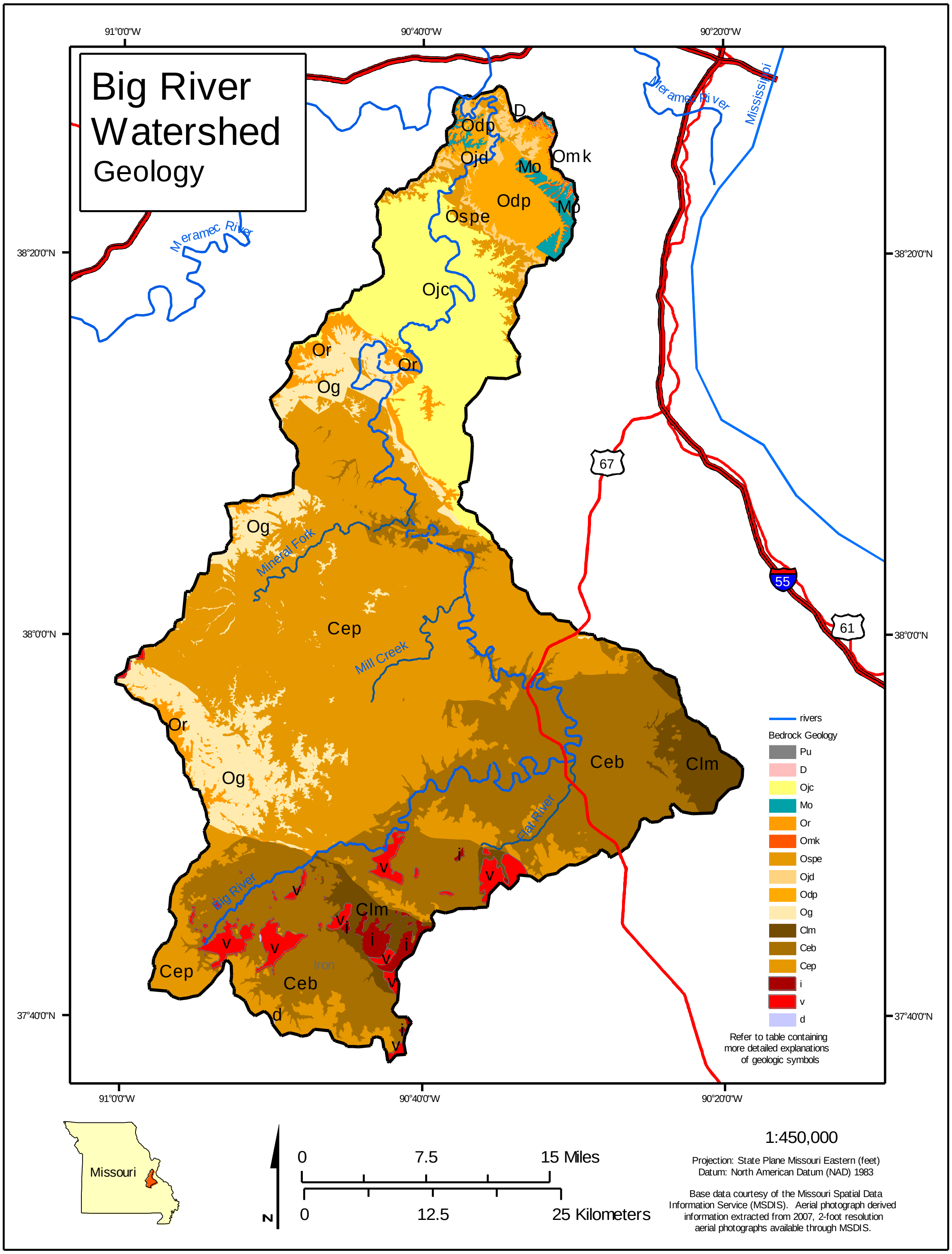


Figure 2. Bedrock Geology of the Big River Basin

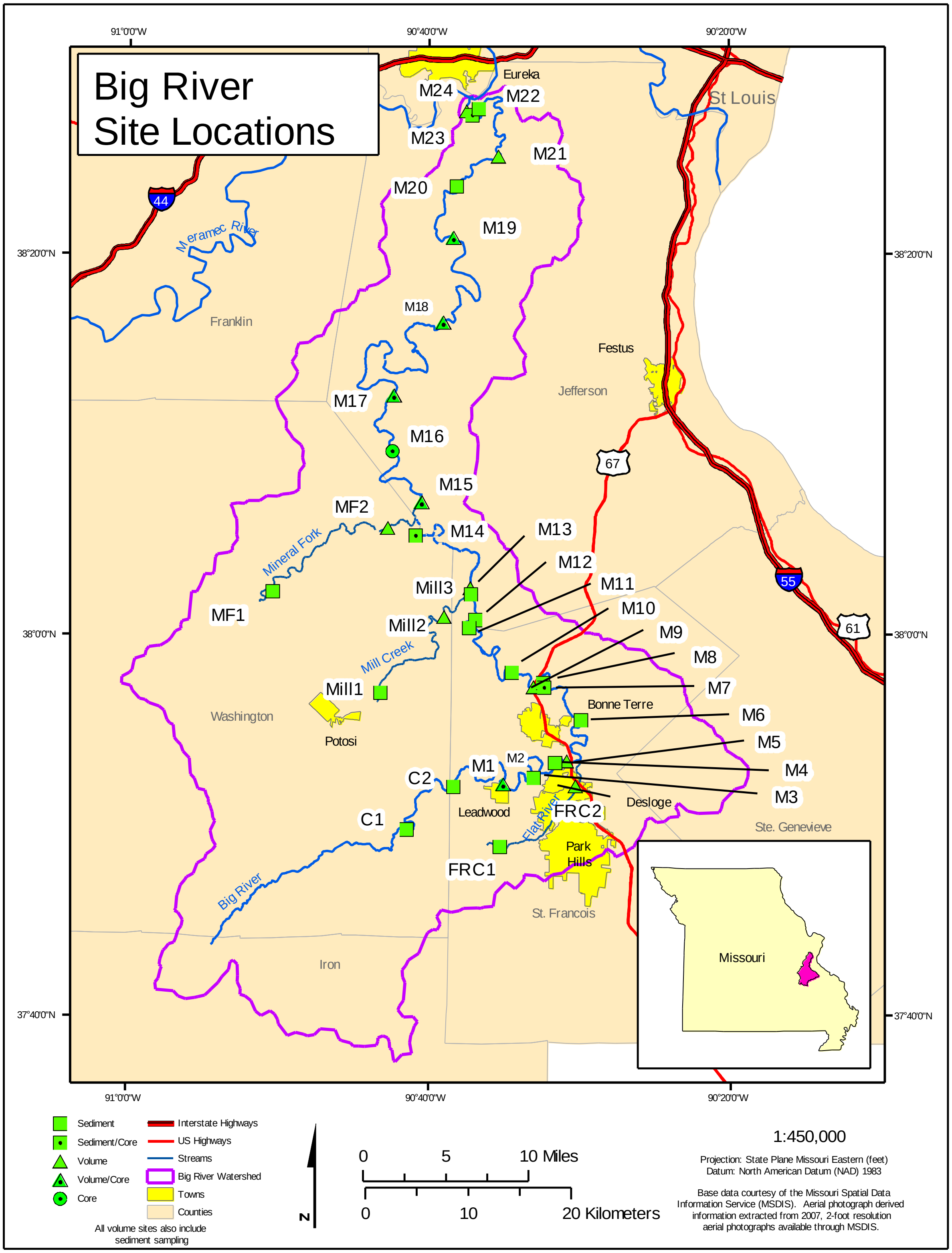


Figure 3: Sample Site Locations

Figure 4A: Glide Photos
Looking down a glide to distant riffle

Figure 4B: Glide Photos - Channel Sediment
Glide at Mammoth Access, River km 97. Note fine-grained sediment on the bed, but lacking grayish tailing and chat deposits.

Figure 4C: Glide Photo - Channel Sediment
Glide at Hwy W DS, river km 2.0. Note coarser gravel and cobble bed with little to fine material present.

Figure 5A: Bar Photo - High Gravel Bar Deposit

Figure 5B: Bar Photo - Low Bar Surface at Cherokee Landing
Note presence of gray tailings and dolomite chips from mining sources. Natural chert gravel is also shown which is tan and light brown.

Figure 6A: Bar Coring
Drill rig at the upper Desloge Pile bar site.

Figure 6B: Bar coring
Bucket auger moving through bar material

Figure 6C: Bar Coring
180 cm core.

Figure 7A: Floodplain Sediment Sampling
Example of pit sampling along a cutbank

Figure 7B: Floodplain Sediment Sampling
Coring floodplain deposits with Giddings probe and geochemical analysis with XRF

Figure 8: Channel Sediment Source Distribution

Results of grain-counts for the Chat-sized fraction (4-8 mm) at St. Francis State Park (R-km 140.3) showing, clockwise from upper left: (i) Dolomite chips related to tailings inputs; (ii) Natural weathered chert and other grains indicative of non-mining sources; (iii) Quartz grains also from natural sources; and (iv) shale grain from tailings inputs.

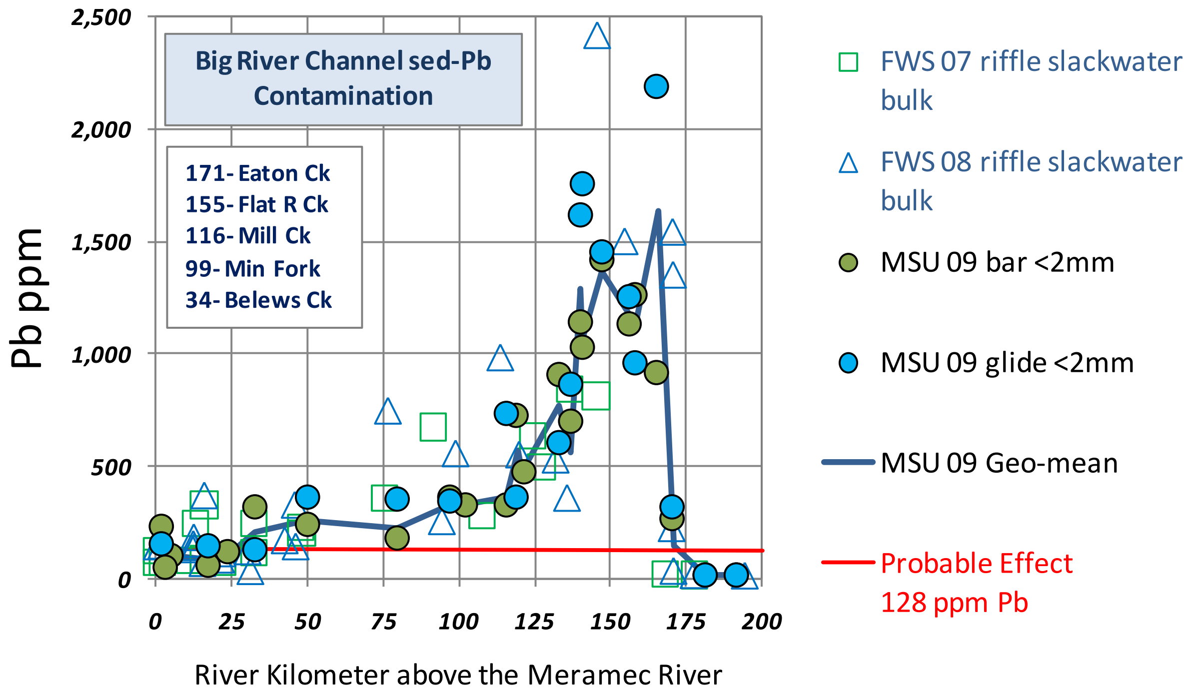


Figure 9: Downstream Pb contamination trends.
Comparison of sediment from MSU (this study) and previous sediment monitoring activities by the US Fish and Wildlife Service (Roberts et al., 2009).

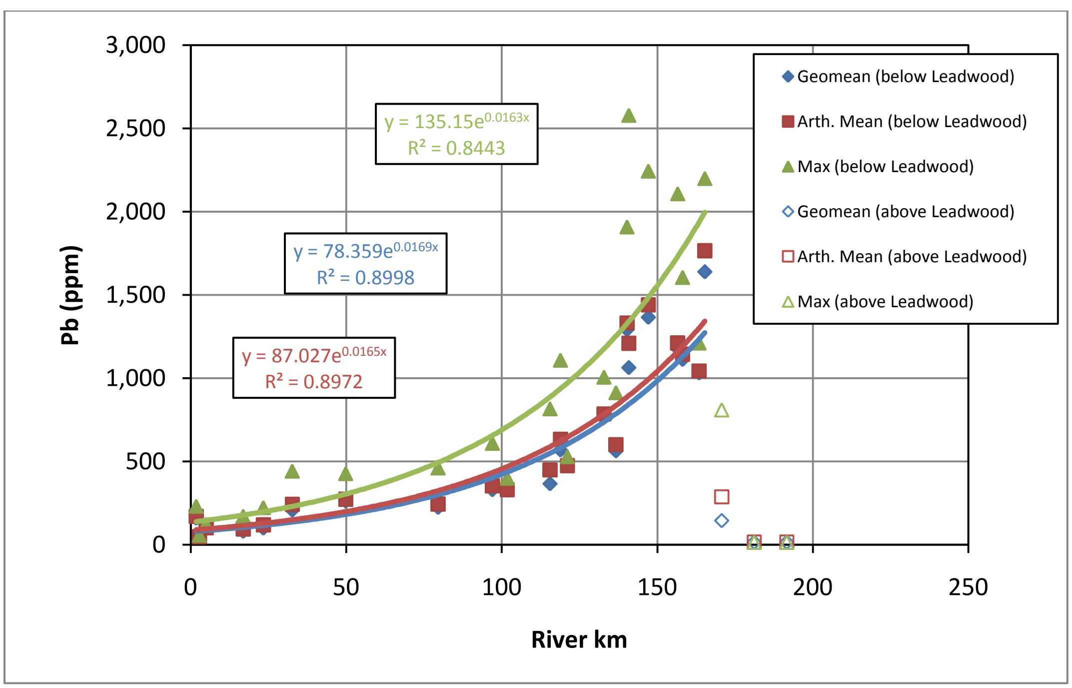


Figure 10: Downstream Trends in Channel Sediment Pb

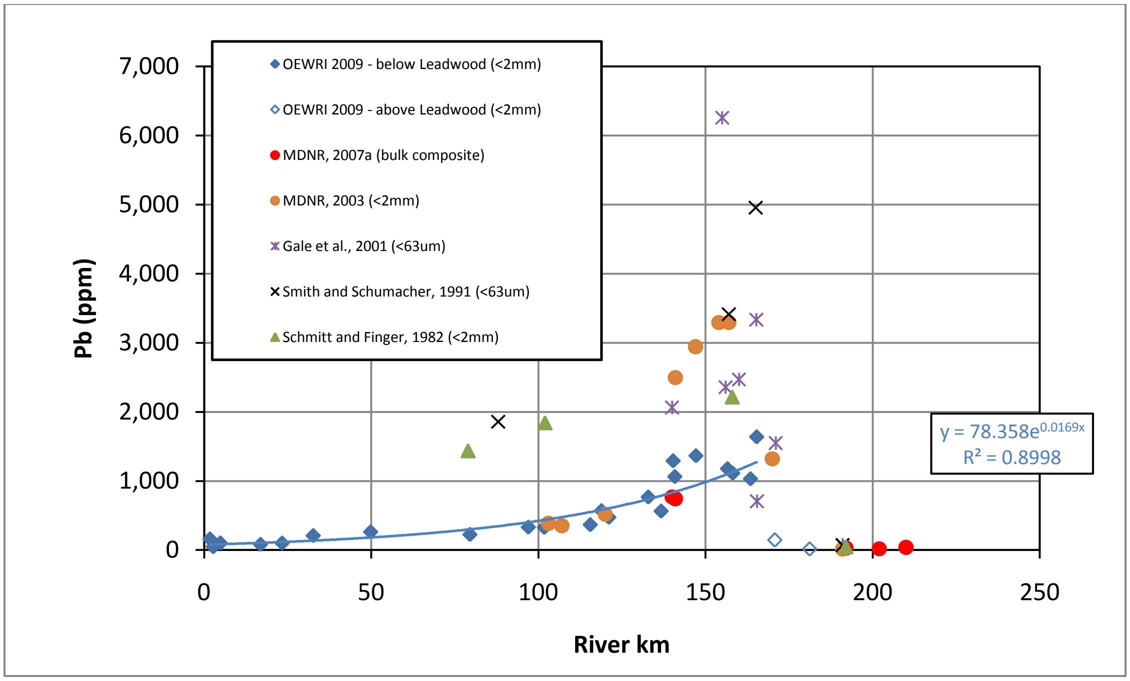


Figure 11: Channel Sediment Pb Comparison with Previous Studies

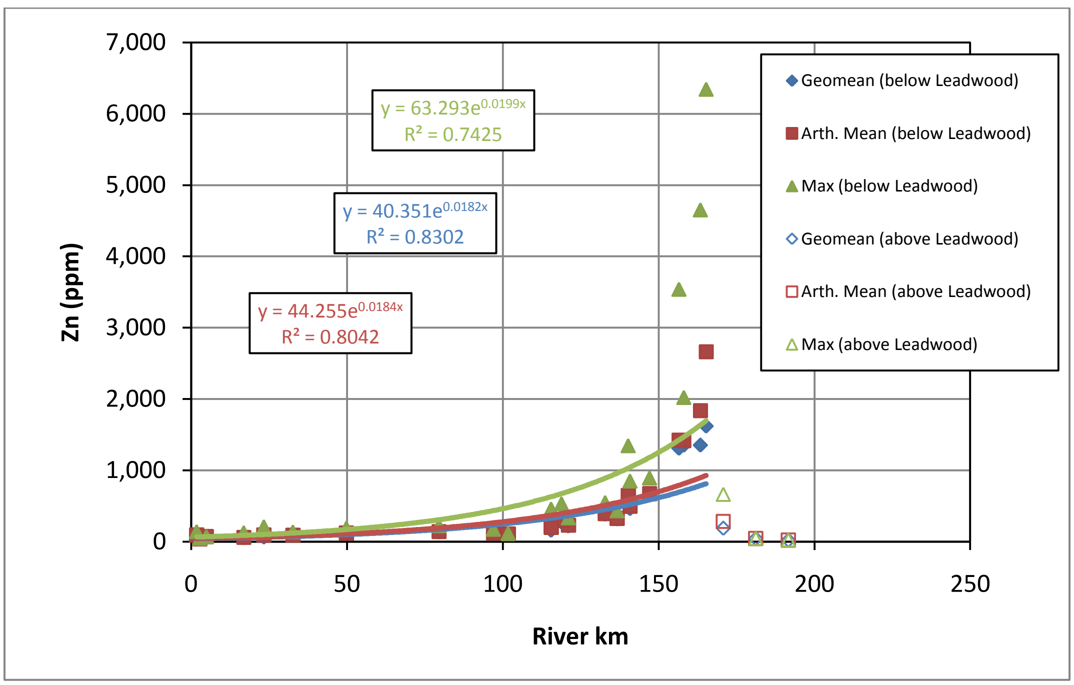


Figure 12A: Downstream Trends in Channel Sediment Zn

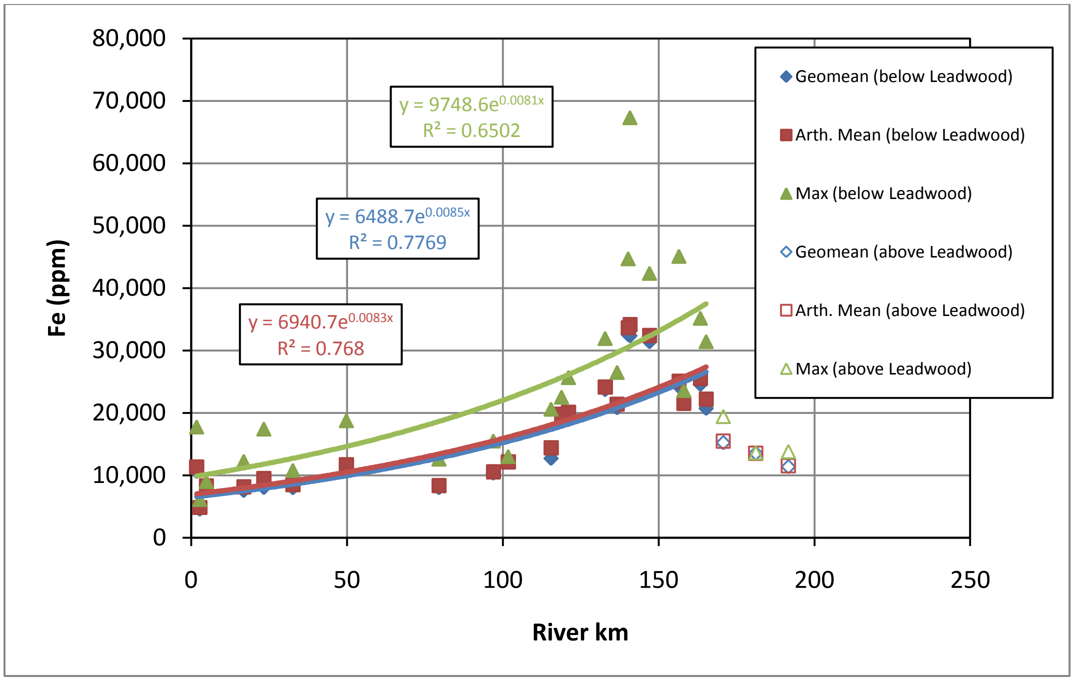


Figure 12B: Downstream Trends in Channel Sediment Fe

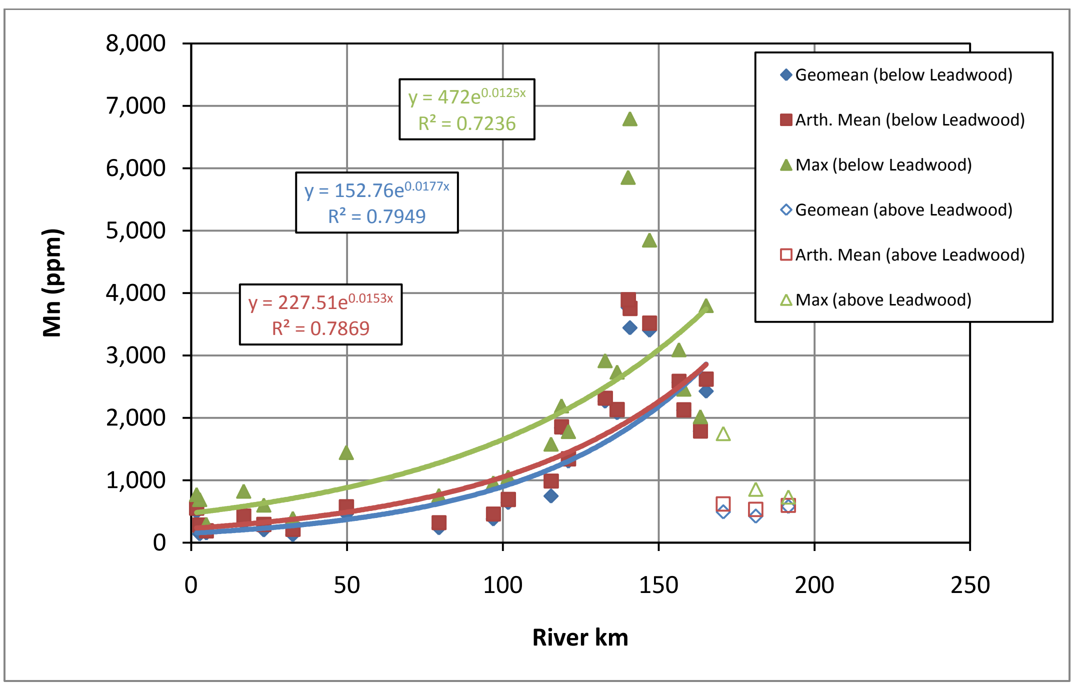


Figure 12C: Downstream Trends Channel Sediment Mn

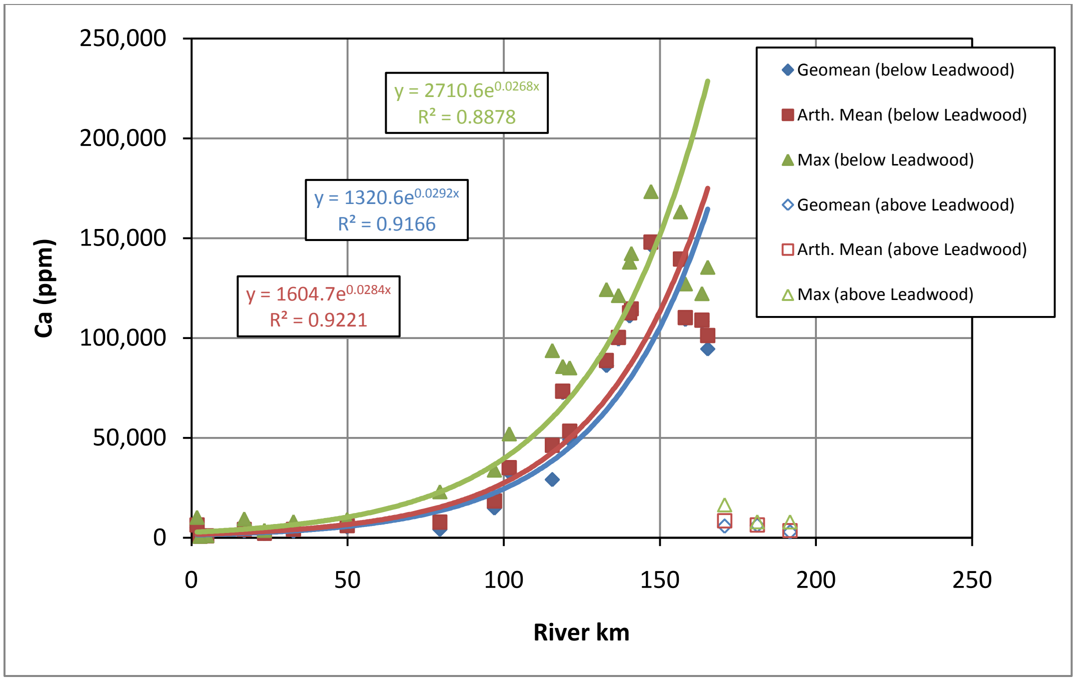


Figure 12D: Downstream Trends Channel Sediment Ca

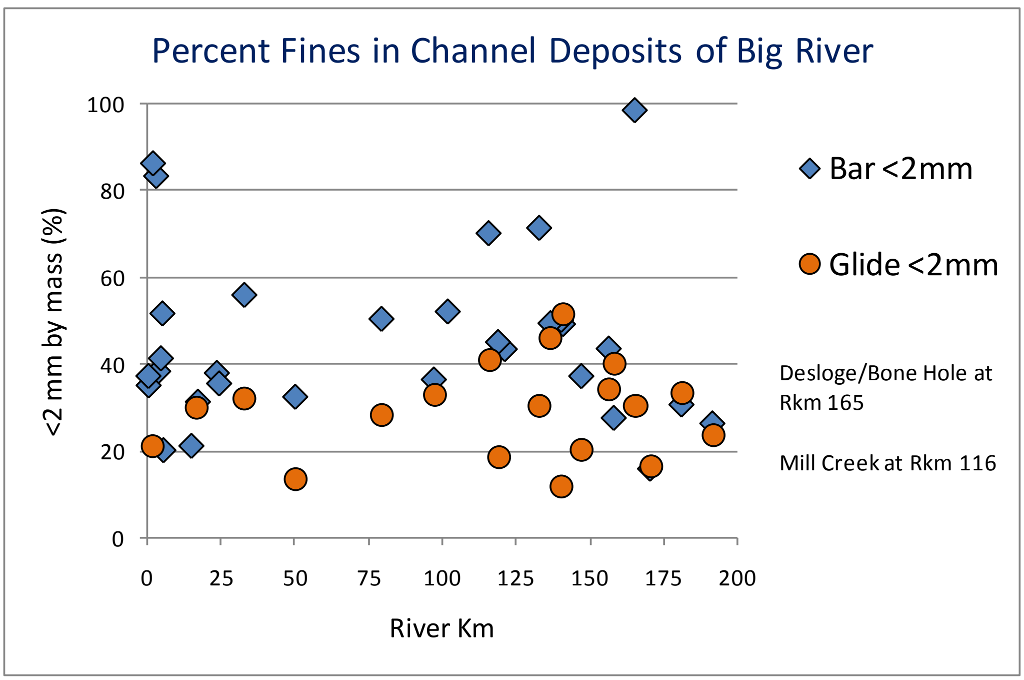


Figure 13: Fine Sediment Distribution in Bar and Glide Samples

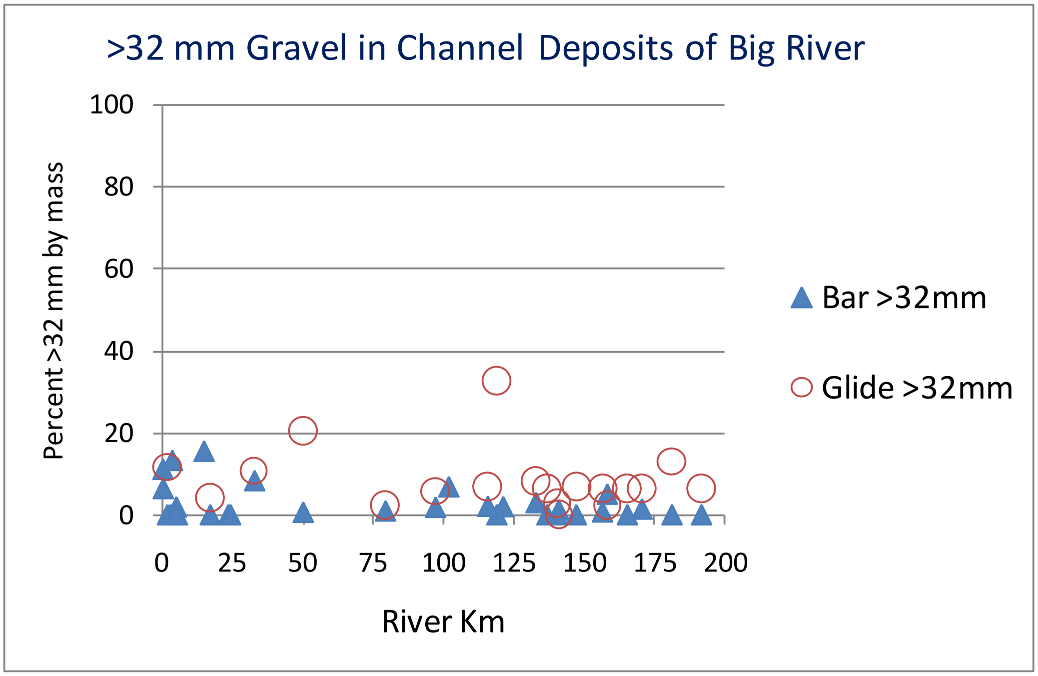


Figure 14: Coarse Gravel Distribution in Bar and Glide Samples

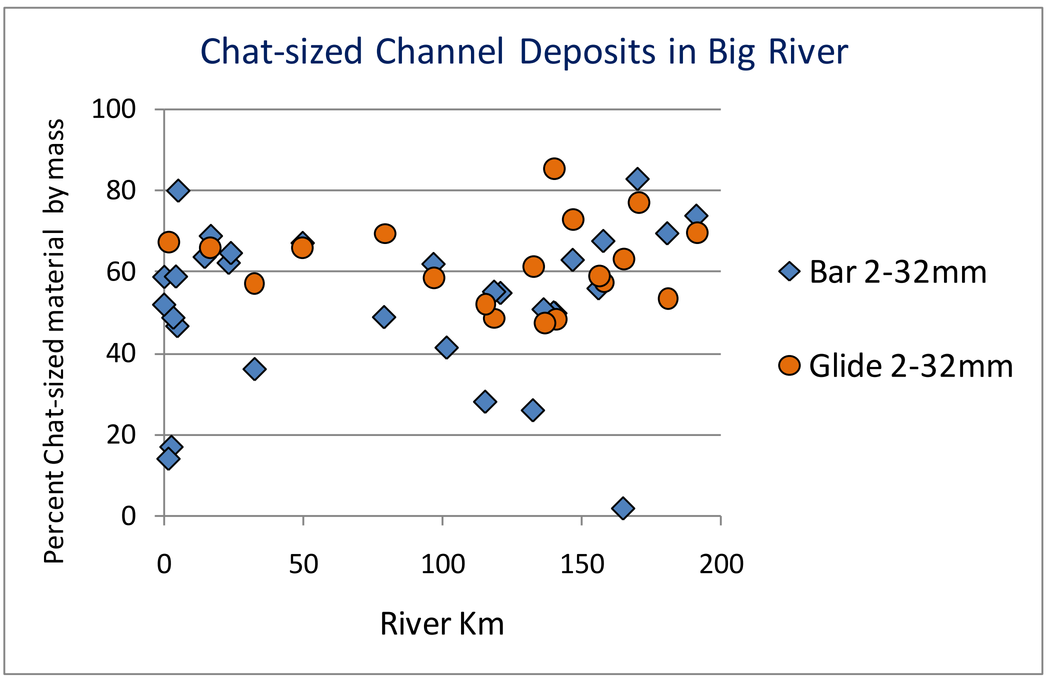


Figure 15: Chat-Sized Sediment Distribution in Bar and Glide Samples

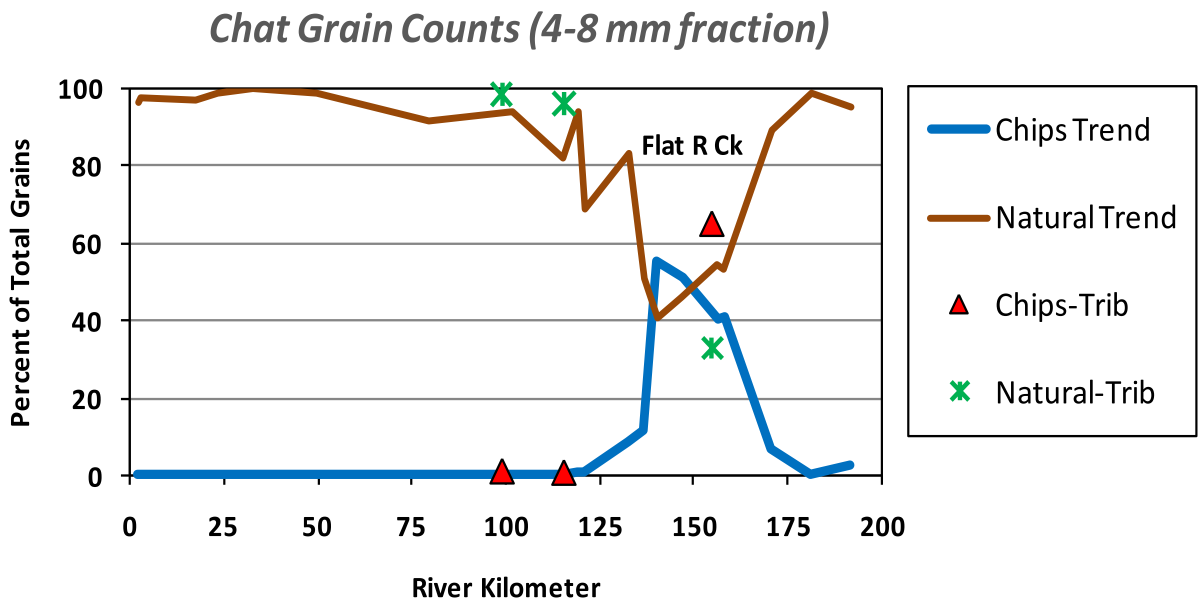
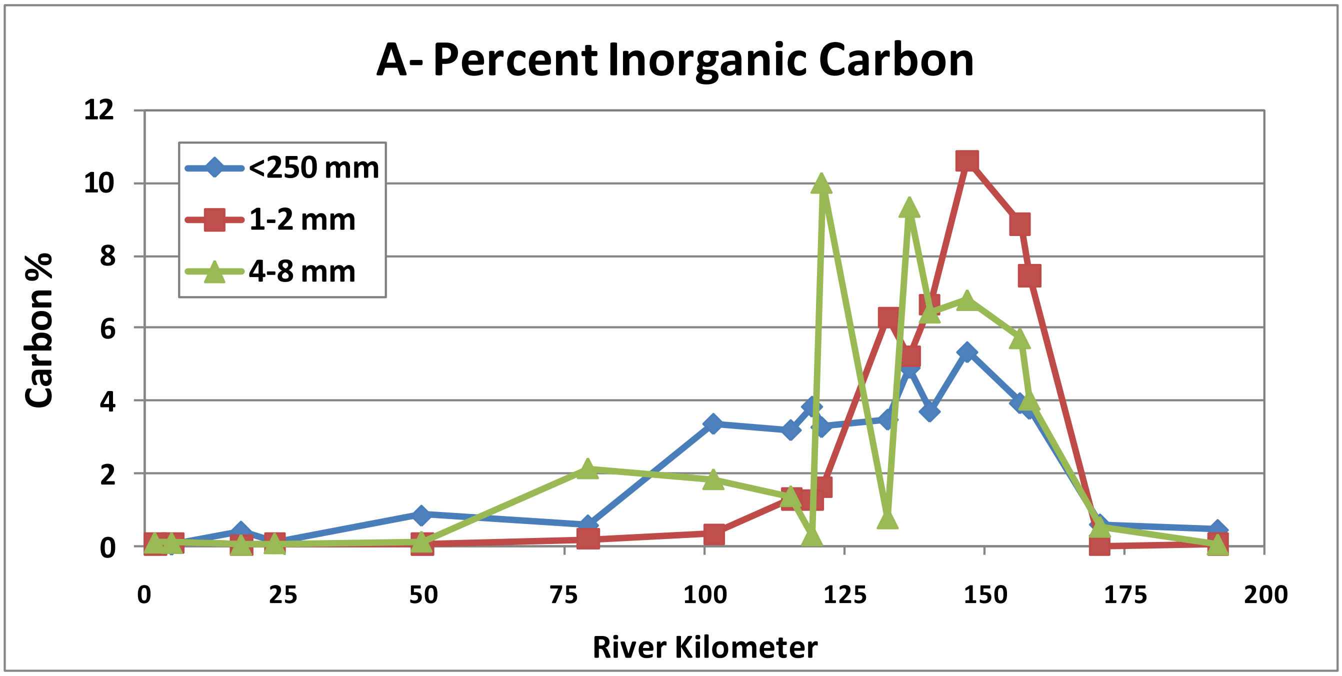


Figure 16: Chat Composition in Channel Sediments
Confluence of Mill Ck is at 116 km and Mineral Fork Creek at 99 km. Flat River Ck flows in to the Big River at 155 km.



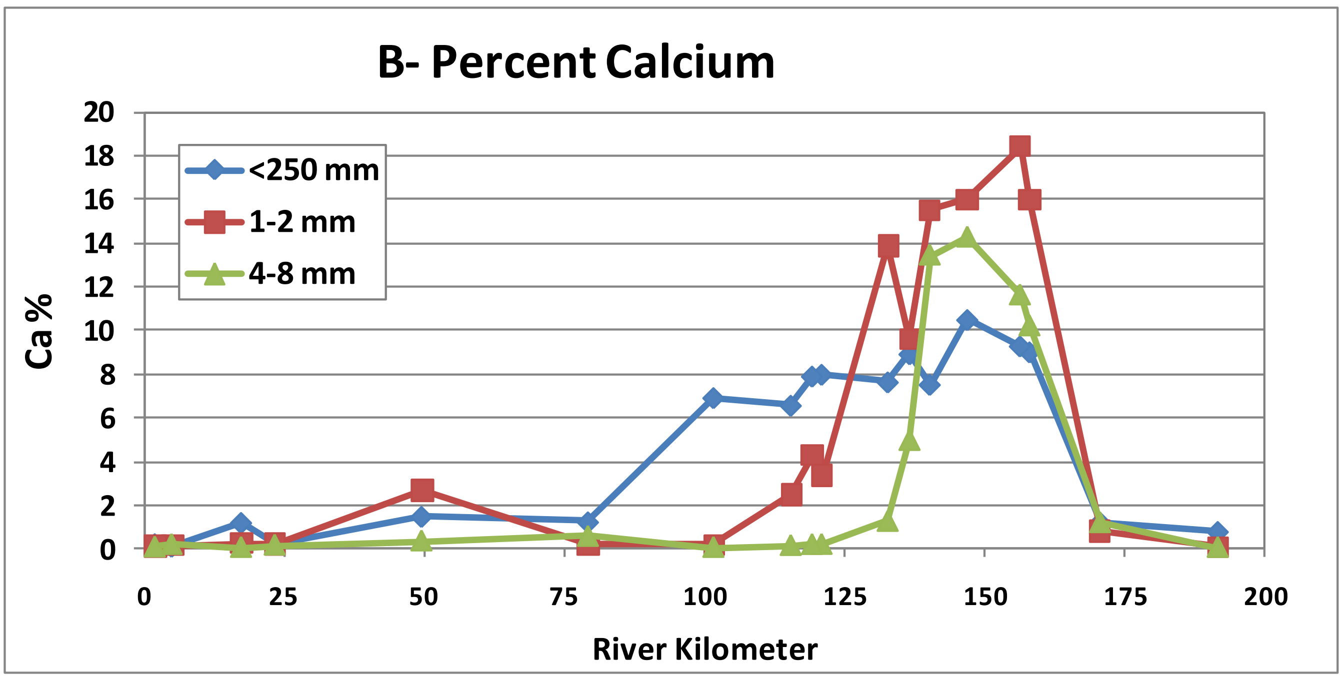
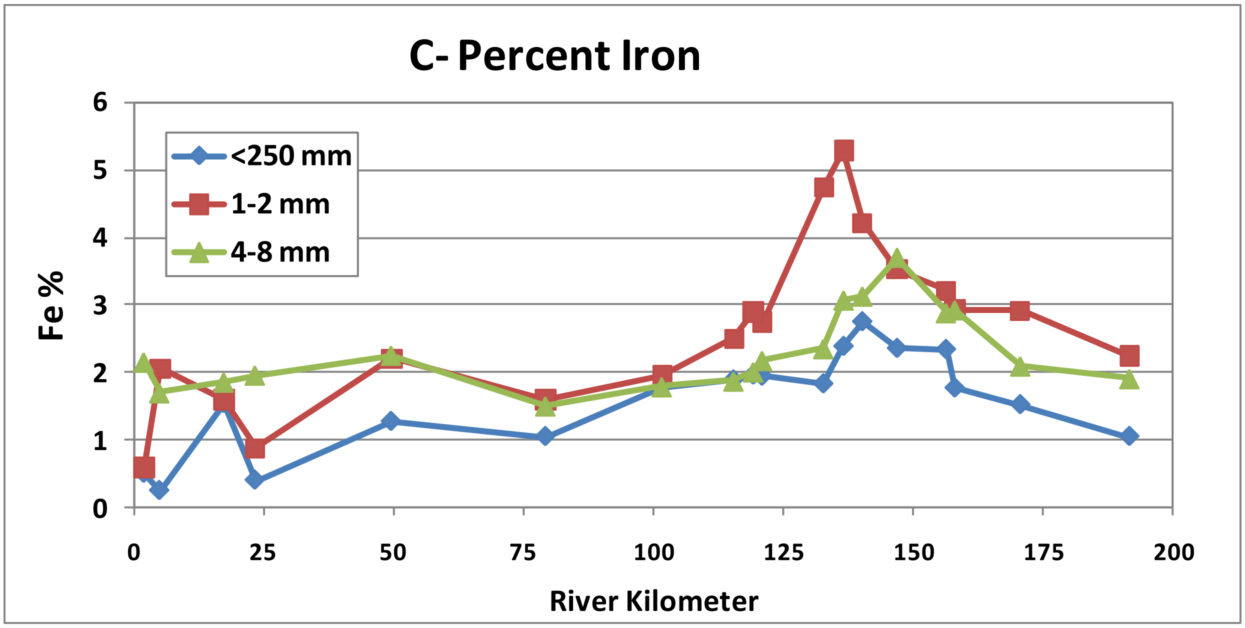


Figure 17 A&B: Downstream Patterns in Metal-Sediment Size Relationships
A- carbon and B-calcium



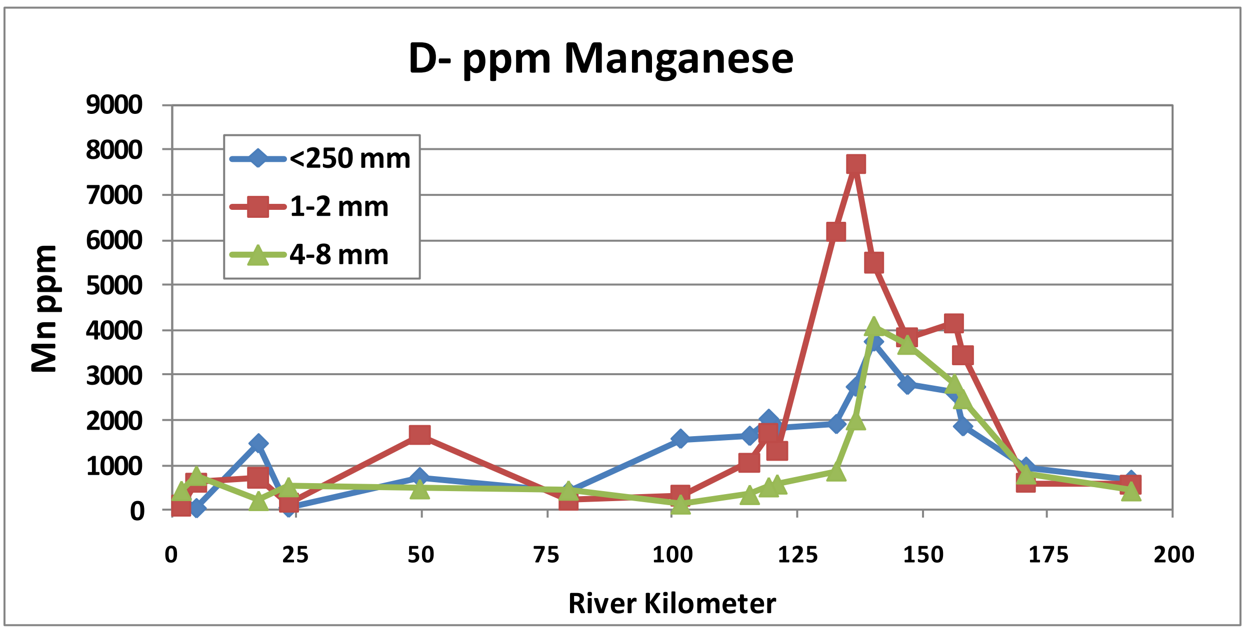
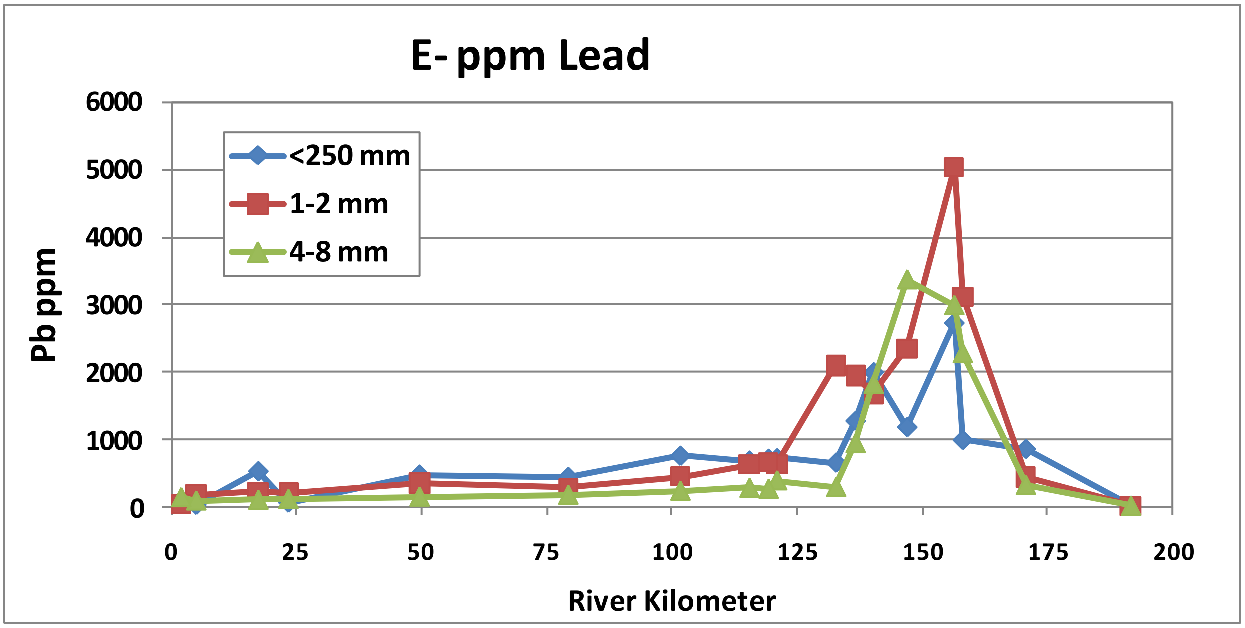


Figure 17 C&D: Downstream Patterns in Metal-Sediment Size Relationships

C- iron and D-manganese



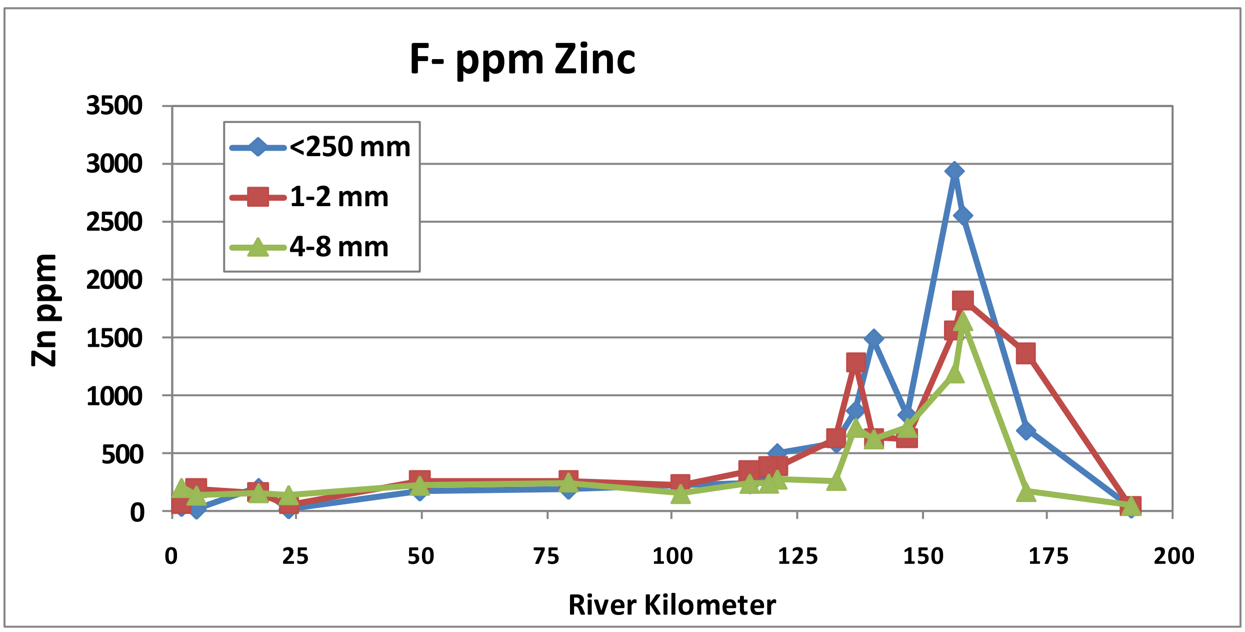


Figure 17 E&F: Downstream Patterns in Metal-Sediment Size Relationships
E- lead and F-zinc

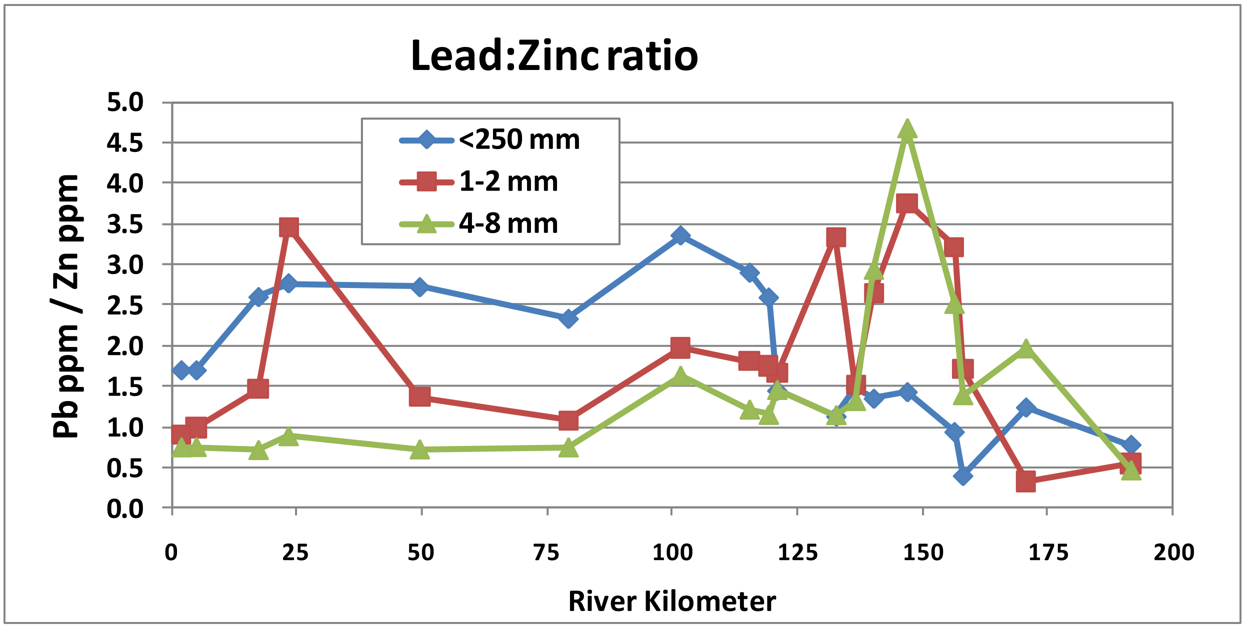
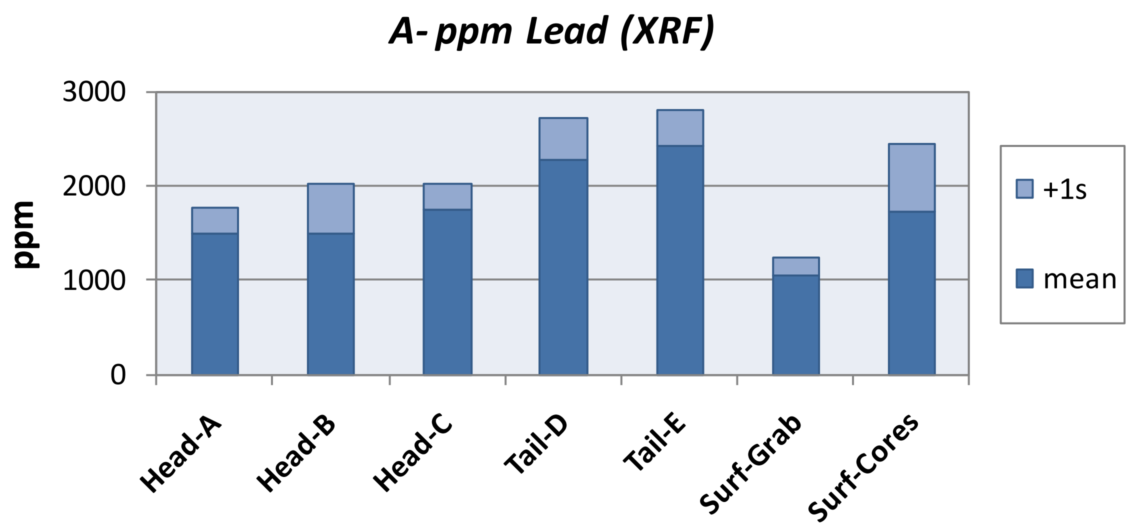


Figure 17 G: Downstream Patterns in Metal-Sediment Size Relationships



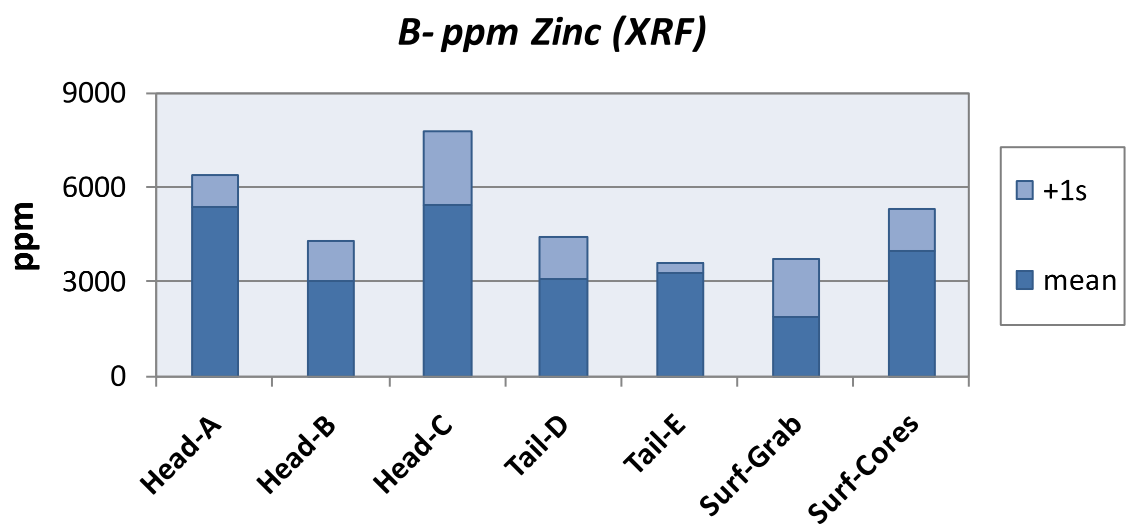
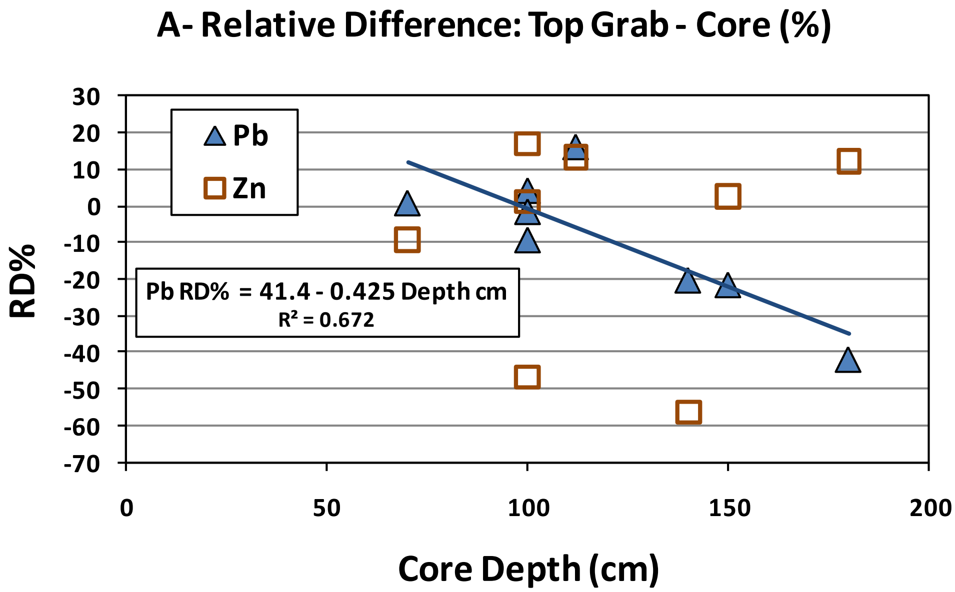


Figure 18: Metal Contaminant Variability Among in Bar Cores and Surface Samples

A- Sample mean and standard deviation for ppm lead

B- Sample mean and standard deviation for ppm Zinc



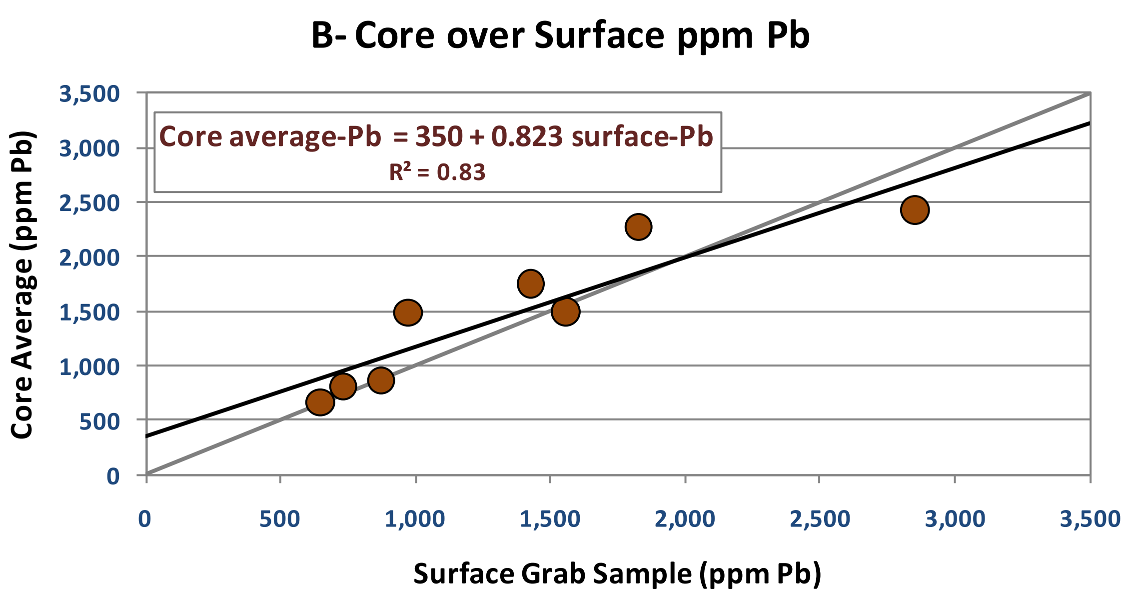


Figure 19: Relationship of Bar Surface Metal Content to Core Composite Average

A- Relative difference % between surface grab sample and composite core average. Trendline shows relationship over depth for Pb.
B- Relationship between surface grab sample Pb and core average Pb. 1:1 line is gray and regression line is black.

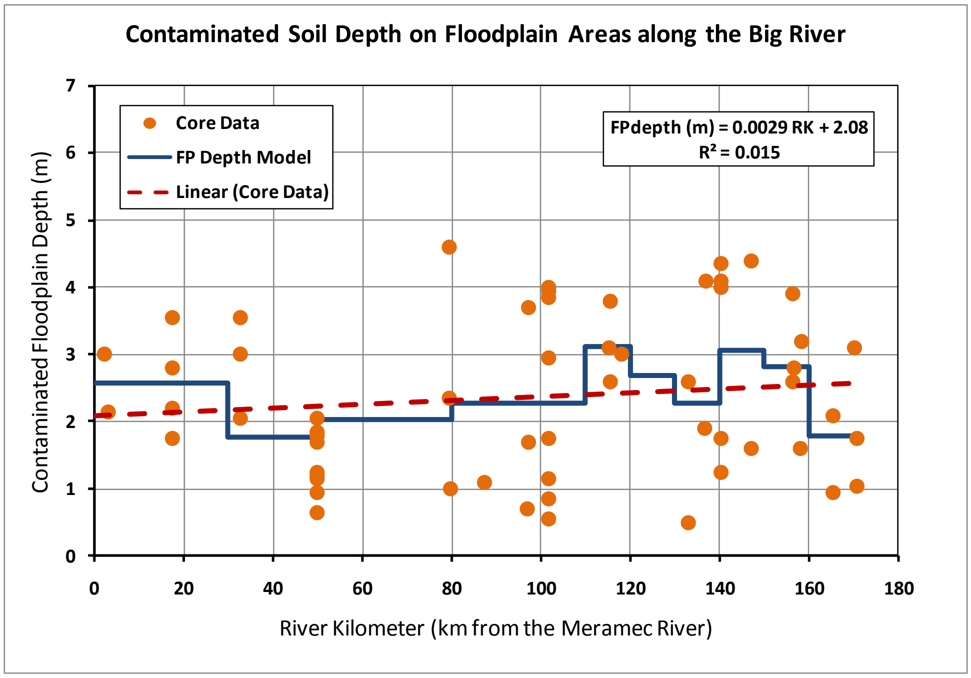


Figure 20: Depth of Contaminated Soil on Floodplain

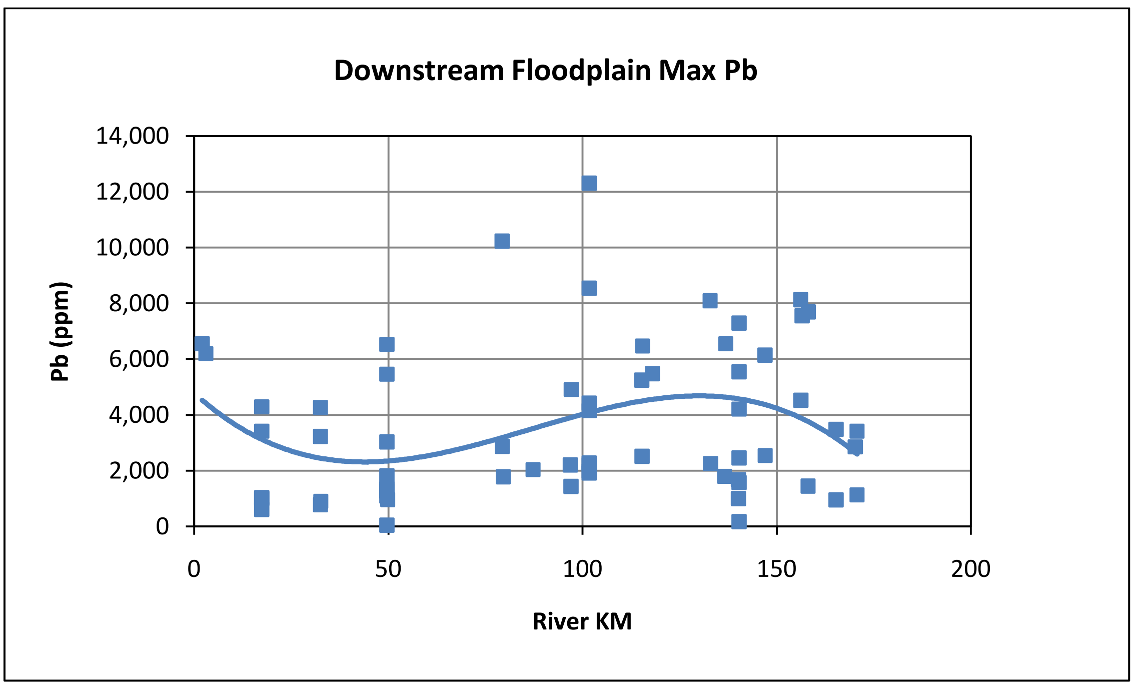


Figure 21: Downstream Trends in Maximum Floodplain Pb Concentrations

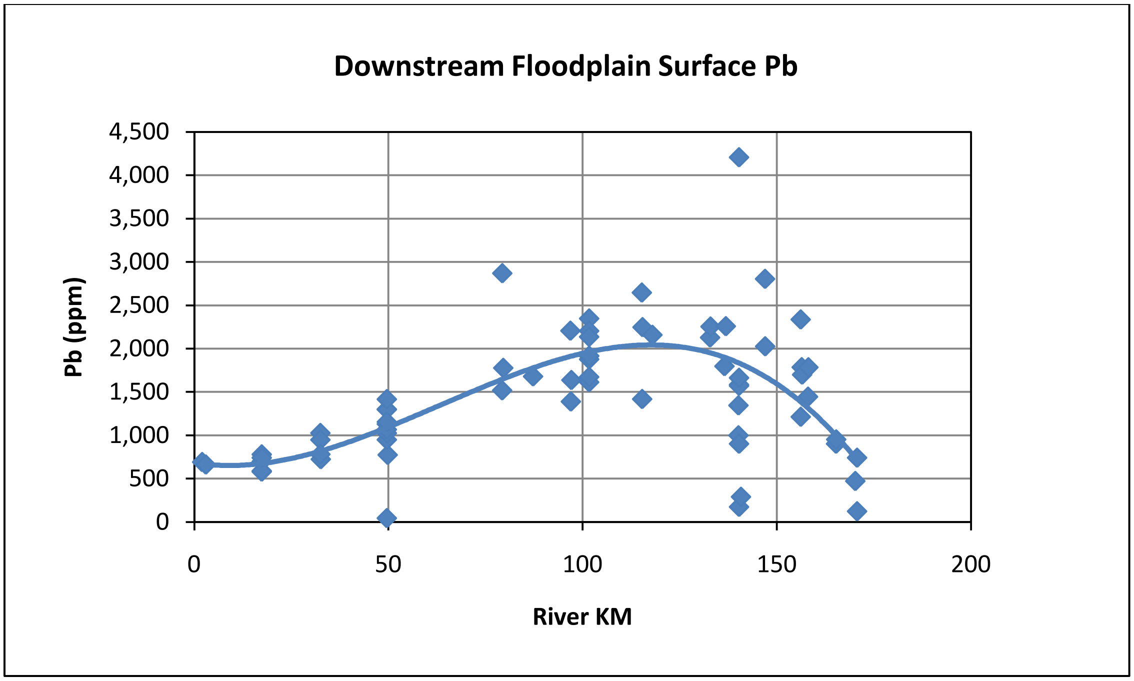


Figure 22: Downstream Pb Concentration at Floodplain Surface

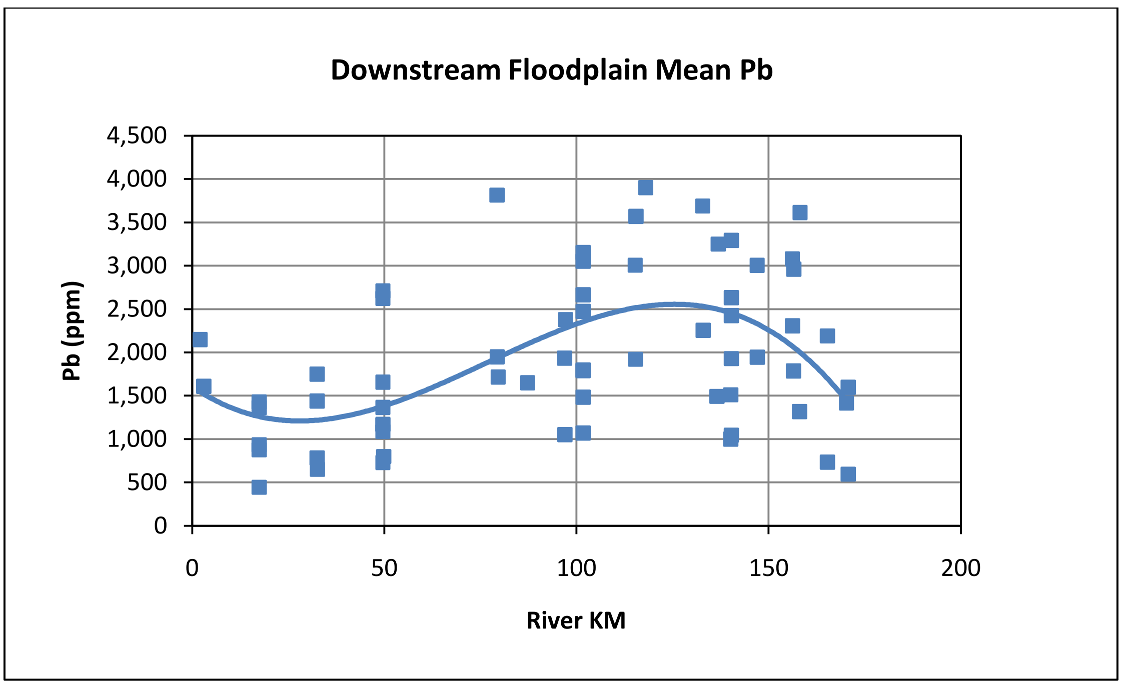


Figure 23: Downstream Mean Floodplain Pb Concentrations

Polynomial regression equation: Pb ppm = -.0029x3 + 0.669x2 – 30.6x + 1606, R2 = 0.294. This equation is used to calculate floodplain storage of sediment and Pb.

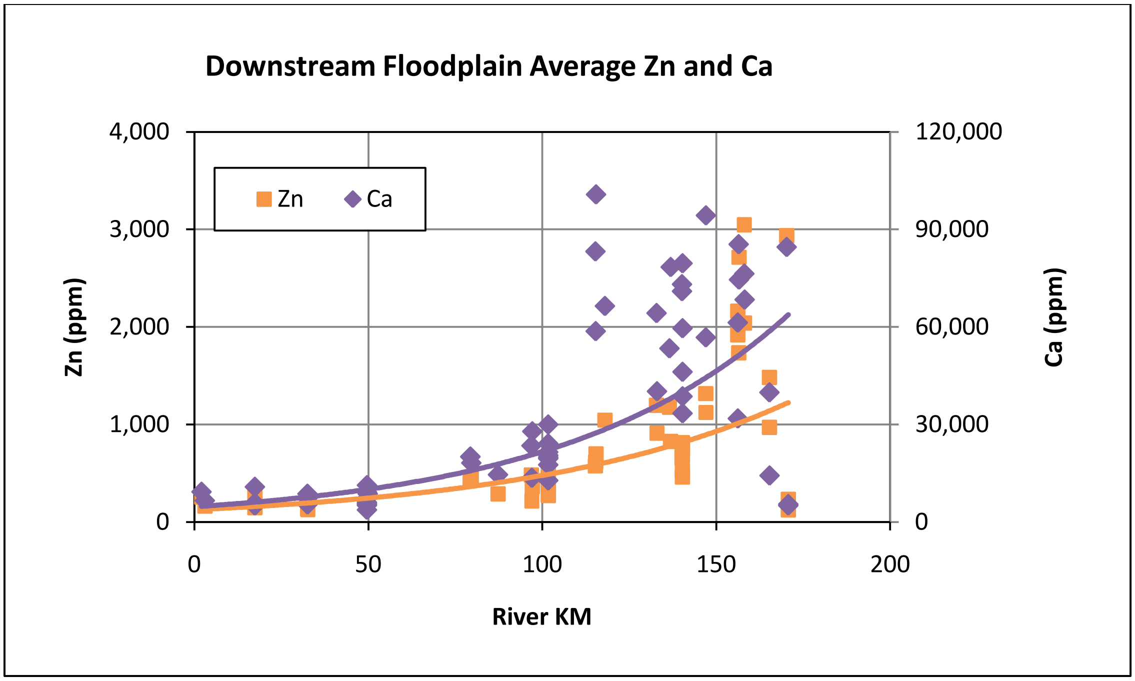


Figure 24: Downstream Mean Floodplain Zn and Ca

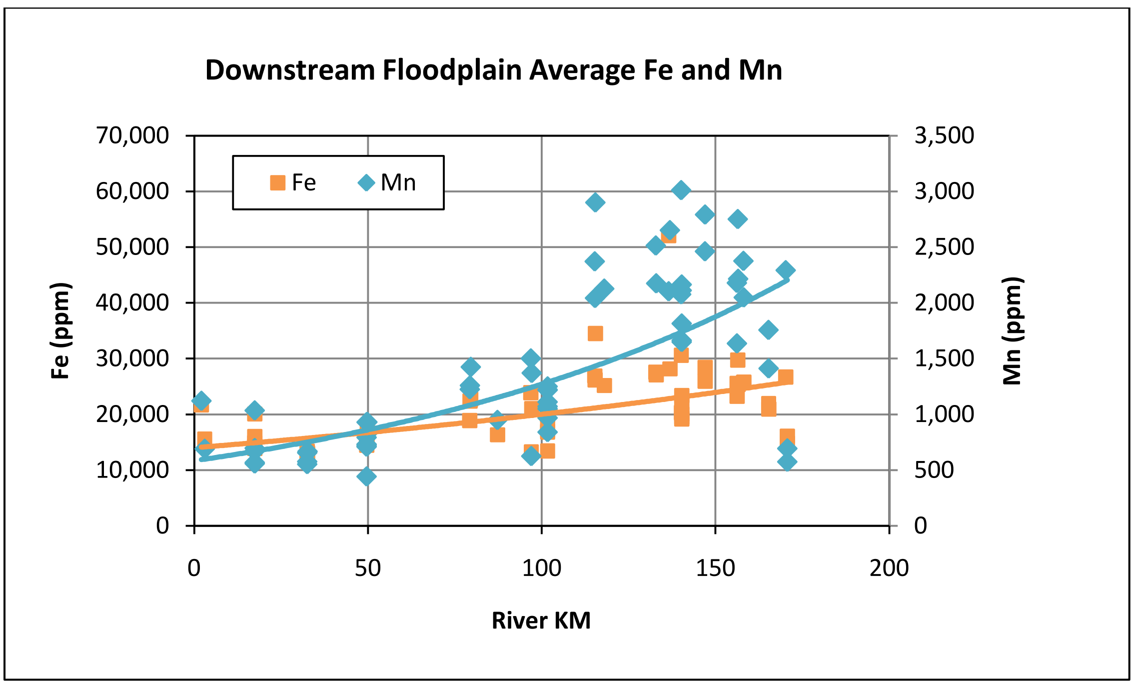


Figure 25: Downstream Mean Floodplain Fe and Mn

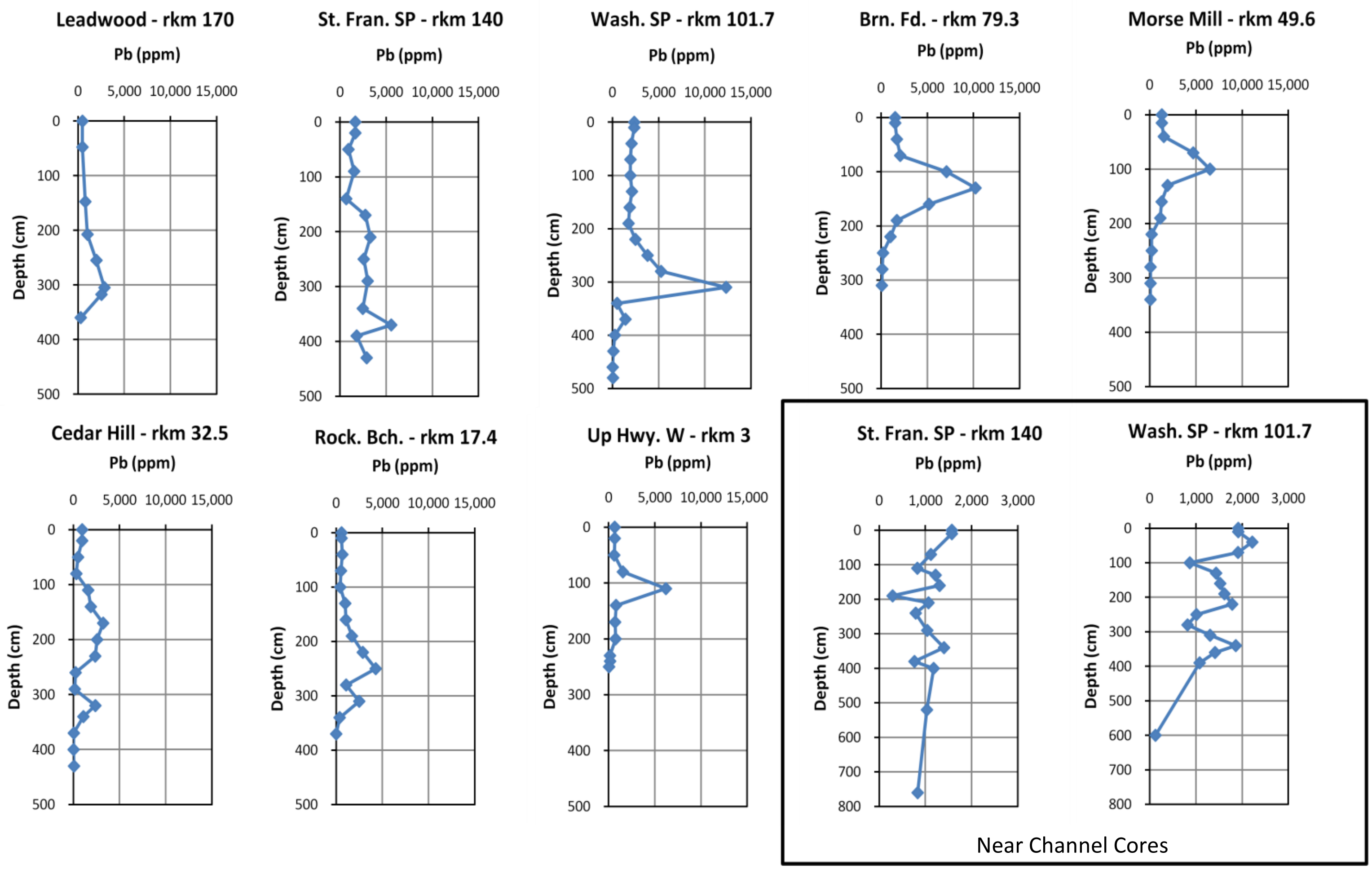


Figure 26: Variability in Floodplain Pb in Cores at Selected Sites

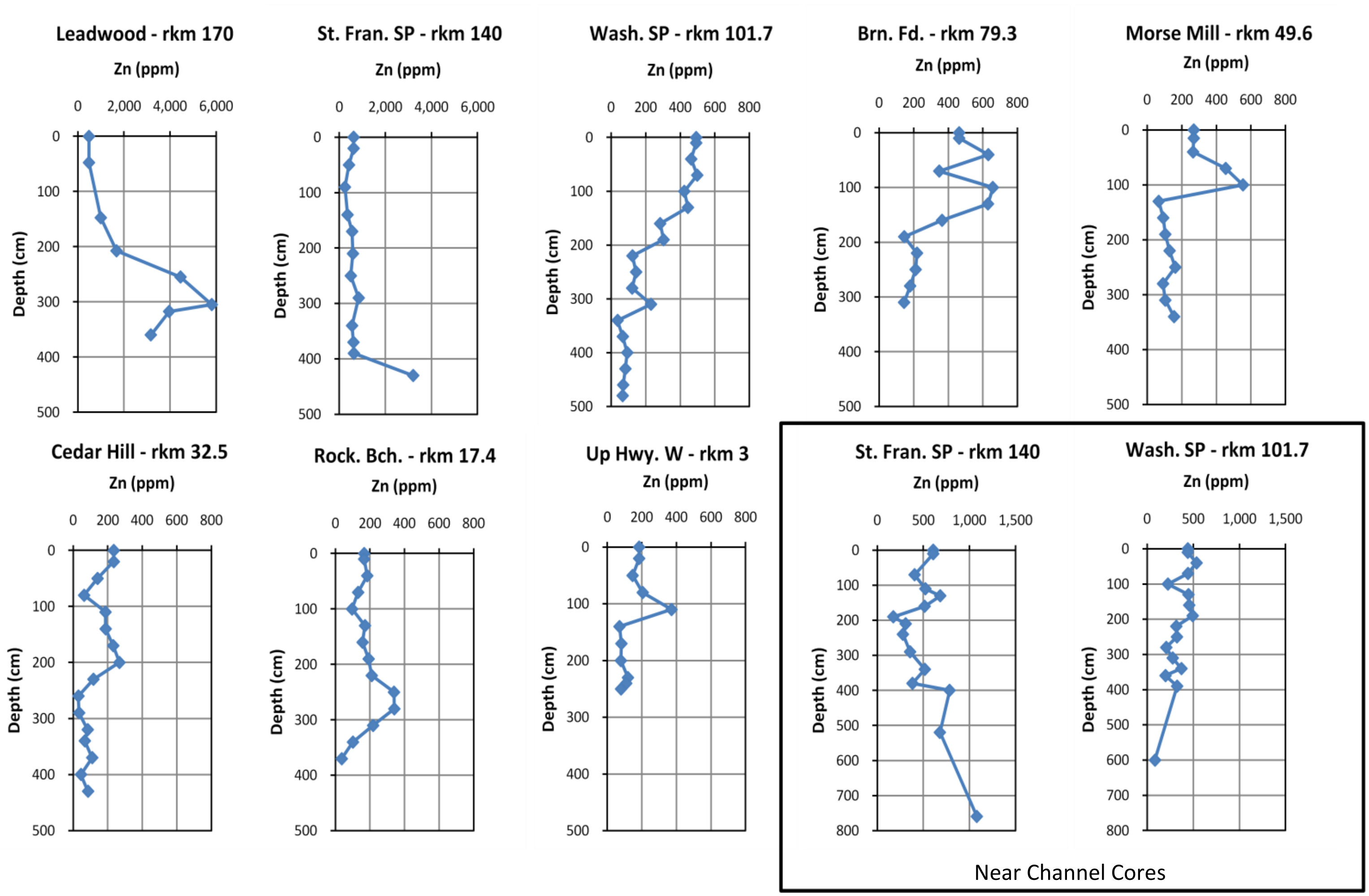


Figure 27: Variability in Floodplain Zn in Cores at Selected Sites

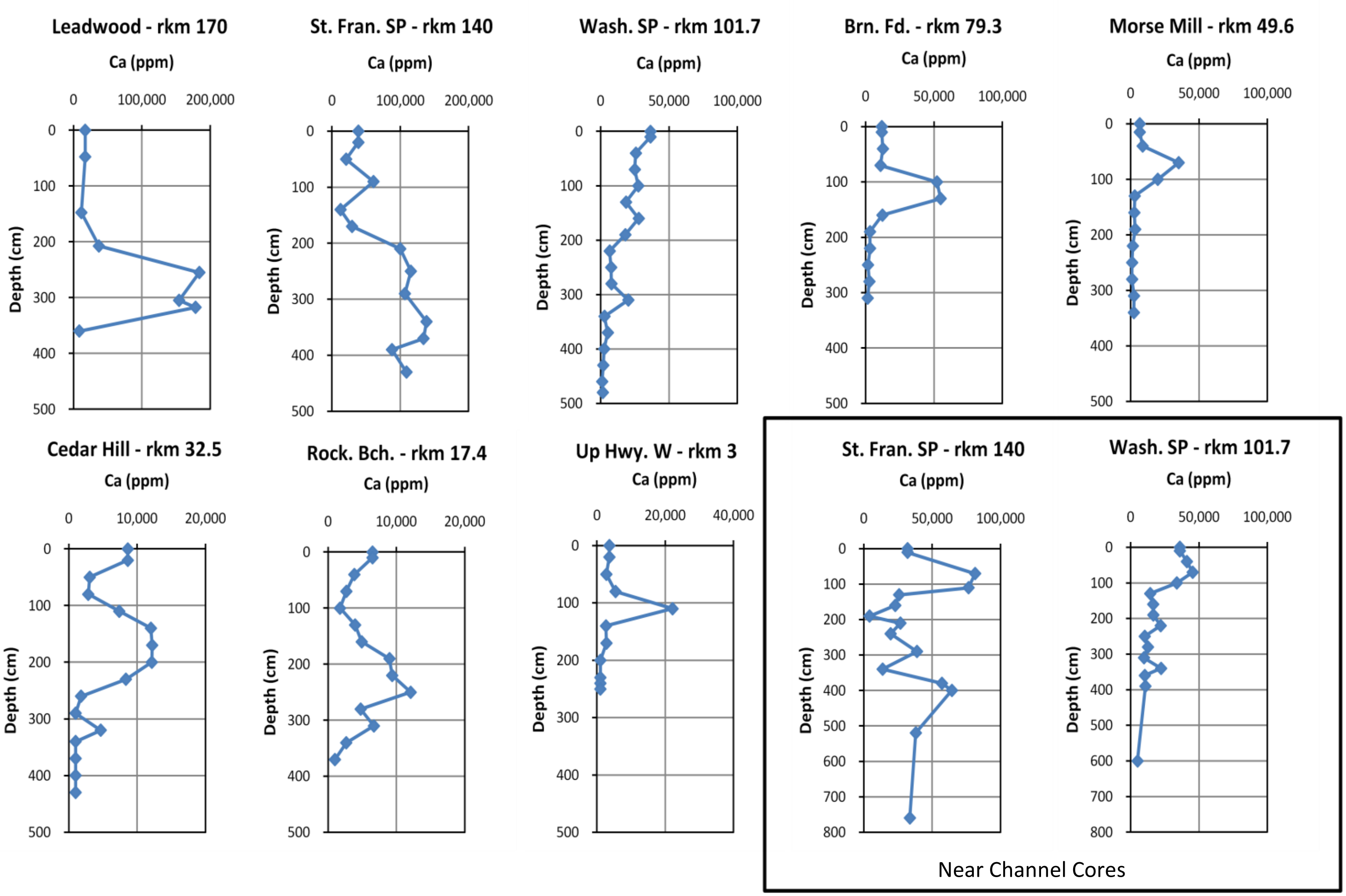


Figure 28: Variability in Floodplain Ca in Cores at Selected Sites

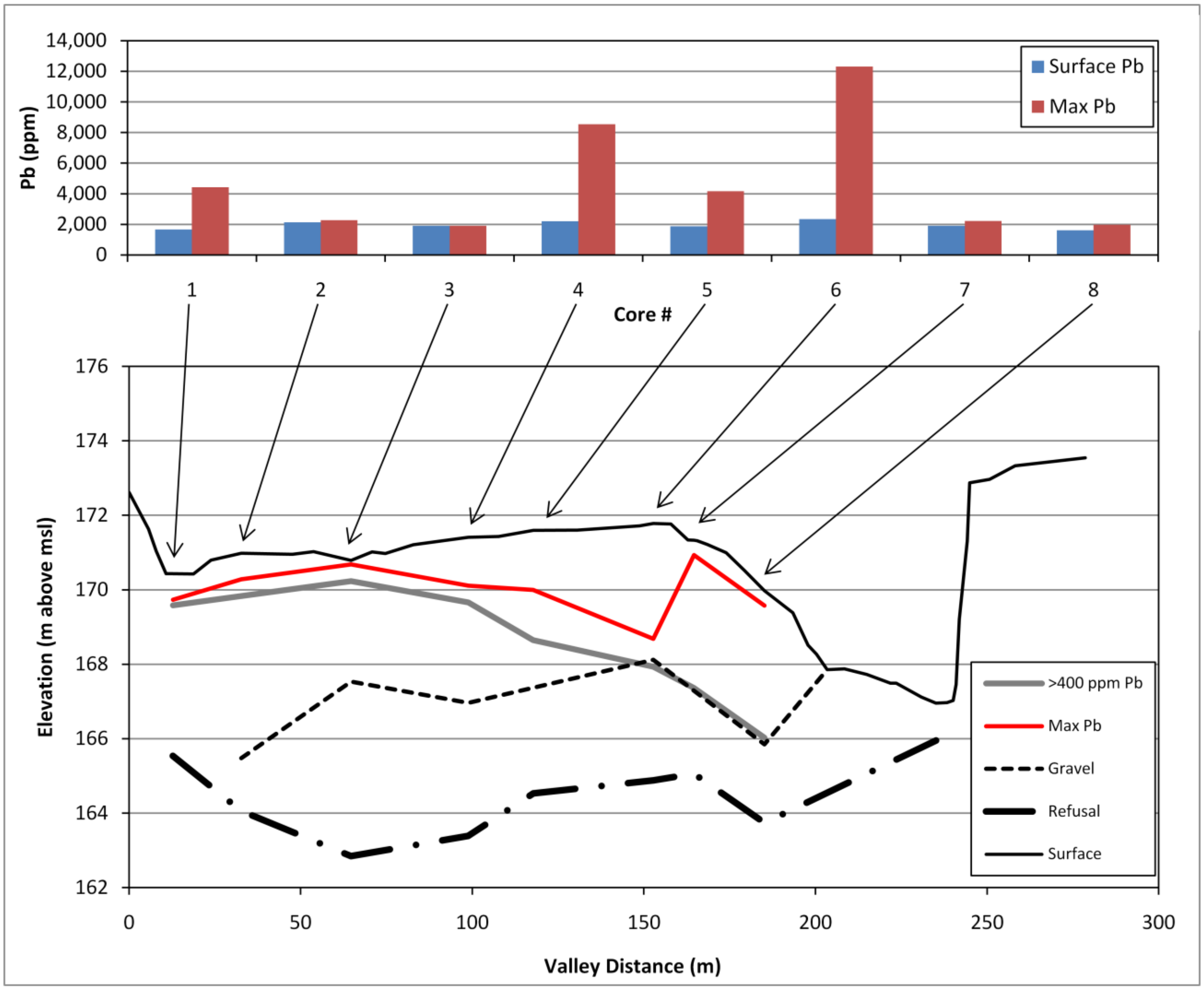


Figure 29: Washington State Park Transect #1

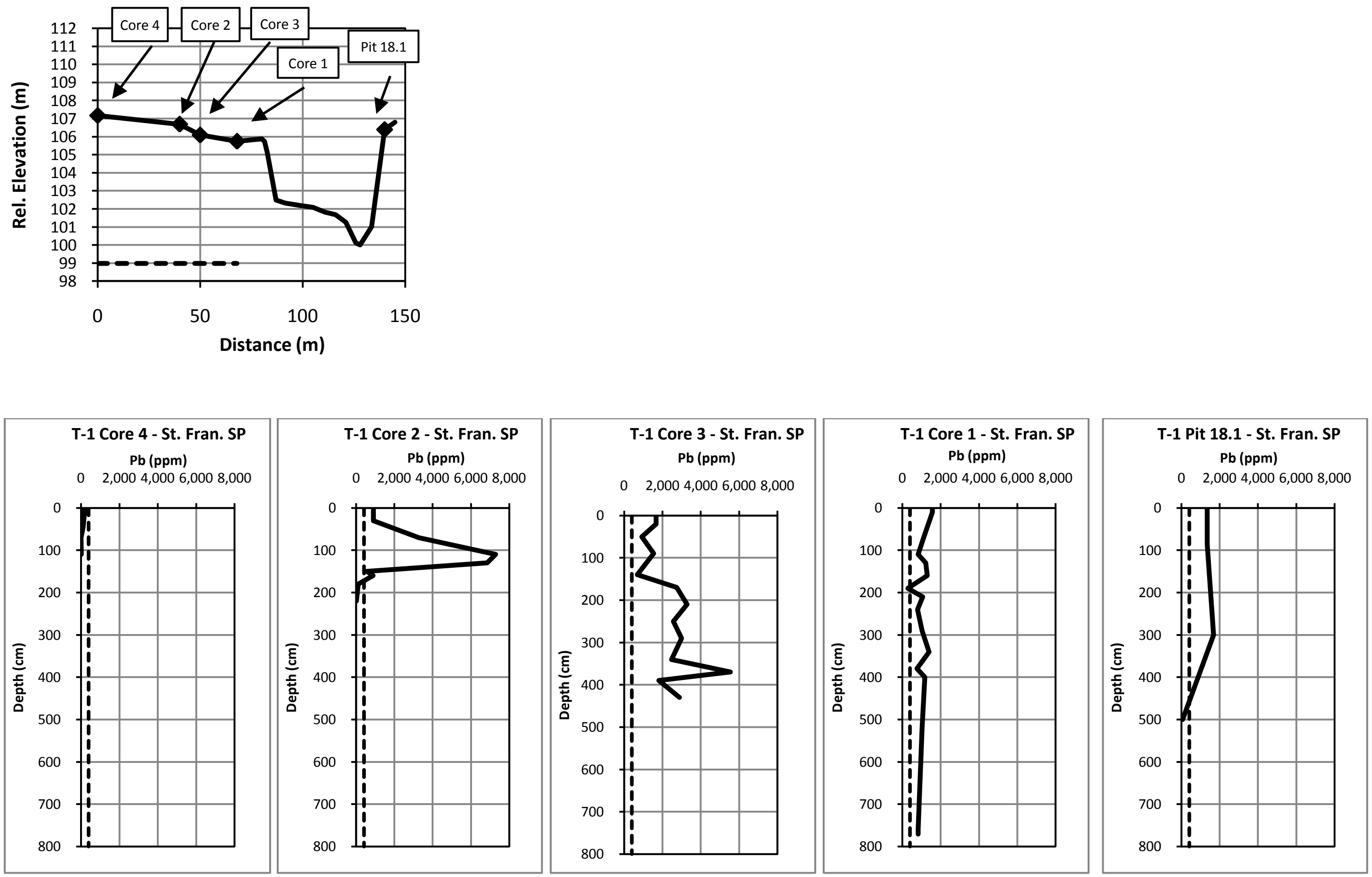


Figure 30: St. Francois State Park Transect #1

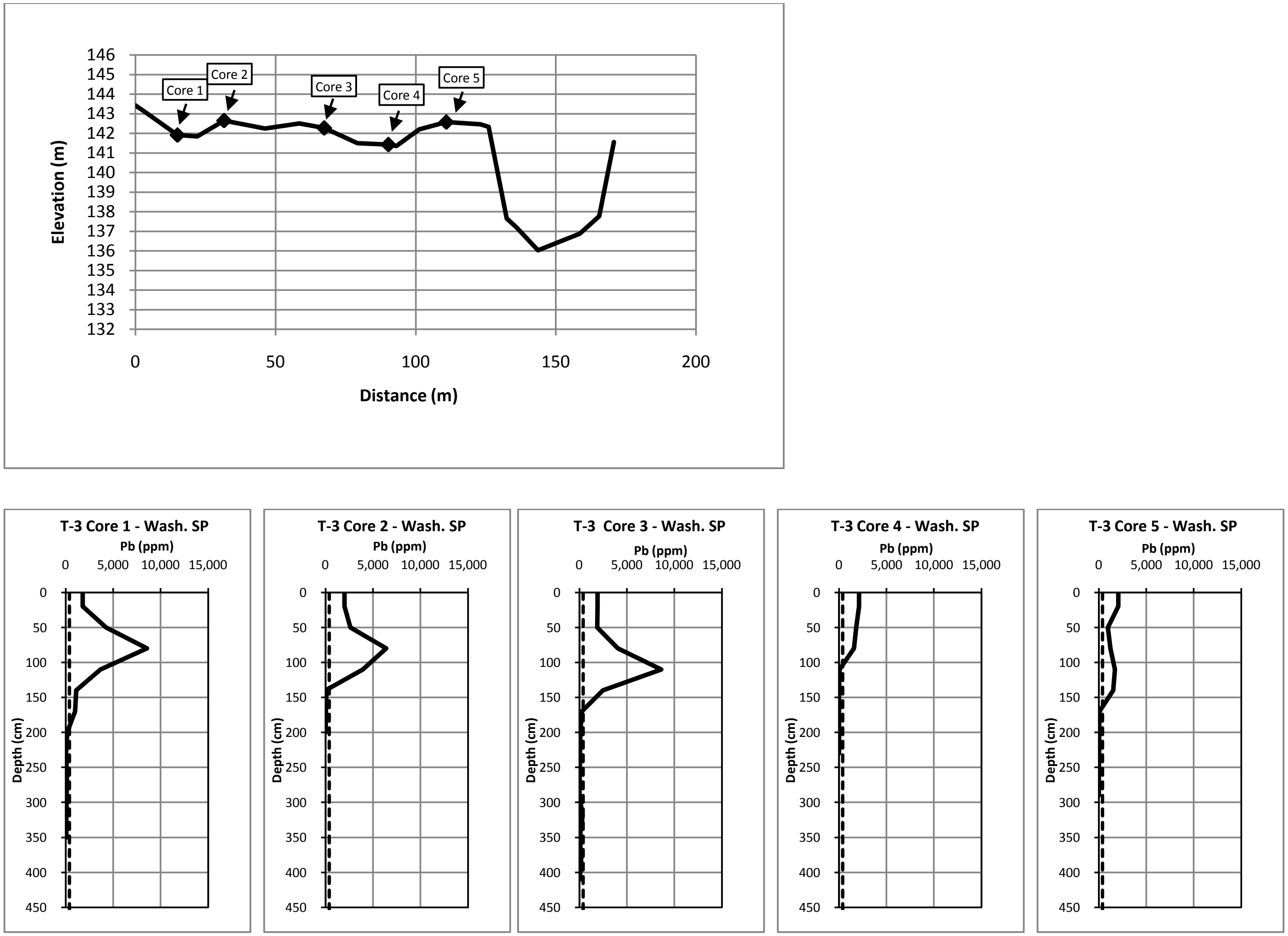


Figure 31: Washington State Park Transect #3

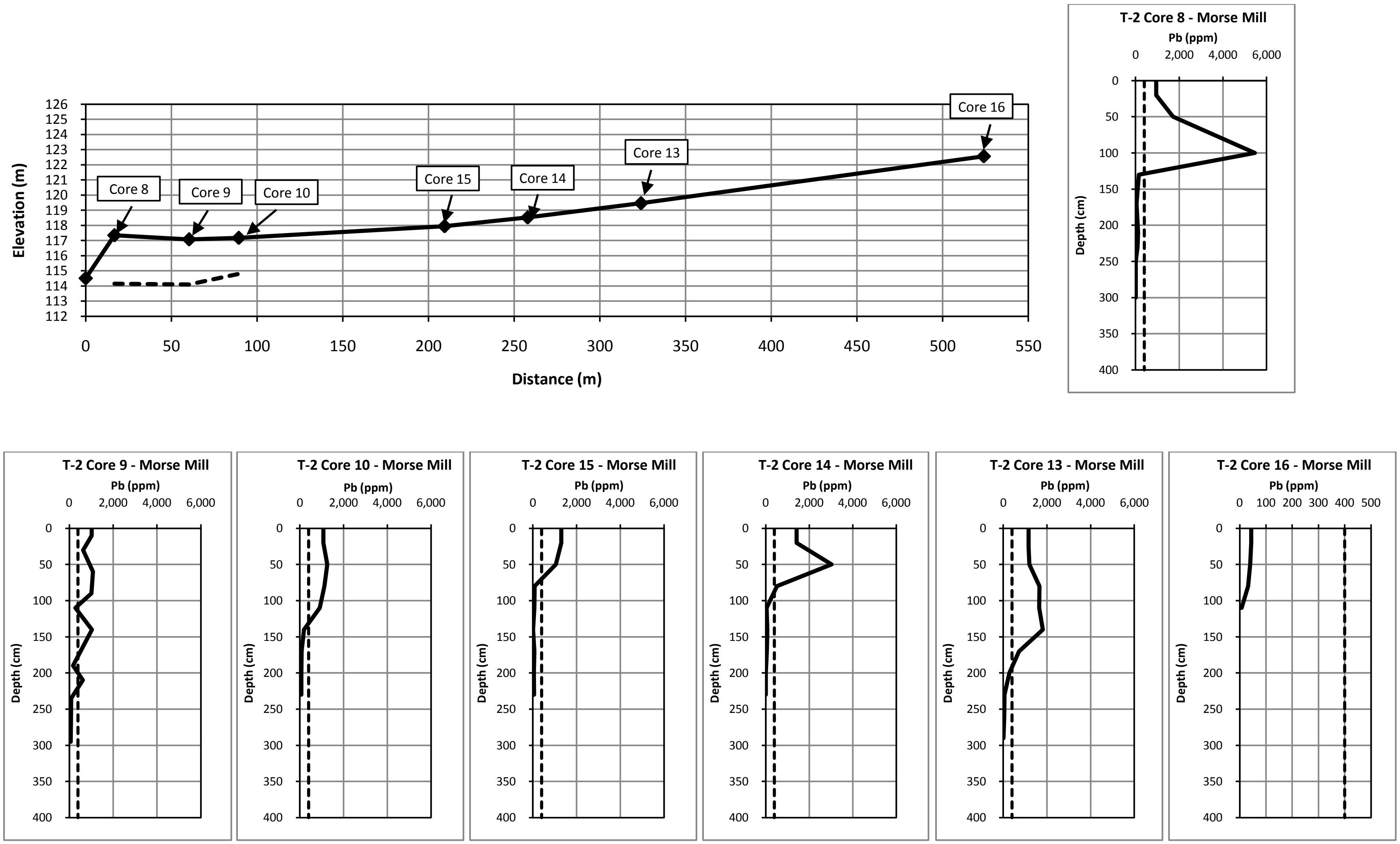


Figure 32: Morse Mill Transect #2

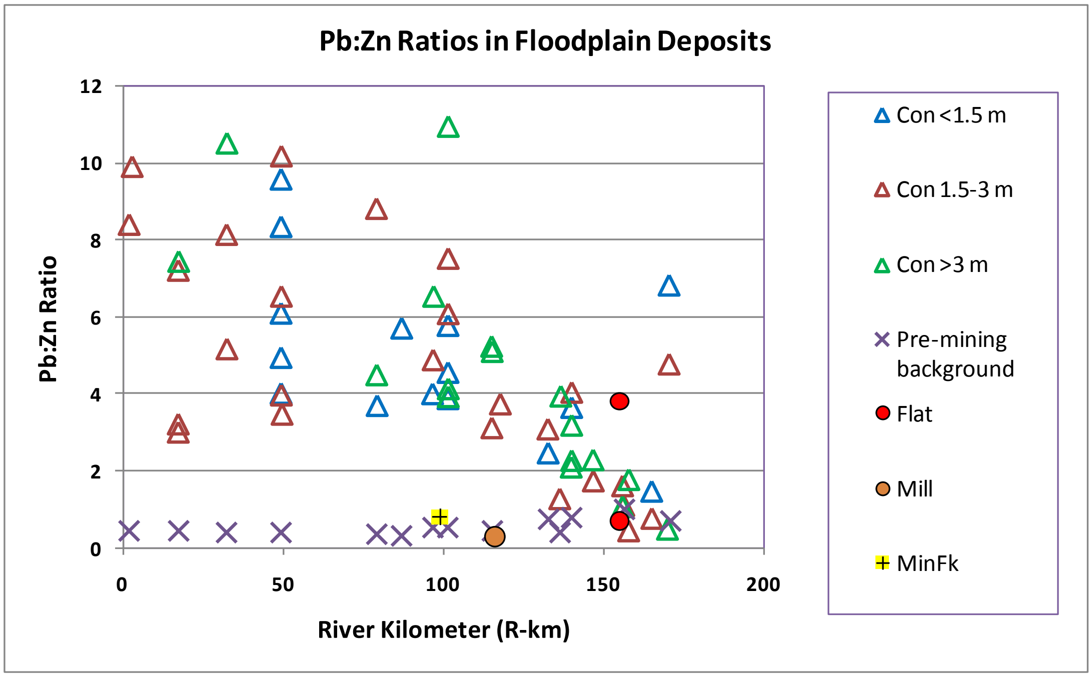


Figure 33: Pb:Zn Ratios in Floodplain Deposits
Symbols are coded according to the depth of contamination. "X" symbols show ratio values for uncontaminated bottom core samples. Ratios are shown for the floodplain cores collected from the major tributaries: Flat River Creek, Mill Creek, and Mineral Fork Creek.

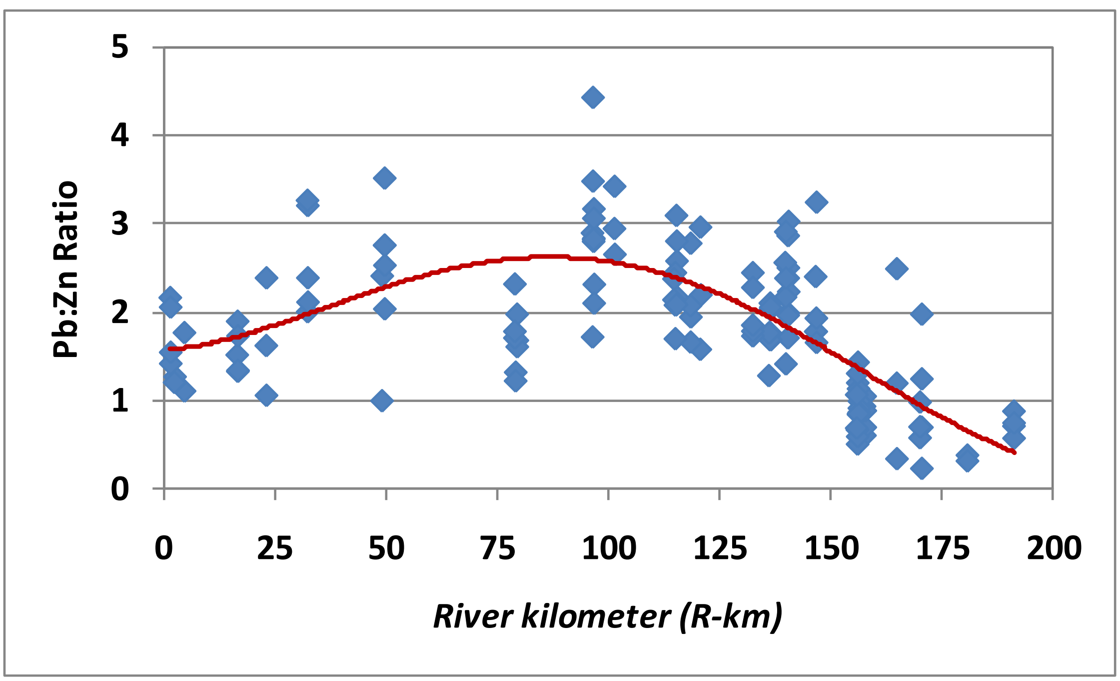


Figure 34: Pb:Zn Ratios in the <2 mm Fraction in Channel Deposits

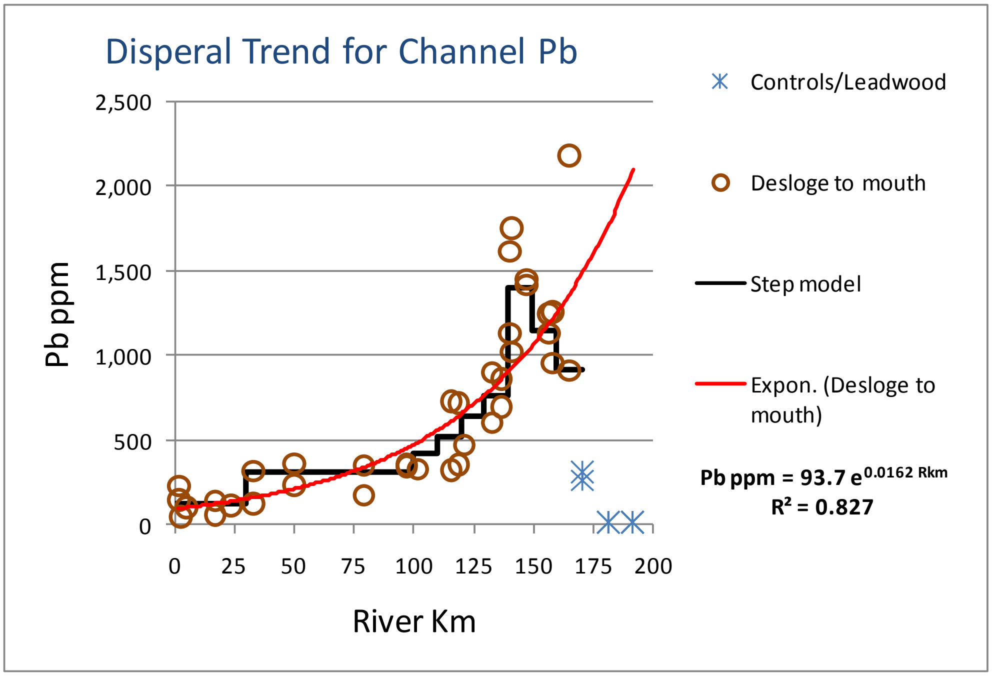


Figure 35: Dispersal Trend for In-Channel Pb Concentrations

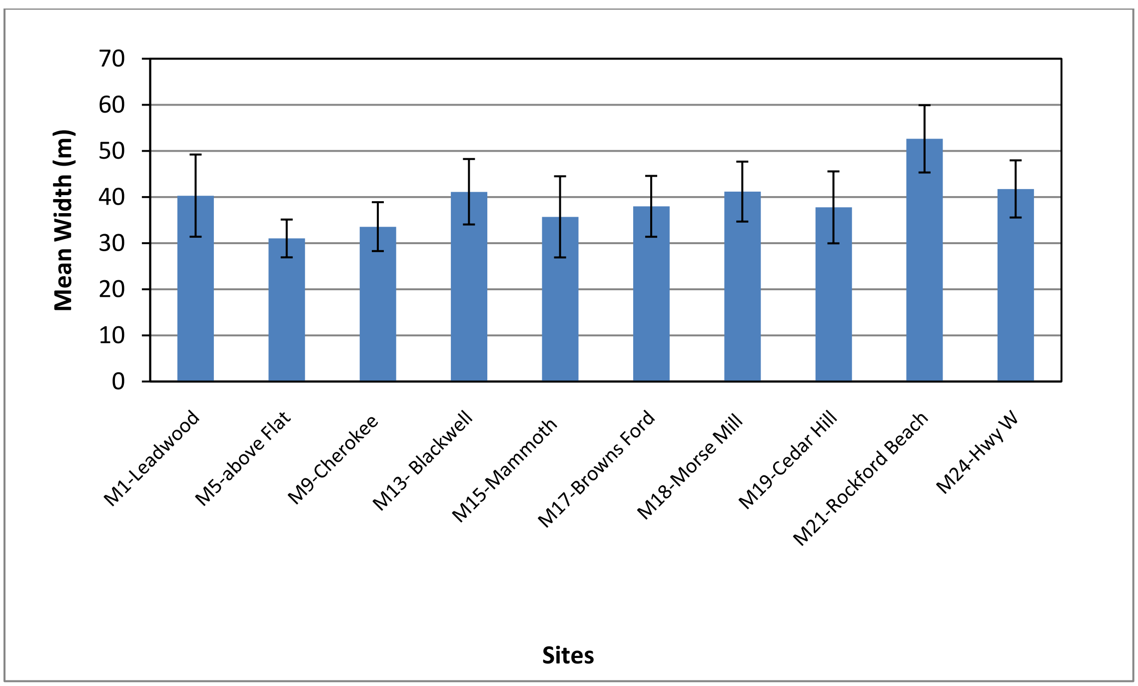


Figure 36: Mean Reach Width by Site

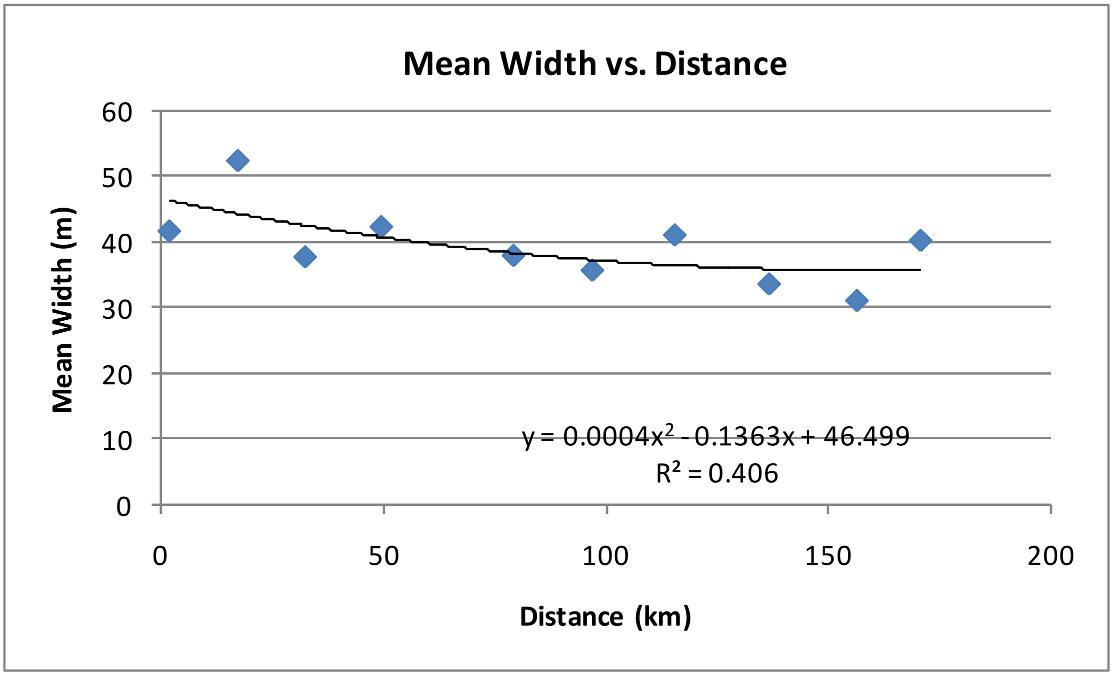


Figure 37: Downstream mean reach channel width

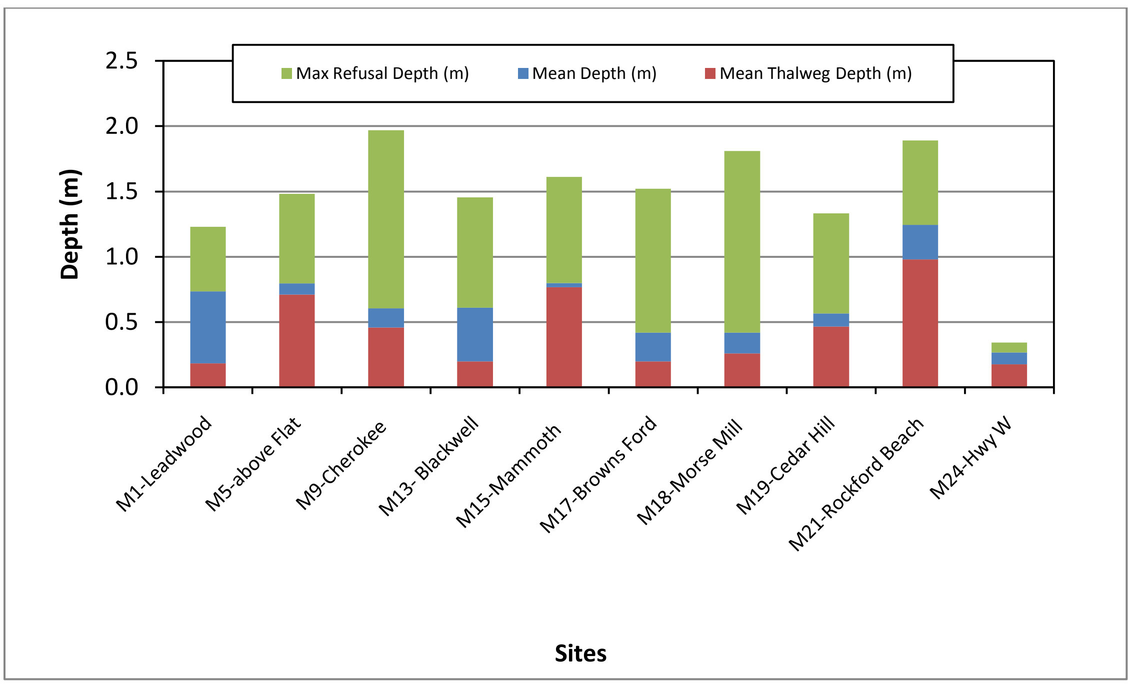


Figure 38: Reach Channel Sediment Depth by Site

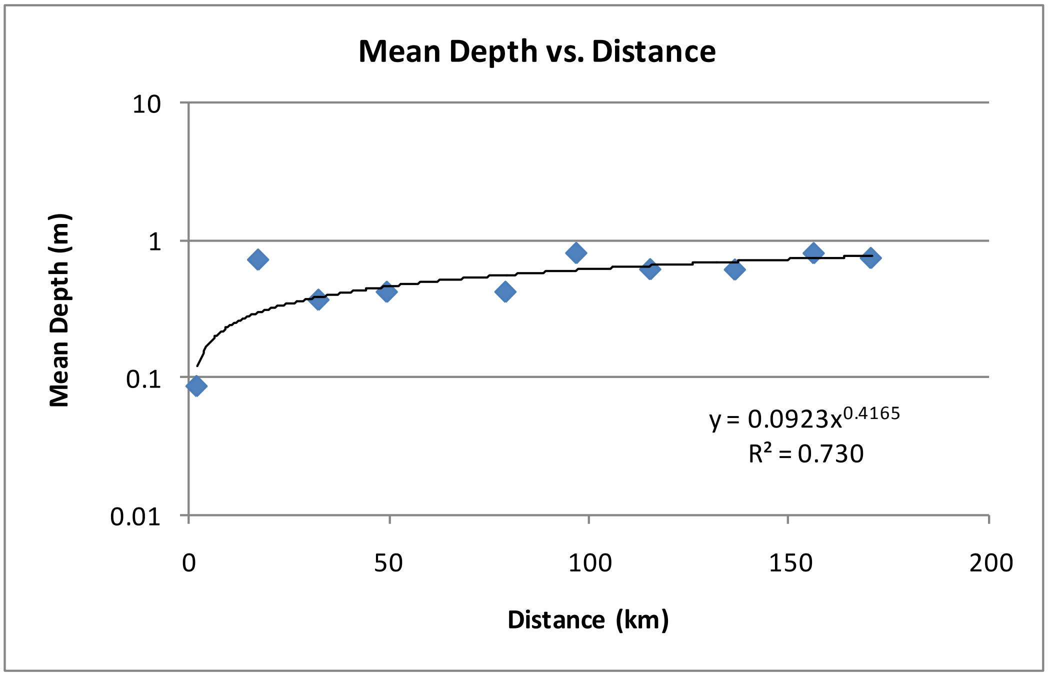


Figure 39: Downstream Mean Reach In-Channel Sediment Depth

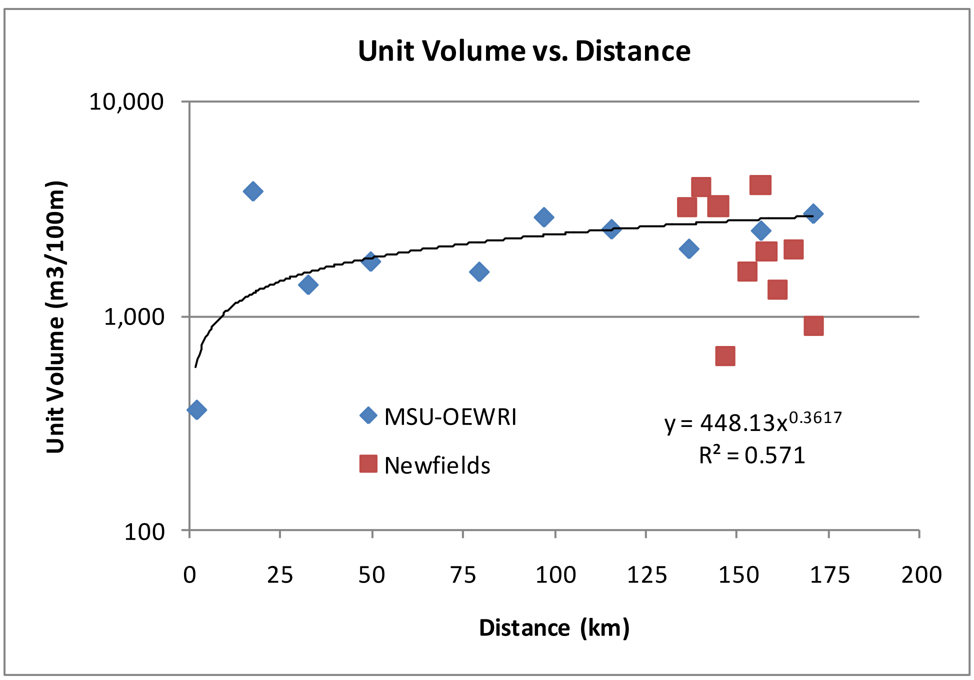


Figure 40: Downstream Unit Volume of In-Channel Storage

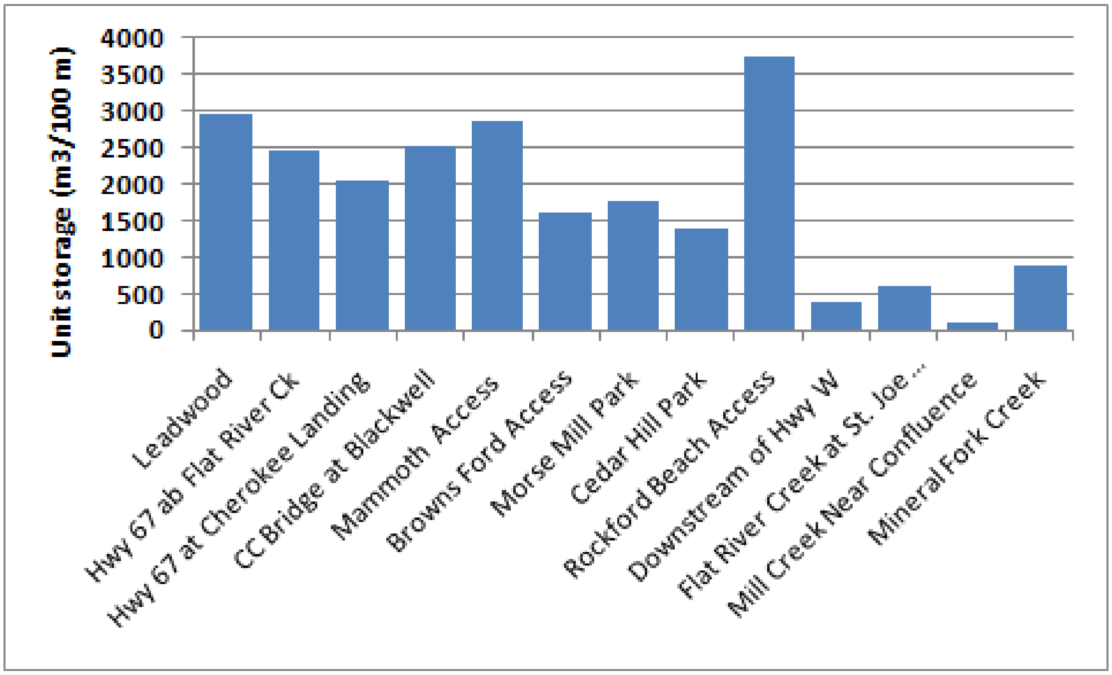


Figure 41: Mean Unit Channel Sediment Storage at each Study Site

Average unit storage rates are 2,570 +/- 14% m3/100 m from R-km 171 to 90 and 1,580 +/- 12% from R-km 90 to 15. Storage rates can be locally high behind low water bridges or old mill dams such as found at Leadwood and Rockford Beach.

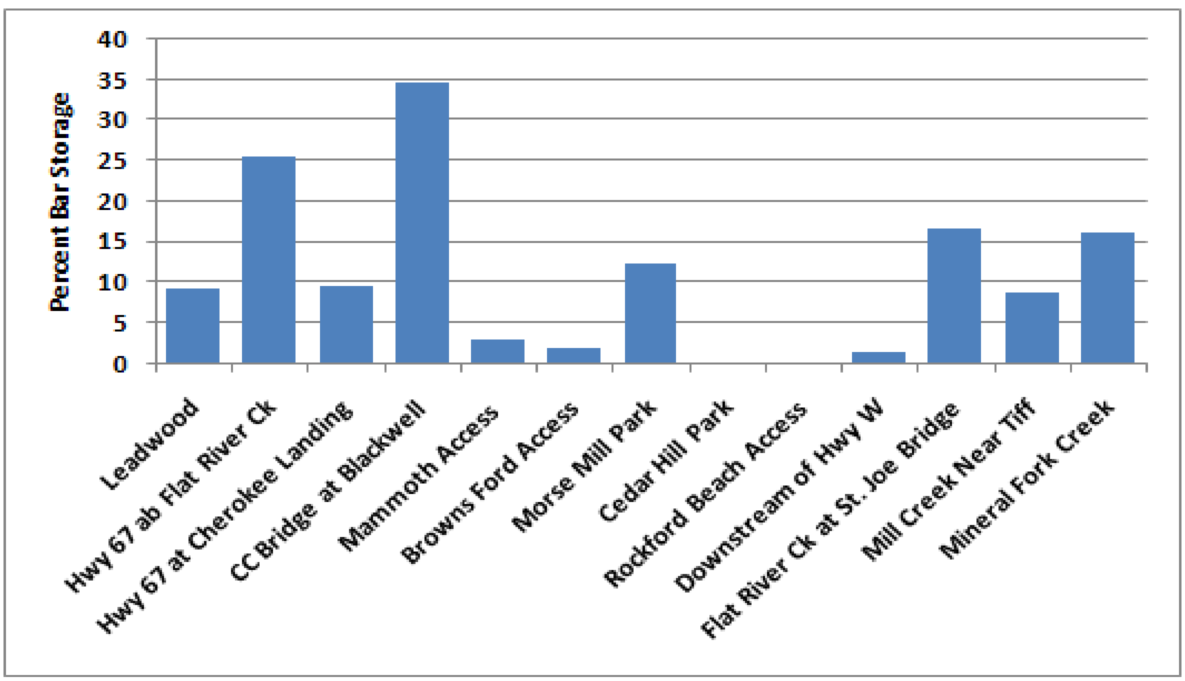


Figure 42: Relative Bar Sediment Storage at each Study Site

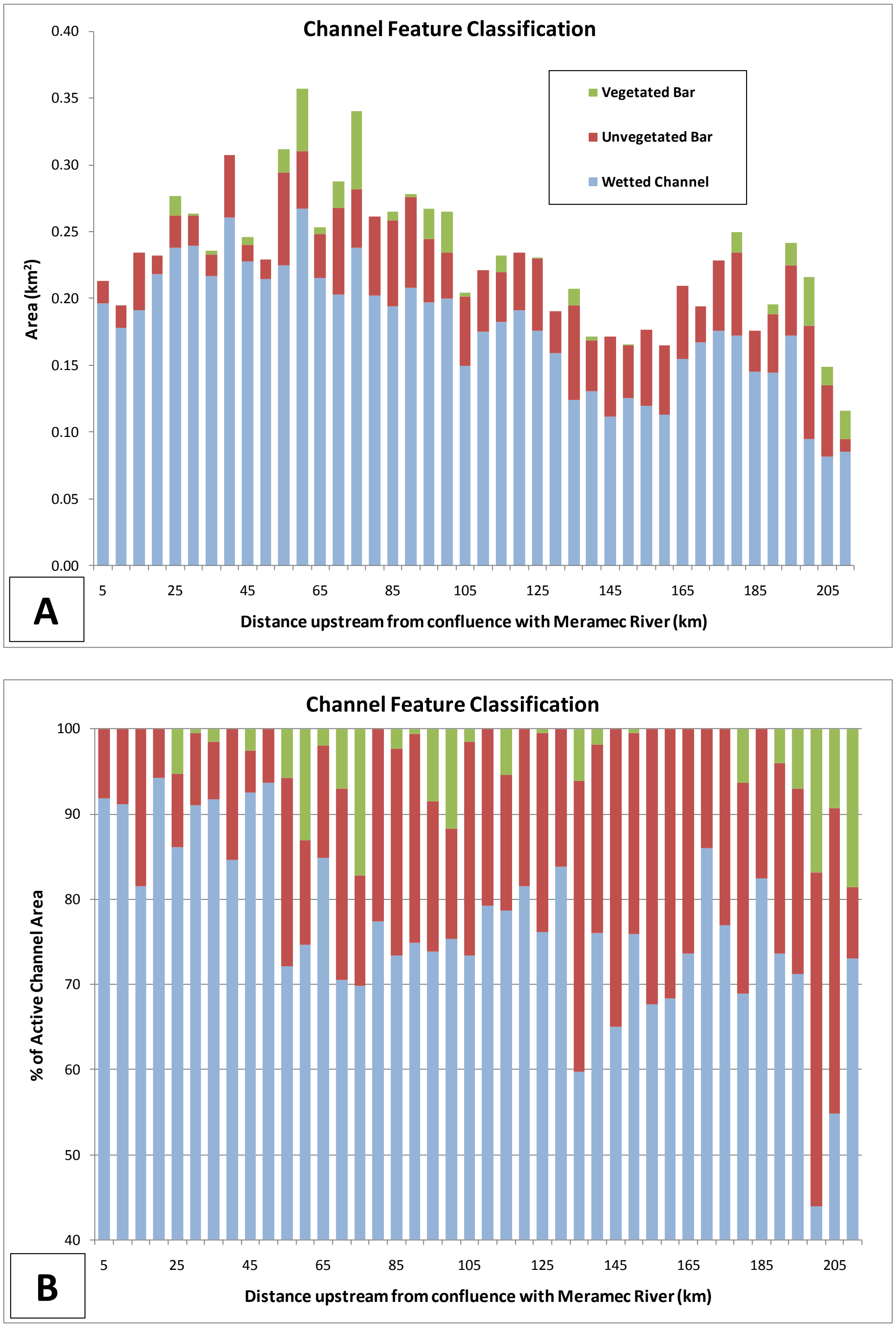


Figure 43: Channel Feature Classification Data Extracted from 2007 2-ft Resolution, Leaf-Off Aerial Photography

(A) Channel feature area per 5km channel unit and (B) channel feature % composition per 5km channel unit.

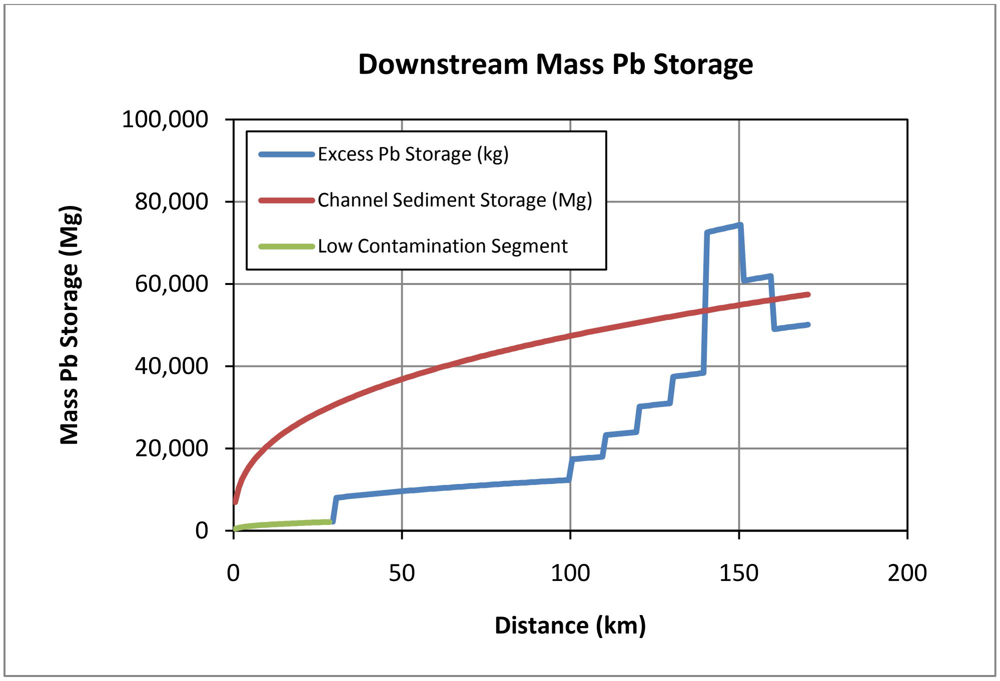


Figure 44: Contaminated channel sediment and lead storage in the Big River

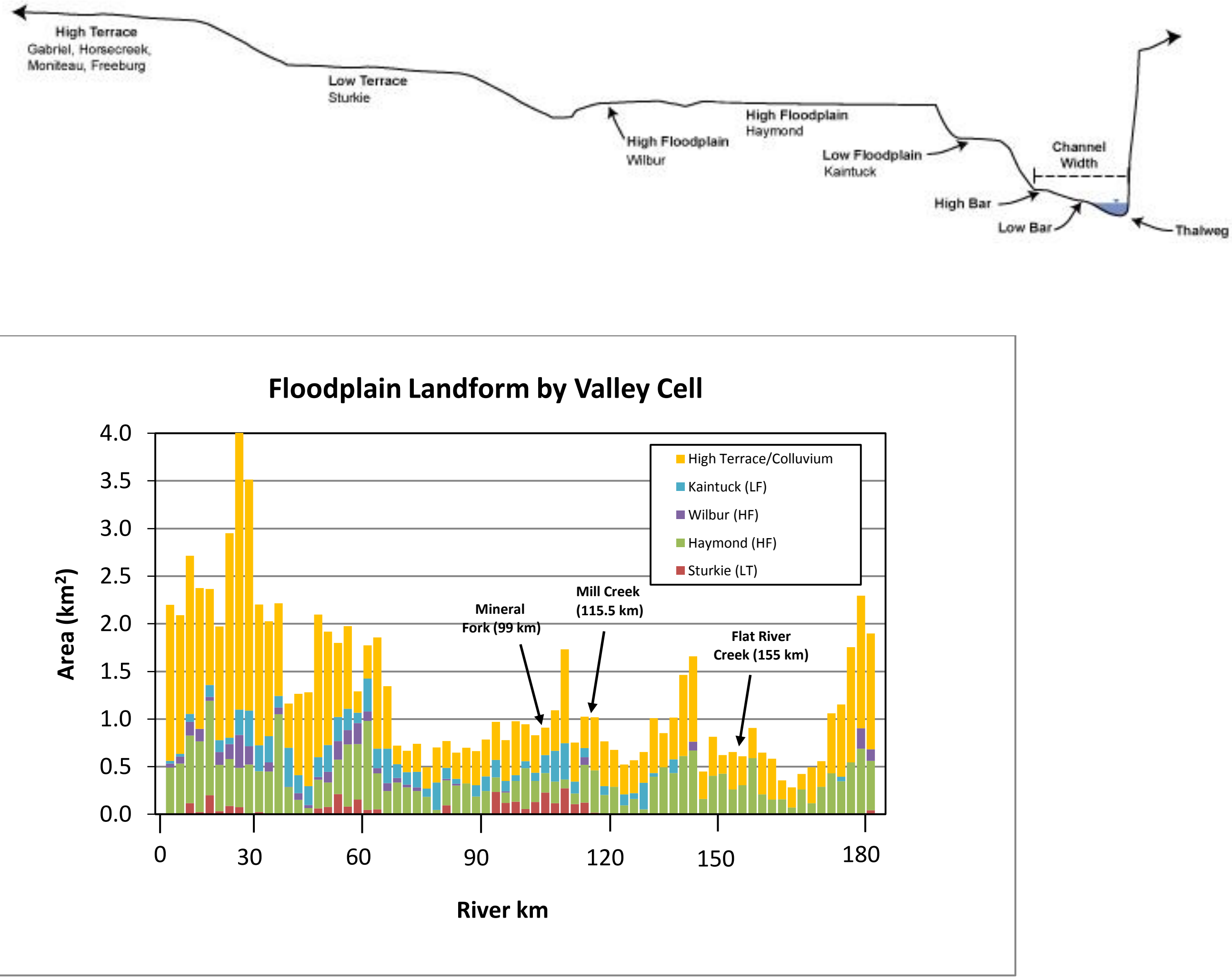


Figure 45: Downstream Floodplain Area by Landform

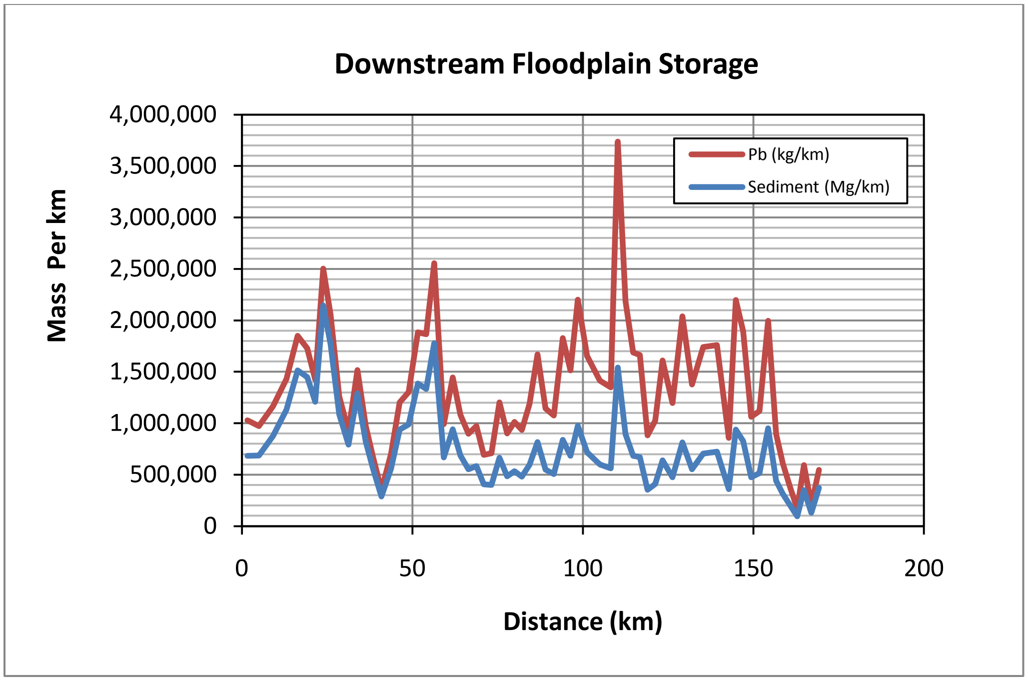


Figure 46: Downstream Floodplain Sediment and Pb Mass per Unit Distance

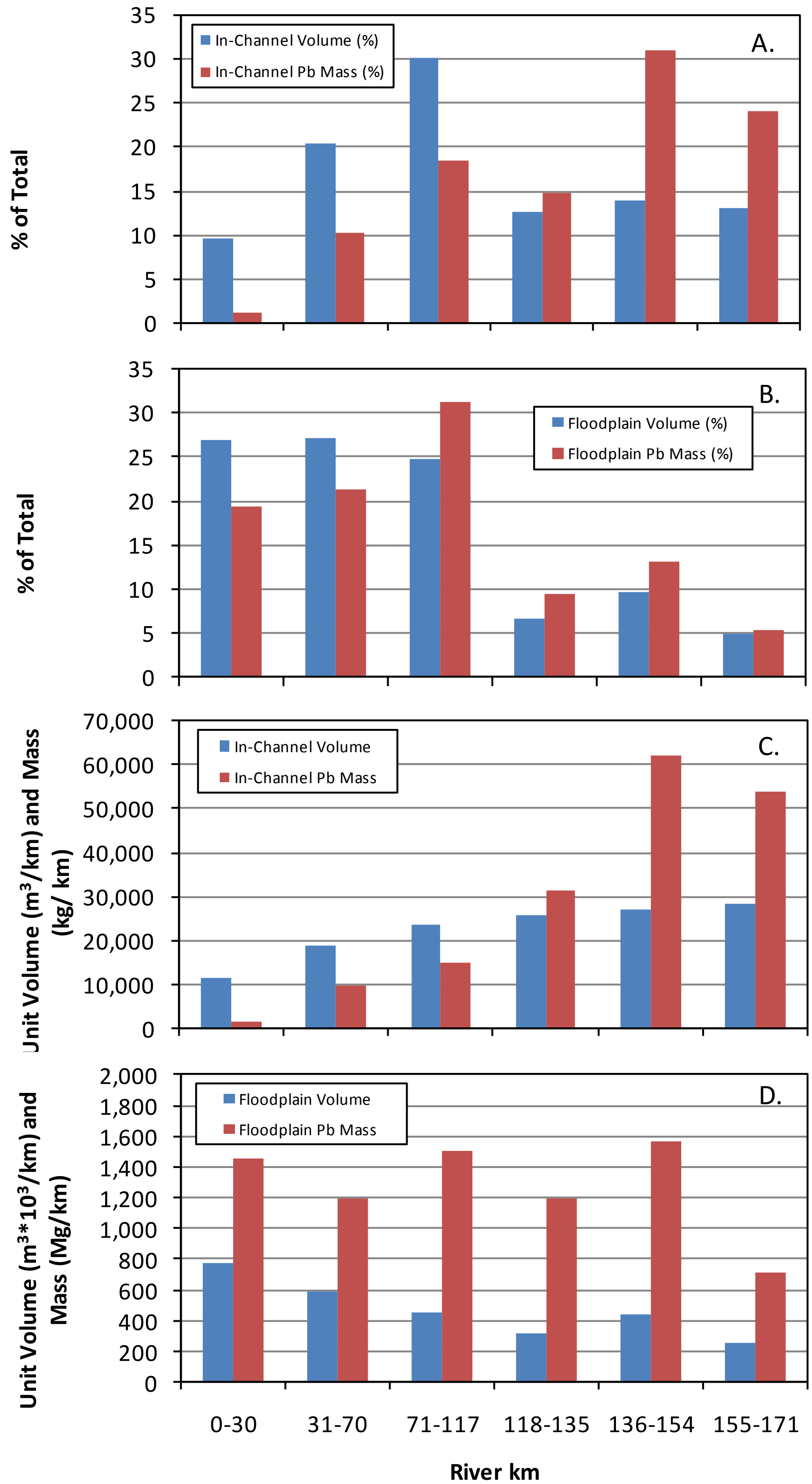


Figure 47: Contaminated Sediment Storage and Pb Mass by River Segment

APPENDIX

River Kilometer Reference Table

Locations along the length of the Big River are referenced by river kilometer (R-km) with R-km 0 at the confluence with the Meramec River. The table below contains reference informaton that relates river kilometer to study reach locations, road crossings, and tributary confluences. For consistency, the River Kilometer scale used in this report can be converted into the river mile scale used by the U.S. Fish and Wildlife Service (Roberts et al., 2009). The conversions use the following equations:

MSU km to USFWS mi	=	MSU km x 0.663
MSU mi to USFS mi	=	MSU mi x 1.06
USFWS mi to MSU km	=	USFWS mi x 1.51
USFWS mi to MSU mi	=	USFWS mi x 0.943

River Mile Reference

MSU River Km	USFWS River Mi	Sample Sites	Trib Confluence	Bridge	USGS Gage	Dams	County Boundary
0	0.0		Meramec River				
0.8	0.5			Twin River Rd.			
1.8	1.3	M24 - Hwy Lower					
2.8	2.0	M23 - Hwy Upper					
4.9	3.3	M22 - Twin River Rd.					
17.0	11.3					Rockford Beach Mill Dam	
16.9	11.5	M21 - Rockford Beach	Heads Creek				
17.5	11.6			Hwy W			
23.4	15.5	M20 - Byrnes Mill		Byrnesville Rd.	07018500 Big River at Byrnesville		
23.8	15.7					Byrnes Mill Dam	
31.5	20.9			St. Rte. 30			
32.2	21.3			Cedar Hill Rd		Cedar Hill Mill Dam	
32.7	21.5	M19 - Cedar Mill					
34.5	22.9		Belews Creek				
44.5	29.5		Jones Creek				
45.5	30.2			Klondike Rd.			
49	32.5			St. Rte. B			
49.8	32.9	M18 - Morse Mill				Morse Mill Dam	
52	34.5		Dry Creek				

MSU River Km	USFWS River Mi	Sample Sites	Trib Confluence	Bridge	USGS Gage	Dams	County Boundary
61.2	**40.6**			St. Rte. Y			
79	**52.4**			Brownford Rd.			
79.5	**52.6**	M17 - Browns Ford					
87.3	**57.9**	M16 - Merrill Horse					
87.5	**58.0**			St. Rte. H	07018100 Big River at Richwoods		
90.6	**60.1**						Washington
92.0	**61.0**						Jefferson
96.5	**64.0**			Mammoth Rd.			
97	**64.3**	M15 - Mammoth Access					
99	**65.6**		**Mineral Fork**				Wash/Jeff Cnty Line
100.5	**66.6**			Big River Heights Rd.			Wash/Jeff Cnty Line
101.7	**67.4**	M14 - Washington S.P.					Wash/Jeff Cnty Line
107	**70.9**			St. Rte. 21			Wash/Jeff Cnty Line
109.2	**72.4**						Wash/Jeff/St. Francois Cnty Line
115	**76.2**			Hwy CC			Jeff/St. Fran Cnty Line
115.5	**76.6**	M13 - Blackwell CC	**Mill Creek**				Jeff/St. Fran Cnty Line
118	**78.2**			Mill Rd.			Jeff/St. Fran Cnty Line
118.9	**79.1**	M12 - US of Mill Cr.					Jeff/St. Fran Cnty Line

MSU River Km	USFWS River Mi	Sample Sites	Trib Confluence	Bridge	USGS Gage	Dams	County Boundary
120.3	**79.8**						Jeff/St. Fran Cnty Line
121.1	**80.2**	M11 - Dickenson Rd		Dickenson Rd.		Low-water bridge	
125	**82.9**		Hill Creek				
125.5	**83.2**		Bear Creek				
128.5	**85.2**		Peter's Creek				
132.5	**87.8**		Cabanna Course				
132.9	**88.3**	M10 - Hwy E		St. Rte. E			
134.5	**89.2**		Bee Creek				
136.5	**90.5**			Berry Rd. (Closed)			
136.7	**90.6**	M9 – Hwy 67 at Cherokee		U.S. Rte. 67			
140.3	**93.0**	M8 – STF Lower					
140.8	**93.4**	M7 - STF Upper					
144.5	**95.8**		Terre Bleue Creek				
147.1	**97.4**	M6 - Hwy K		St. Rte. K			
155	**102.8**		**Flat River**				
156	**103.4**			U.S. Rte. 67, Vo-Tech School Rd.			
156.5	**103.7**	M5 - Hwy 67					
158.1	**104.8**	M4 - Deslodge		Old Bonne Terre Rd.			
163.4		M3 - BS#2 Above Desloge					

MSU River Km	USFWS River Mi	Sample Sites	Trib Confluence	Bridge	USGS Gage	Dams	County Boundary
165.3	**109.7**	M2 - Bone Hole at BS#1	Owl Creek			Low-water bridge	
170.7	**113.2**	M1 - Leadwood		Hunt St.		Low-water bridge	
171	**113.4**		Eaton Creek				
181.2	**120.1**	C2 - Highway 8		St. Rte. 8			
181.8	**120.5**						Washington
182.5	**121.0**			Benny Meyer Rd.			
187.5	**124.3**		Wallen Creek				
191	**126.6**		Mill Creek				
191.7	**127.1**	C1 Irondale		St. Rte. U	00717200 Big River at Irondale		
196	**129.9**		Cedar Creek				
201.5	**133.6**		Flat Creek	St. Rte. 21			
204.5	**135.6**		Clear Creek				
209	**138.6**			St. Rte. C			
211	**139.9**		James Creek	St. Rte. JJ			
215	**142.5**			Big River Rd.			

Lab No.		Site Description: Water Body	Code	Location	Coordinates Missouri State Plane East (feet) X	Y
B	25	Big River	C1	Hwy U at Irondale-control	765,014.772783	727,047.185739
B	26	Big River	C1	Hwy U at Irondale-control	765,013.054611	727,046.427210
G	25	Big River	C1	Hwy U at Irondale-control	764,937.654160	727,070.376930
G	26	Big River	C1	Hwy U at Irondale-control	764,942.348584	727,083.618960
B	61	Big River	C2	Hwy 8 above Leadwood-control	779,910.361759	740,691.821835
G	48	Big River	C2	Hwy 8 above Leadwood-control	779,916.514054	740,673.988041
B	1	Big River	M1	Leadwood Access	794,875.015884	742,152.657824
B	2	Big River	M1	Leadwood Access	794,853.637646	742,195.838840
B	3	Big River	M1	Leadwood Access	794,836.171802	742,239.434882
B	4	Big River	M1	Leadwood Access	794,816.616723	742,241.535271
G	1	Big River	M1	Leadwood Access	795,790.269187	741,240.894355
G	2	Big River	M1	Leadwood Access	795,773.577715	741,205.676418
G	3	Big River	M1	Leadwood Access	795,766.174312	741,167.233308
B	62	Big River	M2	Bone Hole	805,764.882884	743,376.965087
G	49	Big River	M2	Bone Hole	805,641.782288	743,366.924400
G	50	Big River	M2	Bone Hole	805,670.973455	743,432.166944
B	63	Big River	M3	Desloge	812,264.492260	748,192.671991
B	64	Big River	M3	Desloge	812,257.134335	748,335.367244
B	65	Big River	M3	Desloge	812,295.583733	748,584.628556
G	51	Big River	M3	Desloge	812,213.596446	748,079.273200
G	52	Big River	M3	Desloge	812,242.423820	748,101.748780
B	5	Big River	M4	Hwy 67 above Flat River Ck	814,838.719044	748,968.739074
B	6	Big River	M4	Hwy 67 above Flat River Ck	814,910.876380	748,934.488815
B	7	Big River	M4	Hwy 67 above Flat River Ck	815,057.600824	748,918.265094
B	8	Big River	M4	Hwy 67 above Flat River Ck	815,864.611021	748,814.680656
B	9	Big River	M4	Hwy 67 above Flat River Ck	816,047.264527	748,820.154398
B	10	Big River	M4	Hwy 67 above Flat River Ck	816,186.756702	748,855.999142
B	11	Big River	M4	Hwy 67 above Flat River Ck	816,344.974233	748,896.481345
G	4	Big River	M4	Hwy 67 above Flat River Ck	815,533.989987	748,884.028630
G	5	Big River	M4	Hwy 67 above Flat River Ck	815,498.850414	748,861.539955
G	6	Big River	M4	Hwy 67 above Flat River Ck	815,491.718324	748,838.892649
G	7	Big River	M4	Hwy 67 above Flat River Ck	816,110.666985	748,768.029408
G	8	Big River	M4	Hwy 67 above Flat River Ck	816,118.459973	748,780.275730
G	9	Big River	M4	Hwy 67 above Flat River Ck	816,819.180784	748,735.191946
G	10	Big River	M4	Hwy 67 above Flat River Ck	816,807.332378	748,708.825790
B	27	Big River	M5	Hwy K below Flat River Ck	820,698.110892	761,641.323571
B	28	Big River	M5	Hwy K below Flat River Ck	820,504.422303	761,840.910443
B	29	Big River	M5	Hwy K below Flat River Ck	820,191.807442	761,976.531562
G	27	Big River	M5	Hwy K below Flat River Ck	820,674.602305	761,731.845315
G	28	Big River	M5	Hwy K below Flat River Ck	820,591.664239	761,786.313232

Lab No.		Site Description			Coordinates Missouri State Plane East (feet)	
		Water Body	Code	Location	X	Y
G	29	Big River	M5	Hwy K below Flat River Ck	820,179.368784	762,004.368951
B	30	Big River	M6	St. Francois State Park (US)	808,920.250917	772,190.408444
B	31	Big River	M6	St. Francois State Park (US)	808,799.238364	772,224.452011
B	33	Big River	M6	St. Francois State Park (US)	808,799.238364	772,224.450699
B	34	Big River	M6	St. Francois State Park (US)	808,799.238364	772,224.450699
B	35	Big River	M6	St. Francois State Park (US)	808,799.238364	772,224.450699
B	32	Big River	M6	St. Francois State Park (US)	808,650.318714	772,305.370485
G	31	Big River	M6	St. Francois State Park (US)	809,182.655878	772,121.840185
G	30	Big River	M6	St. Francois State Park (US)	809,140.026418	772,159.533703
B	38	Big River	M7	St. Francois State Park (DS)	808,262.441865	773,697.924130
B	37	Big River	M7	St. Francois State Park (DS)	808,361.307809	773,908.155665
B	36	Big River	M7	St. Francois State Park (DS)	808,491.307877	774,057.992308
G	32	Big River	M7	St. Francois State Park (DS)	808,222.958890	773,638.275146
G	33	Big River	M7	St. Francois State Park (DS)	808,200.857627	773,601.135557
B	12	Big River	M8	Hwy 67 at Cherokee Landing	805,681.407598	772,490.904566
B	13	Big River	M8	Hwy 67 at Cherokee Landing	805,611.449405	772,475.264177
G	11	Big River	M8	Hwy 67 at Cherokee Landing	805,972.422899	772,554.138654
G	12	Big River	M8	Hwy 67 at Cherokee Landing	805,952.545133	772,573.876685
G	13	Big River	M8	Hwy 67 at Cherokee Landing	805,373.935922	772,456.934410
G	14	Big River	M8	Hwy 67 at Cherokee Landing	805,373.285776	772,429.173309
G	15	Big River	M8	Hwy 67 at Cherokee Landing	804,626.467567	772,379.509685
G	16	Big River	M8	Hwy 67 at Cherokee Landing	804,626.697130	772,368.821085
B	40	Big River	M9	Hwy E below Bonne Terre	798,580.868709	777,035.939436
B	41	Big River	M9	Hwy E below Bonne Terre	798,555.181752	777,089.025944
B	42	Big River	M9	Hwy E below Bonne Terre	798,518.430514	777,058.618524
G	35	Big River	M9	Hwy E below Bonne Terre	798,559.619465	777,114.387548
G	34	Big River	M9	Hwy E below Bonne Terre	798,541.065732	777,143.528576
B	89	Big River	M10	Dickinson Rd	784,642.095733	791,330.519770
B	88	Big River	M10	Dickinson Rd	784,922.643401	791,387.270969
B	87	Big River	M10	Dickinson Rd	785,057.952841	791,491.875747
B	81	Big River	M11	US of Mill Cr.	786,761.634801	793,765.438457
B	82	Big River	M11	US of Mill Cr.	786,892.434081	793,803.233657
B	83	Big River	M11	US of Mill Cr.	787,063.450799	793,883.809939
G	58	Big River	M11	US of Mill Cr.	786,912.933664	793,899.058356
B	46	Big River	M12	CC Bridge at Blackwell	785,468.334895	802,918.218708
B	47	Big River	M12	CC Bridge at Blackwell	785,424.439313	803,012.177181
B	45	Big River	M12	CC Bridge at Blackwell	785,432.783128	803,089.810884
B	44	Big River	M12	CC Bridge at Blackwell	785,394.549696	804,164.104558
B	43	Big River	M12	CC Bridge at Blackwell	785,354.618947	804,107.475496
B	90	Big River	M12	CC Bridge at Blackwell	785,376.099843	805,069.303316
B	91	Big River	M12	CC Bridge at Blackwell	785,341.732786	805,121.690351

Lab No.		Site Description			Coordinates Missouri State Plane East (feet)	
		Water Body	Code	Location	X	Y
G	36	Big River	M12	CC Bridge at Blackwell	785,331.358214	803,417.571922
G	37	Big River	M12	CC Bridge at Blackwell	785,296.811992	803,425.205365
G	38	Big River	M12	CC Bridge at Blackwell	785,318.602063	804,174.025193
B	94	Big River	M13	Washington Park	767,924.582909	820,736.479659
B	95	Big River	M13	Washington Park	767,755.784362	820,668.468968
B	96	Big River	M13	Washington Park	767,653.895130	820,601.022581
B	20	Big River	M14	Mammoth Access	769,096.183584	831,079.723736
B	19	Big River	M14	Mammoth Access	769,162.324856	831,165.162214
B	23	Big River	M14	Mammoth Access	769,593.757392	831,795.350586
B	24	Big River	M14	Mammoth Access	769,593.046763	831,795.150783
B	21	Big River	M14	Mammoth Access	769,738.782364	832,045.999035
B	22	Big River	M14	Mammoth Access	769,746.211155	832,141.811507
G	22	Big River	M14	Mammoth Access	769,296.772909	831,284.794703
G	21	Big River	M14	Mammoth Access	769,313.150272	831,330.013345
G	20	Big River	M14	Mammoth Access	769,334.438525	831,351.798608
G	23	Big River	M14	Mammoth Access	769,398.757185	831,442.753780
G	24	Big River	M14	Mammoth Access	769,456.986230	831,391.243471
B	14	Big River	M15	Browns Ford Access	759,266.207837	864,584.528118
B	15	Big River	M15	Browns Ford Access	759,316.379653	864,590.151138
B	16	Big River	M15	Browns Ford Access	759,381.749273	864,592.246606
B	17	Big River	M15	Browns Ford Access	760,323.801522	864,926.154075
B	18	Big River	M15	Browns Ford Access	760,348.564268	864,978.344587
G	17	Big River	M15	Browns Ford Access	760,579.139445	865,426.223240
G	18	Big River	M15	Browns Ford Access	760,546.688466	865,433.829586
G	19	Big River	M15	Browns Ford Access	760,511.387549	865,432.561367
B	48	Big River	M16	Morse Mill Park	776,279.511081	887,694.266347
B	49	Big River	M16	Morse Mill Park	776,344.238313	887,739.691125
B	50	Big River	M16	Morse Mill Park	776,371.864571	887,818.460652
B	51	Big River	M16	Morse Mill Park	776,747.928779	889,161.590840
B	52	Big River	M16	Morse Mill Park	776,881.885860	889,191.960530
G	39	Big River	M16	Morse Mill Park	776,282.192661	887,606.103962
G	40	Big River	M16	Morse Mill Park	776,290.243268	887,669.098685
B	53	Big River	M17	Cedar Hill Park	780,060.162312	915,380.947850
B	54	Big River	M17	Cedar Hill Park	779,954.283259	915,427.449069
B	55	Big River	M17	Cedar Hill Park	779,883.274871	915,465.122550
G	42	Big River	M17	Cedar Hill Park	780,225.443579	915,338.137525
G	41	Big River	M17	Cedar Hill Park	780,144.441794	915,370.809785
B	78	Big River	M18	Byrnes Mill	781,018.401865	931,935.754307
B	79	Big River	M18	Byrnes Mill	781,077.100567	931,977.359867
B	80	Big River	M18	Byrnes Mill	781,172.856281	932,039.651081
B	72	Big River	M19	Rockford Beach Access	794,760.434548	942,554.951912

Lab No.		Site Description			Coordinates Missouri State Plane East (feet)	
		Water Body	Code	Location	X	Y
B	73	Big River	M19	Rockford Beach Access	794,646.104579	942,608.033651
B	74	Big River	M19	Rockford Beach Access	794,335.374190	942,697.918324
G	43	Big River	M19	Rockford Beach Access	794,741.894835	942,362.854489
G	44	Big River	M19	Rockford Beach Access	794,757.926184	942,369.640384
B	58	Big River	M20	Twin River Road	788,032.088928	956,584.404724
B	57	Big River	M20	Twin River Road	787,959.212166	956,579.021782
B	75	Big River	M21	Hwy W (upstream)	786,206.868194	954,980.745947
B	76	Big River	M21	Hwy W (upstream)	785,979.781378	954,852.461755
B	77	Big River	M21	Hwy W (upstream)	785,803.782386	954,565.858653
B	60	Big River	M22	Hwy W (downstream)	784,097.111259	956,235.778214
G	46	Big River	M22	Hwy W (downstream)	784,158.374309	955,890.983014
G	47	Big River	M22	Hwy W (downstream)	784,136.817270	955,914.965392
G	45	Big River	M22	Hwy W (downstream)	784,106.088661	955,948.957398
B	69	Flat R Creek	T1	Upper Flat at Davis- control	794,575.765171	721,575.870894
B	68	Flat R Creek	T1	Upper Flat at Davis- control	794,752.216917	721,619.435439
G	53	Flat R Creek	T1	Upper Flat at Davis- control	794,784.247435	721,624.540948
B	67	Flat R Creek	T2	Flat at St. Joe Bridge	818,741.939279	740,779.989638
B	66	Flat R Creek	T2	Flat at St. Joe Bridge	818,769.745982	740,898.292879
G	54	Flat R Creek	T2	Flat at St. Joe Bridge	818,769.053885	740,797.553119
G	55	Flat R Creek	T2	Flat at St. Joe Bridge	818,780.466549	740,797.617886
B	97	Mill Creek	T3	Tributary to Mill Ck at Min Pt	755,446.206291	770,580.279447
B	92	Mill Creek	T4	Mill at Tiff	776,888.000021	794,828.759493
B	93	Mill Creek	T4	Mill at Tiff	776,934.909048	794,929.836062
G	61	Mill Creek	T4	Mill at Tiff	776,907.999417	794,947.800390
G	62	Mill Creek	T4	Mill at Tiff	776,923.157840	794,950.491215
B	84	Mill Creek	T5	Mill at confluence	785,304.853594	801,992.890178
B	85	Mill Creek	T5	Mill at confluence	785,395.284188	802,017.992490
B	86	Mill Creek	T5	Mill at confluence	785,470.600638	801,968.347904
G	59	Mill Creek	T5	Mill at confluence	785,256.959224	801,949.160754
G	60	Mill Creek	T5	Mill at confluence	785,289.330383	801,949.115807
B	98	Mineral Fork Ck	T6	Mineral Fork at Hwy F- control	722,355.177657	802,958.438444
B	70	Mineral Fork Ck	T7	Mineral Fork near mouth	759,014.319561	822,898.237475
B	71	Mineral Fork Ck	T7	Mineral Fork near mouth	759,043.988465	822,940.942114
G	56	Mineral Fork Ck	T7	Mineral Fork near mouth	759,073.908012	823,077.107672
G	57	Mineral Fork Ck	T7	Mineral Fork near mouth	759,061.102181	823,079.018013

Lab No.		River Km (0 =mouth)	Collection Date	XRF Analysis (<2 mm fraction) Pb (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)
B	25	191.64	11/23/2008	15	21	13,826	560	2,037
B	26	191.64	11/23/2008	15	17	11,636	400	8,015
G	25	191.66	10/23/2008	15	26	11,800	730	2,294
G	26	191.66	10/23/2008	15	20	8,851	697	1,915
B	61	181.17	1/19/2009	15	39	13,642	855	4,766
G	48	181.17	1/19/2009	15	47	13,439	212	8,053
B	1	170.91	10/1/2008	196	99	17,403	359	4,126
B	2	170.91	10/1/2008	15	64	14,459	364	1,128
B	3	170.91	10/1/2008	810	649	13,365	847	15,420
B	4	170.91	10/1/2008	42	60	19,453	293	1,862
G	1	170.50	10/1/2008	111	191	15,820	299	8,991
G	2	170.50	10/1/2008	182	258	10,541	424	16,527
G	3	170.50	10/1/2008	656	666	17,322	1,748	10,957
B	62	165.26	1/19/2009	915	763	12,494	1,426	55,347
G	49	165.30	1/19/2009	2,182	6,344	22,668	3,803	112,749
G	50	165.28	1/19/2009	2,200	882	31,435	2,630	135,559
B	63	158.13	1/19/2009	1,606	1,527	23,603	2,004	89,036
B	64	158.08	1/19/2009	1,230	2,023	20,892	2,159	121,391
B	65	158.00	1/19/2009	963	1,027	22,591	2,025	101,721
G	51	158.16	1/19/2009	1,130	1,613	21,379	1,982	111,736
G	52	158.16	1/19/2009	788	887	19,145	2,463	127,236
B	5	156.86	10/2/2008	1,563	1,572	33,202	2,501	138,086
B	6	156.84	10/2/2008	992	1,082	20,286	2,664	162,097
B	7	156.79	10/2/2008	790	910	19,634	2,576	135,317
B	8	156.54	10/2/2008	1,345	936	32,159	2,924	161,131
B	9	156.48	10/2/2008	1,088	904	20,436	2,345	152,898
B	10	156.44	10/2/2008	933	1,831	18,412	1,923	117,199
B	11	156.39	10/2/2008	1,245	1,852	19,992	2,710	146,701
G	4	156.65	10/2/2008	1,265	1,113	45,098	2,946	131,309
G	5	156.65	10/2/2008	1,326	1,569	21,262	2,976	145,762
G	6	156.65	10/2/2008	1,172	1,372	18,717	2,121	96,611
G	7	156.46	10/2/2008	2,108	3,540	26,528	3,094	163,324
G	8	156.46	10/2/2008	1,094	835	24,188	2,324	125,722
G	9	156.24	10/2/2008	1,022	1,478	23,729	2,493	133,582
G	10	156.24	10/2/2008	1,009	944	27,533	2,626	144,345
B	27	147.21	11/24/2008	2,244	691	42,373	3,717	164,338
B	28	147.12	11/24/2008	1,251	701	26,977	3,114	133,858
B	29	147.01	11/24/2008	771	432	19,933	2,223	115,870
G	27	147.19	10/23/2008	1,484	894	33,996	4,852	165,916
G	28	147.15	10/23/2008	1,169	604	41,226	4,311	173,475

Lab No.		River Km (0 =mouth)	Collection Date	XRF Analysis (<2 mm fraction) Pb (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)
G	29	147.00	10/23/2008	1,720	715	29,976	2,879	134,948
B	30	140.85	11/24/2008	1,982	791	34,950	6,796	133,997
B	31	140.81	11/24/2008	1,073	374	29,317	2,516	95,943
B	33	140.81	11/24/2008	1,101	552	32,725	3,952	142,437
B	34	140.81	11/24/2008	750	381	29,193	5,047	97,475
B	35	140.81	11/24/2008	736	308	27,555	2,545	123,555
B	32	140.75	11/24/2008	522	305	21,400	2,114	89,204
G	31	140.93	10/24/2008	932	417	30,853	2,211	107,857
G	30	140.92	10/24/2008	2,579	851	67,315	4,846	126,709
B	38	140.28	11/24/2008	1,422	488	44,707	5,857	138,114
B	37	140.21	11/24/2008	959	441	21,891	3,768	94,978
B	36	140.15	11/24/2008	1,031	402	28,797	2,728	117,398
G	32	140.31	10/24/2008	1,909	1,347	42,013	3,523	87,763
G	33	140.31	10/24/2008	1,335	559	30,865	3,579	124,871
B	12	136.79	10/3/2008	914	434	26,119	2,144	90,289
B	13	136.77	10/3/2008	480	236	18,318	1,817	92,502
G	11	136.88	10/3/2008	632	374	22,493	2,712	121,395
G	12	136.88	10/3/2008	842	409	25,814	2,736	107,221
G	13	136.69	10/3/2008	491	290	20,115	1,786	96,488
G	14	136.69	10/3/2008	708	399	19,901	2,442	110,313
G	15	136.47	10/23/2008	253	197	11,985	1,318	79,297
G	16	136.47	10/23/2008	486	275	26,501	2,099	104,779
B	40	132.86	11/24/2008	1,007	411	26,828	2,919	124,390
B	41	132.86	11/24/2008	723	417	18,627	1,792	72,264
B	42	132.86	11/24/2008	984	550	31,939	1,951	68,481
G	35	132.86	10/24/2008	605	265	21,898	2,894	104,495
G	34	132.84	10/24/2008	607	327	21,466	2,014	74,088
B	89	121.16	1/21/2009	464	211	14,567	978	42,524
B	88	121.07	1/21/2009	430	145	20,019	1,784	85,173
B	87	121.02	1/21/2009	530	335	25,677	1,271	32,660
B	81	118.91	1/21/2009	382	196	18,897	1,473	75,961
B	82	118.87	1/21/2009	679	244	22,533	2,195	85,861
B	83	118.81	1/21/2009	1,109	534	21,052	1,921	59,234
G	58	118.87	1/22/2009	361	217	16,707	1,838	72,342
B	46	115.82	11/24/2008	363	167	16,156	905	49,470
B	47	115.78	11/24/2008	452	175	16,803	1,557	93,833
B	45	115.75	11/24/2008	497	177	16,187	1,079	59,148
B	44	115.43	11/24/2008	50	24	2,737	ND	ND
B	43	115.40	11/24/2008	223	91	7,374	269	7,267
B	90	115.10	1/21/2009	313	146	12,353	759	43,371
B	91	115.10	1/21/2009	388	163	12,914	1,156	58,163

Lab No.		River Km (0 =mouth)	Collection Date	XRF Analysis (<2 mm fraction) Pb (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)
G	36	115.66	10/24/2008	601	194	18,868	1,582	65,039
G	37	115.66	10/24/2008	817	391	20,185	1,169	30,478
G	38	115.42	10/24/2008	783	460	20,609	1,324	55,223
B	94	101.80	1/22/2009	295	111	11,352	412	20,607
B	95	101.74	1/22/2009	401	117	13,017	1,055	52,109
B	96	101.70	1/22/2009	292	99	12,047	604	32,493
B	20	97.16	10/21/2008	299	129	11,571	193	33,932
B	19	97.13	10/21/2008	341	162	15,511	298	6,919
B	23	96.88	10/21/2008	470	106	9,562	476	19,750
B	24	96.88	10/21/2008	610	175	11,014	533	21,073
B	21	96.79	10/21/2008	124	72	6,934	71	3,828
B	22	96.76	10/21/2008	319	110	10,370	276	6,236
G	22	97.07	10/20/2008	422	133	10,747	727	29,680
G	21	97.06	10/20/2008	417	136	11,716	961	32,695
G	20	97.05	10/20/2008	369	130	11,457	705	22,767
G	23	97.01	10/20/2008	286	102	9,134	430	8,907
G	24	97.01	10/20/2008	229	81	8,142	368	17,127
B	14	79.83	10/20/2008	128	76	5,300	81	2,433
B	15	79.81	10/20/2008	195	121	7,100	265	2,099
B	16	79.79	10/20/2008	200	101	6,411	109	4,711
B	17	79.47	10/20/2008	217	164	9,502	177	1,123
B	18	79.45	10/20/2008	152	124	7,743	126	882
G	17	79.29	10/20/2008	202	118	6,673	338	8,519
G	18	79.29	10/20/2008	462	199	11,523	759	19,706
G	19	79.29	10/20/2008	400	224	12,612	702	23,091
B	48	50.00	11/25/2008	253	124	13,261	775	5,823
B	49	49.98	11/25/2008	345	98	10,621	214	7,833
B	50	49.95	11/25/2008	185	67	6,786	261	7,236
B	51	49.42	11/25/2008	210	87	8,455	258	3,411
B	52	49.38	11/25/2008	192	192	18,766	410	1,760
G	39	50.02	10/24/2008	299	118	10,021	640	7,566
G	40	50.00	10/24/2008	428	155	13,842	1,448	9,206
B	53	32.66	11/25/2008	443	138	10,800	392	8,123
B	54	32.63	11/25/2008	265	132	9,618	147	4,179
B	55	32.60	11/25/2008	255	78	7,451	11	6,138
G	42	32.71	10/24/2008	72	34	3,985	127	1,531
G	41	32.68	10/24/2008	177	74	10,683	387	1,149
B	78	23.37	1/21/2009	55	23	4,749	64	1,832
B	79	23.36	1/21/2009	224	211	17,431	605	3,798
B	80	23.32	1/21/2009	78	48	6,315	211	1,169
B	72	16.91	1/20/2009	44	33	6,221	226	2,440

Lab No.		River Km (0 =mouth)	Collection Date	XRF Analysis (<2 mm fraction) Pb (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)
B	73	16.87	1/20/2009	95	50	12,251	828	9,513
B	74	16.77	1/19/2009	38	25	4,111	74	1,543
G	43	16.95	10/24/2008	172	128	11,003	704	3,856
G	44	16.95	10/24/2008	118	68	7,216	290	3,418
B	58	4.91	11/25/2008	80	72	7,606	79	1,089
B	57	4.89	11/25/2008	124	70	9,004	298	ND
B	75	2.86	1/22/2009	58	48	6,133	694	ND
B	76	2.77	1/22/2009	28	22	2,792	31	ND
B	77	2.66	1/22/2009	58	48	5,581	122	ND
B	60	1.70	11/25/2008	232	107	12,564	774	9,968
G	46	1.81	10/24/2008	91	64	7,092	215	1,749
G	47	1.80	10/24/2008	220	142	17,764	719	3,563
G	45	1.79	10/24/2008	136	66	7,976	496	10,291
B	69	14.80	1/19/2009	29	17	18,949	2,226	5,933
B	68	14.75	1/19/2009	68	40	23,526	2,317	8,353
G	53	14.74	1/19/2009	64	35	25,142	2,379	33,918
B	67	3.46	1/19/2009	1,959	689	34,796	3,901	160,328
B	66	3.40	1/19/2009	1,777	709	31,636	3,322	146,098
G	54	3.45	1/19/2009	3,046	1,372	38,380	4,210	147,341
G	55	3.45	1/19/2009	2,373	1,874	38,228	4,443	153,060
B	97	21.10	1/22/2009	306	1,338	74,787	1,267	12,899
B	92	5.27	1/22/2009	105	314	17,413	358	28,617
B	93	5.24	1/22/2009	15	214	17,434	235	7,823
G	61	5.23	1/22/2009	67	316	21,634	123	3,453
G	62	5.23	1/22/2009	79	368	29,624	308	8,500
B	84	0.19	1/21/2009	306	393	23,093	743	16,919
B	85	0.17	1/21/2009	182	245	16,771	380	10,661
B	86	0.14	1/21/2009	260	273	16,473	434	6,918
G	59	0.21	1/22/2009	217	361	26,295	536	11,691
G	60	0.21	1/22/2009	292	326	17,870	584	10,825
B	98	24.16	1/22/2009	46	131	10,129	85	5,838
B	70	4.44	1/19/2009	78	133	14,563	410	6,492
B	71	4.42	1/19/2009	38	88	9,740	109	4,141
G	56	4.38	1/20/2009	106	168	21,109	334	974
G	57	4.38	1/20/2009	105	139	11,549	513	13,584

Lab No.		Size Distribution by Mass (%)					
		Fines (<2 mm)	VFG (2-4 mm)	FG (4-8 mm)	MG (8-16 mm)	CG (16-32 mm)	VCG (32-64 mm)
B	25	31	18	23	16	12	0
B	26	22	18	21	22	17	0
G	25	26	17	20	22	15	0
G	26	21	12	15	18	20	13
B	61	30	21	26	17	6	0
G	48	34	11	12	17	14	13
B	1	8	14	23	34	22	0
B	2	8	10	22	28	26	6
B	3	18	11	22	23	26	0
B	4	29	29	22	14	6	0
G	1	24	22	29	18	7	0
G	2	23	14	20	23	12	6
G	3	3	12	21	29	22	13
B	62	98	2	0	0	0	0
G	49	29	18	17	12	14	11
G	50	32	14	15	11	26	2
B	63	16	27	23	17	11	6
B	64	42	27	20	8	2	0
B	65	24	26	26	12	3	8
G	51	49	18	14	9	5	5
G	52	31	19	23	12	16	0
B	5	27	21	25	15	11	0
B	6	45	29	16	7	4	0
B	7	70	17	9	4	0	0
B	8	40	21	16	11	7	5
B	9	45	18	14	11	12	0
B	10	31	24	17	11	17	0
B	11	47	27	16	7	4	0
G	4	44	24	19	10	2	0
G	5	36	18	15	11	12	8
G	6	23	16	24	17	8	11
G	7	10	6	8	13	25	37
G	8	34	11	14	15	23	4
G	9	44	16	14	9	8	8
G	10	35	23	20	13	7	1
B	27	23	23	28	18	9	0
B	28	11	18	25	15	31	0
B	29	77	11	8	4	1	0
G	27	29	29	28	11	3	1
G	28	7	16	23	13	22	18

Lab No.		Size Distribution by Mass (%)					
		Fines (<2 mm)	VFG (2-4 mm)	FG (4-8 mm)	MG (8-16 mm)	CG (16-32 mm)	VCG (32-64 mm)
G	29	25	12	22	21	18	2
B	30	39	21	18	11	4	7
B	31	63	19	11	5	3	0
B	33	52	14	12	14	8	0
B	34	49	14	14	13	10	0
B	35	47	13	15	9	15	0
B	32	44	20	17	12	6	0
G	31	46	19	21	12	3	0
G	30	58	19	14	6	2	0
B	38	41	39	16	1	2	0
B	37	59	18	12	7	4	0
B	36	50	25	11	4	10	0
G	32	8	23	37	19	13	0
G	33	16	25	24	17	12	6
B	12	47	17	16	16	4	0
B	13	51	15	16	12	6	0
G	11	19	21	25	24	12	0
G	12	59	14	14	10	4	0
G	13	88	5	3	3	1	0
G	14	85	6	2	1	2	5
G	15	43	11	12	16	11	7
G	16	45	16	13	9	16	2
B	40	43	12	11	14	12	9
B	41	82	9	1	4	4	0
B	42	89	6	3	2	1	0
G	35	32	9	11	16	24	8
G	34	29	12	14	14	22	8
B	89	41	10	12	16	14	6
B	88	73	9	8	8	2	0
B	87	16	28	30	16	10	0
B	81	56	9	10	8	17	0
B	82	48	16	15	11	10	0
B	83	31	11	18	27	14	0
G	58	19	5	6	10	27	33
B	46	49	7	12	21	10	0
B	47	35	7	12	17	15	14
B	45	59	10	12	13	5	0
B	44	100	0	0	0	0	0
B	43	85	4	8	3	0	0
B	90	63	9	12	9	7	0
B	91	99	1	0	0	0	0

Lab No.		Size Distribution by Mass (%)					
		Fines	VFG	FG	MG	CG	VCG
		(<2 mm)	(2-4 mm)	(4-8 mm)	(8-16 mm)	(16-32 mm)	(32-64 mm)
G	36	22	10	13	21	22	12
G	37	69	12	12	6	0	0
G	38	32	8	14	20	19	8
B	94	48	11	14	18	4	5
B	95	42	8	11	12	11	15
B	96	66	13	17	4	0	0
B	20	40	12	15	17	17	0
B	19	28	11	14	20	16	11
B	23	31	11	23	29	7	0
B	24	54	10	13	18	6	0
B	21	37	10	14	20	19	0
B	22	28	8	16	24	24	0
G	22	38	15	21	17	9	0
G	21	37	8	13	19	18	5
G	20	28	8	13	19	21	11
G	23	30	7	10	18	21	13
G	24	31	7	11	18	19	0
B	14	43	18	19	14	5	0
B	15	66	9	11	10	4	0
B	16	67	11	9	7	1	5
B	17	41	14	16	17	13	0
B	18	34	12	20	24	10	0
G	17	40	13	20	18	9	0
G	18	22	17	31	21	8	0
G	19	23	12	18	22	19	7
B	48	35	17	19	15	11	3
B	49	26	10	17	18	28	0
B	50	43	14	16	11	15	0
B	51	31	12	16	18	24	0
B	52	27	15	22	25	11	0
G	39	11	7	14	16	28	24
G	40	17	11	13	18	24	17
B	53	28	6	13	23	29	0
B	54	48	7	9	10	3	25
B	55	91	2	5	2	0	0
G	42	42	12	16	19	10	0
G	41	22	10	12	15	20	21
B	78	64	13	13	10	0	0
B	79	12	18	18	37	16	0
B	80	37	27	27	8	1	0
B	72	28	23	23	21	5	0

Lab No.		Size Distribution by Mass (%)					
		Fines (<2 mm)	VFG (2-4 mm)	FG (4-8 mm)	MG (8-16 mm)	CG (16-32 mm)	VCG (32-64 mm)
B	73	19	22	22	25	12	0
B	74	47	11	11	14	16	0
G	43	30	17	19	21	10	4
G	44	31	10	17	24	13	5
B	58	60	10	13	15	3	0
B	57	43	12	18	15	9	4
B	75	56	14	14	12	4	0
B	76	93	3	3	1	0	0
B	77	100	0	0	0	0	0
B	60	86	4	5	4	0	0
G	46	35	12	17	24	9	2
G	47	15	10	17	25	27	5
G	45	12	9	11	18	22	27
B	69	20	9	12	13	14	31
B	68	21	13	23	24	19	0
G	53	3	3	8	15	28	43
B	67	30	12	11	10	11	26
B	66	46	19	13	11	11	0
G	54	37	15	13	10	16	10
G	55	38	28	20	6	8	0
B	97	20	19	29	30	2	0
B	92	49	20	11	14	2	4
B	93	21	18	21	18	13	8
G	61	21	12	11	16	21	18
G	62	19	17	18	19	22	6
B	84	12	21	29	23	6	9
B	85	44	15	14	12	1	14
B	86	56	20	10	4	0	10
G	59	30	12	19	23	14	2
G	60	8	14	23	26	26	4
B	98	35	12	13	14	26	0
B	70	31	17	17	21	14	0
B	71	51	20	20	9	0	0
G	56	15	16	20	22	23	5
G	57	7	7	11	19	38	18

B samples = Bar G samples = glide

Core Locations

Core Name	Core #	Location	RK	GPS Coordinates Y	X	Date Collected	Samples (n)	Max Depth (cm)	Soil Unit
LW-1	1	Leadwood Access	170.7	741001.54661	795815.86538		4	100	HF
LW-2	2	Leadwood Access	170.7	740942.24227	795973.51106		8	190	HF
SF-1	1	St. Francois State Park	140.3	773949.48268	808483.20455		14	760	HF
SF-2	2	St. Francois State Park	140.3	773900.51460	808555.98655		8	220	HF
SF-3	3	St. Francois State Park	140.3	773835.81460	808447.04320		12	430	HF
SF-4	4	St. Francois State Park	140.3	773648.19260	808539.79400		4	110	HF
SF-5	5	St. Francois State Park	140.8	772511.65518	808851.54305		3	100	HF
SF-6	6	St. Francois State Park	140.3	773372.97104	808307.24394		6	220	HF
SF-7	7	St. Francois State Park	140.3	773342.07445	808340.55227		5	180	HF
MA-1	1	Mammoth Access	97.0	832900.58656	769488.25859		6	180	HF
MH-1	1	Merrill Horse Access	87.3	847599.36852	760396.04580		8	220	LT
WP-1	1	Washington State Park	101.7	820059.96902	767932.95688		10	270	LF
WP-2	2	Washington State Park	101.7	820124.15055	767924.39623		10	330	LF
WP-3	3	Washington State Park	101.7	820222.46094	767912.07497		11	700	LF
WP-4	4	Washington State Park	101.7	820336.73160	767895.77072		15	430	LF
WP-5	5	Washington State Park	101.7	820433.68083	767882.63608		14	395	LF
WP-6	6	Washington State Park	101.7	820513.78724	767865.18626		17	461?	LF
WP-7	7	Washington State Park	101.7	820664.23476	768035.51949		15	600	LF
WP-8	8	Washington State Park	101.7	820601.95434	767815.25938		15	410	LF
BF-1	1	Browns Ford Access	79.3	866532.71582	761020.25420		11	310	HF
MM-1	1	Morse Mill Park	49.6	777277.46077	889154.80713		9	300	LF
MM-2	2	Morse Mill Park	49.6	777271.28554	889006.59964		11	295	LF
MM-3	3	Morse Mill Park	49.6	777290.96328	888918.64889		8	230	LF
MM-4	4	Morse Mill Park	49.6	776681.83828	889062.00154		12	340	LF
MM-5	5	Morse Mill Park	49.6	776632.15296	888841.65416		8	200	LF
MM-6	6	Morse Mill Park	49.6	777534.60974	888183.74438		10	290	LT
MM-7	7	Morse Mill Park	49.6	777447.39060	888383.80368		8	230	HF
MM-8	8	Morse Mill Park	49.6	777418.01934	888544.03235		8	230	HF
MM-9	9	Morse Mill Park	49.6	777813.86325	887554.06416		4	110	HT
CH-1	1	Cedar Hill Park	32.5	778873.62213	916033.85223		7	200	HF
CH-1a	1a	Cedar Hill Park	32.5	778873.62213	916033.85223		15	430	HF
CH-2	2	Cedar Hill Park	32.5	778906.01272	915936.94511		6	230	HF
RB-1	1	Rockford Beach Access	17.4	942423.99580	794179.97922		8	220	HF
RB-2	2	Rockford Beach Access	17.4	942568.10509	794276.27528		5	130	HF
RB-3	3	Rockford Beach Access	17.4	942646.13479	794182.54680		13	370	HF
UW-1	1	Upstream of Hwy W	3.0	954285.04473	785743.28765		13	320	HF

Pit Locations

Pit	Location	RKM	Coordinates Missouri State Plane East (feet) Y	X
5	Leadwood Access	171.0	742,572.42735	794,877.86898
4	Leadwood Access	171.0	742,500.62507	794,843.08975
2	Leadwood Access	171.0	742,358.66812	794,804.92479
1	Leadwood Access	171.0	742,230.24460	794,893.57573
3	Leadwood Access	171.0	742,223.93744	794,879.63322
31	Leadwood Access	170.2	740,576.76503	796,326.53961
33	Bone Hole	165.3	743,290.85422	805,578.93554
32	Bone Hole	165.3	743,280.55345	805,679.03770
34	Deslodge	158.2	748,081.71620	812,305.45316
35	Deslodge	158.1	748,397.35151	812,154.96450
36	Deslodge	158.1	748,397.35151	812,154.96450
7	Upstream of Flat	156.5	748,723.37900	815,823.07307
6	Upstream of Flat	156.4	748,850.45704	816,179.16464
9	Upstream of Flat	156.2	748,748.34854	816,946.30802
8	Upstream of Flat	156.2	748,624.91362	816,951.62030
17	Downstream of Flat	147.0	761,936.40933	820,240.19110
16	Downstream of Flat	147.0	762,063.17333	820,209.88916
18	St. Francois State Park	140.2	774,074.18635	808,346.97037
11	Cherokee Landing	136.9	772,546.51567	806,028.30477
10	Cherokee Landing	136.6	772,312.89897	804,916.74292
19	Highway E	133.0	777,071.38045	798,669.02646
20	Highway E	132.8	777,172.51363	798,361.25376
23	Blackwell/Highway CC	115.5	804,087.36436	785,213.16471
22	Blackwell/Highway CC	115.4	804,300.04449	785,494.81243
21	Blackwell/Highway CC	115.3	804,649.15471	785,460.90064
44	Blackwell/Highway CC	115.1	805,086.50110	785,311.02115
14	Mammoth Access	97.1	831,250.71253	769,093.45112
15	Mammoth Access	96.9	831,749.92595	769,757.99543
12	Browns Ford Access	79.6	864,643.17347	760,056.92798
13	Browns Ford Access	79.3	865,302.91892	760,454.15763
24	Morse Mill Park	49.8	888,177.66499	776,601.59946
25	Cedar Hill Park	32.6	915,524.73436	780,012.31541
26	Rockford Beach Access	17.4	941,239.47848	794,109.01030
27	Rockford Beach Access	17.4	941,163.50244	794,258.98156
28	Rockford Beach Access	17.4	NO GPS LOCATION - Slackwater	
41	Mill at Tiff	5.3	794,800.12404	776,837.91999
39	Mineral Fork near Mouth	4.3	823,311.12857	759,126.43582

Pit	Location	RKM	Coordinates Missouri State Plane East (feet)	
			Y	X
37	Flat at Saint Joe Bridge	3.5	740,760.10760	818,746.49979
38	Flat at Saint Joe Bridge	3.4	740,980.65629	818,818.32785
30	Highway W Downstream	2.2	954,880.38598	784,663.35563
29	Highway W Downstream	2.1	955,242.16449	784,490.11788
40	Mill Creek at Mouth	0.1	801,935.58630	785,698.12865

Sample ID Code	No.	Water Body	Sample Site Location	River Kilometer (0 =mouth)	Unit Code	No.	Sample Depth Upper (cm)	Mid (cm)	Lower (cm)	XRF Analysis (<2 mm fraction) **Pb** (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)
OV	25	Big River	Leadwood Access	171.04	Pit	5	0	15	30	ND	63	23579	794	1897
OV	26	Big River	Leadwood Access	171.04	Pit	5	30	55	80	ND	56	21734	439	1573
OV	27	Big River	Leadwood Access	171.04	Pit	5	80	95	110	50	81	28825	815	1832
OV	28	Big River	Leadwood Access	171.04	Pit	5	110	150	190	63	69	23870	653	1334
OV	29	Big River	Leadwood Access	171.04	Pit	5	190	235	280	50	70	22700	931	1886
OV	18	Big River	Leadwood Access	171.02	Pit	4	35	40	45	40	58	16037	826	1884
OV	19	Big River	Leadwood Access	171.02	Pit	4	135	140	145	53	63	20824	638	1242
OV	20	Big River	Leadwood Access	171.02	Pit	4	235	240	245	35	54	19083	697	1086
OV	21	Big River	Leadwood Access	171.02	Pit	4	315	320	325	61	81	22000	1122	1890
OV	22	Big River	Leadwood Access	171.02	Pit	4	415	420	425	56	81	23361	1268	2098
OV	23	Big River	Leadwood Access	171.02	Pit	4	500	505	510	62	101	24867	1736	2213
OV	24	Big River	Leadwood Access	171.02	Pit	4	445	450	455	40	91	32566	1789	2478
OV	3	Big River	Leadwood Access	170.98	Pit	2	0	12.5	25	42	47	13469	829	5391
OV	4	Big River	Leadwood Access	170.98	Pit	2	25	45	65	ND	19	10496	397	2702
OV	5	Big River	Leadwood Access	170.98	Pit	2	65	80	95	47	67	15629	722	3095
OV	6	Big River	Leadwood Access	170.98	Pit	2	95	115	135	35	35	14543	829	1541
OV	7	Big River	Leadwood Access	170.98	Pit	2	135	152.5	170	69	69	25530	1324	5395
OV	8	Big River	Leadwood Access	170.98	Pit	2	170	187.5	205	111	228	14171	544	3257
OV	9	Big River	Leadwood Access	170.98	Pit	2	205	230	255	144	529	11851	202	4391
OV	10	Big River	Leadwood Access	170.98	Pit	2	255	265	275	275	1020	18014	206	7161
OV	1	Big River	Leadwood Access	170.95	Pit	1	0	20	40	47	52	11528	482	3543
OV	2	Big River	Leadwood Access	170.95	Pit	1	40	50	60	36	48	12821	446	3507
OV	12	Big River	Leadwood Access	170.95	Pit	3	10	15	20	98	120	18520	1269	4722
OV	13	Big River	Leadwood Access	170.95	Pit	3	40	45	50	87	92	18299	1213	5578
OV	14	Big River	Leadwood Access	170.95	Pit	3	80	85	90	84	88	17809	1321	6623
OV	15	Big River	Leadwood Access	170.95	Pit	3	100	105	110	51	70	16948	1231	3924
OV	16	Big River	Leadwood Access	170.95	Pit	3	140	145	150	75	103	17356	1175	8120
OV	17	Big River	Leadwood Access	170.95	Pit	3	180	185	190	97	94	18762	1293	7282
FC	183	Big River	Leadwood Access	170.7	Core	22	5	10	15	741	204	13897	557	6989
FC	184	Big River	Leadwood Access	170.7	Core	22	35	40	45	764	225	15837	629	2612
FC	185	Big River	Leadwood Access	170.7	Core	22	65	70	75	1469	228	16406	765	4900
FC	186	Big River	Leadwood Access	170.7	Core	22	95	100	105	3414	278	18177	827	7347
FC	187	Big River	Leadwood Access	170.7	Core	23	5	10	15	123	104	15329	494	ND
FC	188	Big River	Leadwood Access	170.7	Core	23	25	30	35	139	119	14944	563	ND

Sample ID Code	No.	Water Body	Sample Site Location	River Kilometer (0 =mouth)	Unit Code	No.	Sample Depth Upper (cm)	Mid (cm)	Lower (cm)	XRF Analysis (<2 mm fraction) **Pb** (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)
FC	189	Big River	Leadwood Access	170.7	Core	23	45	50	55	668	108	17376	625	ND
FC	190	Big River	Leadwood Access	170.7	Core	23	65	70	75	1129	92	14282	624	ND
FC	191	Big River	Leadwood Access	170.7	Core	23	95	100	105	779	188	14720	567	4539
FC	192	Big River	Leadwood Access	170.7	Core	23	125	130	135	998	162	14380	609	8730
FC	193	Big River	Leadwood Access	170.7	Core	23	155	160	165	855	115	13755	530	1875
FC	194	Big River	Leadwood Access	170.7	Core	23	185	190	195	76	111	13791	590	ND
OV	156	Big River	Leadwood Access	170.24	Pit	31	45	47.5	50	472	479	19468	1319	17110
OV	157	Big River	Leadwood Access	170.24	Pit	31	145	147.5	150	783	993	19680	1224	11550
OV	158	Big River	Leadwood Access	170.24	Pit	31	205	207.5	210	1017	1677	21508	1521	37191
OV	159	Big River	Leadwood Access	170.24	Pit	31	315	317.5	320	2527	3962	27390	3291	2E+05
OV	160	Big River	Leadwood Access	170.24	Pit	31	350	360	370	284	3166	28707	381	8439
OV	161	Big River	Leadwood Access	170.24	Pit	31	250	255	260	1987	4458	22625	3118	2E+05
OV	162	Big River	Leadwood Access	170.24	Pit	31	300	305	310	2851	5816	47535	5193	2E+05
OV	167	Big River	Bone Hole	165.32	Pit	33	10	20	30	952	1082	20084	1418	18343
OV	168	Big River	Bone Hole	165.32	Pit	33	100	105	110	443	542	22203	1424	8811
OV	169	Big River	Bone Hole	165.32	Pit	33	200	205	210	811	1288	20594	1395	15634
OV	163	Big River	Bone Hole	165.28	Pit	32	0	10	20	902	846	20994	1447	16018
OV	164	Big River	Bone Hole	165.28	Pit	32	60	65	70	3478	2118	22923	2067	63652
OV	165	Big River	Bone Hole	165.28	Pit	32	120	125	130	103	346	20002	1338	5801
OV	166	Big River	Bone Hole	165.28	Pit	32	200	205	210	135	82	22240	1453	4800
OV	170	Big River	Desloge	158.16	Pit	34	0	5	10	1784	2224	25382	2325	74184
OV	171	Big River	Desloge	158.16	Pit	34	100	110	120	832	1674	23775	1822	35978
OV	172	Big River	Desloge	158.16	Pit	34	200	210	220	4147	2172	24481	1894	63408
OV	173	Big River	Desloge	158.16	Pit	34	300	310	320	7691	2093	29494	2154	99929
OV	174	Big River	Desloge	158.07	Pit	35	50	55	60	1445	3246	26999	2745	97019
OV	175	Big River	Desloge	158.07	Pit	35	150	155	160	1188	2849	24452	2007	55690
OV	32	Big River	Hwy 67 above Flat River Ck	156.54	Pit	7	0	25	50	1699	2083	27694	2835	1E+05
OV	33	Big River	Hwy 67 above Flat River Ck	156.54	Pit	7	50	75	100	1092	2255	23574	2062	44034
OV	34	Big River	Hwy 67 above Flat River Ck	156.54	Pit	7	100	115	130	1927	1722	24763	1883	52062
OV	35	Big River	Hwy 67 above Flat River Ck	156.54	Pit	7	130	145	160	1983	5010	29156	3349	2E+05
OV	36	Big River	Hwy 67 above Flat River Ck	156.54	Pit	7	160	190	220	7551	2758	25654	2162	69059
OV	37	Big River	Hwy 67 above Flat River Ck	156.54	Pit	7	220	250	280	3505	2457	21402	1001	17574
OV	38	Big River	Hwy 67 above Flat River Ck	156.54	Pit	7	280	305	330	62	2038	15728	1371	2951
OV	39	Big River	Hwy 67 above Flat River Ck	156.54	Pit	7	330	350	370	110	1736	16344	1693	2703
OV	40	Big River	Hwy 67 above Flat River Ck	156.54	Pit	7	370	395	420	51	52	15663	1217	3585

Sample ID Code	No.	Water Body	Sample Site Location	River Kilometer (0 =mouth)	Unit Code	No.	Sample Depth Upper (cm)	Mid (cm)	Lower (cm)	XRF Analysis (<2 mm fraction) **Pb** (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)
OV	30	Big River	Hwy 67 above Flat River Ck	156.44	Pit	6	0	15	30	1785	1735	29752	2751	85396
OV	31	Big River	Hwy 67 above Flat River Ck	156.44	Pit	6	30	48.5	67	1569	1391	26103	1802	28240
OV	46	Big River	Hwy 67 above Flat River Ck	156.20	Pit	9	40	50	60	1213	2029	25672	2093	45473
OV	47	Big River	Hwy 67 above Flat River Ck	156.20	Pit	9	90	100	110	4523	2245	26154	2486	95768
OV	48	Big River	Hwy 67 above Flat River Ck	156.20	Pit	9	90	100	110	1635	2657	22289	1696	44696
OV	49	Big River	Hwy 67 above Flat River Ck	156.20	Pit	9	130	140	150	660	3420	20709	1395	2018
OV	50	Big River	Hwy 67 above Flat River Ck	156.20	Pit	9	195	205	215	1857	2544	23127	1593	9971
OV	51	Big River	Hwy 67 above Flat River Ck	156.20	Pit	9	270	280	290	3549	2102	22301	1002	11206
OV	52	Big River	Hwy 67 above Flat River Ck	156.20	Pit	9	370	380	390	2707	132	22402	1189	13507
OV	41	Big River	Hwy 67 above Flat River Ck	156.18	Pit	8	0	25	50	2336	2279	25339	2263	68267
OV	42	Big River	Hwy 67 above Flat River Ck	156.18	Pit	8	50	75	100	1262	1584	25514	2176	64761
OV	43	Big River	Hwy 67 above Flat River Ck	156.18	Pit	8	100	130	160	1018	926	23721	1814	23515
OV	44	Big River	Hwy 67 above Flat River Ck	156.18	Pit	8	150	175	200	2652	2083	25436	2229	60543
OV	45	Big River	Hwy 67 above Flat River Ck	156.18	Pit	8	200	230	260	8125	2723	27851	2413	89456
OV	99	Big River	Hwy K below Flat River Ck	147.03	Pit	17	10	15	20	2026	1045	23513	2551	72765
OV	100	Big River	Hwy K below Flat River Ck	147.03	Pit	17	100	110	120	2544	1476	26567	2563	74819
OV	101	Big River	Hwy K below Flat River Ck	147.03	Pit	17	140	150	160	1266	850	27790	3261	1E+05
OV	93	Big River	Hwy K below Flat River Ck	147.00	Pit	16	0	15	30	2804	1180	29887	2908	80527
OV	94	Big River	Hwy K below Flat River Ck	147.00	Pit	16	100	110	120	1913	877	29502	2388	59154
OV	95	Big River	Hwy K below Flat River Ck	147.00	Pit	16	200	210	220	6139	1567	30822	2555	76870
OV	96	Big River	Hwy K below Flat River Ck	147.00	Pit	16	320	330	340	205	1575	22589	1715	3808
OV	97	Big River	Hwy K below Flat River Ck	147.00	Pit	16	420	430	440	3960	1383	29279	2744	63405
OV	98	Big River	Hwy K below Flat River Ck	147.00	Pit	16	470	485	500	223	128	21322	2248	14963
FC	1	Big River	St. Francois State Park	140.30	Core	1	5	10	15	1571	608	18038	1579	31987
FC	2	Big River	St. Francois State Park	140.30	Core	1	65	70	75	1116	406	18925	2229	81393
FC	3	Big River	St. Francois State Park	140.30	Core	1	105	110	115	824	523	19436	1763	76600
FC	4	Big River	St. Francois State Park	140.30	Core	1	125	130	135	1219	684	21594	1645	25794
FC	5	Big River	St. Francois State Park	140.30	Core	1	155	160	165	1305	515	20794	1540	22979
FC	6	Big River	St. Francois State Park	140.30	Core	1	185	190	195	288	175	18492	1282	4149
FC	7	Big River	St. Francois State Park	140.30	Core	1	205	210	215	1065	309	21057	1729	26744
FC	8	Big River	St. Francois State Park	140.30	Core	1	235	240	245	788	279	19091	1366	19590
FC	9	Big River	St. Francois State Park	140.30	Core	1	285	290	295	1038	357	20671	1698	38869
FC	10	Big River	St. Francois State Park	140.30	Core	1	335	340	345	1401	517	21367	2158	13747
FC	11	Big River	St. Francois State Park	140.30	Core	1	375	380	385	761	383	21221	1317	57108
FC	12	Big River	St. Francois State Park	140.30	Core	1	395	400	405	1177	785	19469	1661	64422

Sample ID Code	No.	Water Body	Sample Site Location	River Kilometer (0 =mouth)	Unit Code	No.	Sample Depth Upper (cm)	Mid (cm)	Lower (cm)	XRF Analysis (<2 mm fraction) **Pb** (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)
FC	13	Big River	St. Francois State Park	140.30	Core	1	515	520	525	1031	680	23871	1895	38024
FC	14	Big River	St. Francois State Park	140.30	Core	1	755	760	765	830	1081	20780	1591	33668
FC	15	Big River	St. Francois State Park	140.30	Core	2	25	30	35	902	237	16183	1361	10563
FC	16	Big River	St. Francois State Park	140.30	Core	2	65	70	75	3279	721	21861	1830	54104
FC	17	Big River	St. Francois State Park	140.30	Core	2	105	110	115	7287	762	24716	2219	87224
FC	18	Big River	St. Francois State Park	140.30	Core	2	125	130	135	6849	898	21645	1856	42134
FC	19	Big River	St. Francois State Park	140.30	Core	2	145	150	155	552	1385	15487	1402	1604
FC	20	Big River	St. Francois State Park	140.30	Core	2	155	160	165	886	890	15126	1229	4804
FC	21	Big River	St. Francois State Park	140.30	Core	2	175	180	185	102	146	15375	1324	2511
FC	22	Big River	St. Francois State Park	140.30	Core	2	215	220	225	ND	9	10988	604	ND
FC	23	Big River	St. Francois State Park	140.30	Core	3	15	20	25	1663	622	20630	1818	38684
FC	24	Big River	St. Francois State Park	140.30	Core	3	45	50	55	918	421	18290	1539	20715
FC	25	Big River	St. Francois State Park	140.30	Core	3	85	90	95	1534	243	26366	2021	60801
FC	26	Big River	St. Francois State Park	140.30	Core	3	135	140	145	678	357	18757	1077	12539
FC	27	Big River	St. Francois State Park	140.30	Core	3	165	170	175	2749	558	21211	1226	29382
FC	28	Big River	St. Francois State Park	140.30	Core	3	205	210	215	3281	593	26317	2408	#####
FC	29	Big River	St. Francois State Park	140.30	Core	3	245	250	255	2571	500	24404	2673	#####
FC	30	Big River	St. Francois State Park	140.30	Core	3	285	290	295	2998	844	25983	2711	#####
FC	31	Big River	St. Francois State Park	140.30	Core	3	335	340	345	2470	555	27781	3202	#####
FC	32	Big River	St. Francois State Park	140.30	Core	3	365	370	375	5542	616	27520	2849	#####
FC	33	Big River	St. Francois State Park	140.30	Core	3	385	390	395	1811	633	18762	1822	87905
FC	34	Big River	St. Francois State Park	140.30	Core	3	425	430	435	2891	3213	24488	2627	#####
FC	35	Big River	St. Francois State Park	140.30	Core	4	10	15	20	174	65	13572	556	ND
FC	36	Big River	St. Francois State Park	140.30	Core	4	40	45	50	115	23	14250	1080	ND
FC	37	Big River	St. Francois State Park	140.30	Core	4	65	70	75	ND	14	8255	ND	ND
FC	38	Big River	St. Francois State Park	140.30	Core	4	105	110	115	23	20	16211	282	ND
FC	39	Big River	St. Francois State Park	140.30	Core	5	5	10	15	290	94	11780	834	ND
FC	40	Big River	St. Francois State Park	140.30	Core	5	45	50	55	ND	21	12457	560	ND
FC	41	Big River	St. Francois State Park	140.30	Core	5	95	100	105	ND	36	24429	819	ND
FC	42	Big River	St. Francois State Park	140.30	Core	6	15	20	25	1584	582	21263	1730	29161
FC	43	Big River	St. Francois State Park	140.30	Core	6	55	60	65	1740	592	21869	1572	39958
FC	44	Big River	St. Francois State Park	140.30	Core	6	105	110	115	2459	409	22925	3034	1E+05
FC	45	Big River	St. Francois State Park	140.30	Core	6	135	140	145	121	1307	18244	1166	2784
FC	46	Big River	St. Francois State Park	140.30	Core	6	165	170	175	43	69	17065	1115	ND
FC	47	Big River	St. Francois State Park	140.30	Core	6	215	220	225	ND	17	8253	225	ND

Sample ID Code	No.	Water Body	Sample Site Location	River Kilometer (0 =mouth)	Unit Code	No.	Sample Depth Upper (cm)	Mid (cm)	Lower (cm)	XRF Analysis (<2 mm fraction) **Pb** (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)
FC	48	Big River	St. Francois State Park	140.30	Core	7	15	20	25	4207	1050	21588	2198	64896
FC	49	Big River	St. Francois State Park	140.30	Core	7	45	50	55	1055	306	17373	1432	27414
FC	50	Big River	St. Francois State Park	140.30	Core	7	95	100	105	42	37	16318	669	ND
FC	51	Big River	St. Francois State Park	140.30	Core	7	135	140	145	42	47	17718	423	ND
FC	52	Big River	St. Francois State Park	140.30	Core	7	175	180	185	40	51	19624	146	ND
OV	103	Big River	St. Francois State Park (DS)	140.15	Pit	18.1	70	85	100	1345	730	28278	2516	52199
OV	105	Big River	St. Francois State Park (DS)	140.15	Pit	18.1	290	300	310	1677	714	32937	3505	89707
OV	106	Big River	St. Francois State Park (DS)	140.15	Pit	18.1	490	500	510	66	572	19880	1513	3869
OV	102	Big River	St. Francois State Park (DS)	140.15	Pit	18.2	10	20	30	999	656	20322	2077	73092
OV	104	Big River	St. Francois State Park (DS)	140.15	Pit	18.2	90	100	110	979	1088	27437	2548	56789
OV	57	Big River	Hwy 67 at Cherokee Landing	136.90	Pit	11	10	20	30	2258	806	25065	2377	49780
OV	58	Big River	Hwy 67 at Cherokee Landing	136.90	Pit	11	40	50	60	2280	911	27021	2794	66615
OV	59	Big River	Hwy 67 at Cherokee Landing	136.90	Pit	11	100	105	110	1659	942	27867	2664	59304
OV	60	Big River	Hwy 67 at Cherokee Landing	136.90	Pit	11	150	160	170	2164	782	27147	2503	65022
OV	61	Big River	Hwy 67 at Cherokee Landing	136.90	Pit	11	210	220	230	3543	925	28284	2335	72881
OV	62	Big River	Hwy 67 at Cherokee Landing	136.90	Pit	11	280	290	300	4850	905	34295	3859	2E+05
OV	63	Big River	Hwy 67 at Cherokee Landing	136.90	Pit	11	350	360	370	6551	980	30237	2816	1E+05
OV	64	Big River	Hwy 67 at Cherokee Landing	136.90	Pit	11	390	400	410	5670	376	22519	1583	52858
OV	53	Big River	Hwy 67 at Cherokee Landing	136.55	Pit	10	10	15	20	1797	872	26954	2621	62108
OV	54	Big River	Hwy 67 at Cherokee Landing	136.55	Pit	10	100	105	110	1725	761	32222	2964	76199
OV	55	Big River	Hwy 67 at Cherokee Landing	136.55	Pit	10	150	160	170	957	1900	97051	726	21831
OV	56	Big River	Hwy 67 at Cherokee Landing	136.55	Pit	10	215	220	225	33	81	17122	971	3250
OV	108	Big River	Hwy E below Bonne Terre	132.86	Pit	19	0	25	50	2254	912	27055	2175	40162
OV	107	Big River	Hwy E below Bonne Terre	132.86	Pit	19	50	75	100	65	90	27055	1316	3099
OV	111	Big River	Hwy E below Bonne Terre	132.84	Pit	20	0	10	20	2128	665	27620	2273	41178
OV	110	Big River	Hwy E below Bonne Terre	132.84	Pit	20	90	100	110	8096	1007	35648	3976	1E+05
OV	109	Big River	Hwy E below Bonne Terre	132.84	Pit	20	240	250	260	841	1918	19434	1293	4462
OV	192	Big River	Mill Ck confluence	118.00	Pit	40	0	50	100	2158	662	23904	2080	65511
OV	193	Big River	Mill Ck confluence	118.00	Pit	40	100	150	200	5473	813	30611	2968	1E+05
OV	194	Big River	Mill Ck confluence	118.00	Pit	40	200	250	300	4068	1659	20972	1334	19185
OV	122	Big River	CC Bridge at Blackwell	115.45	Pit	23	90	95	100	2247	614	26801	2384	73770
OV	123	Big River	CC Bridge at Blackwell	115.45	Pit	23	200	210	220	1987	805	36364	2263	59537
OV	124	Big River	CC Bridge at Blackwell	115.45	Pit	23	340	350	360	6469	683	40293	4054	2E+05
OV	125	Big River	CC Bridge at Blackwell	115.45	Pit	23	400	410	420	109	250	22908	1369	3293
OV	118	Big River	CC Bridge at Blackwell	115.35	Pit	22	30	40	50	1418	517	20104	1663	68134

Sample ID Code	No.	Water Body	Sample Site Location	River Kilometer (0 =mouth)	Unit Code	No.	Sample Depth Upper (cm)	Mid (cm)	Lower (cm)	XRF Analysis (<2 mm fraction) **Pb** (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)
OV	119	Big River	CC Bridge at Blackwell	115.35	Pit	22	90	100	110	1486	452	21353	2080	81515
OV	120	Big River	CC Bridge at Blackwell	115.35	Pit	22	170	180	190	2513	691	31094	2426	41919
OV	121	Big River	CC Bridge at Blackwell	115.35	Pit	22	250	255	260	2266	807	32086	2004	43058
OV	112	Big River	CC Bridge at Blackwell	115.27	Pit	21	20	30	40	2646	778	26955	2392	69296
OV	113	Big River	CC Bridge at Blackwell	115.27	Pit	21	90	100	110	1286	402	24336	1875	48540
OV	114	Big River	CC Bridge at Blackwell	115.27	Pit	21	170	175	180	2624	706	25431	1970	49163
OV	115	Big River	CC Bridge at Blackwell	115.27	Pit	21	200	210	220	3993	632	26408	2054	60982
OV	116	Big River	CC Bridge at Blackwell	115.27	Pit	21	250	260	270	5244	673	38858	4174	2E+05
OV	117	Big River	CC Bridge at Blackwell	115.27	Pit	21	300	305	310	2241	259	19389	1766	91686
FC	195	Big River	Washington State Park	101.7	Core	24	5	10	15	1673	491	22038	1075	15241
FC	196	Big River	Washington State Park	101.7	Core	24	35	40	45	1320	352	20017	1238	15156
FC	197	Big River	Washington State Park	101.7	Core	24	65	70	75	4426	440	20696	1342	29308
FC	198	Big River	Washington State Park	101.7	Core	24	95	100	105	350	198	15014	818	ND
FC	199	Big River	Washington State Park	101.7	Core	24	125	130	135	229	210	18426	1016	1827
FC	200	Big River	Washington State Park	101.7	Core	24	155	160	165	91	123	17977	328	ND
FC	201	Big River	Washington State Park	101.7	Core	24	185	190	195	56	125	18808	988	ND
FC	202	Big River	Washington State Park	101.7	Core	24	215	220	225	91	126	16194	886	2136
FC	203	Big River	Washington State Park	101.7	Core	24	245	250	255	44	84	15142	818	1435
FC	204	Big River	Washington State Park	101.7	Core	24	265	270	275	43	58	11506	560	ND
FC	205	Big River	Washington State Park	101.7	Core	25	5	10	15	2136	557	22013	1272	12891
FC	206	Big River	Washington State Park	101.7	Core	25	35	40	45	1780	483	23643	1410	23087
FC	207	Big River	Washington State Park	101.7	Core	25	65	70	75	2277	291	17897	989	13168
FC	208	Big River	Washington State Park	101.7	Core	25	95	100	105	958	236	16007	776	1890
FC	209	Big River	Washington State Park	101.7	Core	25	125	130	135	101	89	13845	655	ND
FC	210	Big River	Washington State Park	101.7	Core	25	155	160	165	38	23	5125	ND	ND
FC	211	Big River	Washington State Park	101.7	Core	25	185	190	195	ND	55	8811	211	ND
FC	212	Big River	Washington State Park	101.7	Core	25	215	220	225	ND	26	10754	58	ND
FC	213	Big River	Washington State Park	101.7	Core	25	265	270	275	ND	26	6222	48	ND
FC	214	Big River	Washington State Park	101.7	Core	25	325	330	335	ND	77	12505	475	ND
FC	215	Big River	Washington State Park	101.7	Core	26	5	10	15	1915	476	19597	1181	17803
FC	216	Big River	Washington State Park	101.7	Core	26	35	40	45	1679	450	22789	1263	21193
FC	217	Big River	Washington State Park	101.7	Core	26	65	70	75	190	110	14756	706	ND
FC	218	Big River	Washington State Park	101.7	Core	26	95	100	105	21	64	10094	354	ND
FC	219	Big River	Washington State Park	101.7	Core	26	125	130	135	27	63	9911	274	ND
FC	220	Big River	Washington State Park	101.7	Core	26	155	160	165	15	50	9171	283	ND

Sample ID Code	No.	Water Body	Sample Site Location	River Kilometer (0 =mouth)	Unit Code	No.	Sample Depth Upper (cm)	Mid (cm)	Lower (cm)	XRF Analysis (<2 mm fraction) **Pb** (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)
FC	221	Big River	Washington State Park	101.7	Core	26	185	190	195	ND	52	9573	264	ND
FC	222	Big River	Washington State Park	101.7	Core	26	215	220	225	243	106	11824	442	3094
FC	223	Big River	Washington State Park	101.7	Core	26	345	350	355	ND	56	10923	422	1446
FC	224	Big River	Washington State Park	101.7	Core	26	285	290	295	15	44	9254	340	ND
FC	225	Big River	Washington State Park	101.7	Core	26	695	700	705	50	80	12192	397	2081
FC	226	Big River	Washington State Park	101.7	Core	27	5	10	15	2204	530	19503	1326	22282
FC	227	Big River	Washington State Park	101.7	Core	27	35	40	45	1928	485	20245	1221	22316
FC	228	Big River	Washington State Park	101.7	Core	27	65	70	75	1810	413	20493	1122	23375
FC	229	Big River	Washington State Park	101.7	Core	27	95	100	105	3190	499	23031	1482	35294
FC	230	Big River	Washington State Park	101.7	Core	27	125	130	135	8541	720	19478	1483	39190
FC	231	Big River	Washington State Park	101.7	Core	27	155	160	165	1230	461	16019	870	2170
FC	232	Big River	Washington State Park	101.7	Core	27	185	190	195	113	64	7205	262	ND
FC	233	Big River	Washington State Park	101.7	Core	27	215	220	225	118	20	3778	ND	ND
FC	234	Big River	Washington State Park	101.7	Core	27	245	250	255	221	159	13141	653	2282
FC	235	Big River	Washington State Park	101.7	Core	27	275	280	285	49	107	10296	641	ND
FC	236	Big River	Washington State Park	101.7	Core	27	305	310	315	135	153	18063	1519	1267
FC	237	Big River	Washington State Park	101.7	Core	27	335	340	345	330	156	15830	955	2236
FC	238	Big River	Washington State Park	101.7	Core	27	365	370	375	164	166	20776	1237	ND
FC	239	Big River	Washington State Park	101.7	Core	27	395	400	405	78	94	12829	526	ND
FC	240	Big River	Washington State Park	101.7	Core	27	425	430	435	33	89	14341	648	1775
FC	241	Big River	Washington State Park	101.7	Core	28	5	10	15	1877	451	18236	1404	32846
FC	242	Big River	Washington State Park	101.7	Core	28	35	40	45	2043	552	21188	1377	29071
FC	243	Big River	Washington State Park	101.7	Core	28	65	70	75	1555	402	19697	997	19911
FC	244	Big River	Washington State Park	101.7	Core	28	95	100	105	1800	389	21223	1104	21500
FC	245	Big River	Washington State Park	101.7	Core	28	125	130	135	2542	386	17136	1046	16998
FC	246	Big River	Washington State Park	101.7	Core	28	155	160	165	4159	412	18774	1341	40824
FC	247	Big River	Washington State Park	101.7	Core	28	185	190	195	3877	454	16242	906	11119
FC	248	Big River	Washington State Park	101.7	Core	28	215	220	225	3610	212	16974	1074	7920
FC	249	Big River	Washington State Park	101.7	Core	28	245	250	255	3375	161	14184	887	14648
FC	250	Big River	Washington State Park	101.7	Core	28	275	280	285	1806	123	13463	579	10217
FC	251	Big River	Washington State Park	101.7	Core	28	305	310	315	162	76	11021	572	1596
FC	252	Big River	Washington State Park	101.7	Core	28	335	340	345	108	127	12643	581	ND
FC	253	Big River	Washington State Park	101.7	Core	28	365	370	375	51	79	12557	795	ND
FC	254	Big River	Washington State Park	101.7	Core	28	390	395	400	31	73	11397	690	ND
FC	255	Big River	Washington State Park	101.7	Core	29	5	10	15	2347	492	21243	1372	36354

Sample ID		Water Body	Sample Site	River	Unit		Sample Depth			XRF Analysis (<2 mm fraction)				
Code	No.		Location	Kilometer (0 =mouth)	Code	No.	Upper (cm)	Mid (cm)	Lower (cm)	**Pb** (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)
FC	256	Big River	Washington State Park	101.7	Core	29	35	40	45	2055	463	18598	1278	25667
FC	257	Big River	Washington State Park	101.7	Core	29	65	70	75	1934	498	22462	1448	24899
FC	258	Big River	Washington State Park	101.7	Core	29	95	100	105	1927	423	22666	1303	27460
FC	259	Big River	Washington State Park	101.7	Core	29	125	130	135	2100	444	22648	1322	18455
FC	260	Big River	Washington State Park	101.7	Core	29	155	160	165	1852	283	17247	1261	27774
FC	261	Big River	Washington State Park	101.7	Core	29	185	190	195	1731	303	20588	1239	17964
FC	262	Big River	Washington State Park	101.7	Core	29	215	220	225	2481	123	12106	498	6498
FC	263	Big River	Washington State Park	101.7	Core	29	245	250	255	3791	144	14865	624	7573
FC	264	Big River	Washington State Park	101.7	Core	29	275	280	285	5254	121	14439	993	7798
FC	265	Big River	Washington State Park	101.7	Core	29	305	310	315	12307	230	19136	787	20154
FC	266	Big River	Washington State Park	101.7	Core	29	335	340	345	490	37	5932	241	2711
FC	267	Big River	Washington State Park	101.7	Core	29	365	370	375	1393	67	9962	230	5162
FC	268	Big River	Washington State Park	101.7	Core	29	395	400	405	251	93	9205	164	2494
FC	269	Big River	Washington State Park	101.7	Core	29	425	430	435	87	82	8585	136	1821
FC	270	Big River	Washington State Park	101.7	Core	29	455	460	465	ND	69	7653	ND	ND
FC	271	Big River	Washington State Park	101.7	Core	29	475	480	485	44	66	7512	ND	1484
FC	272	Big River	Washington State Park	101.7	Core	30	5	10	15	1916	439	17658	1310	35943
FC	273	Big River	Washington State Park	101.7	Core	30	35	40	45	2220	534	17880	1301	41102
FC	274	Big River	Washington State Park	101.7	Core	30	65	70	75	1911	441	18894	1421	45349
FC	275	Big River	Washington State Park	101.7	Core	30	95	100	105	867	223	13713	902	33719
FC	276	Big River	Washington State Park	101.7	Core	30	125	130	135	1436	446	23228	1197	14206
FC	277	Big River	Washington State Park	101.7	Core	30	155	160	165	1525	454	22429	1204	16395
FC	278	Big River	Washington State Park	101.7	Core	30	185	190	195	1617	492	21234	847	16510
FC	279	Big River	Washington State Park	101.7	Core	30	215	220	225	1785	314	18300	1345	21895
FC	280	Big River	Washington State Park	101.7	Core	30	245	250	255	1012	321	15925	1136	10196
FC	281	Big River	Washington State Park	101.7	Core	30	275	280	285	818	205	14788	778	12569
FC	282	Big River	Washington State Park	101.7	Core	30	305	310	315	1306	275	16193	1466	9665
FC	283	Big River	Washington State Park	101.7	Core	30	335	340	345	1863	370	12552	834	22189
FC	284	Big River	Washington State Park	101.7	Core	30	355	360	365	1413	197	9294	214	10252
FC	285	Big River	Washington State Park	101.7	Core	30	385	390	395	1080	323	13353	744	10694
FC	286	Big River	Washington State Park	101.7	Core	30	595	600	605	123	83	15989	552	4960
FC	287	Big River	Washington State Park	101.7	Core	31	5	10	15	1613	615	19612	1176	15264
FC	288	Big River	Washington State Park	101.7	Core	31	35	40	45	1982	421	18762	1471	53542
FC	289	Big River	Washington State Park	101.7	Core	31	65	70	75	1919	431	18175	1345	35650
FC	290	Big River	Washington State Park	101.7	Core	31	95	100	105	1525	351	16494	1437	46091

Sample ID Code	No.	Water Body	Sample Site Location	River Kilometer (0 =mouth)	Unit Code	No.	Sample Depth Upper (cm)	Mid (cm)	Lower (cm)	XRF Analysis (<2 mm fraction) **Pb** (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)
FC	291	Big River	Washington State Park	101.7	Core	31	125	130	135	1633	376	17385	1549	46363
FC	292	Big River	Washington State Park	101.7	Core	31	155	160	165	1580	518	20409	1249	41314
FC	293	Big River	Washington State Park	101.7	Core	31	185	190	195	1096	228	13389	893	31258
FC	294	Big River	Washington State Park	101.7	Core	31	215	220	225	818	181	13178	668	29494
FC	295	Big River	Washington State Park	101.7	Core	31	245	250	255	576	133	7613	312	12932
FC	296	Big River	Washington State Park	101.7	Core	31	275	280	285	350	117	7630	246	10807
FC	297	Big River	Washington State Park	101.7	Core	31	285	290	295	620	143	10978	291	26030
FC	298	Big River	Washington State Park	101.7	Core	31	315	320	325	424	93	7626	207	21343
FC	299	Big River	Washington State Park	101.7	Core	31	345	350	355	259	57	7017	431	31418
FC	300	Big River	Washington State Park	101.7	Core	31	375	380	385	587	158	9539	503	17813
FC	301	Big River	Washington State Park	101.7	Core	31	405	410	415	314	77	6736	244	15931
OV	76	Big River	Mammoth Access	97.13	Pit	14	0	10	20	1637	337	17923	1059	24261
OV	77	Big River	Mammoth Access	97.13	Pit	14	60	70	80	1988	500	24290	1511	25850
OV	78	Big River	Mammoth Access	97.13	Pit	14	100	110	120	1936	362	23351	1500	26621
OV	79	Big River	Mammoth Access	97.13	Pit	14	180	190	200	4909	671	29035	2501	74632
OV	80	Big River	Mammoth Access	97.13	Pit	14	260	270	280	2549	130	14079	698	10315
OV	81	Big River	Mammoth Access	97.13	Pit	14	320	330	340	1250	187	17548	959	5421
OV	82	Big River	Mammoth Access	97.13	Pit	14	400	410	420	195	216	19199	1036	5473
OV	83	Big River	Mammoth Access	97.13	Pit	14	430	440	450	94	182	18656	927	3415
FC	328	Big River	Mammoth Access	97	Core	35	35	40	45	1389	262	14779	624	14276
FC	329	Big River	Mammoth Access	97	Core	35	65	70	75	1435	291	16609	1001	21032
FC	330	Big River	Mammoth Access	97	Core	35	95	100	105	1184	267	12900	626	13933
FC	331	Big River	Mammoth Access	97	Core	35	125	130	135	591	127	11289	439	9715
FC	332	Big River	Mammoth Access	97	Core	35	155	160	165	664	131	10879	440	8822
FC	333	Big River	Mammoth Access	97	Core	35	175	180	185	70	61	8352	257	1993
OV	86	Big River	Mammoth Access	96.88	Pit	15	10	20	30	2206	483	20644	1346	27817
OV	87	Big River	Mammoth Access	96.88	Pit	15	50	55	60	1659	481	27137	1657	19101
OV	88	Big River	Mammoth Access	96.88	Pit	15	70	80	90	91	182	24915	1239	3245
OV	90	Big River	Mammoth Access	96.88	Pit	15	150	160	170	49	139	18839	806	3066
OV	91	Big River	Mammoth Access	96.88	Pit	15	250	260	270	58	133	18027	835	3005
OV	92	Big River	Mammoth Access	96.88	Pit	15	270	285	300	47	89	12126	660	2137
FC	334	Big River	Merrill Horse Access	87.3	Core	36	5	10	15	1679	391	18050	1096	21470
FC	335	Big River	Merrill Horse Access	87.3	Core	36	35	40	45	1616	323	16888	913	14577
FC	336	Big River	Merrill Horse Access	87.3	Core	36	65	70	75	2036	287	15920	973	19222
FC	337	Big River	Merrill Horse Access	87.3	Core	36	95	100	105	1263	153	14473	817	2882

Sample ID Code	No.	Water Body	Sample Site Location	River Kilometer (0 =mouth)	Unit Code	No.	Sample Depth Upper (cm)	Mid (cm)	Lower (cm)	XRF Analysis (<2 mm fraction) **Pb** (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)
FC	338	Big River	Merrill Horse Access	87.3	Core	36	125	130	135	115	169	14949	692	ND
FC	339	Big River	Merrill Horse Access	87.3	Core	36	155	160	165	30	96	11865	561	ND
FC	340	Big River	Merrill Horse Access	87.3	Core	36	185	190	195	ND	94	12530	586	ND
FC	341	Big River	Merrill Horse Access	87.3	Core	36	215	220	225	ND	123	15363	586	ND
OV	65	Big River	Browns Ford Access	79.59	Pit	12	10	15	20	1777	489	20667	1484	22415
OV	66	Big River	Browns Ford Access	79.59	Pit	12	50	60	70	1653	437	24790	1367	13886
OV	67	Big River	Browns Ford Access	79.59	Pit	12	130	140	150	250	259	22021	1250	3032
OV	68	Big River	Browns Ford Access	79.59	Pit	12	180	185	190	214	231	21818	1465	3280
OV	69	Big River	Browns Ford Access	79.59	Pit	12	220	225	230	27	147	15234	298	ND
OV	70	Big River	Browns Ford Access	79.34	Pit	13	0	10	20	1534	432	19622	1267	22317
OV	71	Big River	Browns Ford Access	79.34	Pit	13	80	90	100	2064	481	21094	1322	23100
OV	72	Big River	Browns Ford Access	79.34	Pit	13	180	190	200	1511	445	23309	1298	14638
OV	73	Big River	Browns Ford Access	79.34	Pit	13	280	290	300	1464	395	22975	1171	13563
OV	74	Big River	Browns Ford Access	79.34	Pit	13	380	390	400	2869	335	24028	1458	22650
OV	75	Big River	Browns Ford Access	79.34	Pit	13	450	455	460	2243	516	23355	1042	24257
FC	172	Big River	Browns Ford Access	79.3	Core	21	5	10	15	1518	463	17029	836	11719
FC	173	Big River	Browns Ford Access	79.3	Core	21	35	40	45	1704	632	21362	1780	12550
FC	174	Big River	Browns Ford Access	79.3	Core	21	65	70	75	2067	348	18255	1326	10797
FC	175	Big River	Browns Ford Access	79.3	Core	21	95	100	105	7085	658	22475	1758	52118
FC	176	Big River	Browns Ford Access	79.3	Core	21	125	130	135	10231	630	23022	1550	54815
FC	177	Big River	Browns Ford Access	79.3	Core	21	155	160	165	5193	364	17488	812	12191
FC	178	Big River	Browns Ford Access	79.3	Core	21	185	190	195	1704	145	15459	806	3090
FC	179	Big River	Browns Ford Access	79.3	Core	21	215	220	225	1007	219	16104	933	3101
FC	180	Big River	Browns Ford Access	79.3	Core	21	245	250	255	206	211	13818	622	1603
FC	181	Big River	Browns Ford Access	79.3	Core	21	275	280	285	123	179	12849	572	2663
FC	182	Big River	Browns Ford Access	79.3	Core	21	305	310	315	74	144	14101	887	1388
OV	126	Big River	Morse Mill Park	49.82	Pit	24	10	20	30	774	192	14510	761	9648
OV	127	Big River	Morse Mill Park	49.82	Pit	24	50	60	70	966	250	17090	988	8723
OV	128	Big River	Morse Mill Park	49.82	Pit	24	110	120	130	655	249	21833	1045	7634
OV	129	Big River	Morse Mill Park	49.82	Pit	24	200	210	220	70	192	21797	1032	2743
OV	130	Big River	Morse Mill Park	49.82	Pit	24	300	310	320	41	110	14583	178	2447
FC	53	Big River	Morse Mill Park	49.6	Core	8	15	20	25	949	222	13790	628	7201
FC	54	Big River	Morse Mill Park	49.6	Core	8	45	50	55	1721	220	15120	761	7965
FC	55	Big River	Morse Mill Park	49.6	Core	8	95	100	105	5457	406	18105	763	12310
FC	56	Big River	Morse Mill Park	49.6	Core	8	125	130	135	150	118	14392	498	ND

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FC	57	Big River	Morse Mill Park	49.6	Core	8	165	170	175	42	104	12162	409	ND
FC	58	Big River	Morse Mill Park	49.6	Core	8	205	210	215	122	133	14871	559	ND
FC	59	Big River	Morse Mill Park	49.6	Core	8	225	230	235	96	64	9470	345	ND
FC	60	Big River	Morse Mill Park	49.6	Core	8	245	250	255	ND	23	4084	ND	ND
FC	61	Big River	Morse Mill Park	49.6	Core	8	295	300	305	ND	19	3463	ND	ND
FC	62	Big River	Morse Mill Park	49.6	Core	9	5	10	15	1025	240	13583	689	8302
FC	63	Big River	Morse Mill Park	49.6	Core	9	25	30	35	631	126	12546	533	5726
FC	64	Big River	Morse Mill Park	49.6	Core	9	55	60	65	1084	220	16807	639	6067
FC	65	Big River	Morse Mill Park	49.6	Core	9	85	90	95	1012	213	13572	320	4480
FC	66	Big River	Morse Mill Park	49.6	Core	9	105	110	115	272	150	22410	70	ND
FC	67	Big River	Morse Mill Park	49.6	Core	9	135	140	145	1031	212	15930	630	4536
FC	68	Big River	Morse Mill Park	49.6	Core	9	195	200	205	175	126	14306	250	ND
FC	69	Big River	Morse Mill Park	49.6	Core	9	225	230	235	619	188	16022	416	3320
FC	70	Big River	Morse Mill Park	49.6	Core	9	230	235	240	82	133	15035	206	ND
FC	71	Big River	Morse Mill Park	49.6	Core	9	260	265	270	79	130	15138	350	ND
FC	72	Big River	Morse Mill Park	49.6	Core	9	290	295	300	64	130	14461	816	ND
FC	73	Big River	Morse Mill Park	49.6	Core	10	15	20	25	1067	242	14448	728	7606
FC	74	Big River	Morse Mill Park	49.6	Core	10	45	50	55	1256	342	17731	929	6261
FC	75	Big River	Morse Mill Park	49.6	Core	10	75	80	85	1117	249	14610	684	4669
FC	76	Big River	Morse Mill Park	49.6	Core	10	105	110	115	907	248	16121	835	5463
FC	77	Big River	Morse Mill Park	49.6	Core	10	135	140	145	179	155	14624	588	ND
FC	78	Big River	Morse Mill Park	49.6	Core	10	165	170	175	83	162	17211	678	ND
FC	79	Big River	Morse Mill Park	49.6	Core	10	195	200	205	62	136	15568	681	ND
FC	80	Big River	Morse Mill Park	49.6	Core	10	225	230	235	60	174	19047	762	1903
FC	81	Big River	Morse Mill Park	49.6	Core	11	10	15	20	1300	269	15026	735	6575
FC	82	Big River	Morse Mill Park	49.6	Core	11	35	40	45	1513	265	15855	869	8710
FC	83	Big River	Morse Mill Park	49.6	Core	11	65	70	75	4705	454	19026	1394	35142
FC	84	Big River	Morse Mill Park	49.6	Core	11	95	100	105	6526	554	19348	1170	19807
FC	85	Big River	Morse Mill Park	49.6	Core	11	125	130	135	1922	66	11595	657	2905
FC	86	Big River	Morse Mill Park	49.6	Core	11	155	160	165	1277	92	12189	681	2629
FC	87	Big River	Morse Mill Park	49.6	Core	11	185	190	195	1131	104	11411	250	3230
FC	88	Big River	Morse Mill Park	49.6	Core	11	215	220	225	190	129	12248	1005	1520
FC	89	Big River	Morse Mill Park	49.6	Core	11	245	250	255	204	162	13666	653	ND
FC	90	Big River	Morse Mill Park	49.6	Core	11	275	280	285	68	91	9961	628	ND
FC	91	Big River	Morse Mill Park	49.6	Core	11	305	310	315	71	104	12108	165	2381

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FC	92	Big River	Morse Mill Park	49.6	Core	11	335	340	345	62	155	8449	ND	2272
FC	93	Big River	Morse Mill Park	49.6	Core	12	15	20	25	1130	253	16468	713	5293
FC	94	Big River	Morse Mill Park	49.6	Core	12	45	50	55	1254	226	13917	801	5138
FC	95	Big River	Morse Mill Park	49.6	Core	12	75	80	85	1350	219	15197	728	7691
FC	96	Big River	Morse Mill Park	49.6	Core	12	105	110	115	936	245	14285	684	4407
FC	97	Big River	Morse Mill Park	49.6	Core	12	120	125	130	ND	92	13360	523	ND
FC	98	Big River	Morse Mill Park	49.6	Core	12	135	140	145	39	83	11371	324	ND
FC	99	Big River	Morse Mill Park	49.6	Core	12	165	170	175	28	91	12560	487	ND
FC	100	Big River	Morse Mill Park	49.6	Core	12	195	200	205	40	128	15676	662	1398
FC	101	Big River	Morse Mill Park	49.6	Core	13	20	25	30	1154	230	15921	785	4323
FC	102	Big River	Morse Mill Park	49.6	Core	13	45	50	55	1196	234	15114	793	5217
FC	103	Big River	Morse Mill Park	49.6	Core	13	75	80	85	1657	253	17968	1056	6553
FC	104	Big River	Morse Mill Park	49.6	Core	13	105	110	115	1651	221	15240	944	9089
FC	105	Big River	Morse Mill Park	49.6	Core	13	135	140	145	1813	181	14992	901	3595
FC	106	Big River	Morse Mill Park	49.6	Core	13	165	170	175	719	134	17185	1101	1860
FC	107	Big River	Morse Mill Park	49.6	Core	13	195	200	205	284	132	15617	974	1745
FC	108	Big River	Morse Mill Park	49.6	Core	13	225	230	235	67	126	15217	1001	ND
FC	109	Big River	Morse Mill Park	49.6	Core	13	255	260	265	43	129	14947	790	ND
FC	110	Big River	Morse Mill Park	49.6	Core	13	285	290	295	ND	118	16782	626	ND
FC	111	Big River	Morse Mill Park	49.6	Core	14	15	20	25	1416	264	15512	764	6822
FC	112	Big River	Morse Mill Park	49.6	Core	14	45	50	55	3032	203	14726	765	7718
FC	113	Big River	Morse Mill Park	49.6	Core	14	75	80	85	521	128	13135	601	ND
FC	114	Big River	Morse Mill Park	49.6	Core	14	105	110	115	41	125	13915	648	ND
FC	115	Big River	Morse Mill Park	49.6	Core	14	135	140	145	75	142	16128	659	ND
FC	116	Big River	Morse Mill Park	49.6	Core	14	165	170	175	52	158	17955	717	ND
FC	117	Big River	Morse Mill Park	49.6	Core	14	195	200	205	ND	123	14404	552	ND
FC	118	Big River	Morse Mill Park	49.6	Core	14	225	230	235	ND	123	14978	456	ND
FC	119	Big River	Morse Mill Park	49.6	Core	15	15	20	25	1298	256	15932	753	5877
FC	120	Big River	Morse Mill Park	49.6	Core	15	45	50	55	1045	128	13974	708	1554
FC	121	Big River	Morse Mill Park	49.6	Core	15	75	80	85	80	120	14789	680	ND
FC	122	Big River	Morse Mill Park	49.6	Core	15	105	110	115	68	129	16192	657	ND
FC	123	Big River	Morse Mill Park	49.6	Core	15	135	140	145	ND	166	17358	653	ND
FC	124	Big River	Morse Mill Park	49.6	Core	15	165	170	175	60	152	17514	669	1437
FC	125	Big River	Morse Mill Park	49.6	Core	15	195	200	205	40	140	16648	541	ND
FC	126	Big River	Morse Mill Park	49.6	Core	15	225	230	235	52	131	15994	652	ND

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FC	127	Big River	Morse Mill Park	49.6	Core	16	15	20	25	44	83	12681	539	ND
FC	128	Big River	Morse Mill Park	49.6	Core	16	45	50	55	40	70	14811	309	ND
FC	129	Big River	Morse Mill Park	49.6	Core	16	75	80	85	32	102	18965	103	ND
FC	130	Big River	Morse Mill Park	49.6	Core	16	105	110	115	ND	119	22344	529	ND
OV	131	Big River	Cedar Hill Park	32.60	Pit	25	10	20	30	724	198	13755	697	8803
OV	132	Big River	Cedar Hill Park	32.60	Pit	25	70	75	80	331	76	8745	437	3295
OV	133	Big River	Cedar Hill Park	32.60	Pit	25	140	150	160	658	155	15398	798	7992
OV	134	Big River	Cedar Hill Park	32.60	Pit	25	240	250	260	892	75	13951	740	3043
OV	135	Big River	Cedar Hill Park	32.60	Pit	25	340	350	360	81	115	14845	769	4640
FC	131	Big River	Cedar Hill Park	32.5	Core	17	15	20	25	1026	257	15625	746	9708
FC	132	Big River	Cedar Hill Park	32.5	Core	17	45	50	55	548	124	11469	477	2497
FC	133	Big River	Cedar Hill Park	32.5	Core	17	75	80	85	594	118	9271	842	ND
FC	134	Big River	Cedar Hill Park	32.5	Core	17	105	110	115	722	135	14505	525	4280
FC	135	Big River	Cedar Hill Park	32.5	Core	17	135	140	145	1968	144	10488	597	9159
FC	136	Big River	Cedar Hill Park	32.5	Core	17	165	170	175	3135	293	14125	647	12756
FC	137	Big River	Cedar Hill Park	32.5	Core	17	195	200	205	4256	433	16250	762	13455
FC	138	Big River	Cedar Hill Park	32.5	Core	18	15	20	25	948	235	14520	708	8636
FC	139	Big River	Cedar Hill Park	32.5	Core	18	45	50	55	503	141	11293	1249	3062
FC	140	Big River	Cedar Hill Park	32.5	Core	18	75	80	85	317	63	7099	144	2845
FC	141	Big River	Cedar Hill Park	32.5	Core	18	105	110	115	1601	187	16207	405	7382
FC	142	Big River	Cedar Hill Park	32.5	Core	18	135	140	145	1886	188	15979	587	12013
FC	143	Big River	Cedar Hill Park	32.5	Core	18	165	170	175	3229	232	15651	1018	12200
FC	144	Big River	Cedar Hill Park	32.5	Core	18	195	200	205	2577	268	12238	498	12147
FC	145	Big River	Cedar Hill Park	32.5	Core	18	225	230	235	2366	117	13094	198	8352
FC	146	Big River	Cedar Hill Park	32.5	Core	18	255	260	265	239	30	7796	ND	1792
FC	147	Big River	Cedar Hill Park	32.5	Core	18	285	290	295	148	34	6983	90	ND
FC	148	Big River	Cedar Hill Park	32.5	Core	18	315	320	325	2382	84	13610	1156	4675
FC	149	Big River	Cedar Hill Park	32.5	Core	18	335	340	345	1082	67	9436	36	ND
FC	150	Big River	Cedar Hill Park	32.5	Core	18	365	370	375	44	110	10855	160	ND
FC	151	Big River	Cedar Hill Park	32.5	Core	18	395	400	405	20	45	8384	165	ND
FC	152	Big River	Cedar Hill Park	32.5	Core	18	425	430	435	64	86	11379	106	ND
FC	153	Big River	Cedar Hill Park	32.5	Core	19	15	20	25	781	173	13367	577	5362
FC	154	Big River	Cedar Hill Park	32.5	Core	19	45	50	55	261	105	12631	450	ND
FC	155	Big River	Cedar Hill Park	32.5	Core	19	75	80	85	47	106	14181	570	ND
FC	156	Big River	Cedar Hill Park	32.5	Core	19	105	110	115	ND	133	17078	638	ND

Sample ID		Water Body	Sample Site	River	Unit		Sample Depth			XRF Analysis (<2 mm fraction)				
Code	No.		Location	Kilometer	Code	No.	Upper	Mid	Lower	**Pb**	Zn	Fe	Mn	Ca
				(0 =mouth)			(cm)	(cm)	(cm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
FC	157	Big River	Cedar Hill Park	32.5	Core	19	135	140	145	ND	109	14841	560	ND
FC	158	Big River	Cedar Hill Park	32.5	Core	19	225	230	235	22	63	9758	248	ND
FC	302	Big River	Rockford Beach Access	17.4	Core	32	5	10	15	741	204	13897	557	6989
FC	303	Big River	Rockford Beach Access	17.4	Core	32	35	40	45	764	225	15837	629	2612
FC	304	Big River	Rockford Beach Access	17.4	Core	32	65	70	75	1469	228	16406	765	4900
FC	305	Big River	Rockford Beach Access	17.4	Core	32	95	100	105	3414	278	18177	827	7347
FC	306	Big River	Rockford Beach Access	17.4	Core	32	125	130	135	1129	92	14282	624	ND
FC	307	Big River	Rockford Beach Access	17.4	Core	32	155	160	165	668	108	17376	625	ND
FC	308	Big River	Rockford Beach Access	17.4	Core	32	185	190	195	139	119	14944	563	ND
FC	309	Big River	Rockford Beach Access	17.4	Core	32	215	220	225	123	104	15329	494	ND
FC	310	Big River	Rockford Beach Access	17.4	Core	33	5	10	15	779	188	14720	567	4539
FC	311	Big River	Rockford Beach Access	17.4	Core	33	35	40	45	998	162	14380	609	8730
FC	312	Big River	Rockford Beach Access	17.4	Core	33	65	70	75	855	115	13755	530	1875
FC	313	Big River	Rockford Beach Access	17.4	Core	33	95	100	105	76	111	13791	590	ND
FC	314	Big River	Rockford Beach Access	17.4	Core	33	125	130	135	35	81	11890	402	ND
FC	315	Big River	Rockford Beach Access	17.4	Core	34	5	10	15	589	166	12150	500	6503
FC	316	Big River	Rockford Beach Access	17.4	Core	34	35	40	45	677	184	13231	611	3845
FC	317	Big River	Rockford Beach Access	17.4	Core	34	65	70	75	526	131	13324	494	2680
FC	318	Big River	Rockford Beach Access	17.4	Core	34	95	100	105	447	96	9360	369	1742
FC	319	Big River	Rockford Beach Access	17.4	Core	34	125	130	135	987	171	13926	794	3954
FC	320	Big River	Rockford Beach Access	17.4	Core	34	155	160	165	1055	157	16699	655	4925
FC	321	Big River	Rockford Beach Access	17.4	Core	34	185	190	195	1709	192	15111	717	8987
FC	322	Big River	Rockford Beach Access	17.4	Core	34	215	220	225	2889	210	12760	516	9377
FC	323	Big River	Rockford Beach Access	17.4	Core	34	245	250	255	4287	339	16924	718	12080
FC	324	Big River	Rockford Beach Access	17.4	Core	34	275	280	285	1086	341	16580	382	4768
FC	325	Big River	Rockford Beach Access	17.4	Core	34	305	310	315	2501	218	17667	657	6701
FC	326	Big River	Rockford Beach Access	17.4	Core	34	335	340	345	382	101	8485	296	2655
FC	327	Big River	Rockford Beach Access	17.4	Core	34	365	370	375	ND	36	3734	ND	ND
OV	136	Big River	Rockford Beach Access	17.39	Pit	26	0	5	10	697	224	18916	1029	13762
OV	137	Big River	Rockford Beach Access	17.39	Pit	26	50	55	60	959	288	19253	951	11877
OV	138	Big River	Rockford Beach Access	17.39	Pit	26	100	105	110	961	296	19691	1053	9828
OV	139	Big River	Rockford Beach Access	17.39	Pit	26	150	155	160	1033	337	20856	1067	9293
OV	140	Big River	Rockford Beach Access	17.39	Pit	26	200	210	220	1015	307	21587	1077	9128
OV	141	Big River	Rockford Beach Access	17.39	Pit	27	0	10	20	580	171	13792	657	7367
OV	142	Big River	Rockford Beach Access	17.39	Pit	27	100	110	120	516	139	15078	730	6550

Sample ID Code	No.	Water Body	Sample Site Location	River Kilometer (0 =mouth)	Unit Code	No.	Sample Depth Upper (cm)	Mid (cm)	Lower (cm)	XRF Analysis (<2 mm fraction) **Pb** (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Ca (ppm)
OV	143	Big River	Rockford Beach Access	17.39	Pit	27	200	210	220	611	170	14296	727	6340
OV	144	Big River	Rockford Beach Access	17.39	Pit	27	300	310	320	72	113	16487	675	3044
OV	145	Big River	Rockford Beach Access	17.39	Pit	27	370	380	390	482	197	19242	880	9366
FC	159	Big River	Upstream of Hwy W	3	Core	20	15	20	25	662	184	14419	535	3643
FC	160	Big River	Upstream of Hwy W	3	Core	20	45	50	55	604	146	15873	688	2750
FC	161	Big River	Upstream of Hwy W	3	Core	20	75	80	85	1544	205	18520	809	5445
FC	162	Big River	Upstream of Hwy W	3	Core	20	105	110	115	6193	372	18320	969	22145
FC	163	Big River	Upstream of Hwy W	3	Core	20	135	140	145	802	70	13784	703	2646
FC	164	Big River	Upstream of Hwy W	3	Core	20	165	170	175	699	81	13230	367	2782
FC	165	Big River	Upstream of Hwy W	3	Core	20	195	200	205	756	78	14775	767	ND
FC	166	Big River	Upstream of Hwy W	3	Core	20	225	230	235	145	119	15178	769	ND
FC	167	Big River	Upstream of Hwy W	3	Core	20	235	240	245	162	109	13177	873	ND
FC	168	Big River	Upstream of Hwy W	3	Core	20	245	250	255	48	79	13982	569	ND
FC	169	Big River	Upstream of Hwy W	3	Core	20	255	260	265	72	109	13541	844	6642
FC	170	Big River	Upstream of Hwy W	3	Core	20	285	290	295	64	93	14735	822	ND
FC	171	Big River	Upstream of Hwy W	3	Core	20	315	320	325	36	87	13917	975	1952
OV	147	Big River	Upstream of Hwy W	2.05	Pit	29	0	10	20	691	209	18341	947	6166
OV	148	Big River	Upstream of Hwy W	2.05	Pit	29	60	70	80	1122	284	23418	1153	8199
OV	149	Big River	Upstream of Hwy W	2.05	Pit	29	120	125	130	6550	464	25389	1484	22378
OV	150	Big River	Upstream of Hwy W	2.05	Pit	29	180	190	200	1684	134	20708	1049	4084
OV	152	Big River	Upstream of Hwy W	2.05	Pit	29	250	260	270	687	186	20701	974	5493
OV	153	Big River	Upstream of Hwy W	2.05	Pit	29	360	370	380	4584	319	21201	1177	14212
OV	151	Big River	Upstream of Hwy W	2.05	Pit	29	460	470	480	45	95	17508	1800	2806
OV	177	Flat River Creek	St. Joe Bridge	3.48	Pit	37	0	5	10	2025	720	31724	3096	#####
OV	178	Flat River Creek	St. Joe Bridge	3.48	Pit	37	30	35	40	2780	926	34484	3593	#####
OV	179	Flat River Creek	St. Joe Bridge	3.48	Pit	37	60	65	70	3211	685	38541	4250	#####
OV	180	Flat River Creek	St. Joe Bridge	3.48	Pit	37	110	115	120	4002	732	38936	4177	#####
OV	181	Flat River Creek	St. Joe Bridge	3.39	Pit	38	10	15	20	2704	1021	32712	3499	#####
OV	183	Flat River Creek	St. Joe Bridge	3.39	Pit	38	40	45	50	3579	1263	37170	3877	1E+05
OV	182	Flat River Creek	St. Joe Bridge	3.39	Pit	38	100	105	110	2749	1017	37990	4137	2E+05
OV	184	Mineral Fork Creek	Mineral F.	4.30	Pit	39	20	25	30	156	199	15635	636	8609
OV	185	Mineral Fork Creek	Mineral F.	4.30	Pit	39	30	40	50	115	172	14251	380	8483
OV	186	Mineral Fork Creek	Mineral F.	4.30	Pit	39	50	65	80	181	237	17343	578	10266

Sample ID		Water Body	Sample Site	River	Unit		Sample Depth			XRF Analysis (<2 mm fraction)				
Code	No.		Location	Kilometer	Code	No.	Upper	Mid	Lower	**Pb**	Zn	Fe	Mn	Ca
				(0 =mouth)			(cm)	(cm)	(cm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
OV	187	Mineral Fork Creek	Mineral F.	4.30	Pit	39	80	90	100	134	189	16321	551	3909
OV	188	Mineral Fork Creek	Mineral F.	4.30	Pit	39	100	110	120	281	289	20484	960	7423
OV	189	Mineral Fork Creek	Mineral F.	4.30	Pit	39	120	130	140	107	164	12816	553	3519
OV	190	Mineral Fork Creek	Mineral F.	4.30	Pit	39	140	155	170	308	343	23673	1406	5908
OV	191	Mineral Fork Creek	Mineral F.	4.30	Pit	39	170	195	220	169	220	18709	795	6305
OV	195	Mill Creek	Mill Ck at Tiff	5.28	Pit	41	0	10	20	411	780	37771	870	15340
OV	196	Mill Creek	Mill Ck at Tiff	5.28	Pit	41	40	50	60	108	260	16745	338	10533
OV	197	Mill Creek	Mill Ck at Tiff	5.28	Pit	41	80	90	100	79	231	15915	161	4626
OV	198	Mill Creek	Mill Ck at Tiff	5.28	Pit	41	130	135	140	173	430	24140	1410	8545
OV	199	Mill Creek	Mill Ck at Tiff	5.28	Pit	41	170	175	180	127	653	19568	73	7575
OV	200	Mill Creek	Mill Ck at Tiff	5.28	Pit	41	220	230	240	137	589	19050	ND	3105