ZINC MINING CONTAMINATION AND SEDIMENTATION RATES OF HISTORICAL OVERBANK DEPOSITS, HONEY CREEK WATERSHED, SOUTHWEST MISSOURI

A Thesis

Presented to

the Graduate College of

Southwest Missouri State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science in Resource Planning

By

Jason L. Carlson

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ZINC MINING CONTAMINATION AND SEDIMENTATION RATES OF HISTORICAL OVERBANK DEPOSITS, HONEY CREEK WATERSHED, SOUTHWEST MISSOURI

Department of Geography, Geology & Planning

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ABSTRACT

Sediment-associated contaminants released by past mining activities in the Tri-State Lead and Zinc District in southwest Missouri pose a long-term risk to water quality. This study uses sedimentological and geochemical analyses to describe the relationships between mine contaminant dispersal and historical sedimentation patterns of the Honey Creek watershed (176 km^2) which drains the Aurora Sub-district along the eastern boundary of the Tri-State District. This watershed has been subjected to an intense period of Pb-Zn mining that began in 1886, peaked in 1916, and ended by 1930. The objectives of this study are to: (1) determine the magnitude and distribution of metal contaminants in floodplain sediments; and (2) use contaminant profiles as tracers in overbank deposits to determine the patterns and rates of historical overbank sedimentation caused by land clearing beginning about 1870. Results indicate that zinc levels are as high as 575 times their background and lead levels 70 times their background in overbank deposits. These levels decrease exponentially with distance away from mine tailing sources. Depths of historical overbank deposition average 74 cm throughout the Honey Creek basin with a range of 8 cm to 125 cm. Immediately after episodes of land clearing overbank sedimentation rates averaged 0.82 cm/yr (1886-1916) with rates later decreasing to 0.60 cm/yr (1916-1998). Tributary sedimentation rates were highest during the initial phases of settlement (<1910) while the highest rates along the main stem occurred later on (>1920). Little is known about the historical geomorphology of Ozarks floodplains since these floodplains generally lack buried soils that may provide an indication of pre-settlement surfaces. Therefore, the uses of mining-related metal tracers represent an important tool to study floodplain evolution and adjustments to human and climatic disturbances in the Ozarks Plateau.

This abstract is approved as to form and content

Chairperson, Advisory Committee
Southwest Missouri State University

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CHAPTER 1

INTRODUCTION

Mining and land use changes can impact both water quality and sedimentation patterns of streams (Knox, 1987; James, 1989). Since 1886, the Aurora Sub-district located along the eastern edge of the Tri-State Mining District of southwest Missouri has been releasing zinc (Zn), lead (Pb), and other metals into the Honey Creek (Figures 1 and 2). While several studies in Missouri have linked the effects of mining to degraded water quality, little is known about the role sediments play in the dispersal of metal contaminants throughout Missouri watersheds (Davis and Schumacher, 1992; Spruill, 1987; Barks, 1977; Brown, 1951). Base metal mining operations commonly release large quantities of metal contaminated tailings into the environment. Often these materials are not contained properly and enter nearby streams (Davies, 1992; Moore and Luman, 1990). Tailings sediments can be transported far downstream during floods, but large amounts are typically deposited in nearby floodplain and channel bar locations (Bradley, 1989). After floodplain deposits become contaminated, they can act as major sources for long-term non-point pollution when metals are released back to the stream via weathering and bank erosion (Wolfender and Lewin, 1977).

Little is known about the magnitude and spatial distribution of mining contaminants in the Aurora area. While studies related to metal contamination in

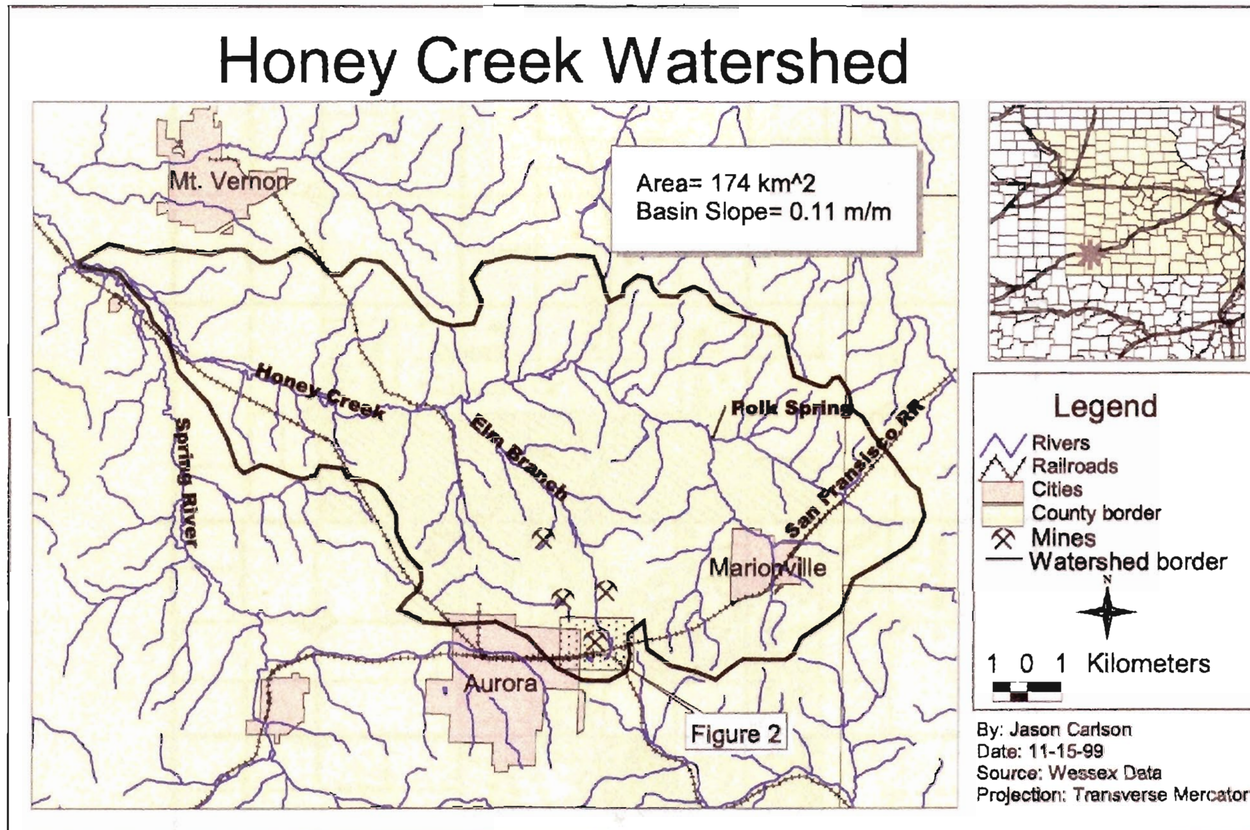

Figure 1: Honey Creek watershed. Notice the inset map of Figure 2 where extensive lead-zinc mining once occurred.

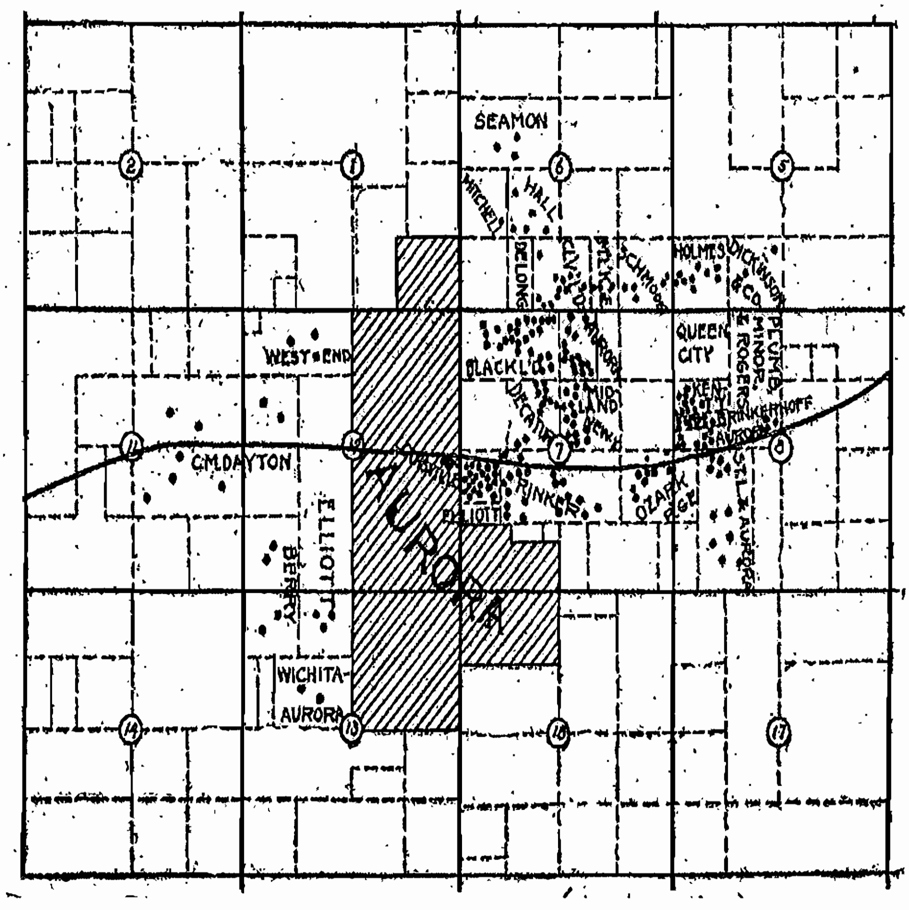

Figure 2: Mine locations in the Aurora Camp (Winslow, 1894).

floodplain sedimentation have been completed in other regions (Knox, 1987; Rowan et al., 1995; Davies and Lewin, 1974; Swennen et al., 1994), few investigations have been completed on this subject in Ozarks streams. Mckenney et. al (1995) related channel migration rates to riparian vegetation patterns in some Ozarks rivers, but did not study floodplain sedimentation patterns. In another study, Jacobson and Pugh (1995) identified stream disturbances caused by land use change by studying channel processes and measuring historical bed elevation changes rather than floodplain sedimentation rates. Preliminary field studies by the Department of Geology, Geography and Planning at Southwest Missouri State University show that floodplains along several streams in the upper Spring River contain lead and zinc at levels greater than 1,000 kg/g. Further, recent United States Geologic Survey (USGS) reports indicate that channel sediments in mining areas are heavily contaminated by metals (Petersen, et al., 1998).

Research Question

This study involves a two-pronged approach to environmental analysis that involves the use of metal sediment tracers to determine historical patterns of overbank floodplain sedimentation. The main question addressed by this study is how has Pb-Zn mining and land clearing affected floodplain geochemistry and sedimentation patterns? To answer this question, three secondary questions are addressed: (1) how contaminated are floodplains in the Honey Creek area? (2)

what are the sedimentology and geomorphology of contaminated floodplain deposits? and (3) what historical overbank sedimentation trends may be found and how have these trends changed throughout time?

Hypothesis

The purpose of this study is to use mining metal-sediment tracers to determine the spatial distribution of historical floodplain deposits along Honey Creek. Therefore, this study will investigate two environmental aspects of the Honey Creek: (1) mine contaminant distribution; and (2) overbank sedimentation. First, it is hypothesized that Ozarks streams will generally respond to mining in a similar manner as other previously studied watersheds in the Midwest. Therefore, mining contamination will show the effects of downstream dilution due to mixing with cleaner or uncontaminated sediments (Marcus, 1987). Metal concentrations in sediment will exhibit a negative longitudinal exponential decay trend away from the source.

Second, episodes of historical land clearing tend to increase flooding and soil erosion rates and thus increase floodplain sedimentation rates (Knox, 1972; 1977; 1987). It is expected that sedimentation rates will be highest immediately after initial episodes of land clearing then moderate through time as the river channel adjusts to the new hydraulic conditions and soil conservation measures. Lateral accretion and channel migration will occur in the upper, narrow and steep reaches of the stream while vertical accretion of floodplains will occur mainly within the lower portions of the watershed that are wider and less steep (Knox, 1977; 1987).

Objectives

There are three specific objectives in this study: (1) to determine the magnitude and spatial distribution of metal contaminants in floodplain sediments; (2) use contaminant profiles as tracers in overbank deposits to determine the patterns and rates of historical overbank sedimentation; and (3) increase the understanding of how mining sediment tracers can be used for geomorphic evaluation.

Benefits

This research increases our understanding of how and where historical mining contaminants act as non-point sources of pollution within the Ozarks due to tailings release and floodplain erosion. By discovering where contaminants are stored within a floodplain and what effects cause their release, much can be learned in terms of preventing mine contaminants as a secondary source of pollution that can affect water quality for centuries. This study will also improve our understanding of how humans change the ecology and sedimentation patterns of Ozarks streams. With an improved understanding of sediment transport and sedimentation patterns managers can better implement wise planning to stream and floodplain areas for environmental protection and restoration purposes. This is particularly important for non-point pollutant control plans that rely heavily on reducing the release rates of sediment-borne pollutants to river systems.

CHAPTER 2

LITERATURE REVIEW

Mining Tracer Studies

Geoindicators provide "high-resolution" measures of geological processes that respond to environmental changes over both short (< 10 years) and long (>100 years) time spans (Berger, 1997). These tools have been developed from standard techniques in geology, geochemistry, hydrology, geomorphology, and other earth sciences (Cooke and Doornkamp, 1990; Goudie, 1990; Fabbri and Patrono, 1995). Studies of river behavior frequently combine the use of geoindicators with stratigraphic and aerial photographic analyses to document the history of channel changes and floodplain sedimentation. This study uses the contamination patterns of metals released by mining as a geoindicator to study historical patterns of floodplain sedimentation.

Mining activities are often responsible for the large-scale contamination of river systems with heavy metals such as lead and zinc. While these metals represent a threat to environmental health, they also can provide a way to study fluvial processes. Heavy metals are released mainly in mineral form associated with tailings inputs although they may also be released via agricultural additives as well as sewage sludge or municipal composts (Forstner, 1995; Mantei and Foster, 1991; Mantei and Coonrod, 1989). When mining-related metal contaminants are redistributed and deposited within a river system they can be used as tracers of sediment transport for environmental assessment. The uses of these tracers can range from the dating of individual fluvial deposits (Swennen, et al., 1994) to the mapping of spatial variations of metal sources throughout an entire watershed (Ottesen, et al., 1989). This section reviews the use of mining tracers in channel and floodplain sedimentation studies by discussing the processes of contaminant dispersal, uses of mining contaminant tracers, and causes of spatial variability of heavy metals within river systems.

Metal Sources and Transport

Metal contamination from mining can enter rivers in three main ways: (1) direct waste from the milling process in forms of tailings and particles within waste water discharges; (2) fluvial erosion and mass-weathering of tailing dumps; and (3) chemical weathering and leaching of waste tailings piles (Pavlowsky, 1995a). Once in the channel, sedimentary processes disperse metal contaminants via hydraulic energy to downstream sediment storage sites in channel and floodplain environments. Generally speaking, after a metal is separated from its host rock by weathering and solution it bonds to fluvial sediments rich in clay or organic matter which have high sorption capacities due to high unit surface area and electrical charge (Horowitz, 1991). Often in mined watersheds much of the metal load is introduced to streams in the mineral form as tailings (Pavlowsky, 1995a).

The fate of metals in a river system is controlled by three factors: (1) sorting or selective transport based upon size and density properties of the contaminated sediment; (2) geochemical forms of the metal in the sediment; and

(3) sedimentation processes active in the river (Foster and Charlesworth, 1996; Horowitz, 1991; Mantei et al., 1993). During transport, metal concentrations in stream sediments tend to increase with the proportion of clay and organic matter. This occurs mainly because the surfaces of fine-grained sediments and organic materials possess chemical characteristics much more suited to the adsorption process of metal ions than coarse-grained sediments (Horowitz, 1991; Rang and Schouten, 1989). Although the smallest particles tend to contain high concentrations of metals, coarser sand-sized particles also tend to become contaminated in mined watersheds. This is because ore milling operations provide a large supply of relatively coarse metalliferous wastes (Horowitz, 1991; Knox, 1987). Through the natural mixing and sorting processes within river systems, these particles soon become concentrated in channel deposits and other high-energy areas.

Based upon the sediment characteristics of the contaminated particles as well as the flow magnitude/frequency relationships of an individual stream, contaminants are deposited and concentrated in two basic areas: (1) overbank floodplain areas; and (2) channel areas (Davies and Lewin, 1974; Horowitz, 1991). Vertical accretion occurs when sediment is deposited on floodplain surfaces during floods, thus resulting in the increase of bank height by overbank deposition. Accelerated rates of overbank deposition tend to occur in watersheds where intense periods of forest clearing and cultivation has occurred (Knox, 1977; 1987). This is a natural sorting process in which the smallest particles are deposited across floodplain surfaces and moderate sized particles are placed closer to the river channel through levee deposition or overbank sedimentation.

In contrast, coarser-grained sediments are deposited in channel areas accumulating on point bars and gravel splays through a process known as lateral accretion (Bradley and Cox, 1986; Knox, 1977; Rowan et al., 1995). Lateral accretion describes the progressive deposition of channel sediments due to bank erosion on the outside and horizontal growth of point bars on the inside of meander bands. When lateral accretion occurs at a fast rate, a river channel can increase its bankfull flow capacity by widening its channel and building up its banks (Knox, 1977). As a river channel increases its flow capacity, it takes progressively larger floods to deposit sediment in overbank areas. Historical "terracing" refers to the decrease of overbank floodplain deposition rates through time as the flow capacity of the channel is increased by lateral accretion and meander belt expansion, which conveys sediment loads to downstream areas. These metal sediment sorting and deposition processes leave a stratigraphic record of alluvial deposition that can be related to the history of mining in the watershed (Rowan et al., 1995; Forstner and Muller, 1981).

Spatial Patterns of Metal Contamination

Downstream Trends

Environmental and geomorphic assessments of metal contamination in mined watersheds generally investigate patterns of both channel and floodplain contamination. While channel sediment sampling indicates the current trends of contamination, floodplain sampling identifies past pollution patterns as well as the future threat of contamination due to the release of stored metals by erosion (Leece and Pavlowsky, 1997). The spatial distributions of metals in channel and floodplain sediments are analyzed in different ways. Channel sediments are analyzed by means of downstream changes in metal concentrations. Floodplain sediments are also analyzed by downstream distribution, however, analysis also includes vertical changes in depths of contamination as well as lateral variations in metal content across the valley floor. Lewin et al. (1977) looked at downstream and lateral changes in floodplain contaminants on the Nant Cwm-Newydion. Lewin et al. (1977) found that zinc concentrations increased with distance away from the mine source. In contrast within the same watershed, lead concentrations decreased exponentially downstream away from the mine source.

Goodyear et al. (1996) investigated downstream decay trends in floodplain deposits in southwest England. They found that zinc and lead decreased at a very rapid rate over a short distance downstream from the mine source. After the initial decay of metal content, zinc and lead levels continued at constant concentrations throughout the remaining watershed. A study done on the Ystwyth River in mid-Wales concluded that spatial and temporal decay functions of metal concentrations resulted from the physical and chemical processes of the metals as well as from varying levels of mining activity (Lewin et al., 1977; Foster and Charlesworth, 1996). Because lead ore (galena, 7.5 g/cm3) is more dense then zinc ore (sphalerite, 4.1 g/cm3) and more strongly adsorbed, it is not as mobile or easily dispersed throughout a river system. This becomes apparent in Lewin et. al (1977) where downstream trends in pollution concentrations show that zinc becomes more prevalent then lead further downstream. Similar decay trends have been found in other studies (Bradley, 1982; Bradley and Cox, 1986; Macklin and Dowsett, 1989; Macklin, 1992; Macklin and Klimek, 1992).

In contrast to Lewin et al. (1977), Wolfender and Lewin (1978) found that downstream sample locations were more heavily polluted than those upstream. The difference between the studies is that one was accounting for pollution sources due to primary dispersal of mine wastes while the other had encountered the re-working and re-mixing of sediment that had been eroded from secondary deposits and transported further downstream. Lewin et al.'s (1977) study shows how the remobilization of previously contaminated floodplain deposits may cloud the downstream decay relationship between metal concentration and distances from the source in river sediment samples. James (1989) further explains that long-term sediment yields will decrease downstream. This trend, however, is often reversed when upland sediment sources stabilize and the channel begins to erode due to the lack of sediment inputs. At this point, it is apparent that bank and channel erosion can become a more important source of metal contamination than upland areas, thus causing the contaminant decay curve to reverse over time spans of 10 to <100 years (Johnson and Hanson, 1976).

Lateral and Vertical Distribution

Lateral and vertical variations of metal contaminants in floodplain deposits are related to the age of the deposit, distance downstream from the mine source, and prevailing hydraulic conditions. Hence, the effects of these controls on metal-sediment distribution can be accounted for by sampling different geomorphic features (Rowan et al., 1995; Graf, 1996). For example, metal concentrations can be measured across entire valley-bottoms taking into account various fluvial terraces, abandoned channels and point bars. This sampling scheme provides for understanding of the spatial variability among a variety of geomorphic features and helps to account for the possibility of channel re-working and other potential limitations. Often higher elevation and older floodplains will generally yield the highest metal concentrations. This is because these older deposits retain metal contaminants corresponding to active sedimentation locations during peak mining periods when tailings were directly added to the channel. Contamination patterns in the younger deposits are a result of a more complicated metal distribution due to re-working by channel erosion and transport of eroded contaminants from abandoned mine sites and tailing dumps (Swennen et al., 1994; Bradley, 1989; Leenaers and Schouten, 1989; Lewin et al., 1977). However, in similar cases, the most heavily contaminated floodplain deposits may be buried by post-mining era sediments. In these situations, the watersheds were exposed to an intense period of agricultural land clearing and cultivation which led to accelerated overbank sedimentation during and after the mining period (Knox, 1987).

Tracer Application

Tracer Rational

Metal tracers serve as a reliable and acceptable way to study sedimentation trends within a river regime (Bradley, 1989; Macklin, 1985; Knox, 1987; Rowan et al., 1995; and Swennen et al., 1994). As metals are dispersed throughout a river system. Fine-grained materials are deposited by overbank sedimentation and coarse-grained materials are placed within channel point bars and gravel splays. Sampling the vertical profile of several cutbanks along a river allows the different types of alluvial deposits and locations of contamination to be accurately assessed. Thus, by linking the concentration profiles and depths of specific metal tracers with upstream historical episodes of mining, dates of individual sediment layers and locations of vertical accretion can be determined (Figure 3).

Analysis of overbank profiles can yield either a complete or incomplete record of sedimentation during the historical period. A complete record shows that the entire historical floodplain was deposited since the mining period thus suggesting the channel was relatively stable throughout time (Figure 3). In contrast, an incomplete record is produced by the efforts of fluvial "terracing" or the building of stream bank height while also increasing channel capacity by lateral expansion of the meander belt resulting in an incomplete vertical history of contamination. Thus, progressively lesser amounts of sediment will be deposited after a certain bank height is reached, as larger and larger flood episodes are required for water to go overbank. This critical bank height is dependent upon flood frequency, magnitude relationships, land use and water use changes and the geomorphic controls on channel widening.

Sedimentation rates can be calculated by dividing in depth intervals between dated layers by the time interval, thus providing key information for historical land use analysis (Knox, 1987; Macklin, 1985; Lecce and Pavlowsky, 1997; Rowan et al., 1995). Post-depositional shifts in the metal profiles may compound the resolution of dates using the tracer method. Such limitations are further described in the following section.

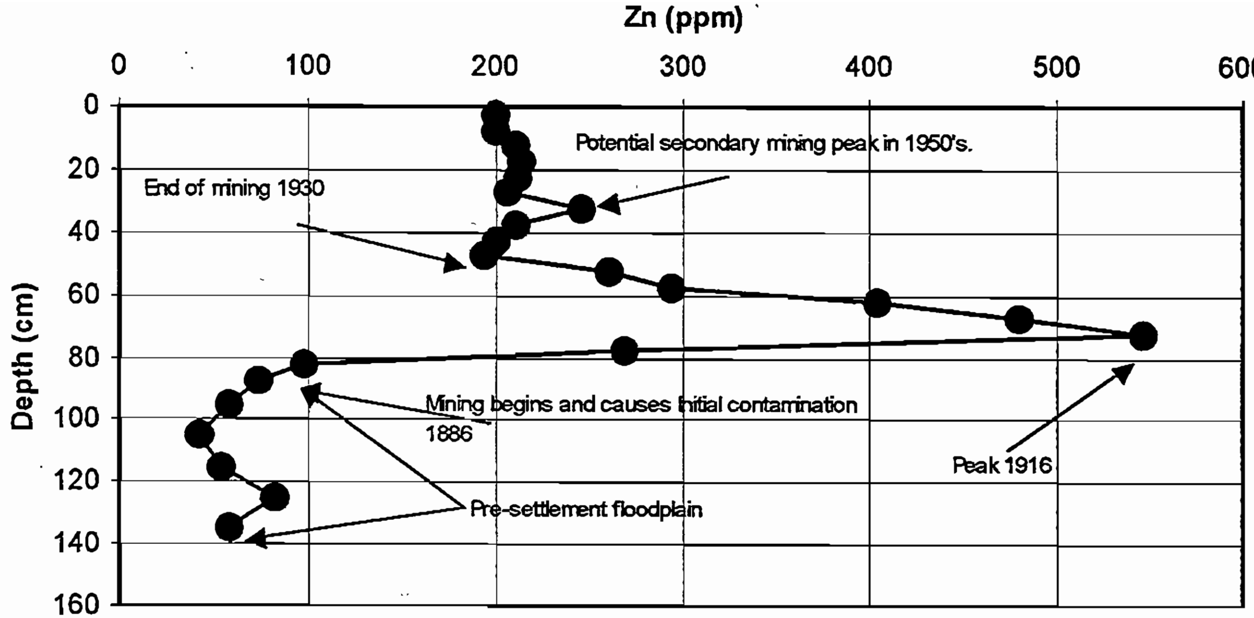

Figure 3: Illustration of profile dating. This sediment sequence represents a complete historical record. Pre-settlement floodplain units are defined by the relative low "background" concentration usually <70 ppm zinc that indicate pre-mining levels of metal transport. If terracing had occurred, sediments above the peak would not be present and the sediment record would end there. Notice post-mining contamination levels are higher than pre-mining levels due to the effects of secondary metal transport.

Floodplain Reworking

One potential limitation of the mining tracer method involves the variable effects of channel re-working (Bradley, 1989; Leenaers and Schouten, 1989; Wolfender and Lewin, 1977). The process of reworking has two possible shortfalls when dating sediment layers: (1) it may remove the tracer record all together by erosion, leaving no mine tracer sequence and; (2) it may transport a secondary metal source via bank erosion to a new floodplain location thus, confusing the chronological order of the profile. These limitations may be accounted for by acquiring data from multiple cutbank profiles sampling the entire vertical depth of each site. By doing this it becomes possible to identify areas that have been reworked and thus able to avoid the limitation.

Chemical Redistribution

Another limitation when using metal-sediment tracers involves the degree of chemical redistribution of metals within the profile. Chemical redistribution is caused by physical and chemical leaching processes as well as bioturbation (Swennen et al., 1994). Chemical redistribution generally mixes and moves metal concentrations within the sediment column changing the stratigraphy of a soil profile eliminating distinct vertical differences. The overall effect of these processes can make interpretations of soil sampling difficult, as it is hard to decipher the exact contact point between the contaminated horizons and the uncontaminated ones. However, most metals tend to bond strongly to sediment and are immobile in most floodplain deposits, except in the zone where seasonal water tables fluctuate (Carroll et al., 1998; Pavlowsky, 1995; Shepard and Gutierrez, 1998). Further the vertical trends of other sediment components such as sand and organic matter can be used to check stability in floodplain layers geochemical.

Summary

After metals such as lead and zinc are introduced to a watershed in association with tailings inputs they can be easily transported downstream by fluvial processes. These metal-contaminated sediments tend to be deposited and stored either in channel or floodplain areas depending upon the degree of sorting by particle size and density involved. Assessments of metal contaminants within active channel sediments identify the present transport patterns of contaminants while floodplain sediment sampling determines the location of past contaminated deposits as well as future threats of contamination due to bank erosion inputs. The spatial patterns of contamination are assessed by means of downstream, vertical and lateral changes in concentration levels. Studies have shown downstream trends of zinc to both increase and decrease with distance downstream from the mine source. These trends are often dependent upon geomorphic processes such as channel reworking, lateral accretion and terracing. When tracking mine contaminant levels within floodplains, vertical changes in metal concentrations can be related to specific episodes of mine history. Thus floodplain units can be dated for the purposes of quantifying the location, amounts, and rates of historical floodplain sedimentation in a watershed.

CHAPTER 3

STUDY AREA

Regional Setting

Honey Creek is a small tributary of the Spring River, located in Lawrence County, Missouri (Figure 1). There are two main cities in Lawrence County, Mount Vernon, which is located in the northwest portion of the county, and Aurora, which is located in the south central part of the county. While Mount Vernon is the county seat, Aurora is the largest of the cities with a population of 5,389 and is located in the Honey Creek watershed. Other cities and villages that may be found within the Honey Creek watershed are Marionville, Elliot, Orange, Logan and Chesapeake. Land uses according to a seven class supervised classification of the study area consists of 53.0% grassland and cropland, 22.3% forest, 20.7 sparse forest, 1.8% urban, 1.3% water, 0.5% row crops and 0.41% commercial (Figure 4).

Hydrology

The Honey Creek watershed (174.35 km^2) drains the eastern edge of the Spring River basin beginning as an intermittent stream flowing northwest from the small town of Marionville, in western Christian County (Figures 1 and 5). Honey Creek travels 6.8 kilometers to Polk Springs, which is the creek's main source of flow during base flow periods.

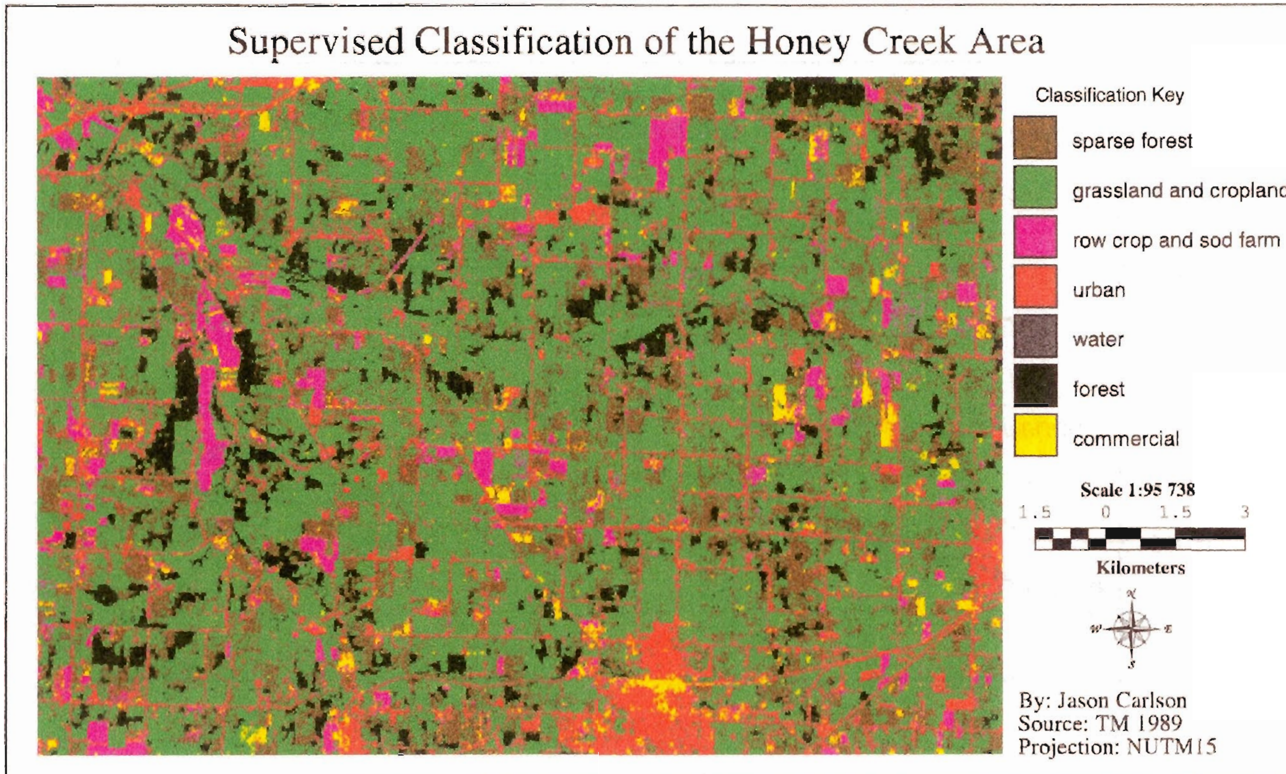

Figure 4: Supervised classification of the Honey Creek area. Notice the majority of the area consists of grassland and crop land.

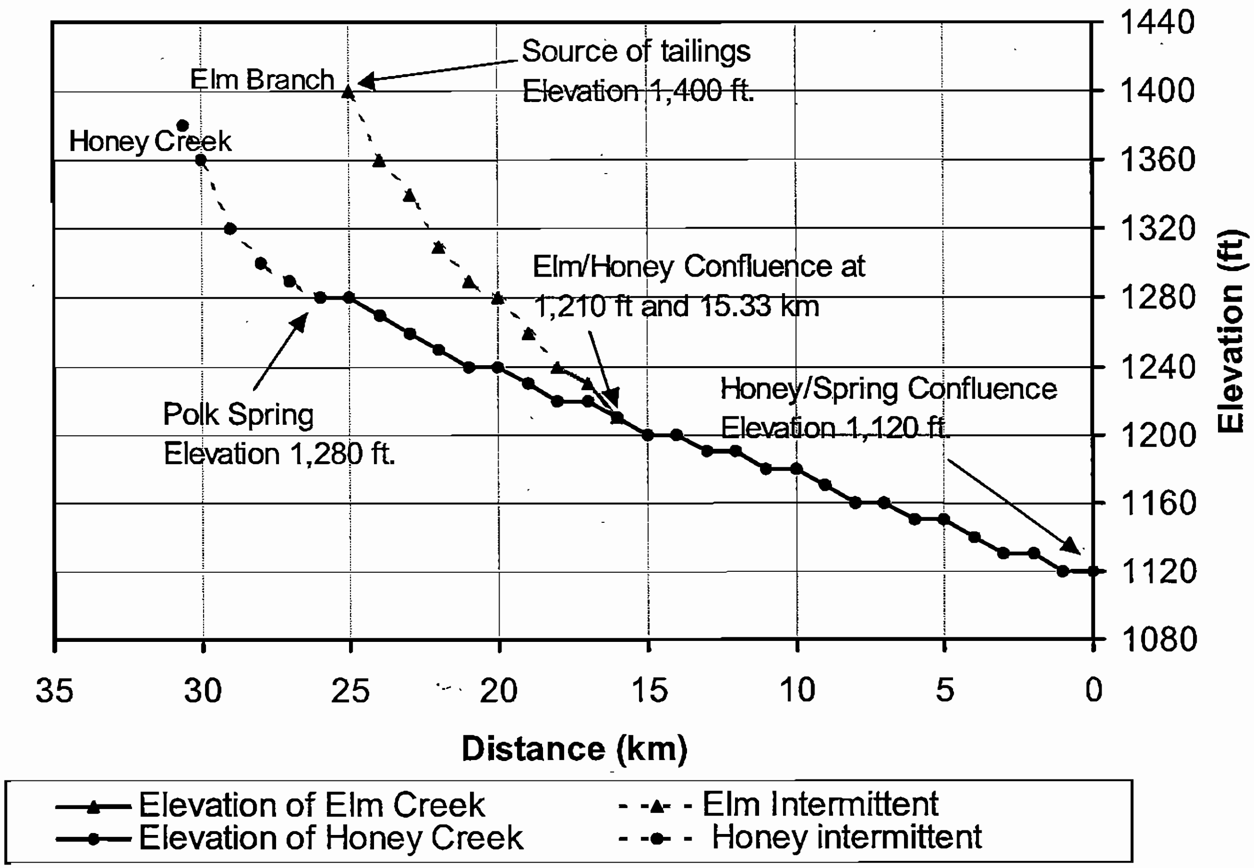

Figure 5: Longitudinal profile of Honey Creek and Elm Branch

From Polk Springs, Honey Creek meanders through Lawrence County for 9.6 kilometers where it joins the Elm Branch. Elm Branch is an intermittent stream and its upper reach provides the primary source of lead and zinc contamination to Honey Creek. This is due to the extensively mined Aurora Sub-district that existed in and near the city of Aurora (Figure 2). Elm Branch begins just northeast of Aurora traveling northwest 9.4 kilometers to the confluence of Honey Creek. From its confluence with the Elm Branch, the river flows westward for approximately 13.0 kilometers where it converges with the Spring River just south of Mount Vernon. From the confluence of Honey Spring to Polk Spring an average pool depth is 1.5 to 3.0 feet (Kiner et al., 1997).

Climate

The climate of the study area is a combination of continental and subtropical types. Rainfall is fairly evenly distributed seasonally throughout the area and snow generally falls every winter, but snow cover rarely lasts more than a few days (Hughes 1982). The climate is generally affected by weather moving from west to east with moisture often coming from the Gulf of Mexico.

According to the Soil Survey of Greene and Lawrence Counties, Missouri and records taken from 1951-1975 for Springfield, MO, a daily low average summer temperature of 76° Fahrenheit can be expected with a daily average high of 87° Fahrenheit (Hughes, 1982). Winter daily high average temperatures of 35° Fahrenheit are expected with the average daily low of 24° Fahrenheit.

Precipitation is highest during the month of June with 60% of the yearly rainfall occurring between April and September. A total annual precipitation between 32 and 47 inches is common with 17.1 inches of it being snow.

Geology

This study area is located on the western edge of the Ozarks Plateau, within an area more specifically known as the Springfield Plateau (Hughes, 1982). The Springfield Plateau is on the western slope of the Ozarks dome which ultimately crests at the St. Francois Mountains located in south central Missouri. Surface rocks in the study area are mainly Mississippian limestones (Kinderhookian, Osagean, Meramecian, and Chesterian Series; predominantly limestone, shale, and sandstone) containing varying amounts of chert (Table 1) (Kiilsgaard and Hayes, 1967). A small Pennsylvanian shale outcrop (Desmoinesian Series; Cherokee and Marmaton Groups) line stretches across the very northeast tip of the study area, although the main outcrop area is limited to an area northwest of the Spring River. Below the Mississippian limestone is the Devonian Chattanooga shale that is underlain by Ordovician cherty dolomites containing minor sandstone units. The Keokuk, Warsaw and parts of the Reeds Springs and Grand Falls formations are host rocks for zinc and lead mineralization as were the once referred to "Boone" formations which include the Kinderhookinan, Osagean, and Meramecian Series (Kiilsgaard and Hayes, 1967; Rafferty, 1970; Whitfield, 1986; Winslow, 1894).

Table 1: Principal Paleozoic stratigraphic units (Guild, 1967).

System	Series	Group or formation
Mississippian	Meramecian	Ste. Genevieve Formation St. Louis Limestone Salem Formation Warsaw Formation
	Osagean	Keokuk Limestone Burlington Limestone Reeds Spring Formation Pierson Formation Fern Glen Formation
	Kinderhookian	Chouteau Group
Devonian	Upper	Chattanooga Shale
	Middle	Fortune Formation
	Lower	(absent in southwest)
Silurian	Niagaran	Bainbridge Creek Limestone
	Alexandrian	Sexton Creek Limestone Edgewood Formation Girardeau Limestone
Ordovician	Cincinnatian	Orchard Creek Shale Thebes Sandstone Maquoketa Shale Cape Limestone
	Champlainian	Kimmswick Formation Decorah Formation Plattin Formation Rock Levee Formation Joachim Dolomite Dutchtown Formation St. Peter Sandstone Everton Formation
	Canadian	Smithville Formation Powell Dolomite Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite
Cambrian	Croixan	Elvins Group

Mineral formation within the Tri-State District consists mainly of the sulfides galena and sphalerite, with sphalerite being four times more abundant then galena (Kiilsgaard and Hayes, 1967). Secondary oxidation minerals of galena and sphalerite are minimal in the area. Ore deposits that form in the Tri-State area are referred to as Mississippi Valley-type deposits that consist of joint-controlled ore bodies that fill vertical fractures and horizontal bedding planes in bedrock. Residual ore deposits form in tightly packed clays that overlie fractures extending down to bedrock containing galena and sphalerite (Keller, 1992).

A karst drainage system has developed throughout the area creating a "swiss cheese" effect in the underlying limestone and dolomite bedrock. In the karstification process, precipitation mixes with CO_2 in the atmosphere as well as with ground litter ultimately creating a weak carbonic acid. As runoff and groundwater percolate down through the bedrock, chemical dissolution of the coarser crystalline structured carbonic rocks occurs. As this dissolution process continues, several dissolution-type landforms are produced consisting of sinkholes, losing and gaining streams, cutters, pinnacles, swallow holes and caves. The spring system, which feeds the upper portions of Honey Creek, is a product of karst formation.

Soils

Five main soil associations are found in the watershed: (1) Wilderness-Viraton Association (deep, well drained and moderately well drained sloping soil); (2) Basehor-Bolivar Association (shallow and moderately deep, well drained, gently sloping to strongly sloping soil); (3) Hoberg-Keeno-Creldon Association (deep, moderately deep, well drained, gently sloping and moderately sloping soil); (4) Clarksville-Nixa Association (deep, somewhat excessively drained and moderately well drained, gently sloping to steep sloping soil); and (5) Huntington Association (deep, well drained, nearly level soil) (Table 2). The Wilderness-Viraton, Basehor-Bolivar, Hoberg-Keeno-Creldon and Clarksville-Nixa are all found on the uplands while the Hoberg-Keeno-Creldon and Clarksville-Nixa soils are found on adjacent terraces or benches sloping towards the floodplains.

Floodplains cover 4% of Lawrence County and consist of mainly the Huntington series (Table 3) (Hughes, 1982). This series consists of a silty loam A-horizon 0-12 inches in depth above a silty loam B-horizon 12-25 inches in depth. Below this another silty loam B-horizon is commonly found at a depth of 25-48 inches. Within this soil a final C-horizon is found from 48-60 inches and is made of a dark silty loam. Other floodplain soils may include Hepler, Lanton, Cedargap, Osage, Peridge, Secesh and Waben (Table 3).

Soils in the study area commonly contain fragipan layers in the upland and older terrace type soils. A fragipan is a clayey, brittle subsurface horizon, which lacks organic matter and becomes very compact (Steila and Pond, 1989). This layer is semi-impermeable often restricting roots and water from penetrating

Table 2: Forming processes and family names of main soil associations in the Honey Creek watershed (Hughes, 1982).

Association		Parent Material	Family or Higher Taxonomic Class
1	Wilderness	Residuum weathered from cherty limestone	Loamy-skeletal, siliceous, mesic Typic Fragiudalf
	Viraton		Fine-loamy, siliceous, mesic Typic Fragiudalf
2	Basehor	Residuum weathered from acid sandstone with thin beds of clayey and sandy shale	Loamy, silicious, mesic Lithic Dystrochrept
	Bolivar		Fine-loamy, mixed, thermic Ultic Hapludalf
3	Hoberg	Thin loess and residuum weathered from chert limestone	Fine-loamy, siliceous, mesic Mollic Fragiudalf
	Keeno		Loamy-skeletal, siliceous, mesic Mollic Fragiudalf
	Creldon		Fine, mixed, mesic Mollic Fragiudalf
4	Clarksville	Loamy residuum weathered form cherty limestone	Loamy-skeletal, siliceous, mesic Typic Paleudult
	Nixa		Loamy-skeletal, siliceous, mesic Glossic Fragiudalf
5	Huntington	alluvium	Fine-silty, mixed, mesic, Fluventic Hapludoll

Table 3: Soils that were sampled in the Honey Creek watershed (Hughes, 1982). (*Denotes a neighboring or bordering soil type that may have been sampled)

Soil Series	Site Where Sampled	Landform Position	Parent Mat.	Clay (%)	Bulk Density (G/cm^3)	Ph	Organic Matter In (A) Horizon (%)
Hepler (76) Silt loam	23.3	Low Terrace	Alluvium	27-35	1.3-1.5	4.5-6.5	0.5-2.0
Huntington (55) Silt loam	13.0, 11.6, 9.9, 8.1, 6.5, 4.3, 1.0 and 21.2*	Broad Floodplain	Alluvium	18-30	1.3-1.5	5.6-7.8	3.0-6.0
Secesh-Cedargap (921) Silt loam	24.3, 21.2, 20.4 and 18.9	Low Terrace Meanderbelt	Alluvium	25-35 12-27	1.2-1.4 1.3-1.5	4.5-6.0 5.6-7.3	<2.0 1.0-4.0
Waben-Cedargap (931) Cherty silt loam	14.7	Low Terrace Alluvial fan	Alluvium	16-27 12-27	1.3-1.5 1.3-1.5	5.1-6.5 5.6-7.3	1.0-4.0 1.0-4.0
Clarksville (45E) Cherty silt loam	13.0*	Low Terrace Colluvial Material	Cherty Limestone Residuum	28-35	1.4-1.7	4.5-5.5	1.0-2.0
Lanton (54) Silt loam	6.5*	Broad Floodplain	Alluvial	20-30	1.4-1.6	6.1-7.3	2.0-6.0
Dumps-orthents (940) Complex	24.3* and 23.3*	Tailings Waste and Waste rock	Limestone; Pb and Zn ores	--------	---------	--------	---------

vertically through the layer. This has direct impacts upon runoff as the layer above the fragipan quickly becomes saturated forcing excess water to flow horizontally, directly into lakes and streams. In general the upland, terrace type soils found within the study area have formed a fragipan layer 12-15 inches below the surface with a thickness of about 12-20 inches in depth. This has a direct impact on flooding reducing infiltration rates and increasing runoff. Thus flood hydrographs for Honey Creek are expected to be flashy in nature.

Mining History

The discovery of mineral deposits occurred in Missouri almost as soon as European settlers entered the area. First to be discovered were the Lead Belts of eastern Missouri which presented settlers with very pure forms of Galena. In this area mining began as early as 1718 and was fairly established by 1725. A later discovery was the Tri-State Lead and Zinc District of south central and southwestern Missouri, Kansas and Oklahoma – the region which Honey Creek is located. This area became known for its less pure forms of galena that were often found with other minerals such as barite and sphalerite. Until 1874, lead was the only mineral sought, as zinc and barite were simply discarded, mainly because of their low market price. The price changes of zinc reflected the growing importance of zinc as smelting technologies improved: 1872, <$3 per ton; 1873, $8 per ton; 1879, $12 per ton; 1886, $21 per ton and in 1888, $27 per ton (Gibson, 1972).

Before 1874, the Tri-State Lead and Zinc District produced impressive amounts of lead although it soon after became known for its zinc production. The most active mining within the Tri-State District occurred between 1875 and 1915 and centered around Joplin, Carthage and Webb City all found to the west of this study (Forrester, 1950; Rafferty, 1970). As mining became more and more prevalent, miners moved southeast to the Aurora and Mount Vernon areas. Mining within the Aurora area became known as the "poor man's camp" because of the initial primitive mining methods that were used. Such methods involved a double pointed pick, head light, ore can and shovel. The camps in Aurora began production in 1886 and developed very rapidly. By 1891, Lawrence County ranked second in the state in the production of zinc ore and third in the production of lead. Total values of the Aurora Camp went from $379,920 in 1890 to $439,439 in 1891, $445,757 in 1892, ultimately to $453,325 in 1893, thereafter, documentation of actual production values remain unrecorded (Winslow, 1894). The active periods of mining for the Aurora Camp began in 1886 (Winslow, 1894), peaked in 1916 (Kiilsgaard and Hayes, 1967), and nearly came to a halt through the 1920s period, with low-level production continuing through 1957 (Figure 6) (Winslow, 1894; Forrester, 1950; Rafferty, 1970; Gibson, 1972 and Wharton, 1987). Table 4 shows published mine locations as well as their production over time. Overall, approximately 2,628,000 Mg of lead and 10,650,000 Mg of zinc were produced by Tri-State District accounting for about one-third of Missouri's total production.

Table 4: Published Mining Information.

	Reference	Mine Name	Location	Production	Notes
1	Wharton, 1987	Red Wasp & Arrow mines	S31 T27N R25W	1916-1918= $380,000	Production for 1 & 2 1886-1951 =$11,528,696
2	Wharton, 1987	Scott & Phelps shaft	S31 T27N R25W	No record	
3	Winslow, 1894	Aurora Camp	See Map 2	1890-1893 =$124,846	
4	Keyes, 1894	All of Lawrence County (June-1892)	Lawrence County	123,861 tons of ore	116-mines 819-employes

Population and Economic Boom

According to Rafferty (1970) "probably the most important results of lead and zinc mining were the increase in immigration and the stimulation of the economy of the area." This may be seen in Rafferty's historical documentation of Aurora's population from 1886-1960 taken from the U.S. Bureau of the Census. Documentation shows a five fold increase in population between 1886 and 1890 (Table 5 and Figure 6). Providing further evidence of impacts of mining on the population of the study area is Rafferty's historical documentation of the number of farms in Lawrence County which shows a definite increase in agricultural population between 1890 and 1900 (Table 6 and Figure 6).

Table 5: Population of Aurora from 1886-1960

Date	1886	1888	1890	1900	1920	1940	1960
Population	700	2,000	3,482	6,191	4,148	4,056	4,683

Table 6: Number of farms in Lawrence County from 1880-1964

Date	1880	1890	1900	1910	1920	1930	1940	1950	1954	1964
# of farms	2,052	2,845	3,414	3,278	2,979	3,082	3,067	3,096	2,863	2,205

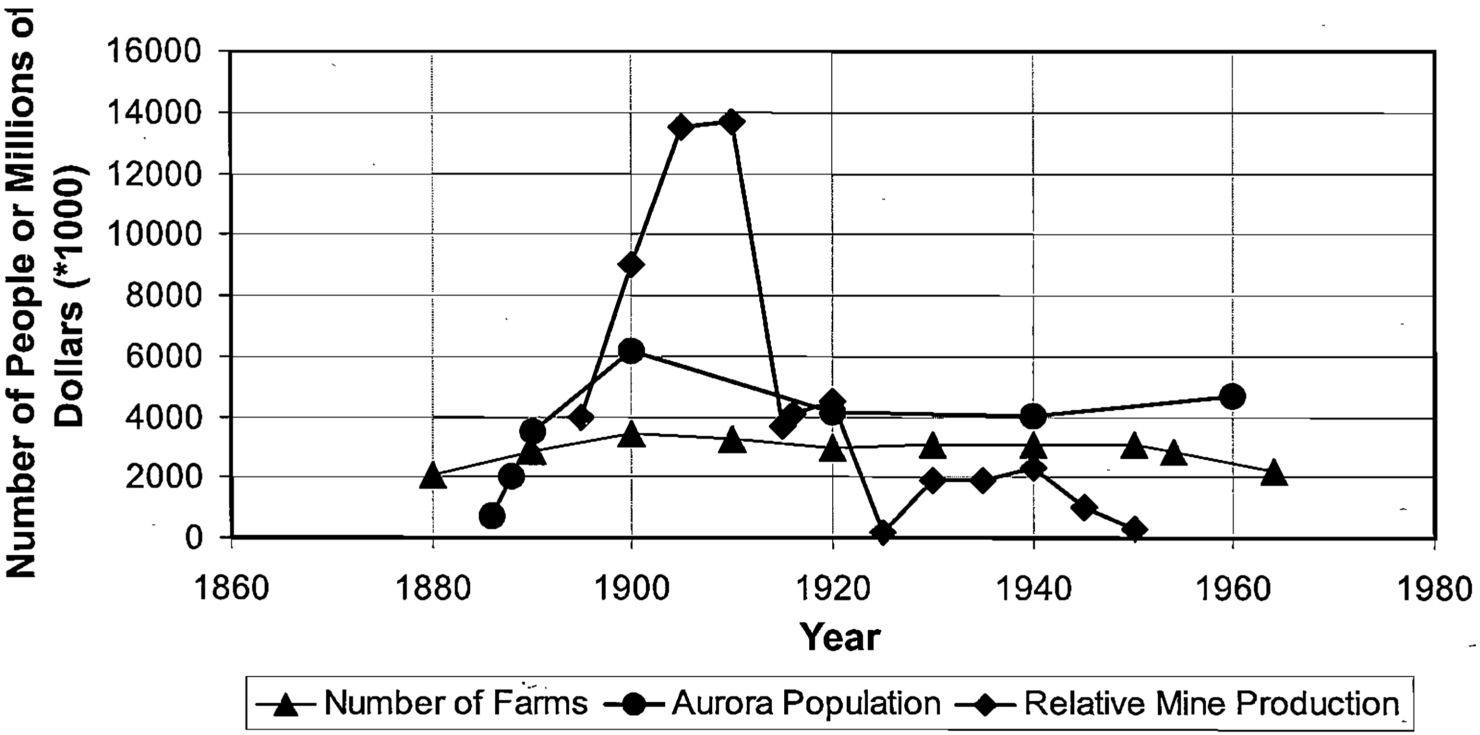

Figure 6: Settlement and mine history of the Aurora Sub-district. Shows when immigration into the Aurora area occured. Mine history is based on Missouri ore production which shows identical trends to the Aurora Sub-district (Kiilsgaard and Hayes, 1967).

One of the main factors having a direct impact on the population boom between 1890-1900 was the construction of the San Francisco (Frisco) rail line in 1870. The Railroad Expansion Era of the region occurred between 1870 and 1910 and provided increased support to the mining industry as well as the economy in general. Within the study area, the San Francisco railroad tracks were built running from Springfield southwest to Aurora and from there northwest to Mount Vernon (Figure 1). Although the construction of the railroad was important to the mining industry, it also spurred on an increase in land clearing since the railroad ties came from loggers cutting local forests. As the establishment of the railroad occurred some reports of extensive logging continued through to the 1920s (Rafferty, 1970).

Although farming began prior to 1870 in the Lawrence County area (Rafferty, 1970), a period of rapid population growth relating to land clearing began just before the onset and initiation of mining around 1886 in the Aurora Sub-District (Figure 7). As mining became more and more established within the area railroads were soon developed, thus laying the foundation for extensive land clearing. Historical mining operations in the Midwest released large quantities of zinc-rich tailings into local streams. Hence, the location and depths of contaminated floodplain deposits indentify the post-settlement record of sedimentation in the Honey Creek watershed. This being the case, impacts of mining and land clearing conveniently occurred during the same time frames thus providing a key link between geochemical contamination of lead and zinc mining and impacts of land clearing on floodplain sedimentation along Honey Creek (Figure 7).

History of study area (Rafferty 1970)

pre-1870	1870	1886	1900	1916	1920's	1950	1998
-Subsistence and livestock farming -Spring -burning of prairie grasses	-Onset of the general farm -Railroad Expansion Era -Timber Era -Main episode of timber exploitation	-Onset of zinc and lead mining	-Agricultural development within Lawrence County Peaks -Population of Aurora peaks	-Zinc production peaks	-Large-scale Zn mining ends	-Zinc mining ends	-Last year of this study

Figure 7: Historic timeline of land clearing.

CHAPTER 4

METHODOLOGY

This study examines the floodplain sedimentation patterns caused by agricultural land clearing and railroad-related land clearing between 1870-1920 in Honey Creek watershed. This is accomplished through careful analysis of both channel grab and floodplain profile samples collected at sites systematically spaced downstream from lead and zinc mining areas. After collecting, soil samples were analyzed for geochemical and sedimentology properties to assess spatial and temporal variability of geomorphic changes. Aiding in this assessment was the use of GIS, remote sensing, Watershed Modeling System (WMS) and statistical analyses.

Field Methods

Site Selection

Fourteen study sites were sampled to identify the sedimentological and geochemical properties of the historical floodplain and active channel deposits in the Honey/Elm Creek system (Figure 8). By choosing test sites in the upper, middle and lower reaches of the system, comparisons of the longitudinal distribution and patterns of mine contaminants and sediment deposition were possible at a watershed-scale. The location of each site was quantified by collecting information like location, drainage area, channel slope, channel

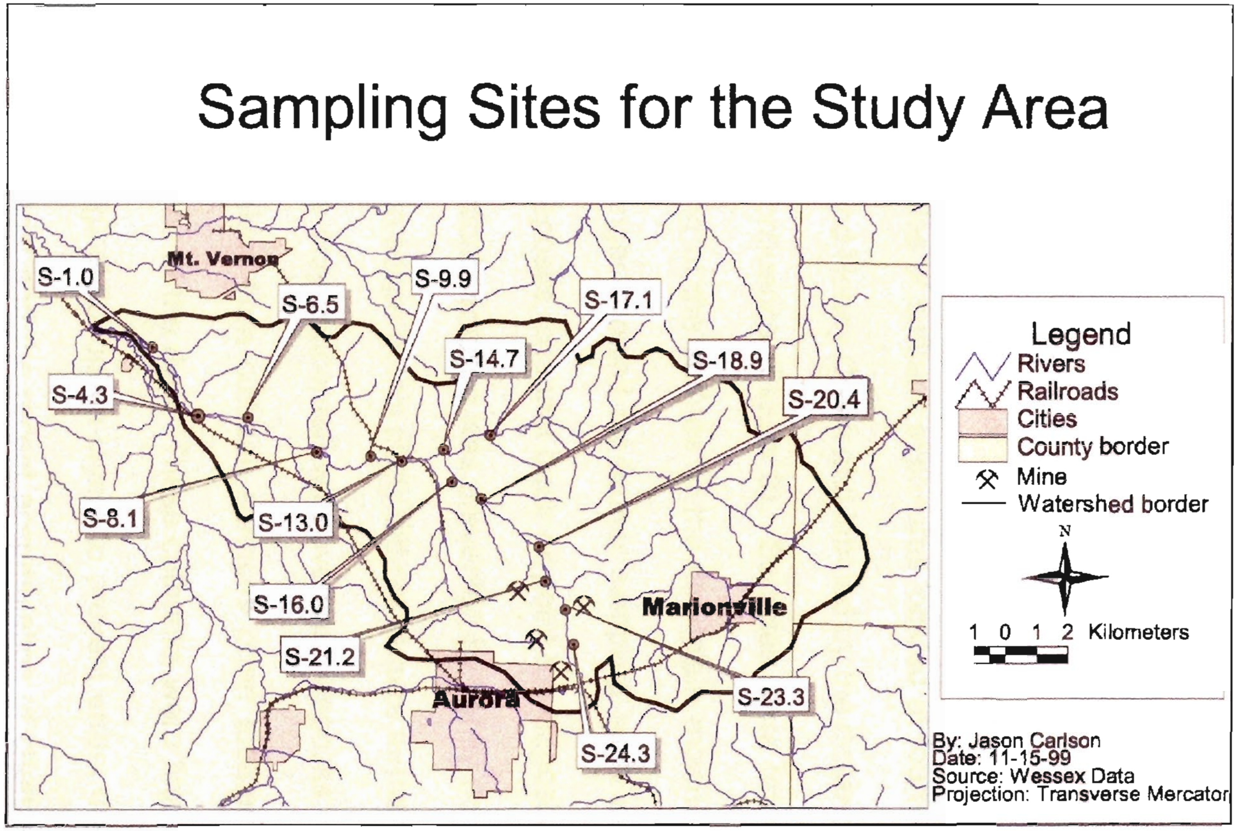

Figure 8: Sampling sites for the study area. Sites are labeled by kilometers upstream of Honey/Spring Confluence.

sinuosity, and valley width. Hand-level surveys, were collected at each site to allow for variations in width and depth dimensions along the channel cross-section. This procedure provided data on bankfull levels and widths and adjacent terrace elevations at each site.

Overbank Sediment Sampling

In this study, 278 samples of overbank floodplain sediments were collected from vertical profiles of cutbank exposures located at fourteen valley sites along the Elm Branch and Honey Creek and labeled by the distance upstream from the Honey/Spring confluence (Figure 8). Samples were taken at five centimeter intervals beginning at the surface of the floodplain moving down until physical capabilities no longer allowed for further sampling such as when encountered with gravel lag deposits, channel beds or point bar deposits were encountered. Often, further vertical sampling was prevented by tightly compacted gravel point bars, however, the scope of this study did not require further penetration into this layer since it was only concerned with overbank deposits. Overbank sediment samples were taken from cutbank surfaces often located on outer banks of meander belt areas of the river. These cutbanks were first cleared and scraped to expose the original floodplain layers to prevent errors due to the sampling of bank slump material and the recent accumulation of channel sediments. Once collected, each sample was immediately bagged, labeled and sealed for transport back to the laboratory.

Channel Sediment Sampling

In order to account for longitudinal variations in recent mine-related metal transport, 45 channel sediment samples were collected. These samples were taken at ten sites (1.0, 4.3, 6.5, 9.9, 11.6, 17.1, 20.4, 21.2, 23.3, and 24.3) (Figure 8). Three samples spaced one meter apart were collected from each site from the edge of point bars just above the low flow water line. These samples consisted of the top five cm of sediment which were immediately bagged, labeled and sealed for transport back to the laboratory.

Laboratory Methods

After field collection, the samples were first opened and allowed to air dry for several days. The samples were then further dried in an oven at 50° to 60° Celsius and then disaggregated with a mortar and pestle and passed through a two mm sieve. A 5 gram portion of each sample was then packaged within a new plastic bag and sent to a private commercial laboratory for geochemical analysis.

Geochemistry

Chemex Labs in Sparks, Nevada determined the geochemistry of each sample using the inductively-coupled plasma-atomic emission spectroscopy (ICP-AES) to find the concentrations of 32 elements within each sediment sample. Metals were extracted using the Hot Aqua Regia with a 3:1 $HCl:HNO_3$ ratio. This ultimately provided the contrast in metal concentrations between the pre-mining, uncontaminated soils and the post-mining, contaminated soils. This also provided the metal concentrations necessary to link peak mining periods to peak concentrations within the cutbank profile.

Texture

Sand content was determined for sample profiles at sites 24.3, 18.9, 14.7, 8.1 and 4.30 in the Geomorphology Laboratory in the Department of Geography, Geology and Planning located at Southwest Missouri State University (Figure 8). The wet sieve method was used which separates sand particles of >63 μm in diameter from smaller clay and silt particles. First, 20-30 grams of sediment were placed in a 250 ml beaker and dried in an oven at a temperature of 105° Celsius for >2 hours. After heating and cooling, the samples were weighed and prepared for wet sieving. This entailed the dispersal of the sediment in 20 ml of concentrated Sodium Hexametaphosphate (46 g/l) solution and 80 ml of deionized water which were added to each sample. The samples were stirred several times while being left to soak overnight in the dispersant. Each sample was wet sieved through a 63 μm brass sieve with warm tap water. After thoroughly rinsing sediment back and forth over the sieve the samples were rinsed several times with deionized water and guided back into the 250 ml beaker. The samples were again dried at 105° Celcius for >2 hours. After cooling, the samples were again weighed and this weight was divided by the initial weight and the percent sand of each sample calculated. These numbers were calculated to compare and contrast the sediment properties of the pre-mining soils with that of the post-mining soils. This also aided in the discovery of the sedimentology of the mine contaminants providing valuable data for interpreting the longitudinal transport of sediments and related metal-grain size relationships (Marcus, 1987; Horowitz, 1991).

Organic Matter

Organic matter content was also determined in the Geomorphology Laboratory (Department of Geography, Geology and Planning at SMSU) and measured by the percent loss of ignition at 500° Celsius (Dean, 1974). This method entailed a five gram portion of each sample placed within a procelain crucible and dried within an oven at 105° Celsius. Once the samples were cooled to room temperature in a desicator for several hours, they were weighed and ignited in a muffle furnace at 500° Celsius for six hours. After cooling in a desicator the samples were weighed and the difference in weight and percent weight loss of organic matter within the sample was calculated. This process was done in an attempt to find a buried A-horizon, which would have marked the pre-settlement soil within the profiles (Knox, 1987).

Data Analysis

Text and Spreadsheet Operations (Microsoft Office)

Geochemical and sedimentology data were stored on spreadsheets of Microsoft Excel 97. Excel was also used to formulate scatter-plots and linegraphs as well as tables and simple statistical analyses such as mean values and slopes of trend lines (Halvorson and Young, 1997). Micosoft Word was used for word processing and formatting in this study.

Remote Sensing (ER Mapper)

In order to assess land uses of the study areas, remote sensing images were created using Landsat Thematic Mapper, 1989 with a 30-meter resolution. These images were created in May when a considerable amount of vegetation had developed over the region. In order to get images of the study area from the master image the TAPE command in ArcInfo was used. This ultimately cut a specified pixel, line location from the master image illustrating my study area. Once this was done, bands 1, 2, 3, 4, 5 and 7 were transferred and imported into ER Mapper. The Thematic Mapper bands were then combined and made into a data set. Once the data set was created the image was rectified. Wessex data were used to rectify the image. By down loading Wessex data into ArcView a rectified (NAD83, UTM) map of the roads for the study area was created. The data set was then rectified using the ArcView image in which eighteen ground control points with an RMS error less than one were implemented. This consisted of systematically substituting various bands and ratio combinations with different transforms and filters. Once a suitable image was found that brought out various land uses a supervised classification was attempted (Figures 4 and 9).

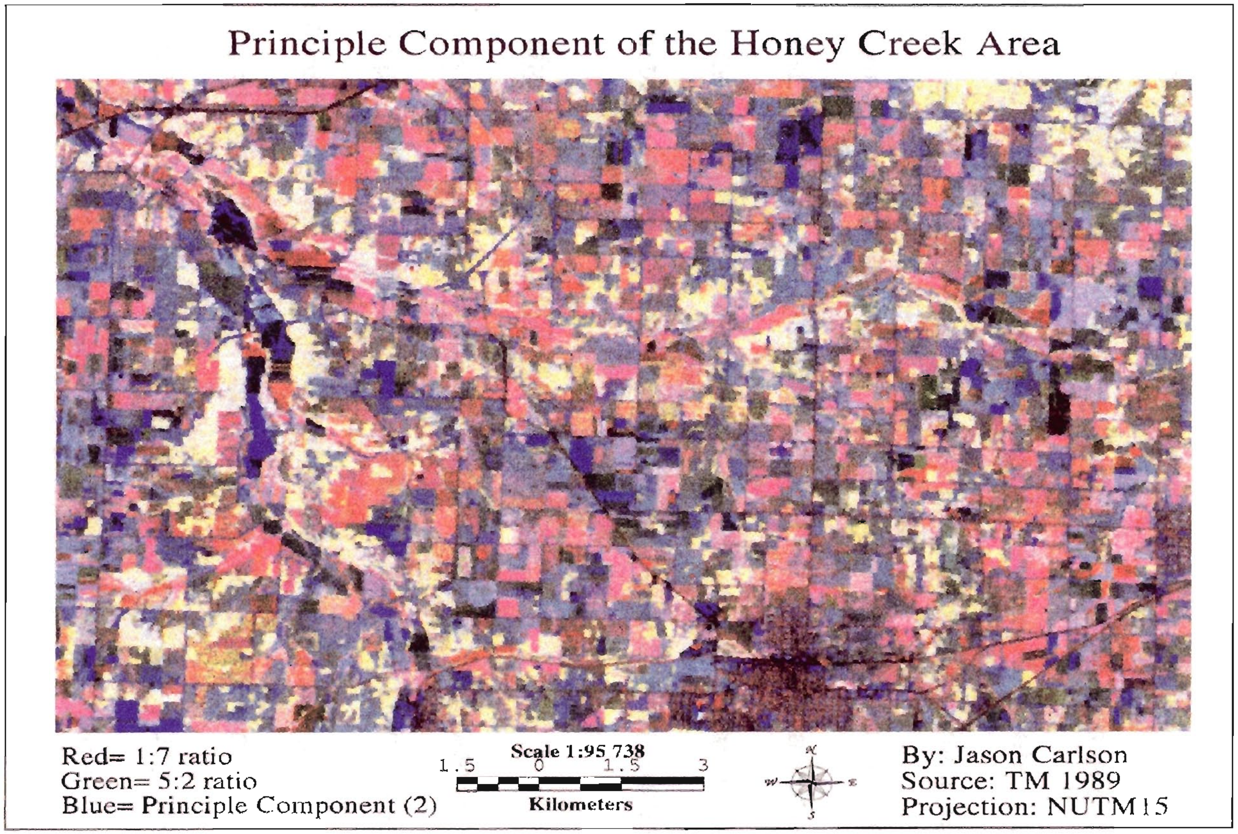

Figure 9: Principle component image of Honey Creek area.

Band width choices involved a red, green, and blue (RGB) combination with a 1, 4, and 7 or a 5, 4, and 1 created a very clear and useful land use image as did a RGB with a complex set of ratios and a principle component. For the red layer, a 1:7 ratio with a histogram equalization transform was combined with a green clay ratio of 5:2 auto clip transformation and the blue layer was supplied with a principle component of two and an auto clip transform (Figure 9). On this image one may notice various land uses as well as areas of water that are brought out with a bright orange shade. Of notable interest, areas where tailings piles were once prominent, could be identified using these data. However, they were very subtle and unable to be implemented as a separate class during supervision (Figure 9). After this image was created, a supervised classification of the general study area was performed. Seven classes were created using several training sets for each class. Land use statistics were then tabulated.

Watershed Modeling (GIS/WMS 5.0)

A Geographic Information System (GIS) was combined with Watershed Modeling System (WMS), a hydrologic model, and used to delineate the watershed and interpret basin and subasin sinuosity, perimeter, flow distances, slope and drainage area. This process began by downloading USGS DEM's from their website. Six DEM's were needed for the study area as they were first brought into Arc/Info and converted into lattices using the DEMLATTICE command. Next each DEM was brought into GRID and combined using the

MERGE command, which ultimately combined all six DEM's. Once the maps were joined as one grid they were converted to an ascii file. This was computed in Arc/Info using the GRIDASCII command. The ascii file was then imported into WMS using the import Arc/Info-DEM option. A contour map was then created from the elevation data. Next, flow direction and accumulations were computed using the TOPAZ program, which is part of the WMS. This was computed using the slope and slope direction of each individual pixel ultimately establishing watershed divides. Once this was completed outlet points were defined and added. Once the outlet points were established the DEFINE BASIN and COMPUTE BASIN PARAMETERS commands were used which ultimately provided the delineated basin and subbasins along with the watershed data desired for this study. This consisted of drainage area, slope, sinuousity, flow length, and perimeter of the basins.

Sedimentation Rates

Sedimentation rates were determined for the time spans of 1886-1916 and 1916-1998. These sedimentation rates were calculated by first identifying the total depth of contamination and the depth to peak contamination at each zinc profile site. These sediment depths represent the amount of overbank sedimentation that has been deposited since 1886 and 1916 respectively (Figure 8). Once this was determined these depths were then divided by the time span in which the sedimentation had been formed. For example, if there is 100 cm of contaminated overbank deposition, which formed from 1886 to 1916, with a peak concentration at a depth of 30 cm, sedimentation rates can be calculated as follows: (1) 100 cm minus 30 cm equals 70 cm of sedimentation had been deposited from 1886 to 1916; (2) 70 cm is then divided by the time span of 30 years and yields a sedimentation rate for the 1886-1916 time span is 2.3 cm/year; and (3) the 30 cm peak level is then divided by the time span of 82 years during which gives a sedimentation rate of 0.4 cm/year.

CHAPTER 5

RESULTS AND DISCUSSION

This chapter describes the important geochemical and geomorphological trends found in the Honey Creek watershed in the following sections: (1) geomorphic characteristics; (2) zinc and lead levels and the degree of contamination; (3) longitudinal distribution of contaminants; (4) key geochemical relationships; and (5) sediment distribution patterns.

Geomorphic Charateristics of Each Site

The geomorphic characteristics of each site are described in Table 7. These characteristics tend to change downstream. Sites are generalized in order to compare zinc and lead concentrations within the different reaches of the stream (Table 8). Four subdivisions are established each having similar geomorphic and geochemical patterns: (1) upper Elm Branch, includes sites 24.3, 23.3, 21.2 and 20.4; (2) lower Elm Branch, sites 18.9 and 16.0; (3) middle Honey Creek sites 14.7, 13.0 and 9.9; and (4) lower Honey Creek including sites 8.1, 6.5, 4.3 and 1.0.

Table 7: Geomorphic characteristics of each site. Soil series codes found in Hughes, 1982. (*Denotes neighboring soil type that may have been sampled).

Site	Lat./Long.	Dr. Area (km^2)	Slope (m/m)	Valley Width (km)	Bankfull Width (m)	Max. Depth (m)	Soil Series	Sinuosity (M/m)
24.3	N3658.714 W9341.525	1	0.005	0.03	1.0	0.95	921 940*	1.12
23.3	N3659.422 W9341.503	3	0.020	0.10	9.0	1.10	76 940*	1.02
21.2	N3700.472 W9341.788	7	0.030	0.28	28.1	1.01	921 55*	1.09
20.4	N3700.930 W9342.064	8	0.022	0.13	13.6	2.32	921	1.16
18.9	N3701.220 W9342.757	16	0.020	0.13	5.0	1.70	921	1.05
16.0	N3701.437 W9343.105	21	0.018	0.21	10.1	2.40	55	1.11
14.7	N3702.495 W9344.464	111	0.007	0.86	9.7	2.44	931	1.27
13.0	N3702.538 W9345.645	130	0.018	0.60	20.5	2.36	55 45E*	1.30
9.9	N3702.581 W9347.041	150	0.025	0.79	40.0	1.20	55	1.07
8.1	N3702.901 W9347.688	155	0.007	0.42	12.5	1.90	55	1.46
6.5	N3703.351 W9348.362	159	0.002	0.45	18.5	2.70	55 54*	1.22
4.3	N3703.615 W9349.840	167	0.022	0.77	23.0	2.30	55	1.63
1.0	N3704.624 W9351.317	174	0.005	1.10	25.0	4.00	55	1.19

Table 8: Summary of geomorphic characteristics by stream reach.

Stream Reach	N	Slope (m/m)	Valley Width (km)	Bankfull Width (m)	Max. Depth (m)	Sinuosity (m/m)
Upper Elm	4	0.019	0.14	12.9	1.35	1.10
Lower Elm	2	0.019	0.17	7.5	2.05	1.08
Middle Honey	4	0.014	0.67	20.4	1.98	1.28
Lower Honey	3	0.010	0.77	22.2	3.00	1.34

Slope remains consistent in the Elm Branch and decreases downstream. Valley width consistently increases with river distance to a maximum width of 0.77 km in the lower Honey reaches. In the headward reaches of the Elm Branch bankfull width begins fairly wide narrowing through the lower Elm sections and again widening in the middle and lower Honey Creek. Bankfull heights tend to increase from the upper Elm to the lower Elm with heights decreasing in the middle Honey Creek. Levels once again increase in the lower Honey Creek, where a maximum depth of 3.00 m is found. Sinuosity or degree of meandering consistently increases with distance as some variation becomes evident in the lower Elm reaches.

Table 9: Geomorphic characteristics at the watershed-scale.

Elm/Honey Watershed	Slope (m/m)	Valley width (km)	Bankfull width (m)	Max Depth (m)	Sincuosity (m/m)
Mean	0.016	0.45	16.62	2.03	1.31
Range	0.005-0.030	0.03-1.10	1.0-40.0	0.95-4.00	1.02-1.46

The average trends of the geomorphic characteristics of the watershed are shown in Table 9.

Background Zinc and Lead Levels

To determine the degree of metal pollution it is first necessary to identify the "natural" levels or the background of the metal in stream sediments (Forstner and Muller, 1981; Thornton, 1986). It is important to find areas of local differences in metal content as a result of various rock, mineral and soil forming processes as well as the secondary dispersion of chemical elements in the surface environment. In order to account for local variations in sediments, background samples must be collected from areas that have not been subjected to a contamination source making sure the samples correspond in their: (1) grain size distribution; (2) material composition; and (3) conditions of origin (Forstner and Muller, 1981). Once background levels have been determined, the degree of contamination is calculated by dividing the metal concentration measured in the potentially contaminated sample by the background to determine the anthropogenic enrichment factor.

The results of two previous studies are used to help identify uncontaminated sites in the present study. Coonrod (1985) used hot HCl and HNO_3 extraction with atomic absorption spectroscopy to look at metal contamination trends in stream sediments located above and below a sanitary landfill in Webster County, Missouri. Mean background levels of 17 ppm zinc and 34 ppm lead were found in tributaries upstream of the pollution source. Contaminated levels of zinc rose as high as 33 ppm and lead went up to 36 ppm.

A second study conducted by Keller (1992) used atomic absorption techniques to describe heavy metal dispersal in soil materials due to natural weathering and erosion processes near a shallow lead-zinc ore deposit in Webster County. In this study, mean background levels of 26 ppm zinc and 20 ppm lead were found furthest from the deposit while peak levels of 840 ppm zinc and 552 ppm lead were found near the exposed ore body.

After consideration of these previous studies, it becomes evident that two overbank deposit sites for this study can serve as background controls. The first of these being located 17.2 km upstream of the Honey/Spring confluence and the other 1.0 km upstream of the Honey/Spring confluence (Figure 8). The upstream site (17.2) shows mean background levels in overbank deposits of 70 ppm zinc and 20 ppm lead. Adjacent channel sediments contained 96 ppm zinc and 55 ppm lead. The downstream control site (1.0) shows lower mean overbank levels of zinc, much closer to Coonrod (1985) and Keller's (1992), measuring 58 ppm zinc and 15 ppm for lead. Both sites, 17.2 and 1.0 may be affected by mining pollution to some degree as this becomes apparent by slightly exaggerated levels of lead and zinc in comparison to Coonrod (1985) and Keller (1992). Channel sediments at the upstream site may also be slightly contaminated by urban source inputs. Background levels are considered to be the average concentrations of both overbank deposits: 64 ppm Zn and 17 ppm Pb (Table 10).

Table 10: Background zinc and lead concentrations in overbank deposition.

Site	Type	N	Zn (ppm)	Pb (ppm)	St Dev Zn	St Dev Pb
Upstream 17.2 km	Overbank	21	70	20	11	6
Downstream 1.00 km	Overbank	39	58	15	7	2
Mean	Overbank	60	64	17	9	4

Degree of Zinc and Lead Contamintation

Active Channel Sediments

Channel sediment samples represent the present-day patterns of metal contaminant transport in the Honey Creek watershed. Channel samples are highly contaminated near the mines with levels decreasing downstream (Table 11 and Figures 10A and 10B). The highest zinc concentration is found at site 23.3, which is only 50 meters below the location of a mine source in the Aurora Sub-district. At site 23.3 Zn levels, are 163.2 times the background level (Table 11). Moving downstream, zinc levels decrease to 904 ppm and are still 14.1 times the background, at 3 km below the mine source. After this point levels drop to 2-3 times the background as far downstream as 23.3 km of the mining source. In comparison mean lead concentrations are as high as 20.5 times the background at site 23.3 then decrease longitudinally to 1 to 2 times the background1.8 km downstream of the main mine source.

Table 11: Mean channel zinc and lead concentrations at each site.

Site	N	Mean Zn (ppm)	Mean Pb (ppm)	st dev Zn	st dev Pb	Degree of Contamination (mean Zn/64)	Degree of Contamination (mean Pb/17)
24.3	2	9,365	120	5706	3	146.3	7.1
23.3	3	10,443	349	3800	55	163.2	20.5
21.5	3	1,340	34	600	14	20.9	2.0
20.4	3	904	30	157	2	14.1	1.8
11.6	3	148	21	6	1	2.3	1.2
6.5	3	145	23	1	1	2.3	1.4
4.3	3	209	29	2	2	3.3	1.7
Entire Watershed	20	2,555	77	--	--	39.9	4.5

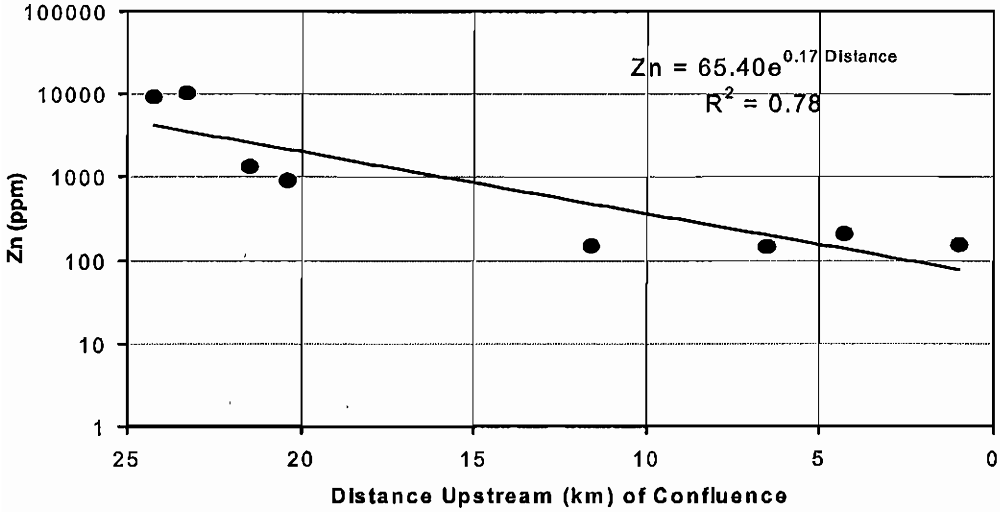

Figure 10A: Longitudinal decay of zinc in channel sediments using distance.

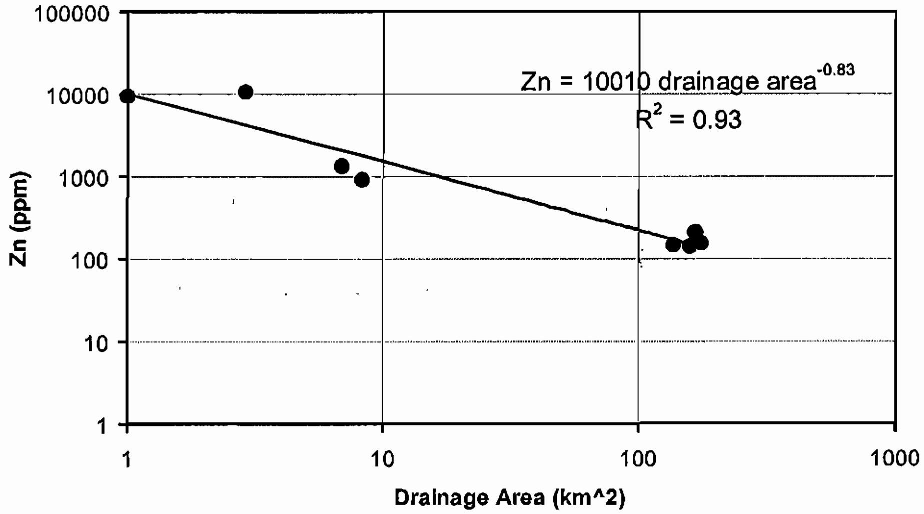

Figure 10B: Longitudinal decay of mine contaminants in channel sediments using drainage area.

Historical Overbank Deposits

Overbank sediment samples reflect the dispersal of contaminants during and after the mining period. They also suggest the degree of contaminant storage in floodplain deposits that can be remobilized at a later date. The contaminated portions of each overbank profile were determined by natural breaks within the profile which is further explained in following sections (Knox, 1987). Mean overbank zinc concentrations peak at 36,795 ppm at site 23.3, which is 574.9 times the mean background (Table 12 and Figures 11A and 11B). Mean overbank concentrations remain 30.1 times the background level with a concentration of 1,925 ppm, 2.9 km downstream of the main mine source. Just 4.4 km downstream, Zn levels drop to 421 ppm that is 6.6 times the background. Levels continue to drop until a distance of 10.5 km downstream where levels are two times the background of the mine source. This remains fairly consistent until 22.3 km downstream of the mine source where levels are the lowest recorded in the study area at 0.9 times the background.

Table 12: Mean overbank zinc and lead concentrations at each profile. (*Indicates location of former mine site).

Site	N	Mean Zinc (ppm)	Mean Lead (ppm)	St Dev Zn	St Dev Pb	Degree of Contamination (Mean Zn/64)	Degree of Contamination (Mean Pb/17)
24.3*	17	2,180	96	2,615	86	34.1	5.7
23.3*	21	36,795	1,196	10,909	1,960	574.9	70.4
21.2	13	92	14	31	1.9	1.4	0.8
20.4	17	1,925	86	2,133	95	30.1	5.1
18.9	13	421	23	361	11	6.6	1.4
16.0	10	200	20	92	5	3.1	1.2
14.7	19	240	24	123	5	3.8	1.4
13.0	22	265	29	228	11	4.1	1.7
9.9	19	138	30	29	8	2.2	1.8
8.1	22	119	24	28	4	1.9	1.4
6.5	13	102	18	16	2	1.6	1.1
4.3	7	144	26	103	18	2.3	1.5
1.0	3	56	17	8	3	0.9	1

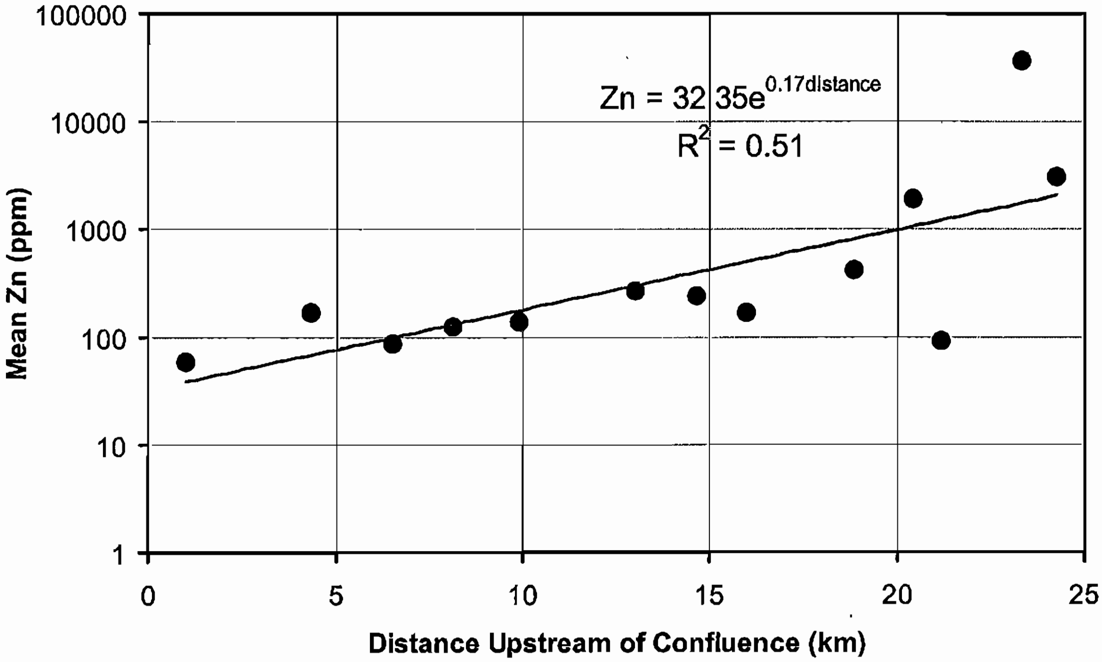

Figure 11A: Longitudinal decay of zinc in overbank deposits using distance.

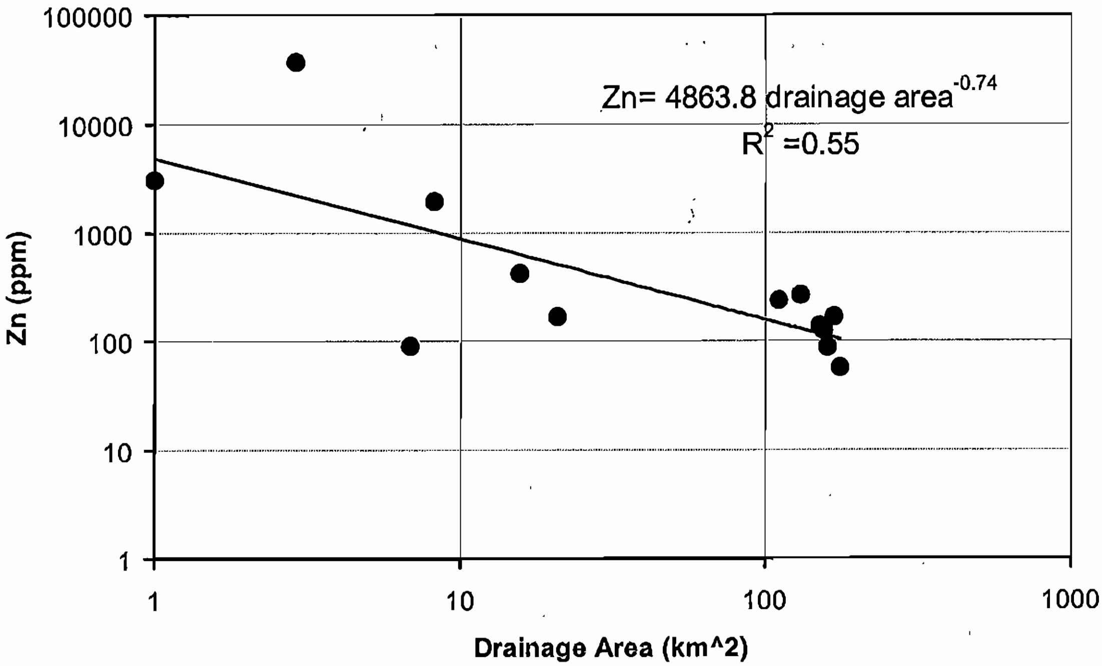

Figure 11B: Longitudinal decay of zinc in overbank deposits using drainage drainage area.

In comparison, lead concentrations are 70.4 times the areas natural level with a peak concentration of 1,196 ppm and a mean overbank background level of 17 ppm (Table 12). While peak levels are found within site 23.3 km, located near a former mine, concentration levels quickly decrease downstream from the mine source to 86 ppm, which is 5.1 times the background, 2.9 km downstream of the main mine site. Lead levels then fall to <2 times the background for the remaining downstream sites.

Channel and Overbank Contamination Trends

Contaminant distribution results show three important trends: (1) the Elm Branch is highly contaminated while the Honey branch is less contaminated; (2) overbank profiles show higher contamination levels than channel grab samples; and (3) contamination of zinc is higher and more spatially dispersed than lead.

High contamination levels within the Elm Branch are due to the close proximity of the mine locations. The Honey branch is 15.5 km downstream of the mine sources as it is apparent dilution due to the mixing of cleaner uncontaminated sediments has occurred. Channel grab samples are less contaminated for two reasons; (1) There are no active mine sites providing a source for zinc and lead; and (2) since channel contaminants are mainly the result of reworking and erosion, they are mixed with larger amounts of clean uncontaminated sediments. While channel sediments are more of a combination of contaminated and uncontaminated particles and have lower concentrations than overbank areas it is important to note that channel concentrations are high in the Honey/Elm Creek and may still be an environmental concern. Zinc concentrations in both overbank and channel sediments are higher and more dispersed than lead because zinc production within the Honey Creek watershed was much higher then lead. Also because zinc is less dense and less adsorbable its geochemical characteristics allow it to be dispersed at higher levels further downstream.

Watershed-scale Trends

Mean concentrations at the watershed-scale are highest in the upper Elm Branch, closest to the tailings source, with values decreasing downstream. Overall, watershed scale trends for overbank deposition show mean Zn concentrations of 3,080 ppm ranging from 40 ppm to 58,700 ppm (Table 13). Overall Pb concentrations were 123 ppm with a range of 8 ppm to 9,590 ppm

Table 13: Mean zinc and lead concentrations for each stream segment.

Reach	N	Mean Zn (ppm)	Min. Zn (ppm)	Max. zn (ppm)	Mean Pb (ppm)	Min. Pb (ppm)	Max pb (ppm)
Upper Elm	68	10,248	48	58,700	348	10	9,590
Lower Elm	39	311	54	1,128	22	8	36
Middle Honey	86	191	42	922	27	12	58
Lower Honey	91	101	40	292	20	12	34
Entire Watershed	284	3,080	40	58,700	123	8	9,590

Comparison to Previous Studies

In comparing zinc and lead concentrations in this study to other studies on mined watersheds, the extent of the contamination within Honey Creek is quite high. Lecce and Pavlowsky (1997) looked at zinc contamination within floodplain sediments of the Blue River, Wisconsin using extraction of the <2 mm sediment fraction by Aqua Regia (3:1 $HCl:HNO_3$) and analysis by ICP-AES methods. Lecce and Pavlowsky's (1997) findings showed four contamination levels; (1) historic overbank (6/92): mean 1,151 ppm with a range of 220 ppm to 12,700 ppm; (2) historic overbank (6/94): mean 1,205 ppm with a range of 112 ppm to 51,500 ppm; (3) active channel (6/94): mean 436 ppm with a range of 38 ppm to 3,550 ppm; and (4) active channel (6/96); mean 45 ppm with a range of 36 ppm to 54 ppm.

Pavlowsky (1995) looked at tailings and mine waste within the Galena watershed with Agua Regia (3:1 $HCl:HNO_3$) extraction and analysis by ICP-AES of <2 mm sediments. Pavlowsky observed a mean Zn level, in the main stem of the Galena River, of 1,428 ppm with a range of 213 ppm to 5,404 ppm. Pavlowsky also documents a mean zinc level of 1,689 ppm with a range from 201 ppm to 21,185 ppm in overbank sediments within mined tributary basins.

Rowan et al. (1995) looked at the impacts of lead mining on floodplain contamination in the Leadhills of Scotland. Atomic adsorption techniques used on <2 mm floodplain sediments, found mean levels of zinc at 1,200 ppm with a range of 400 ppm to 2,ppm. While zinc concentrations appear consistent with other studies extremely high concentrations of lead were found with mean floodplain levels of 33,200 ppm with a range of 3,800 ppm to 75,600 ppm

Bradley (1989) looked at historic mining effects on river floodplains in Britain assessing concentrations of particles with a median of 1.4 mm. Bradley found mean Zn levels on the River Hamps with a range of 489 ppm to1,843 ppm and on the Manifold Valley a range of 1,072 ppm to 6,391 ppm.

Another study performed by Swennen et al. (1994) looked at contamination of overbank sediments on the Geul River in Eastern Belgium. Swennen et al. (1994) looked at particles <125 microns and <63 microns with findings ranging in the upper reaches from 134 ppm to 6,665 ppm Zn and in the lower reaches from 20 ppm to 6,730 ppm Zn.

Results from Honey Creek are comparably higher then previous studies in Wisconsin and over seas (Table 14). Zinc levels in overbank sedimentation for Honey Creek average 3,080 ppm with a range of 40 ppm to 58,700 ppm. This being the case, Honey Creek is more contaminated than the other studies with the closest levels being in Wisconsin where an average of 1,205 ppm Zn were found in overbank sediments. Zinc concentrations in channel sediments in Honey Creek are also higher then found in Wisconsin. In the Honey Creek channel, samples averaged 2,555 ppm Zn when compared with Lecce and Pavlowsky (1997) which found an average concentration of 436 ppm and a range of 38 ppm to 3,550. One thing to note in these comparisons is a fewer

Table 14: Comparison of previous studies to the results in Honey Creek.

Author	Location	Particle Size	Mean Zn (Ppm)	Range Zn (Ppm)
Lecce and Pavlowsky (1997)	Blue River WI	<2 mm	1,151 1,205	220-12,700 112-51,500
		Channel	436 45	38-3,550 36-54
Pavlowsky (1995)	Galena Watershed WI-IL	<2 mm	1,428 1,689	213-5,404 201-21,185
Rowan et al. (1995)	Leadhills Scotland	<2 mm	1,200	400-2,300
Bradley (1989)	River Hamps Britain	Median 1.4 mm	NA	489-1,843
	Manifold Britain			1,072-6,391
Swennen et al. (1994)	Geul River Belgium	<125 µm <63 µm	NA	Upper 134-6,665
				Lower 20-6,730
Carlson (1998)	Honey Creek MO	<2 mm overbank	3,080	40-58,700
		<2mm channel	2,555	136-14,800

number of channel samples were taken on the Honey Creek, possibly offering a slightly exaggerated average concentration.

Longitudinal Decay Trends

Channel Sediments

Average Zn concentrations in channel sediments tend to decrease in a predictable manner with distance downstream from the main mine source (Figures 10A and 10B). A relatively sharp decrease in Zn concentrations occurs in the headward reaches of Elm Branch. This trend continues for 3.1 km at which point the rates of decrease become more gradual. An exponential negative sloping trend line possessing a correlation (R2) of 0.78 demonstrates this. The same channel sediments observed with drainage area exhibit a comparable R^2 of 0.93 with a negative sloping trend line that moves towards the lower reaches of the watershed (Figure 10B).

Floodplain Deposits

Zinc concentrations in overbank floodplain deposits also decrease at an exponential rate with distance down stream from the mines (Figure 11A and 11B). Average zinc concentrations in contaminated overbank units tend to decrease downstream with the highest concentrations being observed within the headward reaches of the Elm Branch nearest to the mine sources at sites 24.3, 23.3 and 20.4 located within 3.9 km of the mines. However, as distance increases away from the mining source, average zinc concentrations decrease relatively fast in comparison to the middle and lower portions of the basin (Figure 11A). At site 16.0 km, 8.3 km downstream of the mine source it becomes apparent that less and less change in zinc concentrations is occurring from site to site. This becomes evident as the slope decreases between site 16.0 km and site 1.0 km. These longitudinal differences in zinc concentration form an exponential shaped decay curve with a slope of –0.17. A similar decay curve is evident when comparing contaminated overbank deposits to drainage area (Figure 11B). This comparison shows a steeper, more uniform digressing decay curve with little variation in concentrations between the headward reaches of the

Elm Branch and the lower reaches of Honey Creek. This exponential decay curve takes on a slope of –0.74 yielding a R^2 of 0.55.

Zinc-Sediment Geochemistry

Sediment-Metal Sources

Present-day contamination sources of Honey Creek are found in two locations: (1) pure tailings from former mine locations and (2) from secondary tailings as a result of floodplain reworking. Pure tailings were sampled from the Bullfrog Mine, Joplin, MO, northwest of the study area located within the Tri-State Lead and Zinc District for the sake of comparison with uncontaminated soil samples (Table 15). Pure tailings had mean zinc concentration of 6,060 ppm with a range from 4,960 ppm to 7,160 ppm. Lead concentrations ranged from 214 ppm to 362 ppm with a mean of 288 ppm.

Table 15: Geochemical levels of tailings taken from Bullfrog Mine, Joplin, Mo.

Location	Al (%)	Ca (%)	Al:Ca	Zn (ppm)	Pb (ppm)
Bullfrog Mine, Joplin, MO	0.14	12.5	0.01	4960	214
Bullfrog Mine, Joplin, MO	0.12	10.9	0.01	7160	362
Mean	0.13	11.7	0.01	6,060	288

Aluminum (Al) percentages averaged 0.13 with a range of 0.12 to 0.14 and Calcium (Ca) percentages ranged from 10.9 to 12.5 with an average of 11.7. These values combined to form a mean Al:Ca ratio of 0.01. In comparison with the pure tailings, very different trends were found in the control sites (Table 16). On Table 15, sites 1.0 and 17.1 show very low Zn (64 ppm) and Pb (17 ppm) concentrations as these samples represent uncontaminated soils. In further comparison very high Al levels are found ranging from 1.33 to 1.72 with a mean percent of 1.53. Very low Ca percentages are found in the uncontaminated samples ranging from 0.14 to 0.31 with a mean of 0.23. In combining these to form the Al:Ca ratio a range from 1.72 to 4.58 is found with a mean of 3.15, much higher then 0.01 found in the pure tailings.

Table 16: Geochemical levels of bank sediments at the control sites.

Location	Al (%)	Ca (%)	Al:Ca (%)	Zn (ppm)	Pb (ppm)
1.0	1.72	0.14	1.72	57.8	14.5
17.1	1.33	0.31	4.58	70	20
Mean	1.53	0.23	3.15	64	17

Relationships show tailings have low Al percentages and high Ca percentages, which combined to form low Al:Ca ratios. In contrast bank sediments have lower concentrations of Pb and Zn, higher Al percentages, and lower Ca percentages which combined to form Al:Ca ratios that are much higher. These relationships show that a definite geochemical contrast exists between tailings and bank sediments. Interpretation of these relationships would suggest that tailings are rich in carbonate, less weathered, and contain coarse materials while the bank sediments are silic, more weathered, and fine grained.

Role of Weathering

Downstream distributions of aluminum percentages in Honey Creek show levels that slightly decrease as aluminum calcium ratios increase. This is shown by a regression slope of -0.01 in uncontaminated Al samples and 0.00 in contaminated Al sediments (Figure 12A). In comparison uncontaminated Al:Ca ratios have a slope of 0.01 and in contaminated samples a slope 0.04 (Figure 12B). In further assessment of the spatial distribution of aluminum and its association with tailings in the watershed, two relationships become apparent: (1) zinc and aluminum are weakly related in an inverse fashion in contaminated sediments and unrelated in uncontaminated sediments (Figures 13A); and (2) Al and Al:Ca trends combined with Zn concentrations providing important geochemical differences between pre-mining soils and post-mining soils (Figures 13B through Figure 26).

Aluminum percentages and their relationship with Zn concentrations are very significant to this study because they are related to both age and grain-size of sediments. Generally higher aluminum percentages are related to higher clay

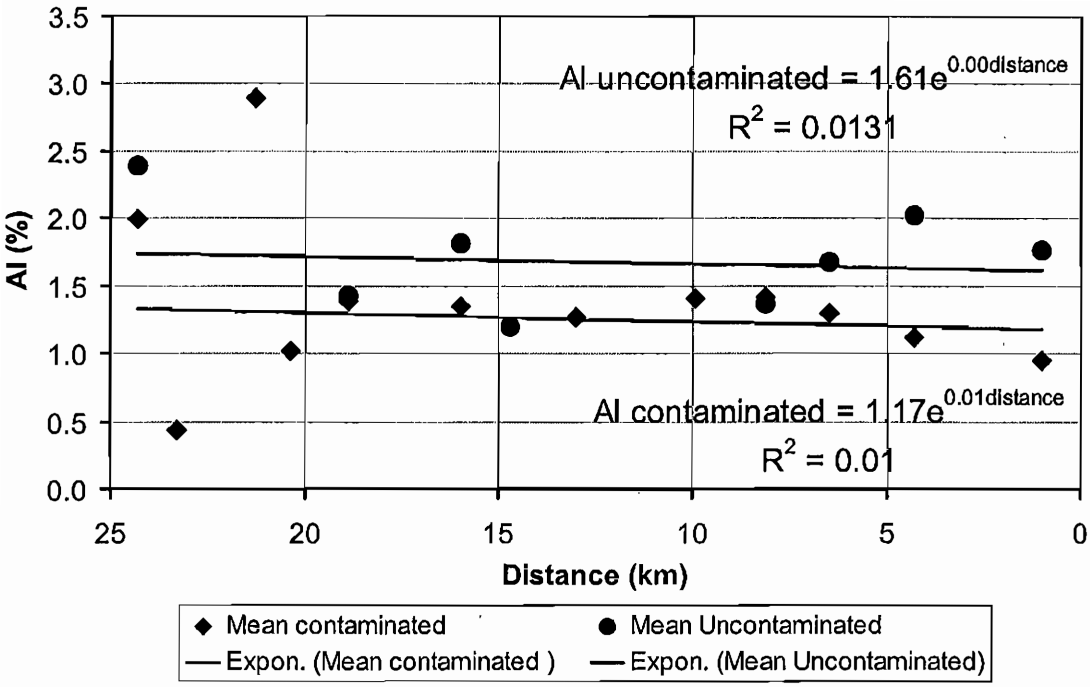

Figure 12A: Longitudinal distibution of mean Al in overbank contaminated and uncontaminated deposits.

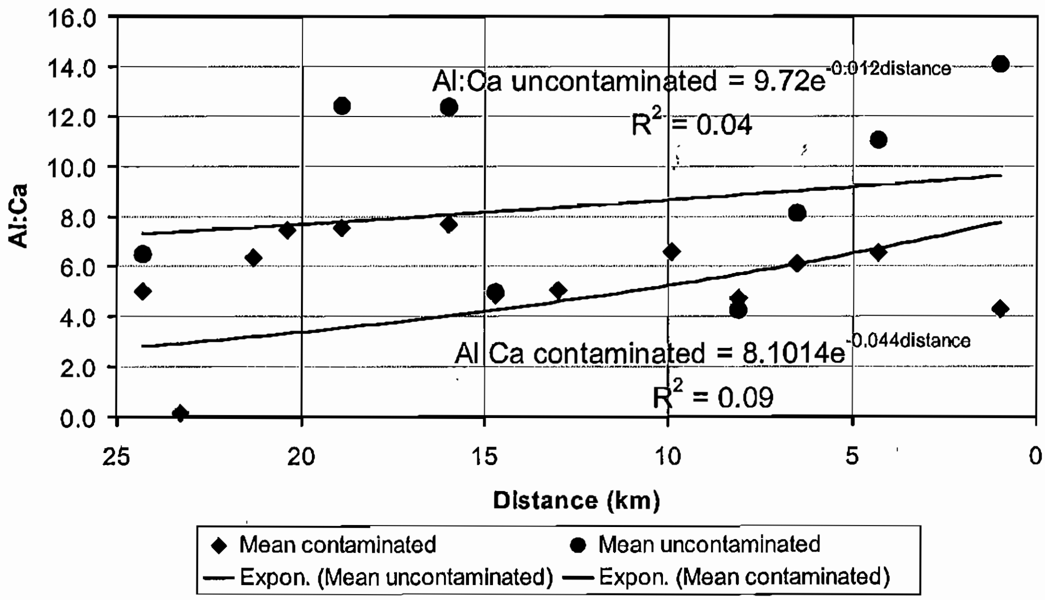

Figure 12B: Longitudinal distribution of mean Al:Ca in overbank contaminated and uncontinated deposits.

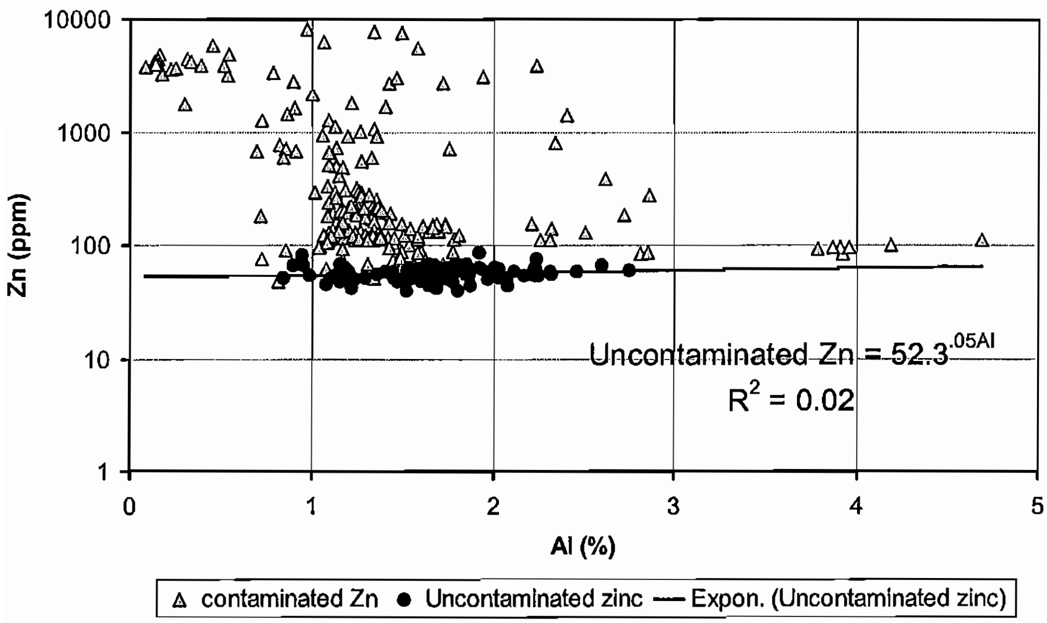

Figure 13A: Relationship between Zn and Al in contaminated and uncontaminated overbank deposits. Zinc enrichment relative to Al is easily observed in this plot.

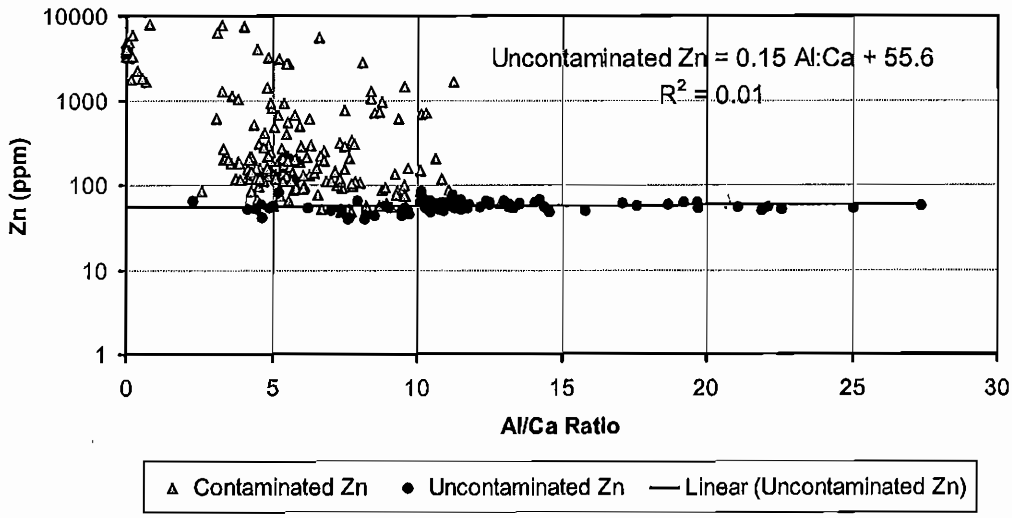

Figure 13B: Relationship between Zn and Al/Ca. Notice along the uncontaminated trend line the outlyers have been removed. This graph shows the geochemical difference between the contaminated and uncontaminated soil layers.

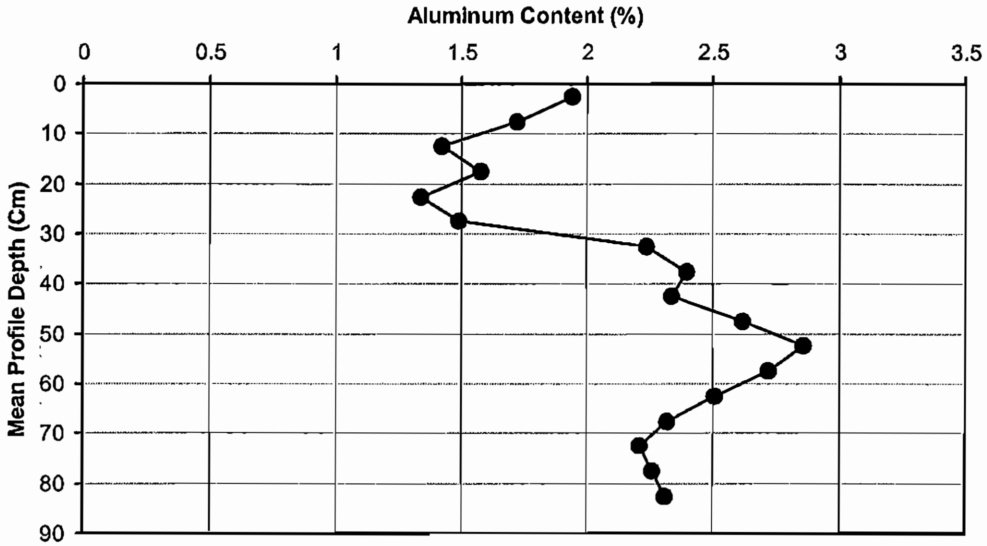

Figure 14: Profile of aluminum content at site 24.25 km. Initial contamination is at 52.5 cm and peak levels are at 22.5 cm.

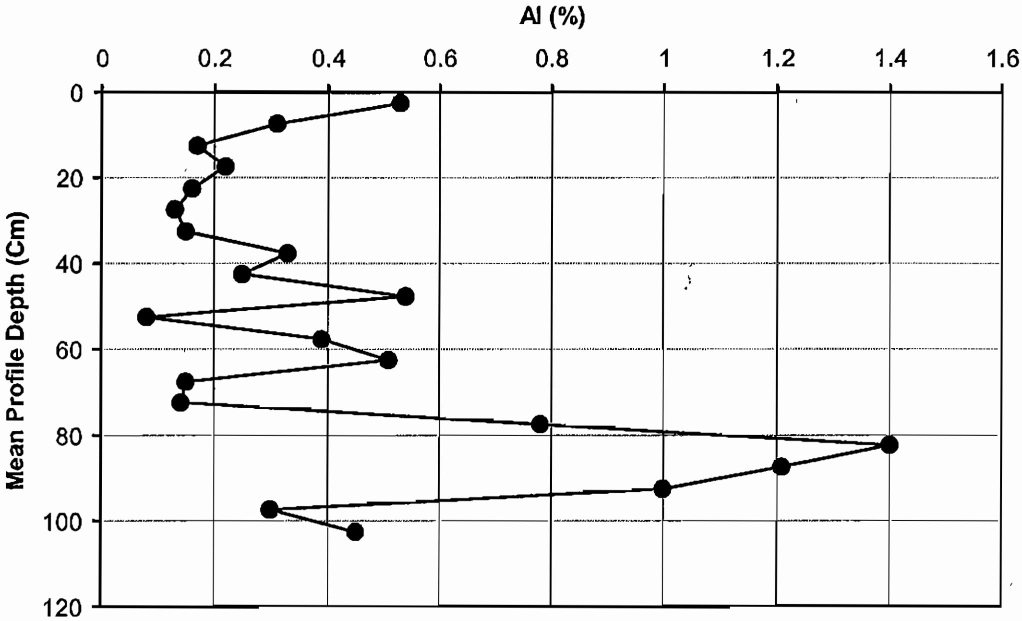

Figure 15: Profile of aluminum content at site 23.31 km. Entire profile is contaminated with main zinc peak at 102.5 cm.

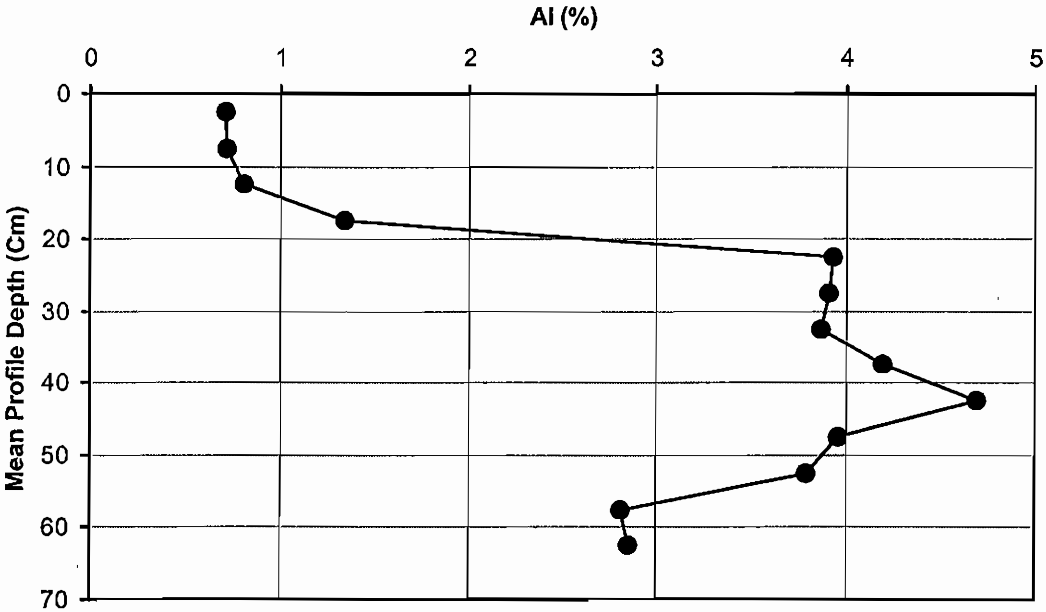

Figure 16: Profile of aluminum content at site 21.2 km. Initial contamination is at 7.5 cm with peak levels at the surface.

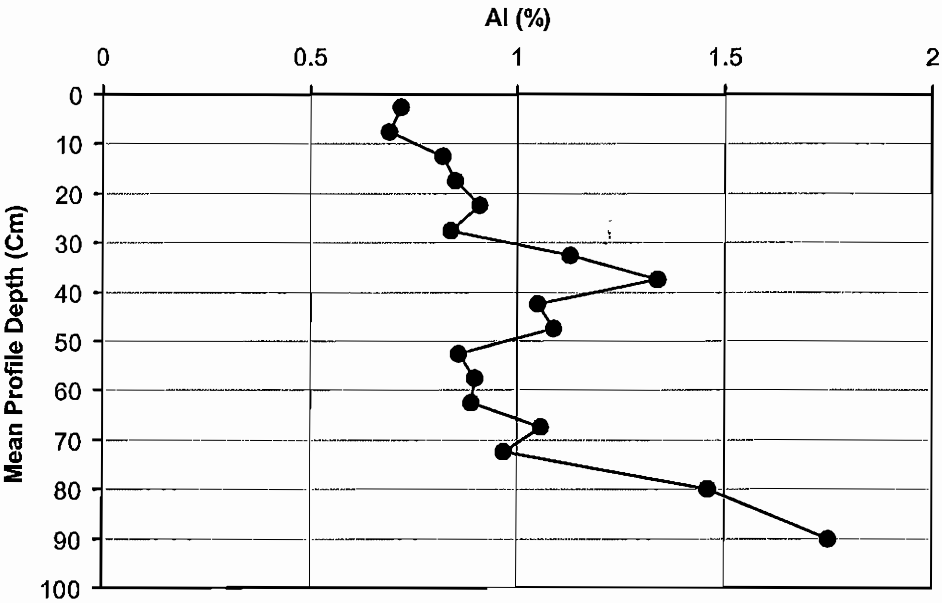

Figure 17: Profile of aluminum content at site 20.4 km. Entire profile is contaminated with peak levels at 72.5 cm.

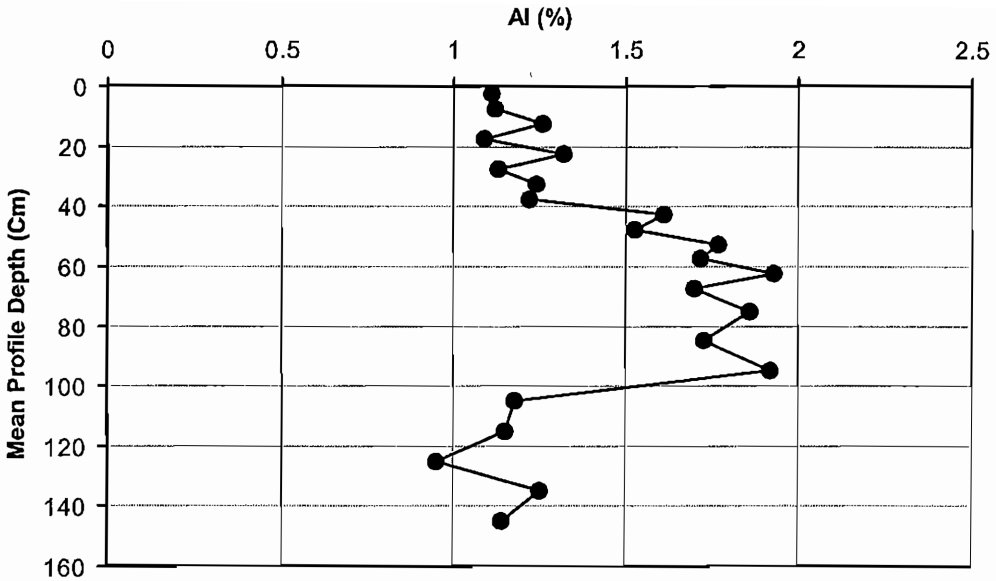

Figure 18: Profile of aluminum content at site 18.9 km. Initial contamination is at 62.5 cm with peak levels at 7.5 cm.

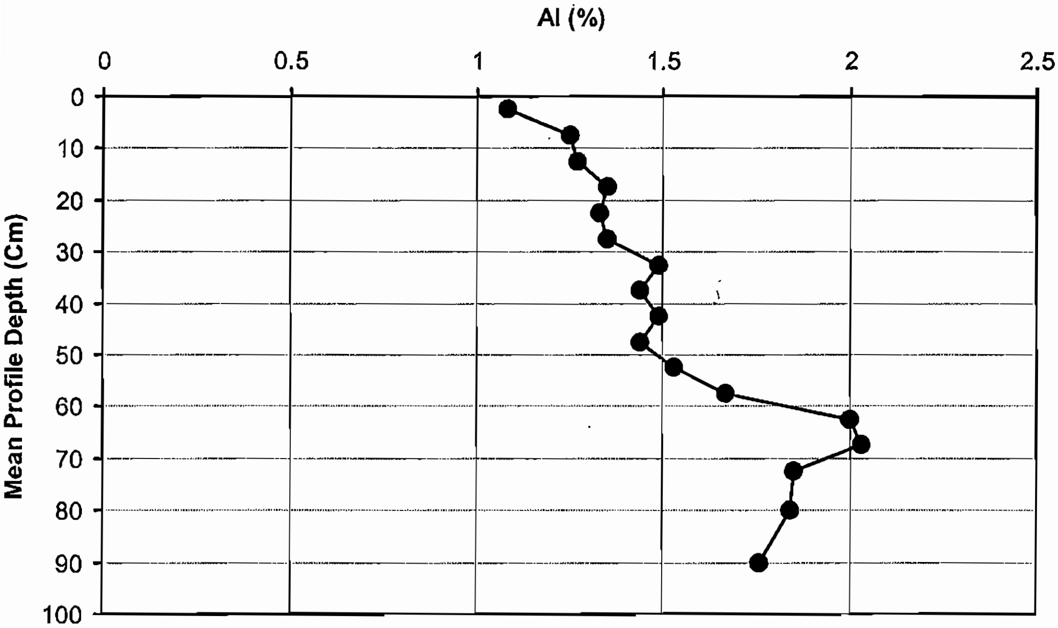

Figure 19: Profile of aluminum content at site 16.00 km. Initial contamination is at 47.5 cm with peak levels at 2.5 cm.

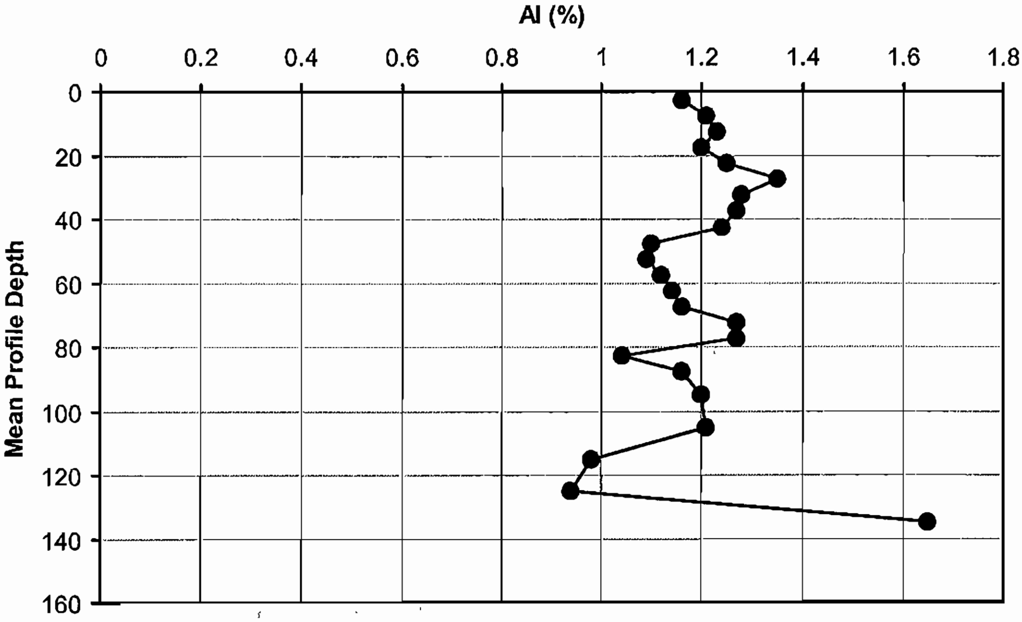

Figure 20: Profile of aluminum content at site 14.7 km. Initial contamination is at 95.0 cm with peak levels at 72.5 cm.

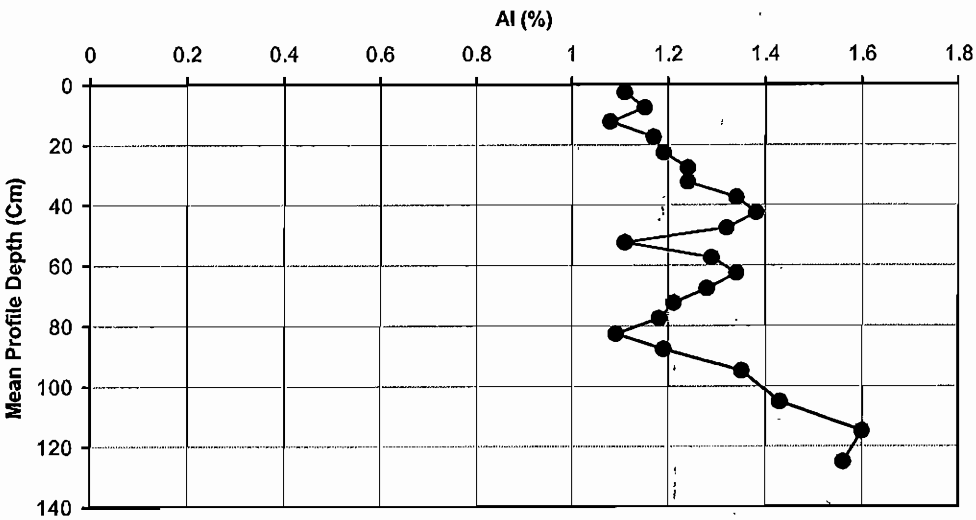

Figure 21 Profile of aluminum content at site 13.00 km. Entire profile is contaminated with peak levels at 87.5 cm.

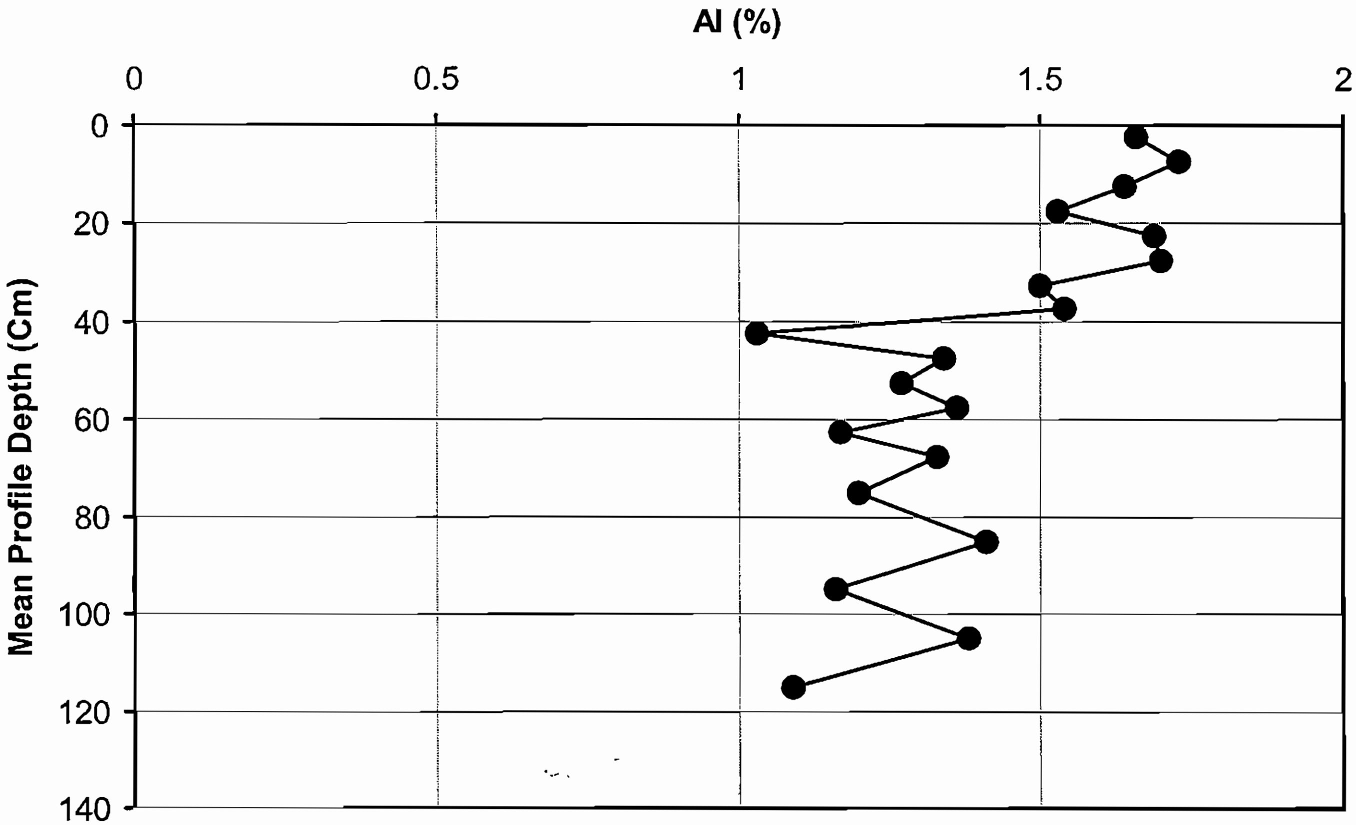

Figure 22: Profile of aluminum content at site 9.90 km. The entire profile is contaminated with peak levels at 57.5 cm.

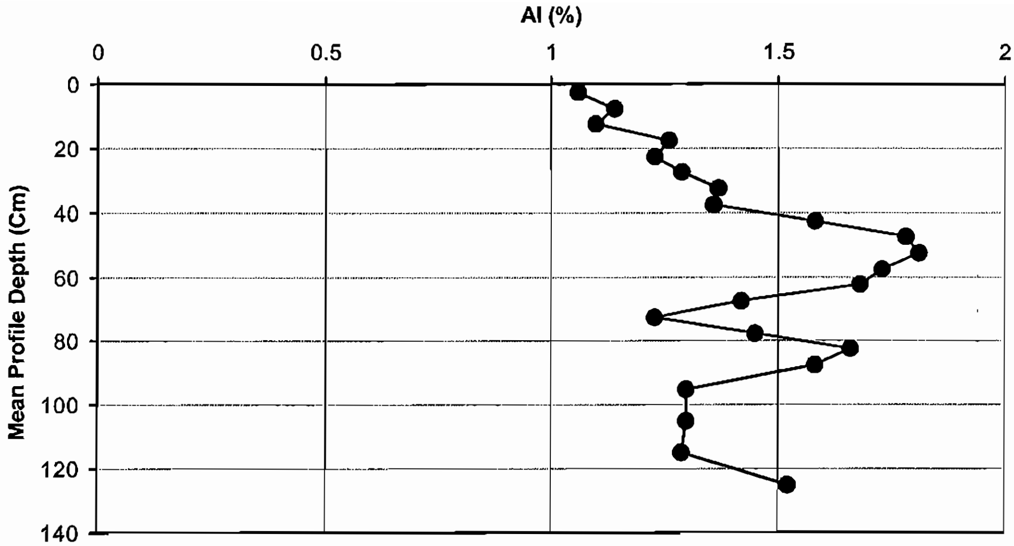

Figure 23: Profile of aluminum content at site 8.10 km. Initial contamination levels are at 95.0 cm with peak levels at 67.5 cm.

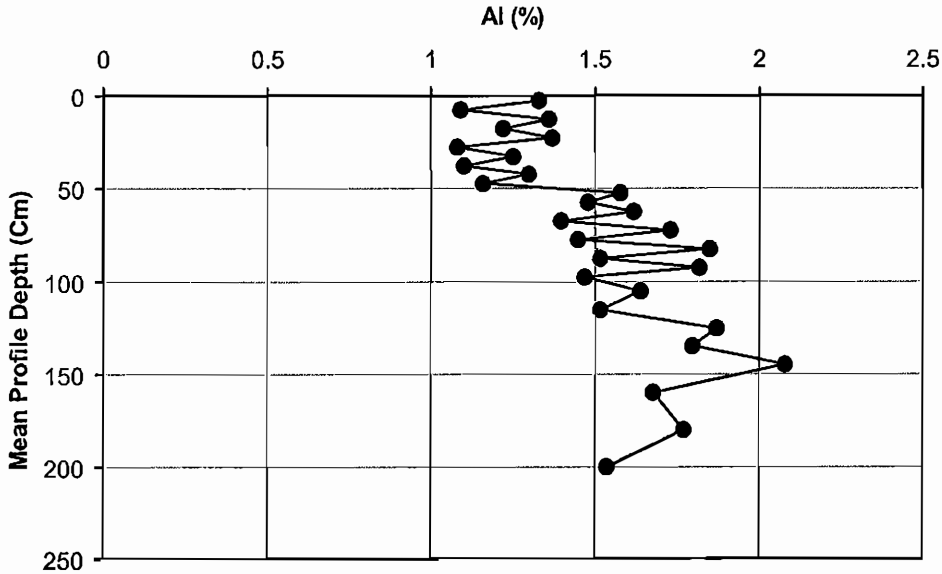

Figure 24: Profile of aluminum content at site 6.50 km. Initial contamination levels are at 62.5 cm with peak levels at 37.5 cm.

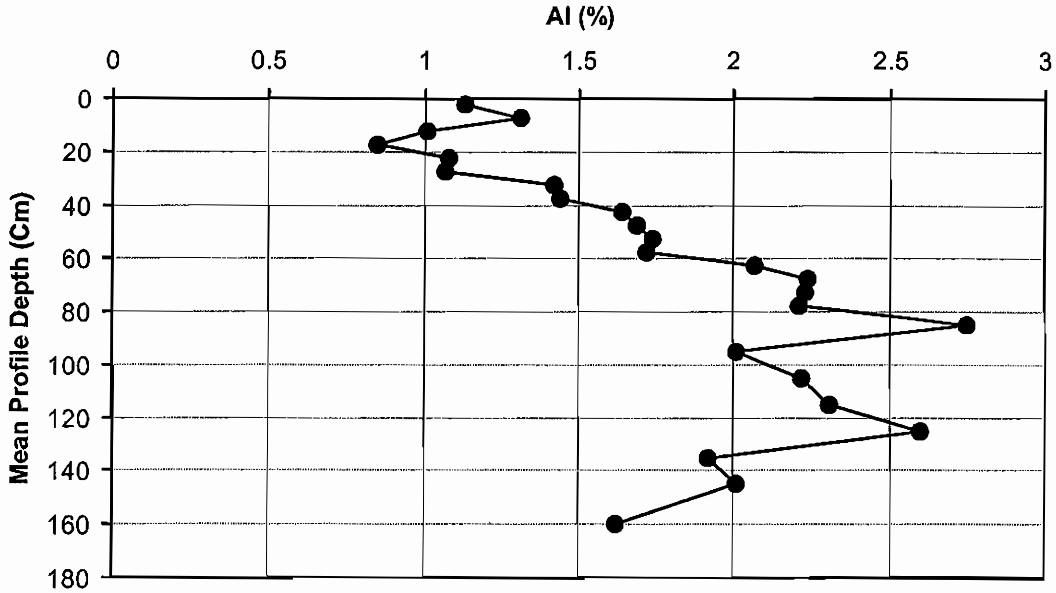

Figure 25: Profile of aluminum content at site 4.30 km. Initial contamination levels are at 32.5 cm while peak levels are at 12.5 cm.

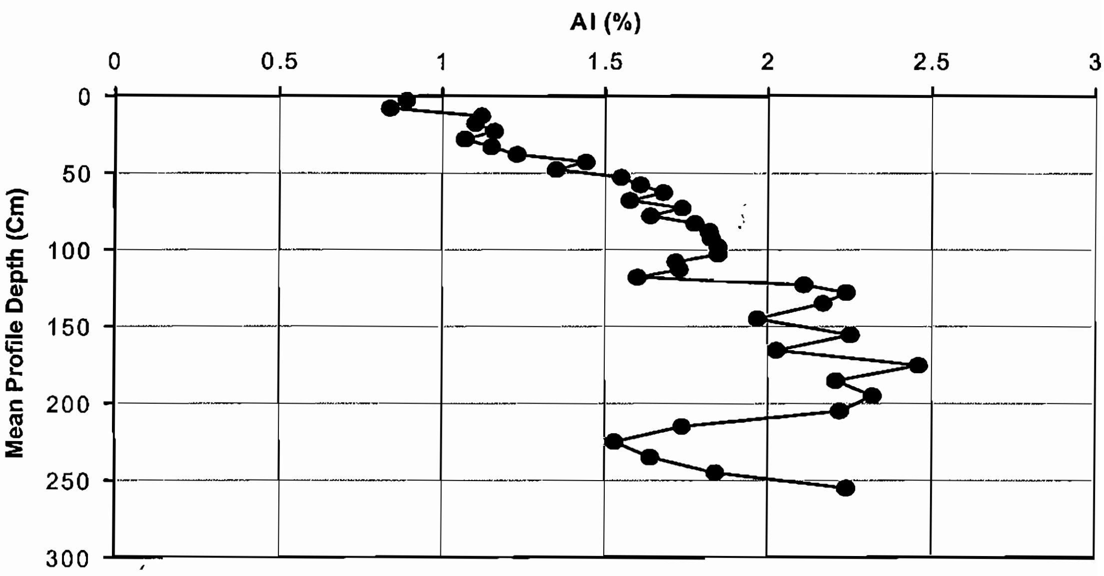

Figure 26: Profile of aluminum content at site 1.00 km. Initial contamination levels are at 2.5 cm.

content and/or residual concentrations as a result of the weathering or aging of a soil. This relationship is found in both contaminated and uncontaminated sediments in Honey Creek (Figure 27). Further, the inverse scattered relationship between Al and the contaminated sediments within this study is quite predictable (Figure 13A). Because the younger or post-mining sediments have high concentrations of zinc, less Al would be expected since these mining sediments contain relative high sand percentages and have been subject to small amounts of weathering. In contrast, older floodplain units tend to contain more Al because of natural weathering processes provides increases in clay content. A less predictable association exists between Al and the uncontaminated sediments (Figure 13A). No relationship is observed between the uncontaminated sediment samples and aluminum percentages with very little natural variability seen in the sample distribution. This is significant to this study because it shows a definite geochemical difference between the pre-mining, pre-settlement soils and the post-mining, post-settlement soils. This is shown by an inverse relationship with a scattered distribution between Al and Zn in the contaminated sediments and a poor but highly concentrated relationship found in the uncontaminated sediments, thus indicating that the two layers formed during different times with sediment with different geochemical properties. Therefore, aluminum percentages were used to help find the contact level between pre-mining soils and post-mining soils (Figures 14-26). In the overbank aluminum profiles the contact point between the pre-mining and post-mining soils is

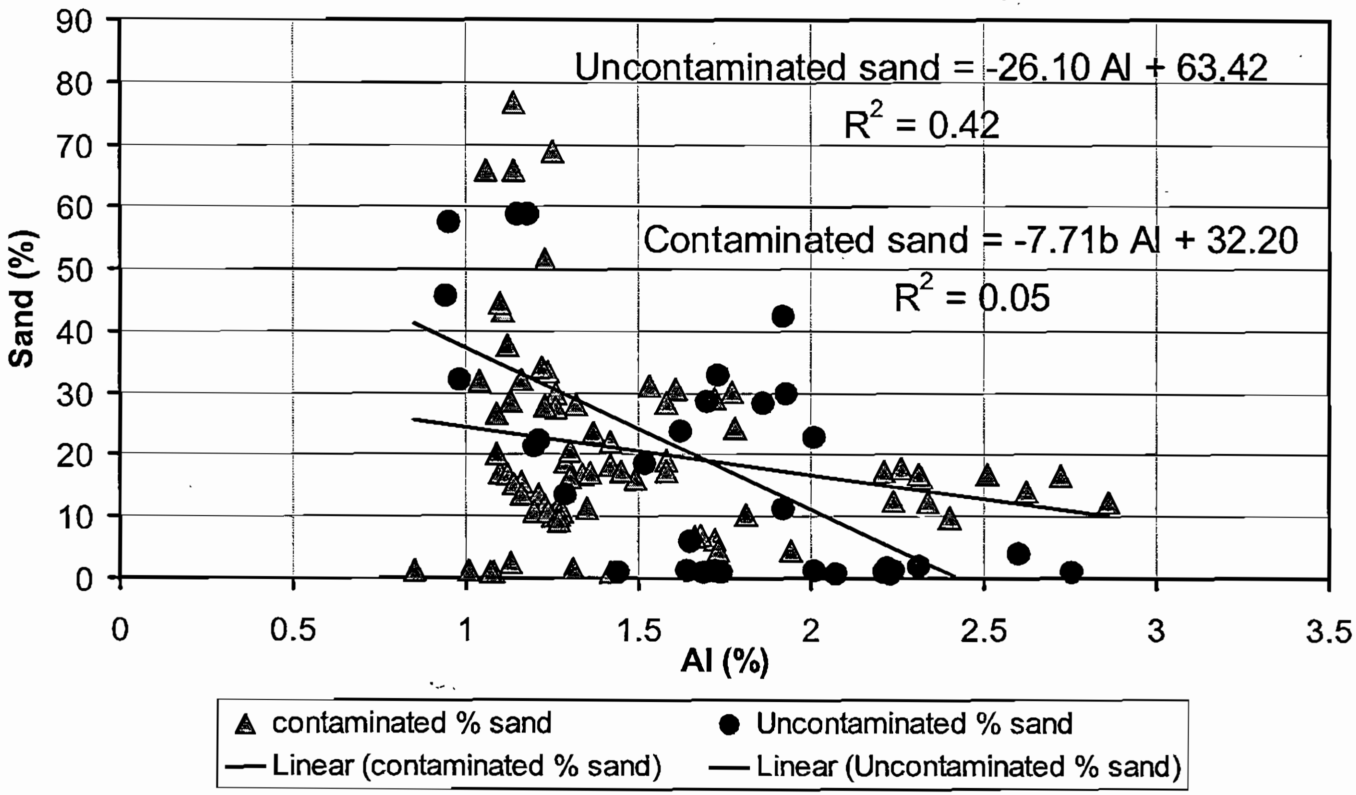

Figure 27: Relationship between Al and sand.

identified by a sudden decrease in Al percent. Although this sudden decrease in Al percent is not present in all the sites it serves as a fairly consistent trend throughout many of the study sites.

When comparing Zn and Al in the scatter plot, a number of contaminated points stretch to the far right of the graph and follow the trend line of the uncontaminated sediments (Figure 13A). This is of some concern, because the use of natural breaks in determining the difference between the pre-mining and the post-mining layers as an acceptable method of operation, because it does not show a definite geochemical difference between the two layers. However, this is easily remedied with the use of the Al/Ca ratio (Figure 13B). This ratio takes the aluminum percent and divides it by the calcium percent thus eliminating the effects of weathering and the deposition of calcium within the samples. Therefore, the higher the Al:Ca ratio the more weathered and older the soil material. By using the Al:Ca ratio, the outliers seen in the relationship between Zn and Al are eliminated and shows an almost flat trend line, and a slightly positive trend line relating uncontaminated Al:Ca ratios to zinc concentrations (Figure 13B). Therefore, both Al and Al:Ca relationships with zinc are able to serve as an aid when searching for natural breaks between the contaminated and uncontaminated layers (Figures 14-26).

Effect of Sorption Capacity

Relationships between zinc concentrations and other sediment properties like sand and organic matter content are important in understanding how mine contaminants are geochemically related with sediments and thus transported within the river system (Figures 28A and 28B). Contaminated sediment samples show no relationship with sand percentages, which is exhibited by a flat trend line possessing a R^2 of 0.02 (Figure 28A). This relationship suggests that contamination has occurred within both fine and coarse-grained sediments. This bimodal contamination trend would be expected because zinc tends to adsorb more readily to fine-grained particles, however, larger-grained particles are more commonly produced during mine operations and contaminated via natural sorting (Horowitz et al., 1989). In comparison, the uncontaminated sand percent has a slightly positive relationship with Zn contamination revealed by a slope of 0.09 (Figure 28A). This weak relationship may exist due to the sediment-metal association with iron-manganese oxide coatings, which commonly forms on sand grains in floodplain deposits affected by changes in seasonal water table levels, thus causing selective bonding of redistributed metals by larger sized particles (Horowitz et al., 1989).

In order to understand the role of organic matter content and its association with the geochemical processes within the watershed it is important to understand the relationship it has with zinc. Contaminated sediments show a positive relationship within organic matter (Figure 28B). This direct relationship

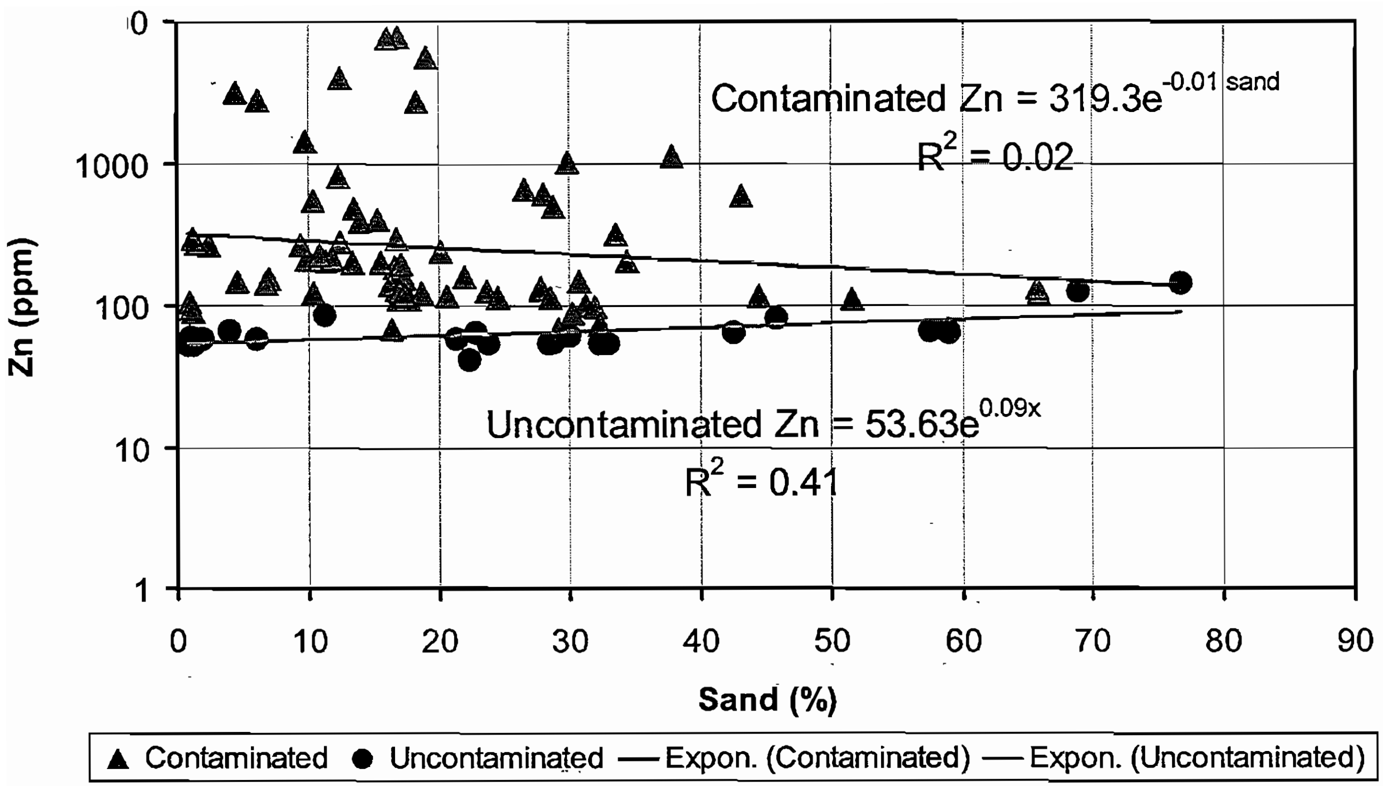

Figure 28A: Relationship between zinc and sand in overbank contaminated and uncontaminated samples.

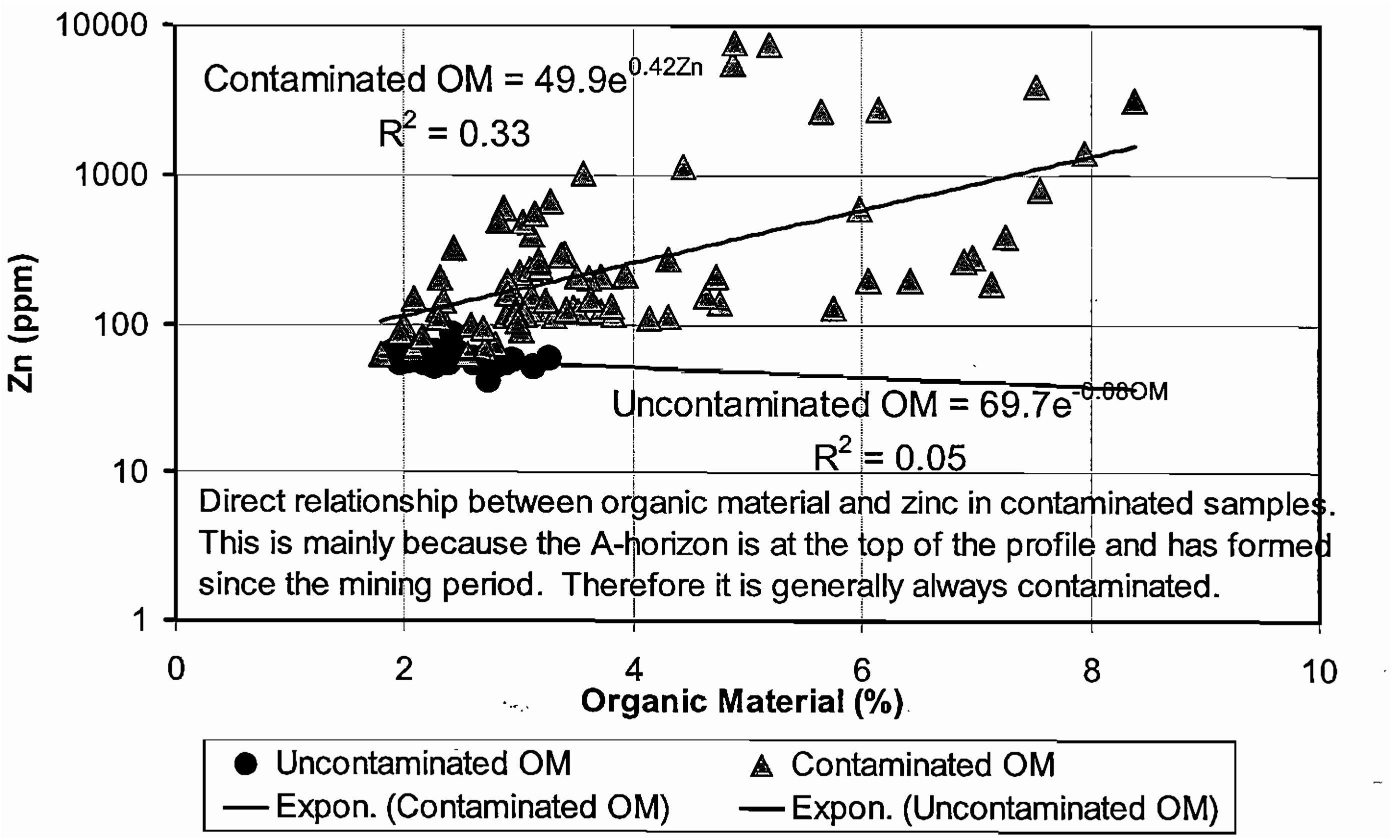

Figure 28B: Relationship between zinc and organic matter in overbank contaminated and uncontaminated samples.

may exist for two reasons: (1) zinc may be adsorbed and concentrated by organic matter in a "casual" fashion: and/or 2) since the organic rich A-horizon is at the top of the profile, it has formed during or just after times of contamination therefore, zinc is spatially associated with the upper organic matter-rich units. Due to the young age of the upper contaminated deposits, little weathering of the tailings and organic matter has occurred, thus, the zinc-organic matter trend represents the effects of the second relationship.

Relationship of Geochemistry to Dating Rationale

Zinc variations within site profiles are directly related to pulses of tailings released during active mining periods and not a result of natural factors such as weathering enrichment or sorption effects. This is supported by three factors: (1) pH levels within floodplain soils range from 5.6-7.8, meaning Zn precipitates are stable and not being chemically transported, rather they are physically redistributed; (2) little time has passed for tailings in the mineral form to weather, and released in dissolved and adsorbable forms; and (3) there are geochemical differences between more recent, historical overbank deposits and older, Holocene deposits. Because of the high contrast in zinc concentrations between the contaminated and uncontaminated portions of the profiles as well as the contrast between zinc, Al and Al:Ca ratios of the pre-mining and post-mining layers evidence supports the fact that soil layers are formed during different geochemical environments.

Dating of Overbank Deposits

Dating Layers of Sediment

Zinc contamination trends can be used to date distinct layers of historical overbank sedimentation. Three sediment layers are identified, for each profile beginning at the bottom of the profile and moving towards the surface (Figure 3): (1) site specific background level (pre-mining); (2) depth of initial contamination (beginning of mining); and (3) depth to peak contamination (maximum production). These age-control points in the overbank profile correspond to key historic mining events within the Aurora Sub-district. The site specific background level represents zinc transport in the pre-1886 era and the floodplain present at the time of pre-settlement. The second layer, marks the onset of mining in 1886 and overbank deposits formed during the early phases of settlement in the area. The third layer represents the period of maximum ore production in the Aurora Sub-district and during 1916. The profile surface (0.0 cm depth) is assumed to be presently active and represents the contemporary floodplain in 1998.

While lead and cadmium exist within the watershed at elevated levels and would also serve as adequate vertical tracers of the mining era, zinc concentrations have been chosen for detailed assessment of each site. Because zinc ore (sphalerite) is less dense then lead ore (galena) it is more easily transported downstream by flow energy and thus provides a more up to date and accurate historical record of contamination. Also, zinc concentrations are found at relative high levels throughout the watershed so that a definite distinction may be made between the uncontaminated, pre-mining, pre-settlement period and the contaminated, post-mining, post-settlement period at all sites.

Site-specific Backgrounds

Because several of the sites within the study area show very high natural enrichment of Zn and Pb, site-specific background levels are identified by natural breaks within each overbank profile (Knox, 1987). In order to discover the profile depth at which the natural break occurs, concentration levels of the near bottom layers and by definition the oldest layers within the profiles are examined first (Figure 3). These older layers generally contain the lowest concentrations of Zn and Pb within the profiles and thus are considered the site-specific backgrounds that indicate uncontaminated floodplain deposits formed during the pre-mining and pre-settlement era. A distinct jump in concentration is generally discovered moving upward towards the profile surface. Natural breaks in the zinc profile are usually seen when concentrations exceed 50-70 ppm with some exceptions in the upper reaches where natural zinc enrichment is evident (Table 17). In some profiles the 1886 date is unable to be established since all sampled Zn concentrations are above the background. In such cases it is assumed that the entire profile is contaminated and has been deposited since 1886. A final date for each profile is established at the peak concentration level in which it is assumed that this level has formed since the peak era of lead-zinc mining thus being deposited since 1916.

Table 17: Site-specific background levels determined by natural breaks.

Site	N	Zinc (ppm)	Lead (ppm)
24.3	6	139	31
23.3	0	N/A	N/A
21.2	0	N/A	N/A
20.4	0	N/A	N/A
18.9	7	61	10
16.0	7	62	15
14.7	4	59	16
13.0	0	N/A	N/A
9.9	0	N/A	N/A
8.1	3	60	17
6.5	15	49	13
4.3	17	59	14
1.0	36	58	14

Dating of Bank Exposures Along Elm Branch

Beginning at the farthest upstream site, nearest to the mining locations and moving downstream towards the confluence of the Honey/Spring River, each profile is described below (Figures 29-42). Locations of these sites are shown on Figures 8 and Figure 5.

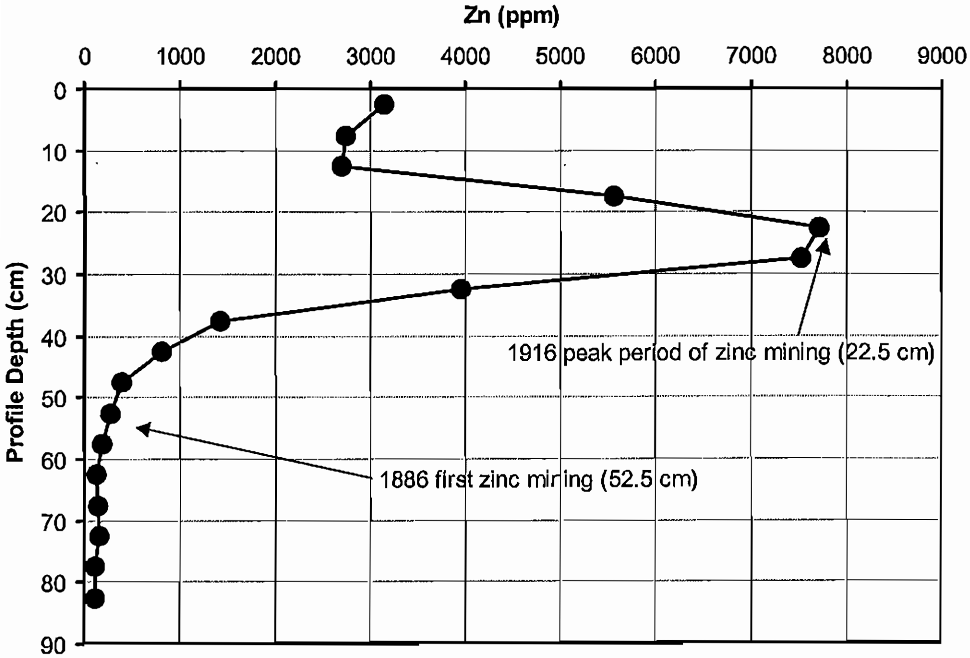

Figure 29: (Upper Elm) Zinc concentration profile for site 24.3 km. Notice the highly contaminated upper profile.

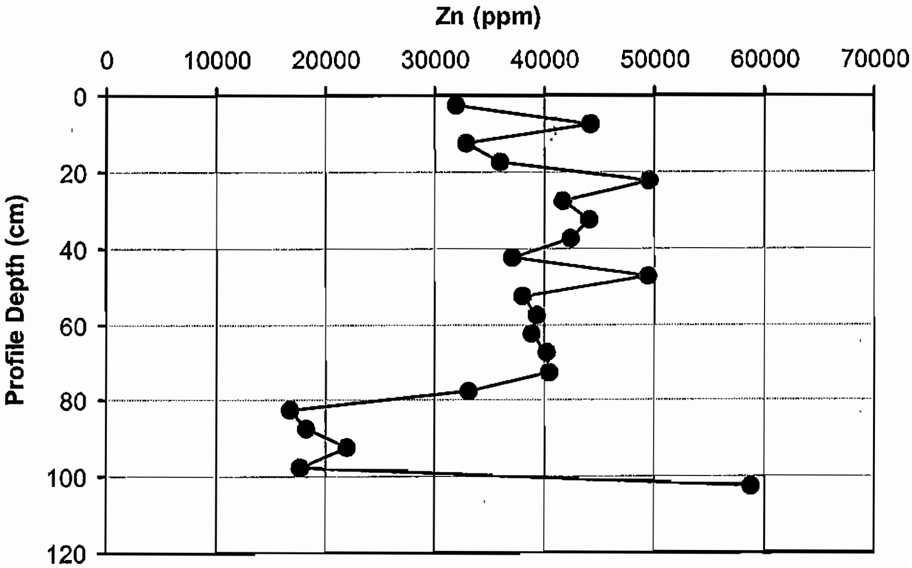

Figure 30: (Upper Elm) Zinc concentration profile for site 23.3 km. Entire profile is contaminated with main zinc peak at 102.5 cm and minor peaks at 22.5 and 47.5 km.

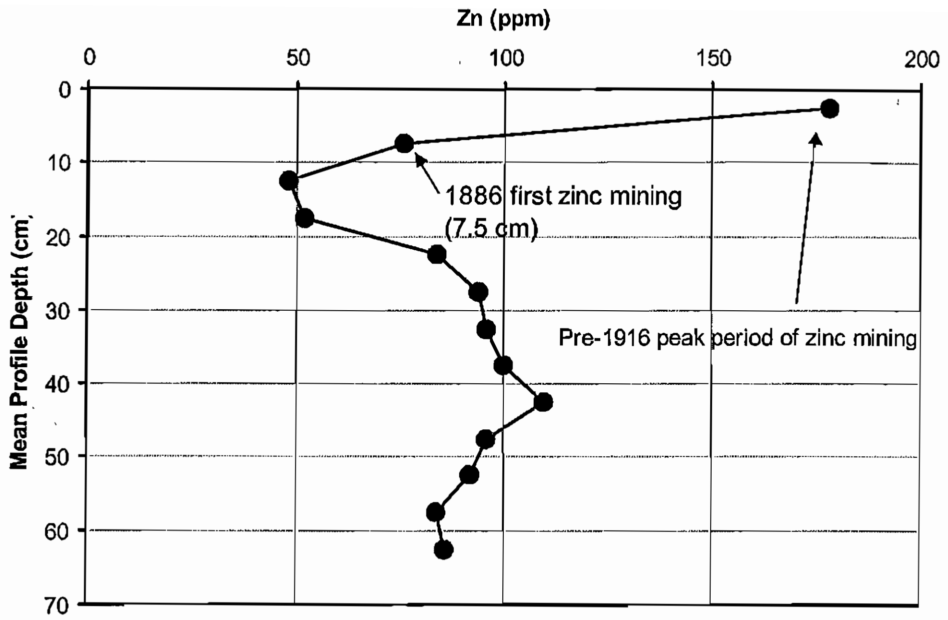

Figure 31 (Upper Elm) Zinc Concentration Profile for Site 21.2 km. Contamination levels low beginning at 7.5 cm.

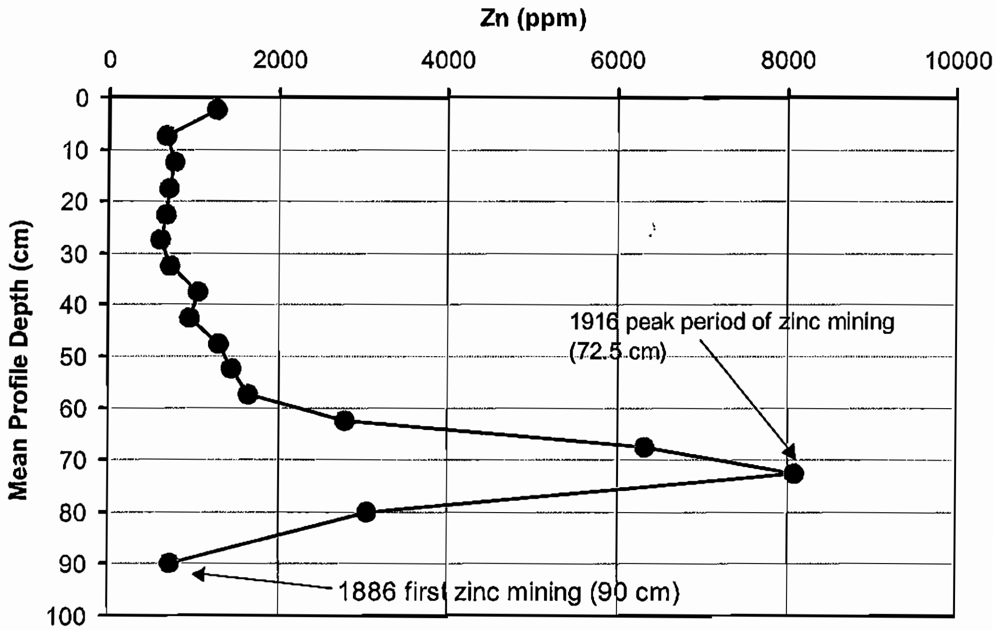

Figure 32: (Upper Elm) Zinc concentration profile for site 20.4 km. Notice the entire profile is contaminated meaning it formed since 1886 when mining began.

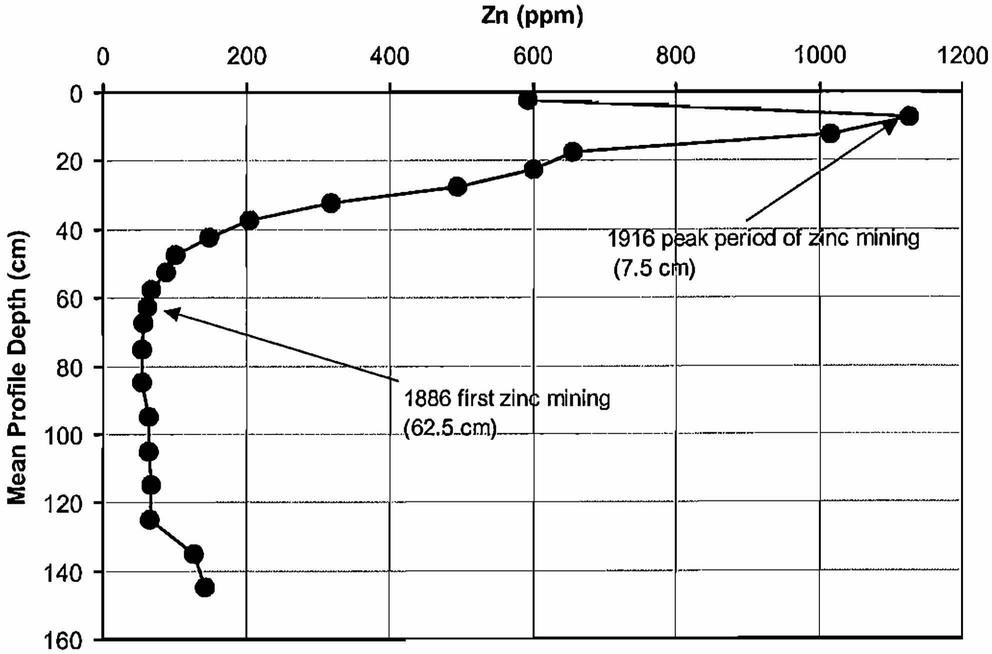

Figure 33: (Lower Elm) Zinc concentration profile for site 18.9 km with contamination beginning at 62.5 cm.

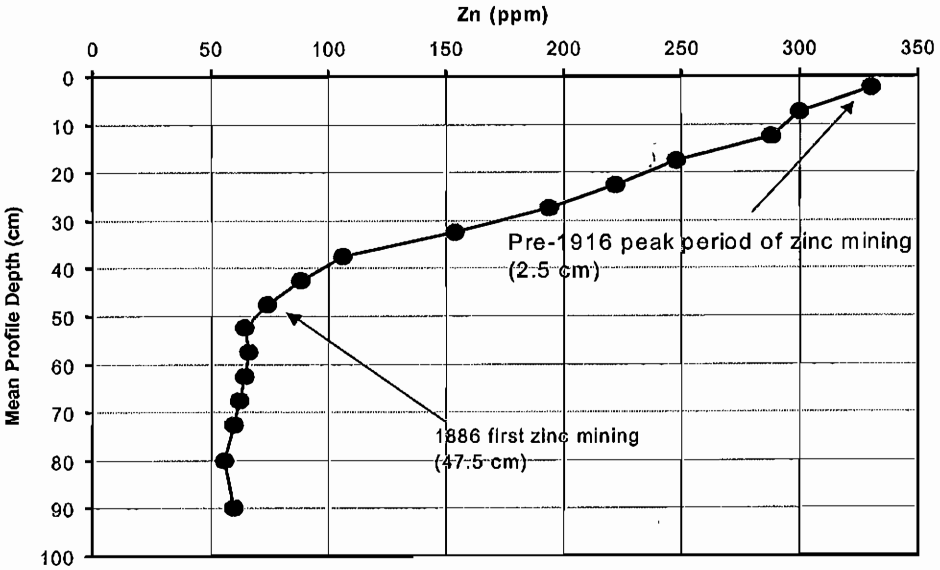

Figure 34: (Lower Elm) Zinc concentration profile for site 16.00 km with contamination beginning at 47.5 cm.

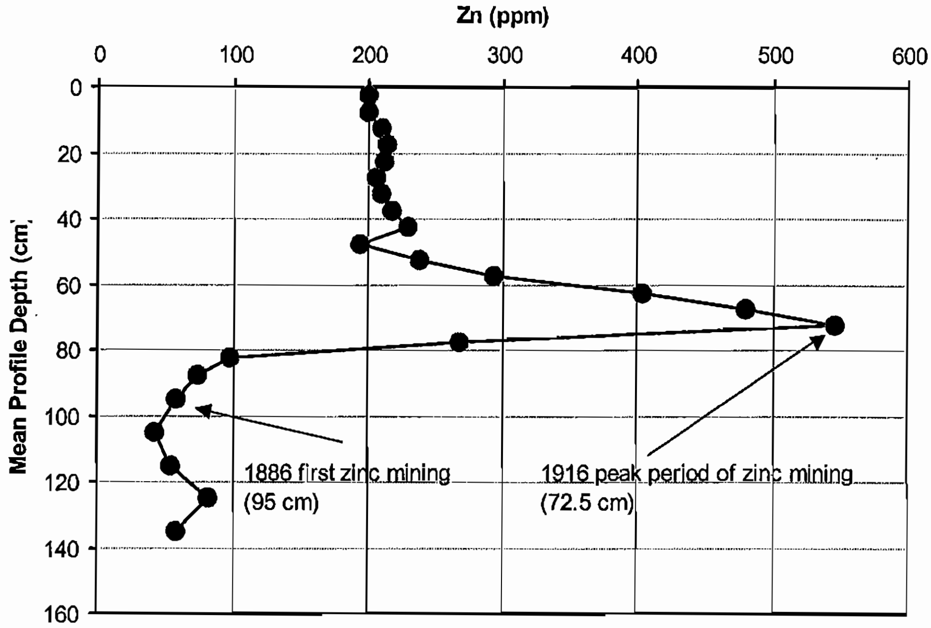

Figure 35: (Middle Honey) Zinc concentration profile for site 14.7 km with contamination beginning at 95.0 cm.

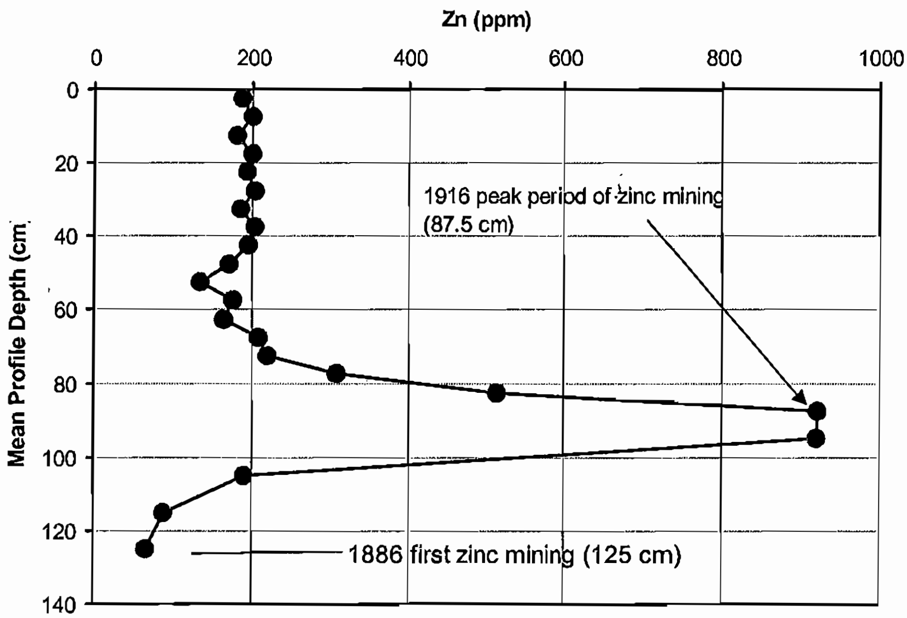

Figure 36: (Middle Honey) Zinc concentration profile for site 13.0 km with the entire profile being contaminated.

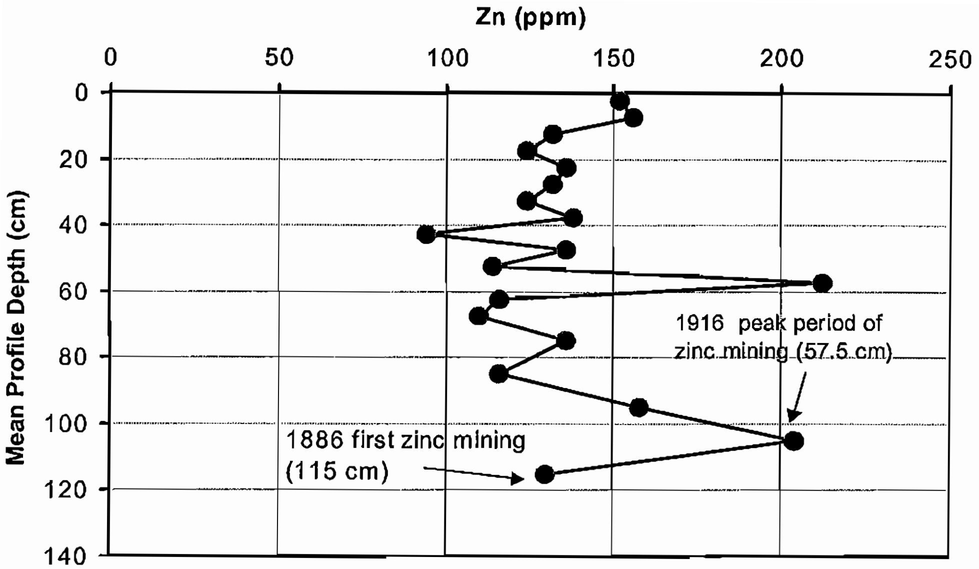

Figure 37: (Middle Honey) Zinc concentration profile for site 9.90 km with the entire profile being contaminated.

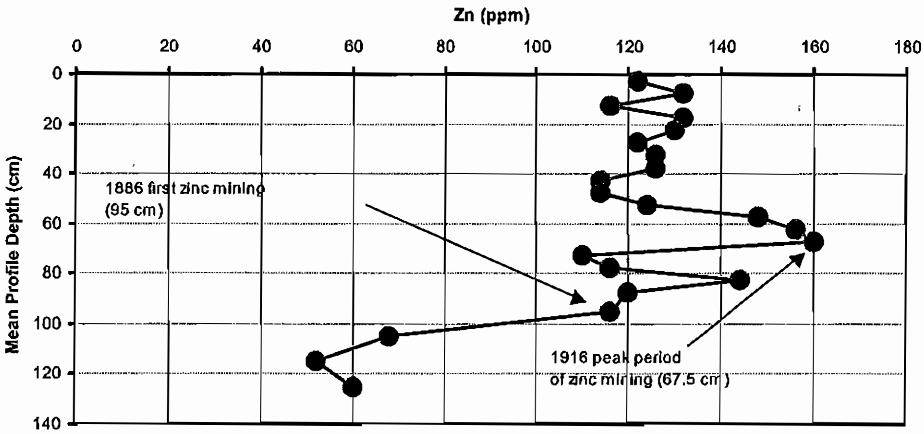

Figure 38: (Middle Honey) Zinc concentration for site 8.10 km with contamination beginning at 95 cm.

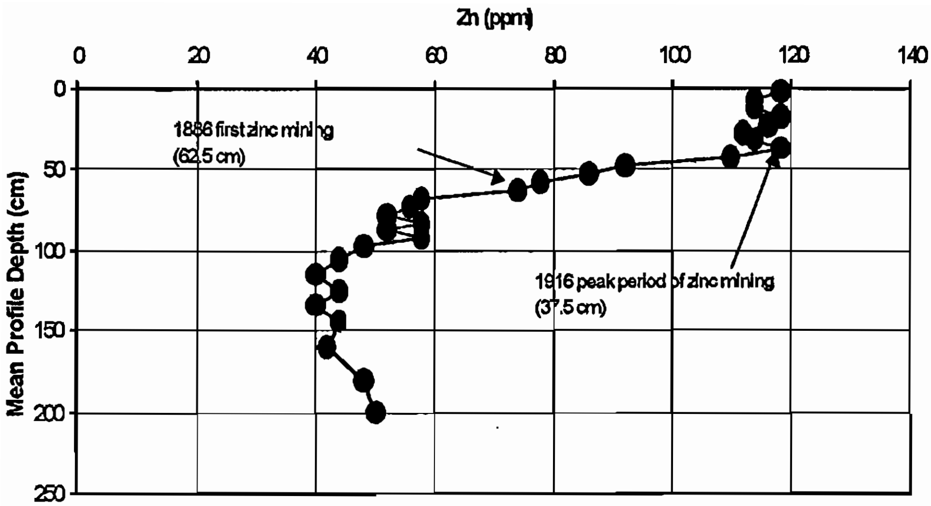

Figure 39: (Lower Honey) Zinc concentration for site 6.50 km with contamination beginning at 62.5 cm

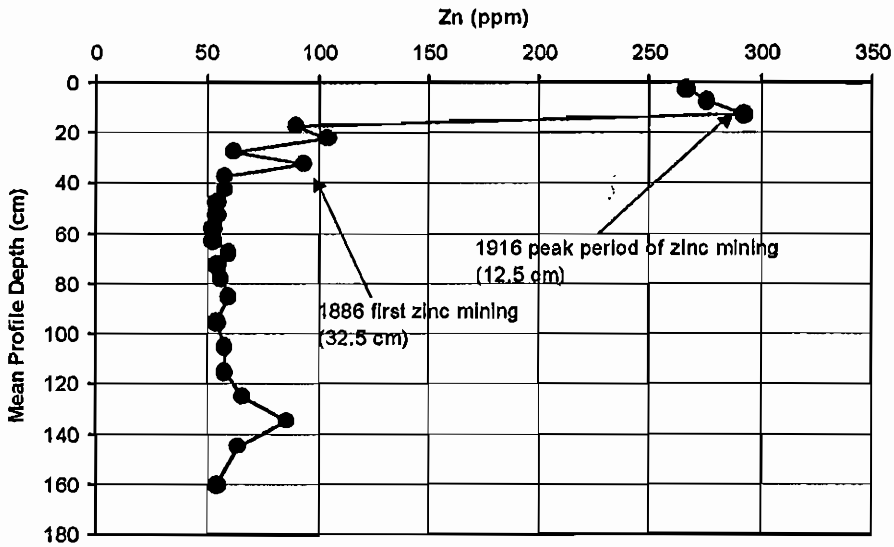

Figure 40: (Lower Honey) Zinc concentration profile for site 4.30 km contamination beginning at 32.5

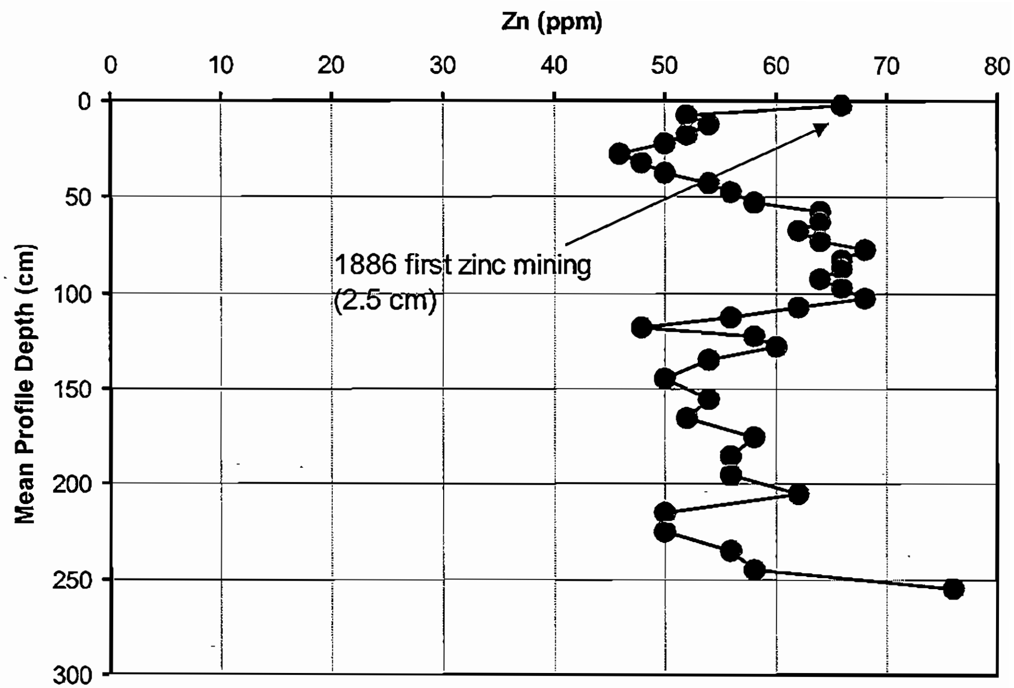

Figure 41(Lower Honey) Zinc concentration profile for site 1.00 Km showing contamination beginning at 2.5 cm.

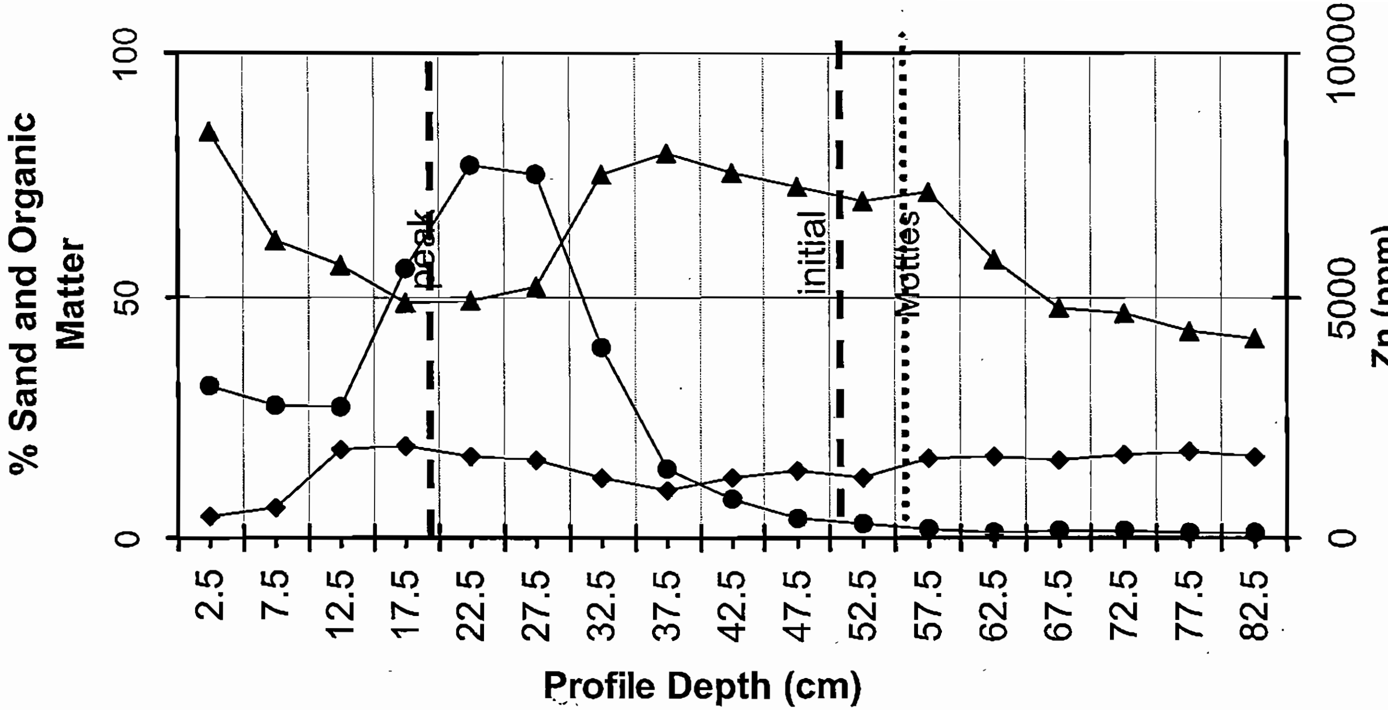

Figure 42: Sediment properties at site 24.3 km. Notice the buried A-horizon revealed by an increase in organic matter correlating with the initial level of zinc contamination at 52.5 cm. Circle=Zn (ppm), Diamond=sand (%) and Triangle=organic matter (%),

Upper Elm Branch

Site 24.3 km shows very high concentrations throughout its entire profile (Figure 24). The high concentrations found at this site are products of natural ore body weathering. Within this profile a natural break in contamination occurs at 52.5 cm identifying the 1886 dated layer. Peak levels in zinc concentrations of 7,710 ppm are found at the 22.5 cm depth indicating the time of peak mining in 1916.

Site 23.3 km contains the highest Zn (58,700 ppm) and Pb (9,590ppm) concentrations measured in floodplain deposits for this study (Figure 30). At this location, very high concentrations of zinc are evident due to its location so close to a former mine site. Tailings dumps are mapped only 50 m away from this site (Hughes, 1982). Also the 105 cm level is the peak Zn concentration thus suggesting the profile has been deposited since 1916. It is possible that this bank has cut into tailings fill materials placed here during periods of reclamation.

Site 21.2 km contains zinc concentrations that are fairly low throughout the entire profile (Figure 31). At this site initial contamination is at the 7.5 cm level, where 76 ppm zinc is found. Peak levels of contamination would be marked at the current surface of the profile were concentrations of 178 ppm zinc are found. Because peak concentrations are found at the top of the profile it becomes apparent that this is the first site in which terracing has occurred. Basically this site has stopped receiving overbank deposition since 1916 because of the channels capability to hold episodes of flooding.

Site 20.4 km contains high zinc concentrations throughout its entire profile with no obvious natural breaks (Figure 32). This being the case the entire profile (90 cm) has be deposited since 1886 with the 1916 peak concentrations found at 72.5 cm.

Lower Elm Branch

Site 18.9 km shows evident of a natural break in zinc concentration at 62.5 cm, ultimately rising to a peak concentration of 1,125 ppm at 7.5 cm. From this depth concentrations again decrease towards the surface (Figure 33). At this site it appears an incomplete historical record exists as zinc concentrations never stabilize above the peak 1916 level. Because of this it seems some terracing has occurred at this site with overbank deposition ceasing shortly after 1916.

Site 16.0 km shows contamination levels that begin at 47.5 cm and continue to increase to a peak level of 330 ppm located at the surface of the profile (Figure 34). This site is located just 0.5 km upstream of the Honey/Elm confluence that is located at 15.5 km upstream of the Spring/Honey confluence. At this site it appears the historical deposition ceased pre-1916 as peak concentrations are located at the profile surface.

Middle Honey Creek.

Site 14.7 km is located on the main stem of Honey Creek just .80 km downstream of the Elm Branch confluence. The initial contamination point occurs at 95 cm in depth with a peak concentration at 72.5 cm (Figure 35).

Within the overbank profile, differences in the contaminated and uncontaminated layers are made obvious. Zinc concentrations rise sharply from background levels of 58 ppm to a peak concentration of 546 ppm all within a 20 cm interval. Peak concentrations drop in a similar manner toward the surface stabilizing to levels that remain around 200 ppm zinc.

Site 13.0 km shows a profile that is completely contaminated, with a peak period of contamination (922 ppm) at a depth of 87.5 cm (Figure 36). While the entire profile is contaminated the deepest sample containing 66 ppm zinc and is near background levels, thus suggesting the entire historical record is present within the overbank deposit. After peak concentrations the contaminated levels rapidly decrease to levels that remain around 200 ppm showing uniform zinc concentrations within the upper portions of the overbank profile.

Site 9.9 km is a profile that is entirely contaminated by zinc thus showing its origins that date back to 1886. Peak contamination levels of 212 ppm may be found at a depth of 57.5 cm in which a date of 1916 is given (Figure 37).

Lower Honey Creek.

Site 8.1 km is a typical profile in that a background contamination level is very obvious at the lower depths of the cutbank with a definite natural break at the mining and settlement period of 1886 (Figure 38). Contamination begins at 95 cm rising to a peak of 160 ppm, at a depth of 67.5 cm, abruptly decreasing to levels that remain around 120 ppm.

At site 6.5 km contamination begins at 62.5 cm rising to a peak of 118 ppm. Peak contamination occurs at a depth of 37.5 cm, thereafter, decreasing towards the surface (Figure 39).

Site 4.3 km shows a very obvious division between the pre-settlement and the post-settlements soils (Figure 40). This division occurs at 32.5 cm with a peak contamination of 292 ppm zinc occurring at a depth of 12.5 cm. Zinc concentrations then decrease towards the surface of the profile to 266 ppm.

Site 1.0 km, previously referred to as a downstream control site shows minimal contamination within the top 2.5 cm of the profile (Figure 41 and Table 18). Within this site, levels around 60 ppm may be seen throughout the entire profile with one exception being at the deepest sample. At this depth zinc levels of 78 ppm are found. The low zinc concentrations at this site suggest that it is far enough downstream of the mine source for dilution to reduce Zn levels and/or too high to be flood prone.

Table 18: Summary of initial and peak levels of contamination at each site.

Distance from Confluence (km)	Stream Reach	N	Depth to Initial (cm)	Depth to peak (cm)
24.3	Upper Elm	17	52.5	22.5
23.3	Upper Elm	21	102.5	102.5
21.2	Upper Elm	13	7.5	2.5
20.4	Upper Elm	17	90.0	72.5
18.9	Lower Elm	22	62.5	7.5
16.0	Lower Elm	17	47.5	2.5
14.7	Mid Honey	23	95.0	72.5
13.0	Mid Honey	22	125.0	87.5
9.9	Mid Honey	19	115.0	105.0
8.1	Mid Honey	22	95.0	67.5
6.5	Lower Honey	28	62.5	37.5
4.3	Lower Honey	24	32.5	12.5
1.0	Lower Honey	39	2.5	–

Stratigraphy of Overbank Deposits

The initial and peak episodes of contamination generally show correlation with sediment properties (Figures 42-46). Percent organic material was tested in order to identify any buried A-horizons within the watershed and sand percentages were calculated to get an idea of grain size trends within overbank deposits throughout the watershed.

A buried A-horizon would ultimately provide further evidence that the pre-mining and pre-settlement layers are found at the same vertical depth and have formed at the same time within the profiles (Goudie, 1990; Williams, 1988). Only one buried A-horizon was found within the study area, which exists at site 24.3 km (Figure 42). This buried A-horizon begins at a depth of 32.5 cm and extends down to 57.5 cm. It is important to note that this level would have been the top A-horizon before settlement and the mining era. Since these early times, 32.5 cm of overbank sedimentation has accumulated above the buried A-horizon. Also within the buried A-horizon is the initial break in zinc concentrations at the 57.5 cm level. Although there is a slight difference between the top elevation/depth of the A-horizon and the initial depth of contamination of about 15-20 cm, the close correlation between the two indicators suggest the pre-mining and pre-settlement surface depths are closely related in time within the record of overbank deposition. Also within this site a small decrease in sand percent may be seen at the 52.5 cm level correlating with the depth of initial contamination.

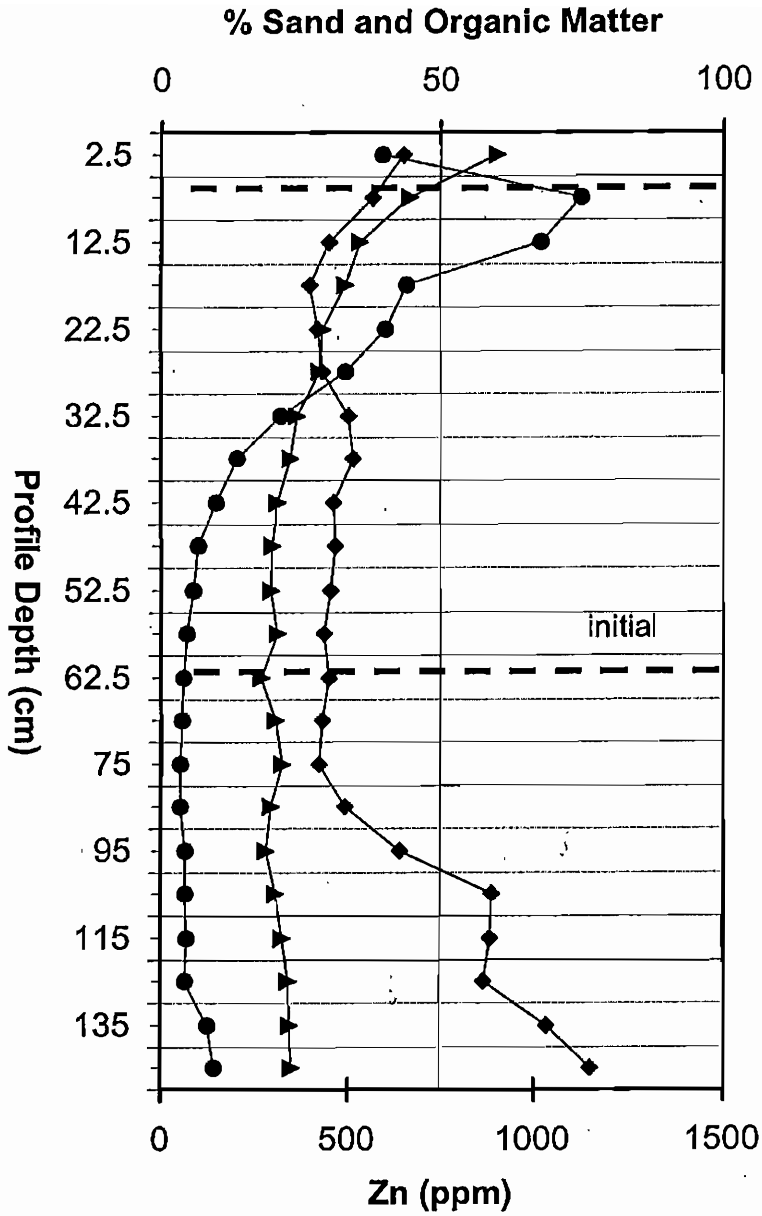

Figure 43: Sediment properties at site 18.9 km. Circle=Zn (ppm), Diamond=sand (%) and Triangle=organic matter (%).

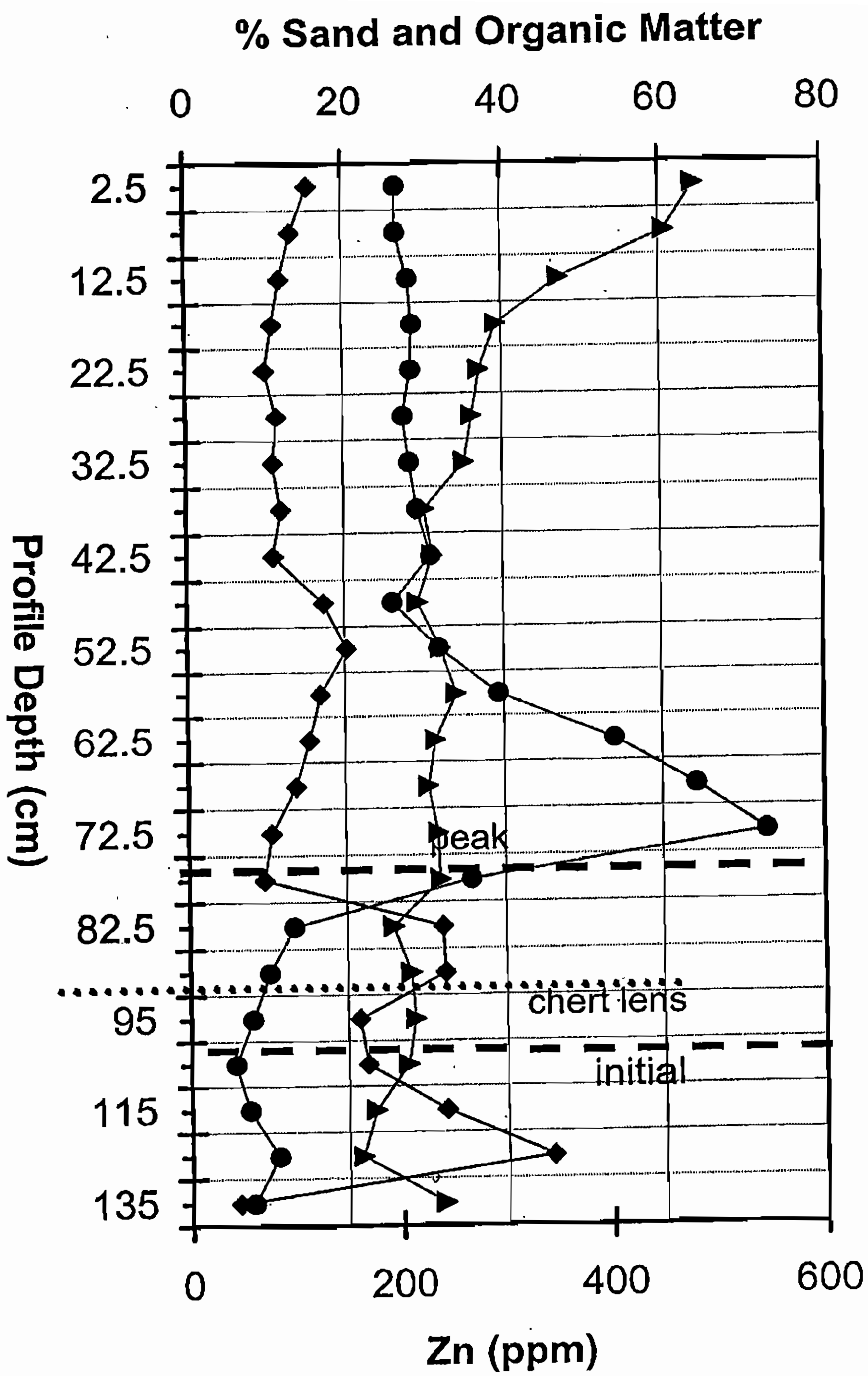

Figure 44: Sediment properties at site 14.7 km. Notice the decrease in sand and increase in organic material around 80 cm very near the level of initial zinc. Circle=zinc, Diamond=sand (%) and Triangle=organic matter (%).

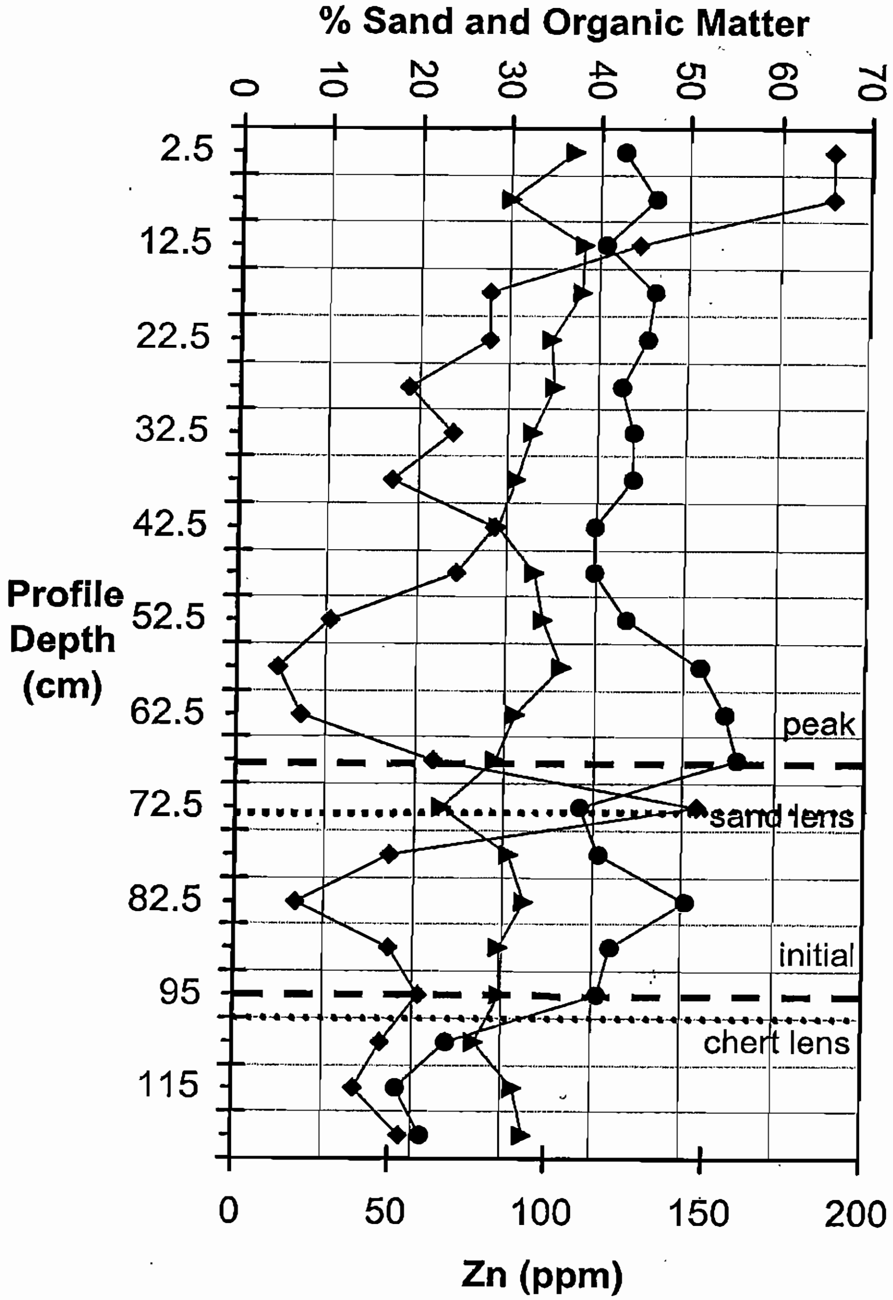

Figure 45: Sediment properties at site 8.10 km. Circle=Zn (ppm), Diamond=sand (%) and Triangle=organic matter (%)

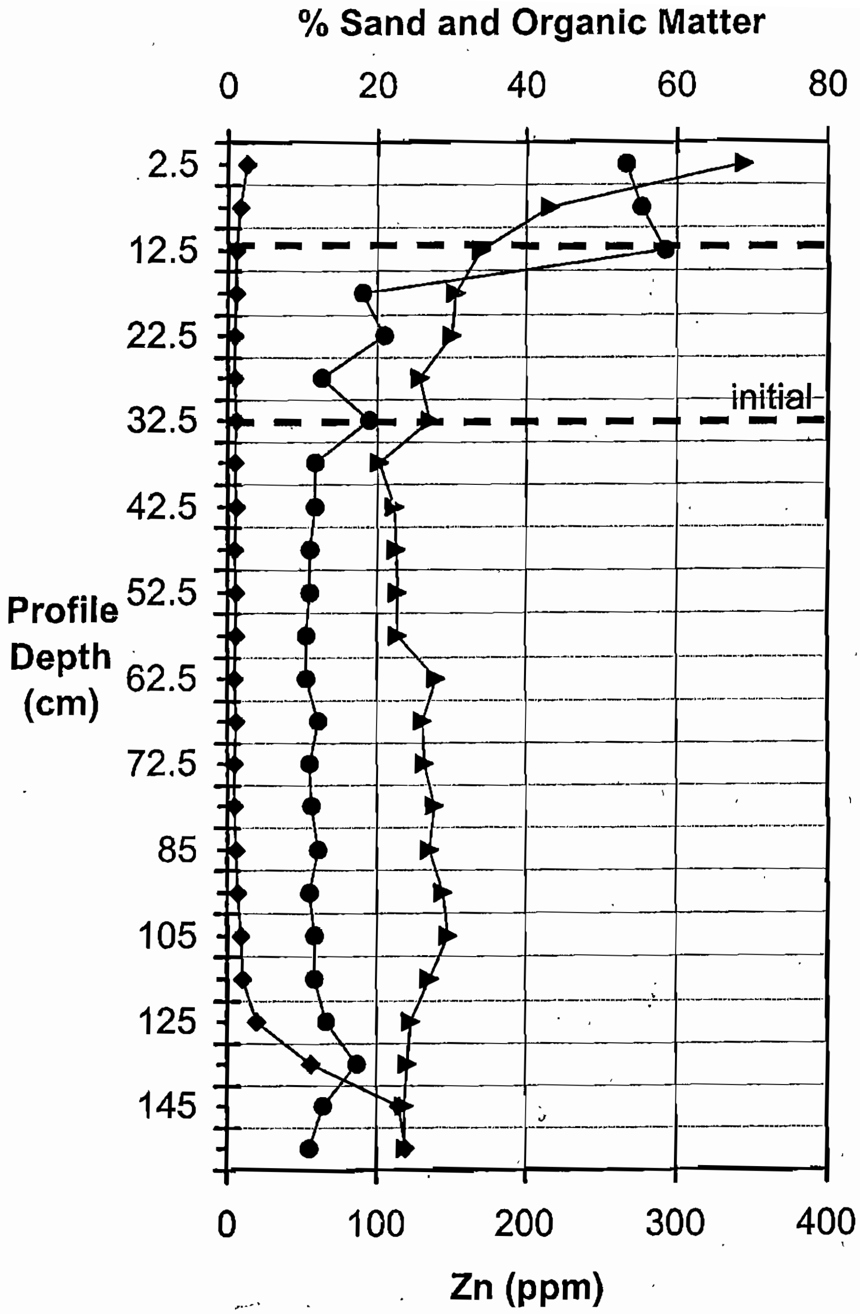

Figure 46: Sediment properties at site 4.30 km. Circle=Zn (ppm), Diamond=sand (%) and Triangle=organic matter (%).

Site 18.9 km shows fairly consistent organic matter percentages that slowly rise towards the profile surface (Figure 43). A small bulge is evident at the 75 cm level, which is very close to the initial contamination level of 62.5 cm. At this site sand percentages are high in the lower levels of the profile due to large amounts of gravel sized chert which ultimately became broken down into sand sized particles during sample preparation. Moving towards the top of the profile a small sand lens may be seen at 32.5 cm providing evidence of coarser-grained particles being deposited as overbank sedimentation indicating increased stream velocities and a wetter climate.

At site 14.7 km unstable organic matter percentages with two large bulges from 82.5 cm to 115 cm and 52.5 cm to 80 cm are observed (Figure 44). These are correlated with the initial level of contamination at 95 cm. Sand percentages are correlated with the organic matter and zinc levels showing a large decrease from 52.5 cm to 82.5 cm. From 81 cm to 92 cm a chert lens was evident during fieldwork providing evidence of a large flood episode.

At site 8.1 km two increases in organic matter percentages at 42.5 cm to 67.5 cm and 72.5 cm to 105 cm are observed (Figure 45). The initial zinc contamination level is at the 95 cm. Sand percentages show a sand lens at 72.5 cm while field observations showed a chert lens at 107 cm. Sand percentages at this site ultimately increase towards the surface of the profile.

At site 4.3 km there is very little change in either the organic matter or sand percent (Figure 46). A small bulge between 62.5cm and 105 cm in organic matter content is evident as percentages slowly increase towards the surface.

Initial zinc contamination begins at 32.5 cm and peaks at 12.5 cm. Sand percentages are high in lower depths, near the channel, where large amounts of chert may be found as percentages remain consistently low through the rest of the profile.

Calculation of Sedimentation Rates

Temporal Trends

Sedimentation rates of historical overbank deposits are described for two time periods 1886-1916 and 1916-1998 at each site (Table 19 and Figures 47A, 47B, and 47C). Depths of overbank sediments for the Honey Creek watershed between 1886 and 1916 average 24.6 cm range between sites from 0.00 cm to 55.0 cm. In comparison, the mean sedimentation depth is 49.4 cm for the period between 1916 and 1998 and ranges from 2.5 cm to 105.0 cm. The total amount of historical overbank deposition that has occurred in the Honey Creek watershed since 1886 is 74.2 cm with ranges of 7.5 cm to 125.0 cm among the thirteen sites investigated for this study.

While more than double the amount of overbank sediment has been deposited between 1916 and 1998 as compared to the earlier 1886 to 1916 year period, this accumulation has been spread over an 82 year time span rather than a 30-year time span between 1986 and 1916. In order to correct for the

Table 19: Sedimentation depths and rates.

Site	Deposition (cm) 1886-1916	Deposition (cm) 1916-1998	Total Deposition (cm)	Sedimentation Rates 1886-1916 (cm/yr)	Sedimentation Rates 1916-1998 (cm/yr)
24.3	30.0	22.5	55.5	1.00	0.27
23.3	0.0	102.5	102.5	0.00	1.25
21.2	5.0	2.5	7.5	0.17	0.03
20.4	17.5	72.5	90.0	0.58	0.88
18.9	55.0	7.5	62.5	1.83	0.09
16.0	45.0	2.5	47.5	1.50	0.03
14.7	22.5	72.5	95.0	0.75	0.88
13.0	37.5	87.5	125.0	1.25	1.07
9.9	10.0	105.0	115.0	0.33	1.28
8.1	27.5	67.5	95.0	0.92	0.82
6.5	25.0	37.5	62.5	0.83	0.46
4.3	20.0	12.5	32.5	0.67	0.15
Mean	24.6	49.4	74.2	0.82	0.60
Range	0.00-55.0	2.5-105.0	7.5-125.0	0.00-1.83	0.03-1.28

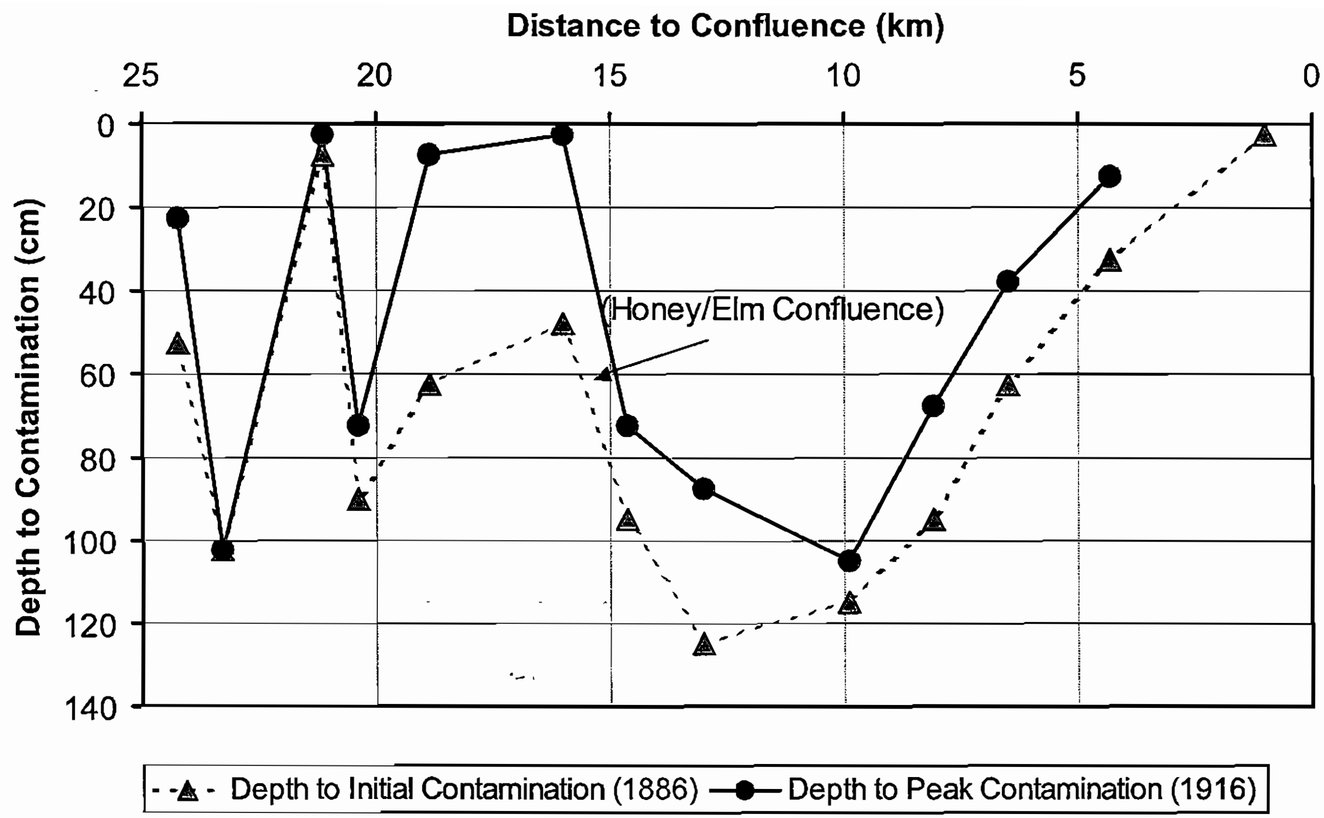

Figure 47A: Downstream changes in historical overbank thickness by distance.

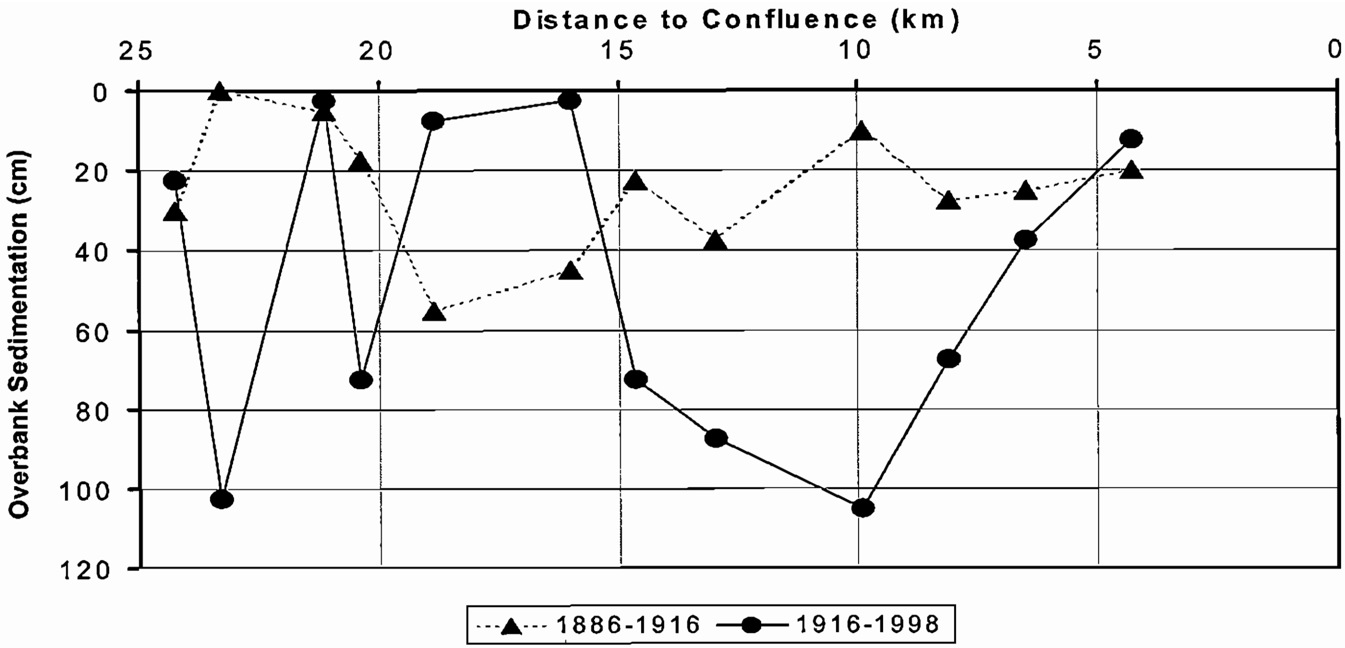

Figure 47B: Comparison of deposit thickness between pre-mining and post-mining peak periods by distance.

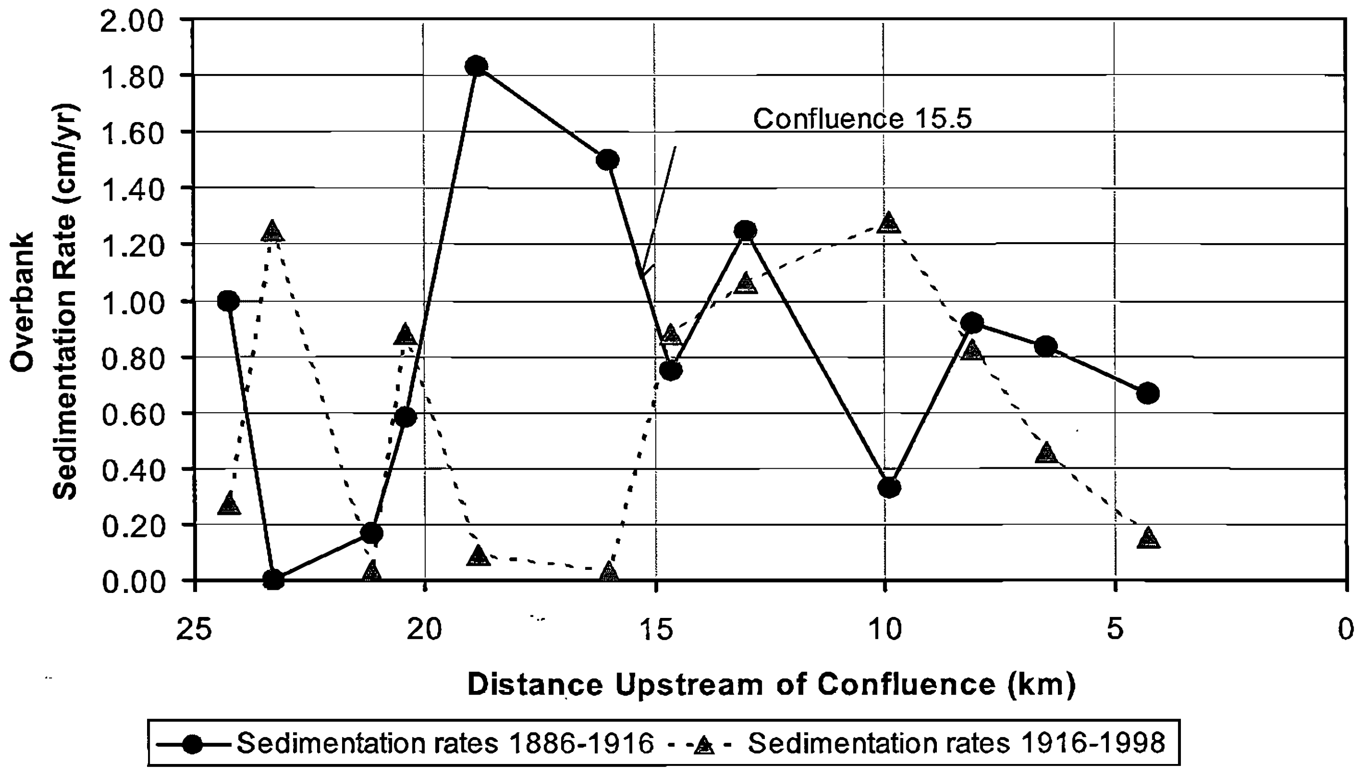

Figure 47C: Downstream changes of sedimentation rates at each site.

differences between the two time spans, sedimentation rates for each site are compared (Table 18 and Figure 47C). Sedimentation rates from 1886-1916 range from 0.00 cm/yr to 1.83 cm/yr with a mean of 0.82 cm/year. Sedimentation rates for 1916-1998 range from 0.03 to 1.28 cm/yr with a mean of 0.60 cm/year.

Spatial Trends

Between 1886 and 1916 the highest depths of overbank sedimentation were deposited in the lower reaches of Elm Branch where drainage areas were between 10 and 30 km^2 (Table 18 and Figures 47A, 47B, and 47C). Additionally, relative high amounts of sediment were deposited along the middle reaches of Honey Creek (Figures 47A, 47B, and 47C). Overbank depths during this time was relatively low within the headward reaches of the Elm Branch until site 21.2 km when sediment deposition began to increase to a peak of 55 cm at site 18.9 km. Depths then decreased to 22.5 cm at site 14.7 just 0.8 km downstream of the Elm/Honey confluence. From this location amounts of sedimentation steadily decreased downstream in the lower Honey Creek to its confluence with Spring River.

Between 1916 and 1998, sedimentation rates were relatively low in the lower Elm Branch with the majority of sediment being deposited in the mid Honey Creek sites (47A, 47B, and 47C). Within the upper reaches of the Elm Branch it may be observed that site 23.3 km received 102.5 cm of deposition. However, this extreme degree of sedimentation is probably related to anthropogenic fills due to the grading of tailings dumps. Moving downstream to site 21.2 km was an area that had been terraced prior to 1916, therefore, it had not received overbank sedimentation since the 1916 era. Site 20.4 km is a local inconsistency with 72.5 cm of sediment being deposited since 1916. At this site a complete historic layer of sedimentation can be seen with no evidence of terracing. Meaning that instead of the channel widening and increasing its capacity, it remained stable in the sense that it retained its ability to go overbank and deposit sediments. Sites 18.9 km and 16.0 km are both terraced and have received very little sedimentation since the 1916 period. Terracing in this sense is a geomorphic process that is a result of historical meander belt development. It is a response of the channel to increased flooding and soil erosion in which the channel increases instability causing an increase in lateral movement and channel capacity ultimately causing a decrease in flooding and overbank deposition (Knox, 1977; 1987; Lecce, 1997). Below the Elm/Honey confluence, located at 15.5 km, large amounts of sediment begin to be deposited within mid Honey Creek sites of 14.7 km, 13.0 km, and 9.9 km. Below site 9.9 km, the depth of sedimentation decreases at a gradual rate towards the Honey/Spring confluence.

Comparison with Previous Studies

Sedimentation rates found within this study are very comparable to other previous studies. Magilligan (1985) studied historical floodplain sedimentation patterns in the Galena River basin, Wisconsin and Illinois using twenty-three stream subsurface floodplain surveys. Depths of overbank deposits were compared to a buried soil which represented the pre-settlement floodplain surface in 1820. Initial surveys were taken in 1940 (Adams) and were resurveyed in 1979 by Magilligan showing average rates of pre-1940 being 1.89 cm/yr and 0.75 cm/yr for post-1940. Magilligan found an association between sediment magnitudes, valley width and drainage area. As valley width increased large accumulations of overbank deposition were found and as valley widths became abnormally narrow overbank deposits became very low. Therefore, Magilligan concluded that zones of deposition were immediately upstream or downstream of a valley constrictions while areas of sediment transport and erosion were common in the constricted areas.

Knox, (1987) used mine sediment tracers to study historical valley floor sedimentation in the upper Mississippi valley. Knox observed 30-50 cm of overbank sedimentation in tributaries since mining with 3-4 m of historical overbank in the main valley. Decadal-scale average sedimentation rates showed a range from 0.3 cm/yr to 4.0-5.0 cm/yr, which exceeded average pre-settlement rates of 0.3 cm/yr. Accelerated sedimentation rates were due to poor agricultural management and frequent above average rainfall episodes.

Faulkner and McIntyre (1996) assessed sediment yields and sediment delivery changes in the Buffalo River, Wisconsin. Faulkner and McIntyre used resurveyed transects and Caesium-137 to find unchanged sedimentation rates of 0.08 cm/yr for 1860-1935 and 1935-1992.

Macklin (1985) used mine sediment tracers to study floodplain sedimentation in the Upper Axe Valley, Mendip, England. Macklin found mining increased fine sediment yields with rates ranging from 0.09 cm/yr to 0.16 cm/yr during active mining with decreasing rates after mining ranging from 0.02 cm/yr to 0.05 cm/year.

Walling and Bradley (1989) used sediment traps, conveyance loss of suspended sediments and Caesium-137 to establish rates and patterns of contemporary floodplain sedimentation in the River Culm, Devon, United Kingdom. Findings show typical sedimentation rates of 0.02 cm/yr with values being in excess of 0.15 cm/year.

Bradley and Cox (1990) used metal concentrations and Caesium-137 to discover the significance of floodplain cycling of metals in the River Derwent, United Kingdom. They found sedimentation rates ranging from 0.08-0.46 cm/year.

Walling et al. (1992) investigated contemporary rates of floodplain sedimentation in the River Culm and the River Ham, United Kingdom, using Caesium-137 methods. Findings show sedimentation rates ranging from 0.0-0.07 on the River Culm with a similar range in rates of 0.0-0.08 cm/yr on the River Ham.

In comparing results from this study to other previous studies similar rates and characteristics of sedimentation may be seen (Table 20). In general overbank sedimentation rates found along Wisconsin streams are higher than in Missouri streams, however, it is found that Missouri streams have higher overbank sedimentation rates than do the studied England or the United Kingdom streams. Larger rates of overbank sedimentation are found just after initial impacts of land clearing and settlement, as found in this study, with elevated rates of 0.82 cm/yr between 1886-1916 and 0.60 cm/yr between 1916-1998. Also various methods such as mine sediment tracers, resurveys, Caesium-137 or sediment traps all offer similar overbank sedimentation rates, when comparing the various studies and locations.

Table 20: Summary of sedimentation rates found in previous studies.

Study	Location	Method	Time interval (cm/yr)	Time interval (cm/yr)	Range (cm/yr)
Magilligan 1985	Galena River, WI	Resurveyed 23 streams	Pre-1940 1.9	Post-1940 0.75	NA
Knox 1987	Mississippi River WI-IL: Freese Site	Mine sediment Tracers	1820-1870 0.8	1870-1916 3.3	0.3-5.0
	Mississippi River WI-IL: Doyle Site		1820-1890 0.29	1890-1925 1.29	
Faulkner and McIntyre 1996	Buffalo River, WI	Resurveyed 33 transects Caesium-137	1860-1935 0.8	1935-1992 0.8	NA
Macklin 1985	Axe River, England	Mine sediment Tracers	Pre-mining Period 0.09-0.16	Post-mining Period 0.02-0.05	NA
Walling and Bradley 1989	River Culm, UK	Sediment Traps, Conveyance Loss and Caesium-137	Typically 0.02	Values Exceeding 0.15	NA
Bradley and Cox 1990	River Derwent, UK	Caesium Measurements And metal Concentrations	NA	NA	0.08-0.45
Walling Quine and He 1992	River Culm River Sevorn	Caesium-137	NA	NA	0.0-0.07 0.0-0.08
Carlson 1998	Honey Creek MO	Mine sediment Tracers	1886-1916 0.82	1916-1998 0.60	0.0-1.83 0.03-1.28

Watershed-scale Trends

The watershed is again divided into four subdivisions: (1) upper Elm; (2) lower Elm; (3)mid Honey; and (4) lower Honey (Table 21 and Figures 48 and 49).

Table 21: Sedimentation trends of the four river reaches found in the study area.

Reach	N	Average Depth 1886-1916 (Cm)	Average Depth 1916-1998 (Cm)	Average Total Depth (Cm)	Average Rate 1886-1916 (Cm/yr)	Average Rate 1916-1998 (Cm/yr)	Total Rate 1886-1916 (Cm/yr)
Upper Elm	4	13.1	50.0	63.1	0.44	0.61	0.56
Lower Elm	2	50.0	5.0	55.0	1.67	0.06	0.49
Mid Honey	4	24.3	83.1	107.5	0.81	1.01	0.96
Lower Honey	2	22.5	25.0	47.5	0.75	0.30	0.42

Upper Elm Branch.

Within the upper Elm Branch, zinc levels and depths of contamination are inconsistent. At sites 24.3 km and 23.3 km very high zinc concentrations exist, while just 2.1 km downstream at site 21.2 km, very low zinc concentrations are observed. Both sites 24.3 km and 23.3 km were located very near mining locations as human impacts account for the inconsistencies in the data. During 1886-1916 very small amounts of overbank sedimentation are observed as this reach was an area of erosion. Later during the 1916-1998 time span, large

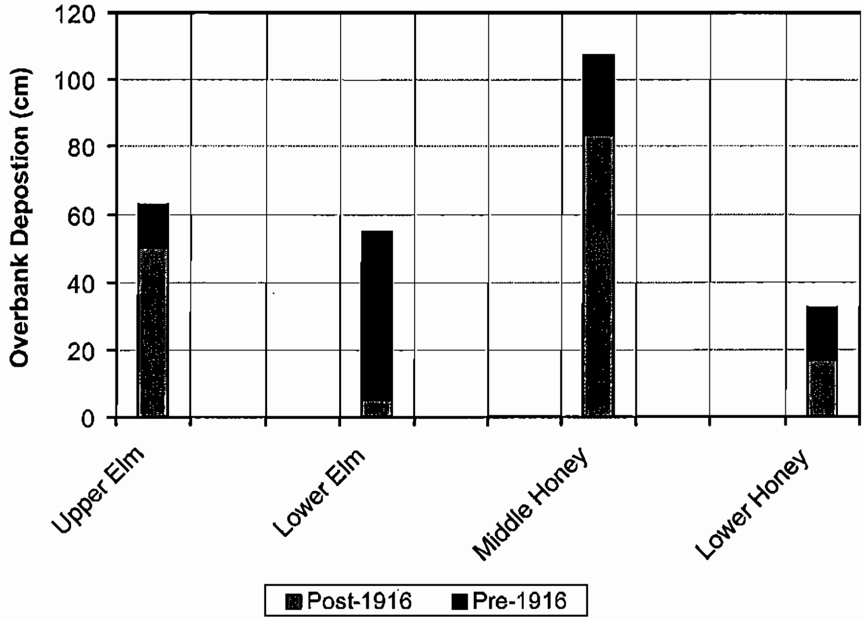

Figure 48: Accumulation of overbank sedimentation for each stream reach.

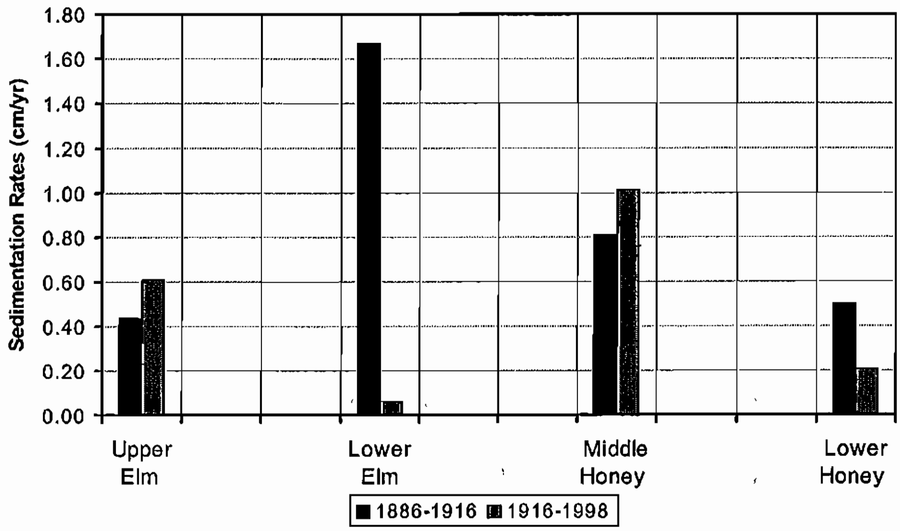

Figure 49: Sedimentation rates for each stream reach.

inconsistencies from site to site are observed in the amounts of overbank sedimentation suggesting instability (Figures 47A, 47B, and 47C).

These variable results suggest different geomorphic responses to site specific changing conditions. Examining specific process that occurred at each site may explain these changing responses. As explain earlier, mine reclamation processes accounting for the high zinc concentrations and the uncharacteristic depths of overbank sedimentation both influence sites 24.3 and 22.5. Site 21.2 km, located in the lower reaches of the upper Elm Branch shows signs of terracing which are evident by the incomplete historic, 1916-1998 soil layer. Terracing, however, may not have been the cause of the incomplete historical layer as three shoot-channels exist at this site. In examining the multiple channels it becomes possible that during episodes of flooding, water and deposition are spread throughout these channels thus accounting for the shallow depth in overbank deposition. Downstream at site 20.4 the opposite extreme exists as 90 cm of overbank deposition have been deposited since 1886. At this site the large amounts of sediment have been transported from upstream sites 24.3 and 23.3 where extensive fill has been placed as well as from site 21.2 where alternative channels have been eroded into the valley bottom. Because this is the first upstream site suitable for deposition, it becomes apparent large accumulations of sediment have been deposited.

Lower Elm Branch.

The lower Elm Branch shows early (1886-1916) deposition and late channel erosion through means of lateral accretion. From 1886-1916 the lower Elm Branch received more overbank sedimentation than any other stretch of the Honey Creek. The source of this sedimentation may be the initial impacts of mining, land clearing due to settlement. From 1916 to 1998 deposition in this area had stopped as lateral accretion and meander belt development increased channel capacity causing terracing of overbank floodplain surfaces.

Middle Honey Creek.

Since 1886, Middle Honey Creek has received more overbank sedimentation than any other in Honey Creek (105.0 cm). This stream reach received large amounts of sedimentation during both time periods with the majority of deposition occurring between 1916 and 1998. In this stream reach large amounts deposition came from the lower Elm Branch, as well as from the unstudied upper Honey Creek, as a result of bank erosion. Higher flood frequencies and magnitudes have caused an increase in rates of bank erosion because of lateral channel migration and meander belt development in the headward reaches. As a result of channel instability in the lower reaches of the Elm Branch the initial wave of sedimentation has been transported downstream to the middle Honey location.

Lower Honey Creek.

Within lower Honey Creek very little sedimentation is observed with overbank deposition depths decreasing further and further downstream. This trend continues to site 1.0 km, where 2.5 cm of overbank sedimentation may be found, since 1886. In explaining why so little overbank sedimentation is found in the lower reaches of Honey Creek several possibilities exist.

First, because the lower reaches of Honey Creek are so far downstream from the mine sources, zinc concentrations are too low and thus limit the ability to identify the 1886 and 1916 tracer depths. This suggests that large amounts of overbank sedimentation may exist in the lower reaches, however, they are simply undetectable with the use of mine contaminant-sediment tracers. A second possibility is that bank erosion is occurring in the upper smaller tributaries as sediments are being deposited on the banks of middle Honey Creek before they reach the lower Honey Creek. Therefore, it is too far for stream power to transport sediments to lower Honey Creek. This would be further supported by the idea that very little bank erosion and lateral movement is occurring in the middle Honey Creek and it is rather an area of stability and deposition. A final possibility is that high stream velocities have lowered channel elevations and in combination increased bank heights thus requiring very large flood events in order for water to go overbank. As the sediments are unable to go overbank they are flushed through the lower Honey Creek and into the Spring River. Combined with this possibility is the increase in valley width, found in the lower reaches of Honey Creek. This increase in valley width would cause sediments to be dispersed over a large area and in tern cause overbank deposits to be very shallow.

Significance to Previous Studies

Jacobson and Primm (1997) assessed historical land-use changes and potential effects on stream disturbance in the Ozarks Plateau, Missouri. In doing so, an elaborate historic land-use record was constructed using land-use data and oral accounts from local residence. Several of the findings in this study correlate with findings in Honey Creek. First, stream instability began in the late 1880s as large amounts of stream erosion and gravel aggradation are described in oral accounts. Historical findings for Honey Creek correlate closely with the 1880 date of initial instability as the population of Aurora and the number of farms in Honey Creek watershed peaked in 1900. While this time period marks peak episodes of land clearing, higher overbank sedimentation rates were found from 1886-1916 suggesting initial episodes of erosion and deposition occurred during this period.

Second, they also observed that land use changes centering around clearing, grazing and railroad construction combined with several extreme floods between 1895 and 1915 as channel banks eroded to supply sediment. Also, upland areas of cultivation were suggested as sediment suppliers. This was supported by a lack of gullied upland and valley-side-slope areas as well as by observations of local respondents that suggest deposition came from upstream runs and valley bottoms rather then hill-slopes. Findings in Honey Creek would also point to relatively small orders of streams as source areas of deposition. This is supported by the distribution of overbank sedimentation being transported form the lower reaches of the Elm Branch to the mid Honey Creek sites.

Thirdly, Jacobson and Primm (1997) describe the greatest rates of accelerated aggradation and channel instability during the 1920 era. Historical land-use changes resulted in a decrease in depth of pools, decrease in depth of riffles, increase in channel width, and ultimately an increase in lateral movement of the channel. Very similar trends may be linked to increases in channel capacities, which were found in Honey Creek during the 1916 period. During this period evidence suggests episodes of terracing and lateral accretion in which wider channels are formed with higher banks increasing channel capacities and decreasing amounts of overbank sedimentation. Examples of these episodes of channel instability are observed within the upper reaches of Honey Creek in sites located in the lower reach of Elm Branch.

Effects of Slope and Valley Width

Stream slope and valley widths in Honey Creek have had weak effects on the amount of sedimentation and the rates at which these sediments were deposited. There is an inverse relationship between stream slope and the amount of sedimentation deposited over time (Figures 50A, 50B, and 50C). In

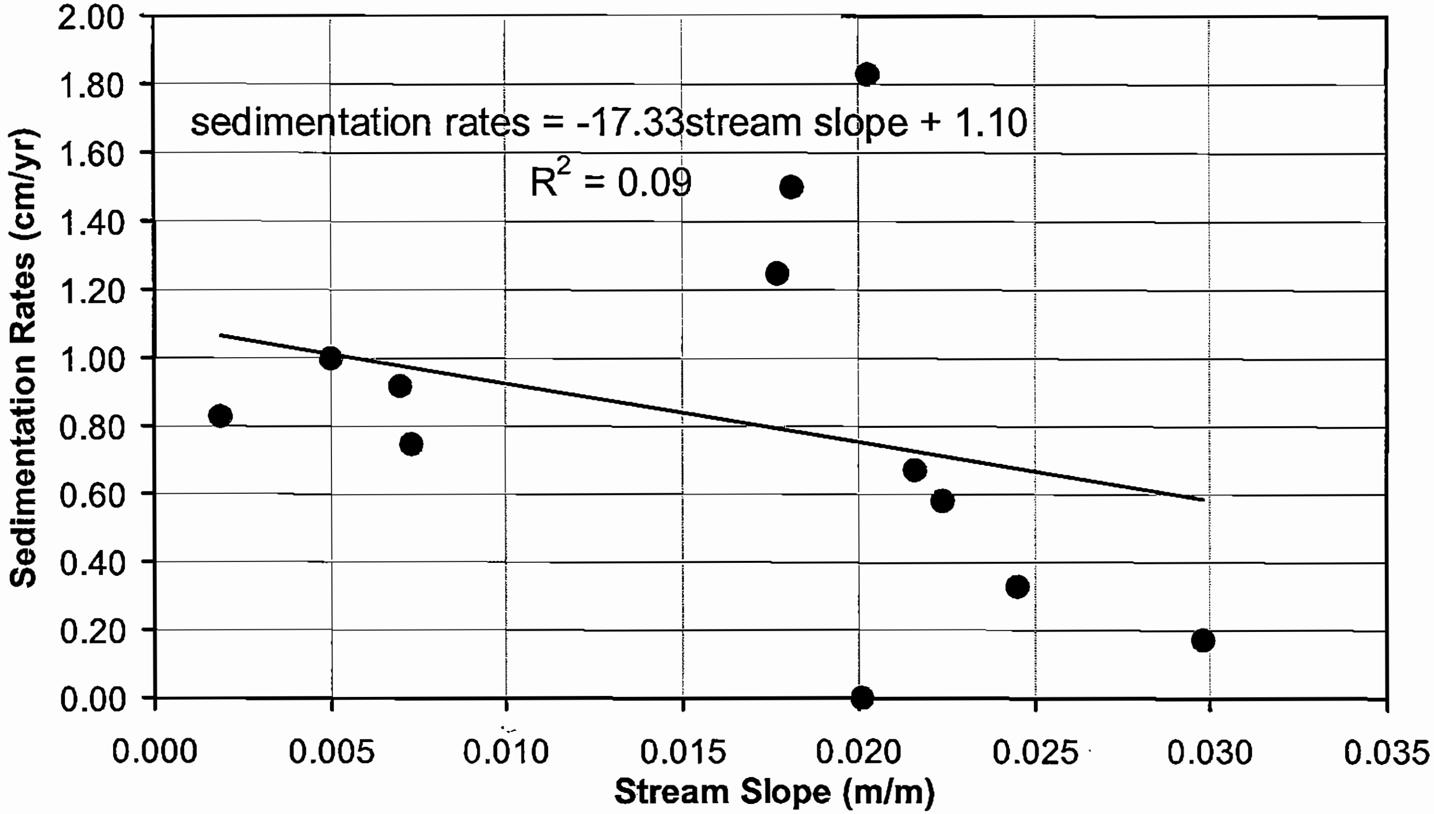

Figure 50A: Relationship between slope and sedimentation rates 1886-1916.

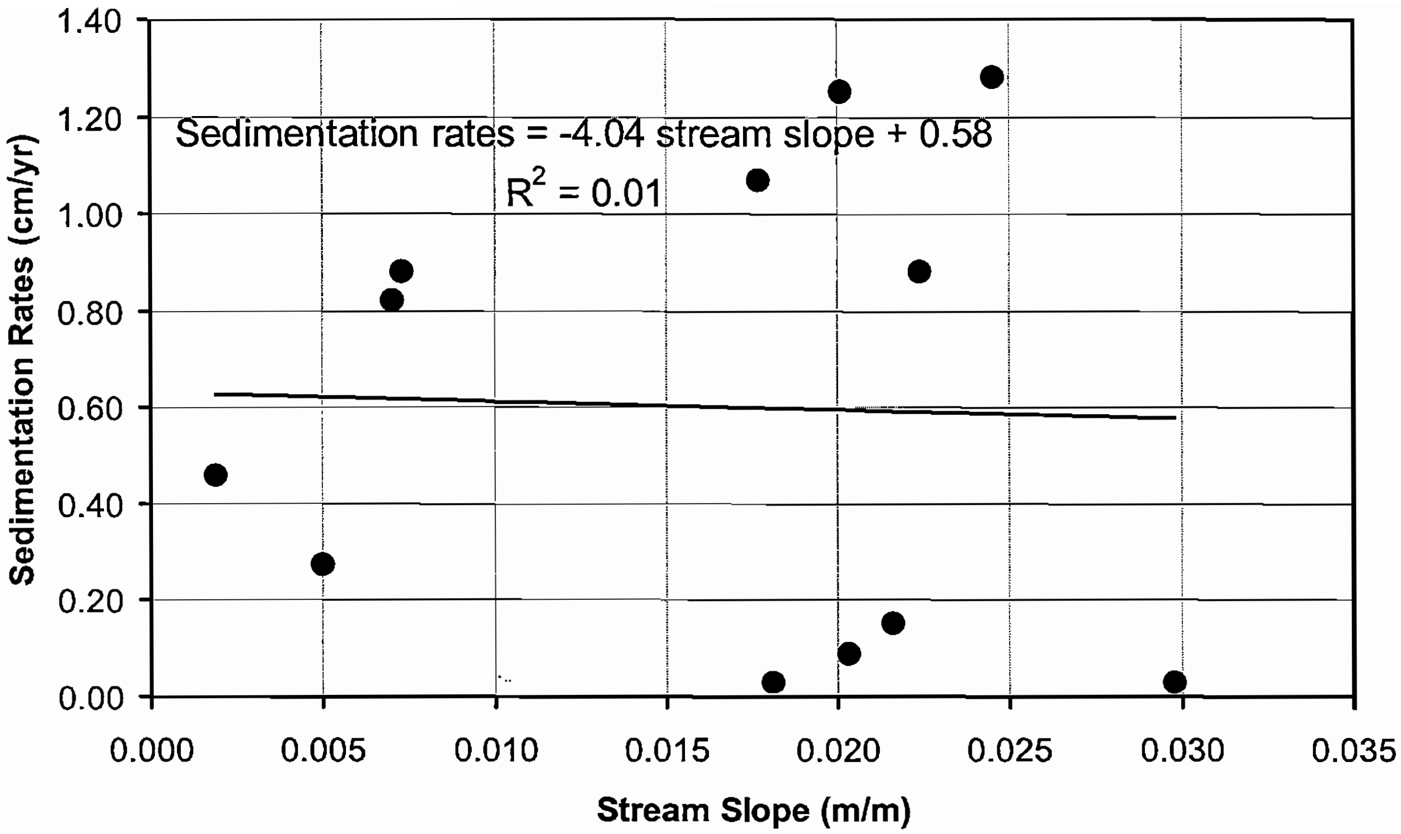

Figure 50B: Relationship between stream slope and sedimentation rates 1916-1998.

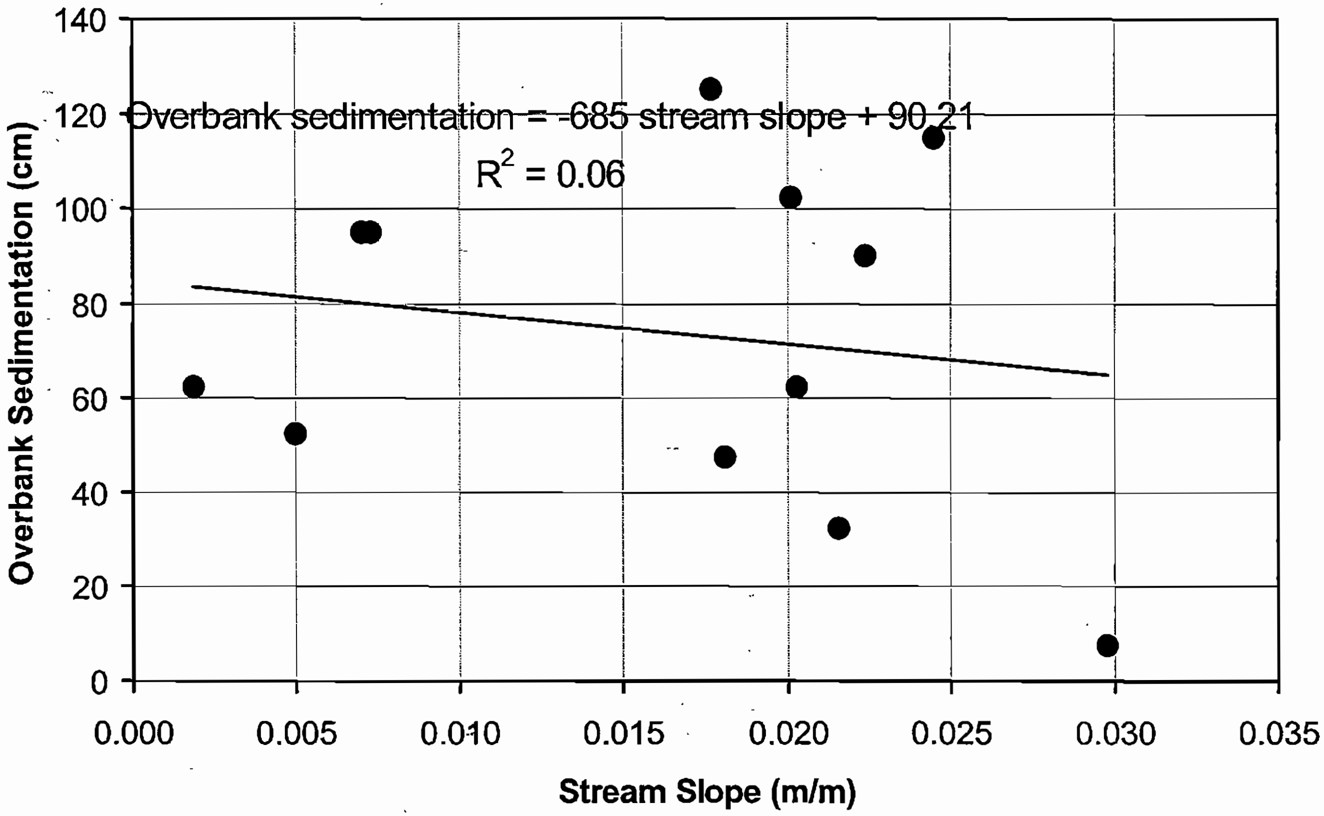

Figure 50C: Stream Slope and amount of total overbank sedimentation since 1886.

comparing the relationship of stream slope to the sedimentation rates of 1886-1916 and 1916-1998, trend line slopes of –11.8 and –4.04 are observed (Figure 50A and 50B). Further evidence that stream slope and sedimentation rates are inversely related may be observed when comparing the relationship of stream slope to the amount of overbank sedimentation at each site (Figure 50C). This relationship yields a slope with a R^2 of 0.06 suggesting a weak inverse relationship between stream sedimentation and stream slope.

The width of the river valley may also have some influence on the amount and rates of sedimentation for an area (Figures 51A, 51B, and 51C). Although no relationship may be found between valley width and sedimentation rates between 1886 and 1916, this is an exception to what occurs later in time looking at valley width and sedimentation rates of 1916-1998 (Figures 51A and 51B). A slope having a R^2 of 0.18 depicts a fairly strong direct relationship, between valley width and sedimentation rates. A similar relationship exists between valley width and depth of sedimentation as a trend line displaying and R^2 of 0.18 (Figure 51C).

Study Summary

Before 1886 effects of settlement within the Honey Creek watershed were sparse, however, populations slowly increased with the onset of zinc and lead mining in1886 (Figure 52). With populations peaking around 1900 production of

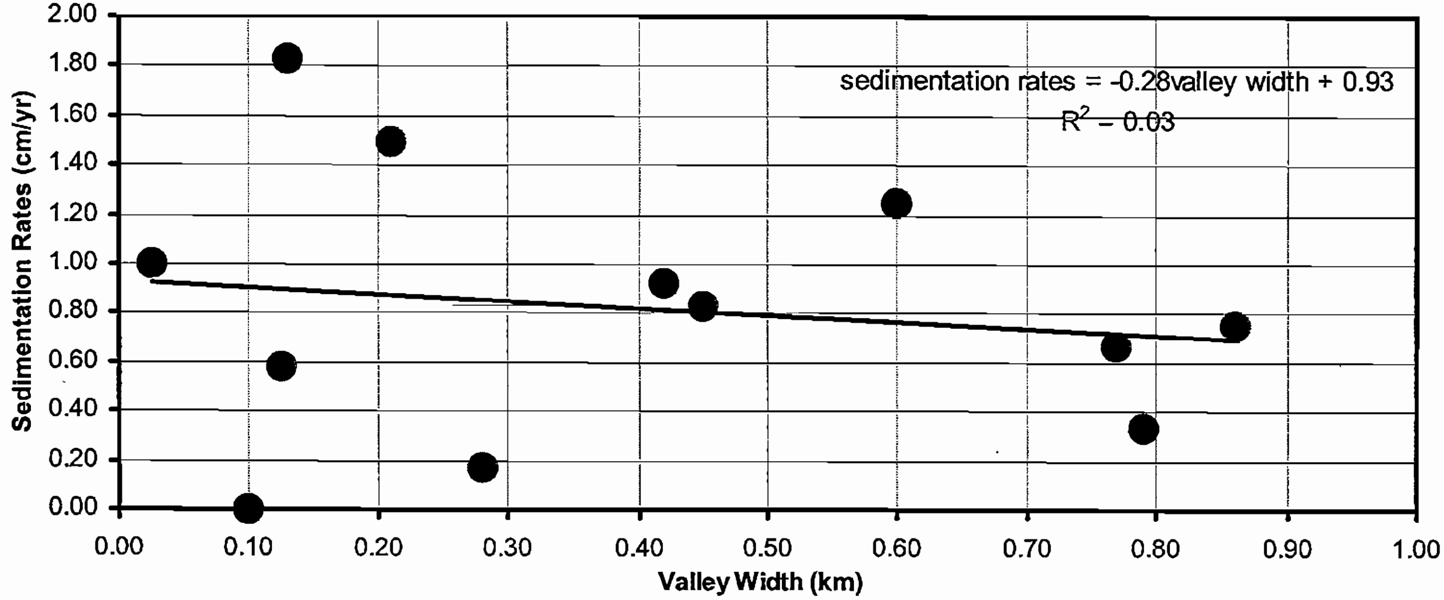

Figure 51A: Relationship between valley width and sedimentation rates 1886-1916.

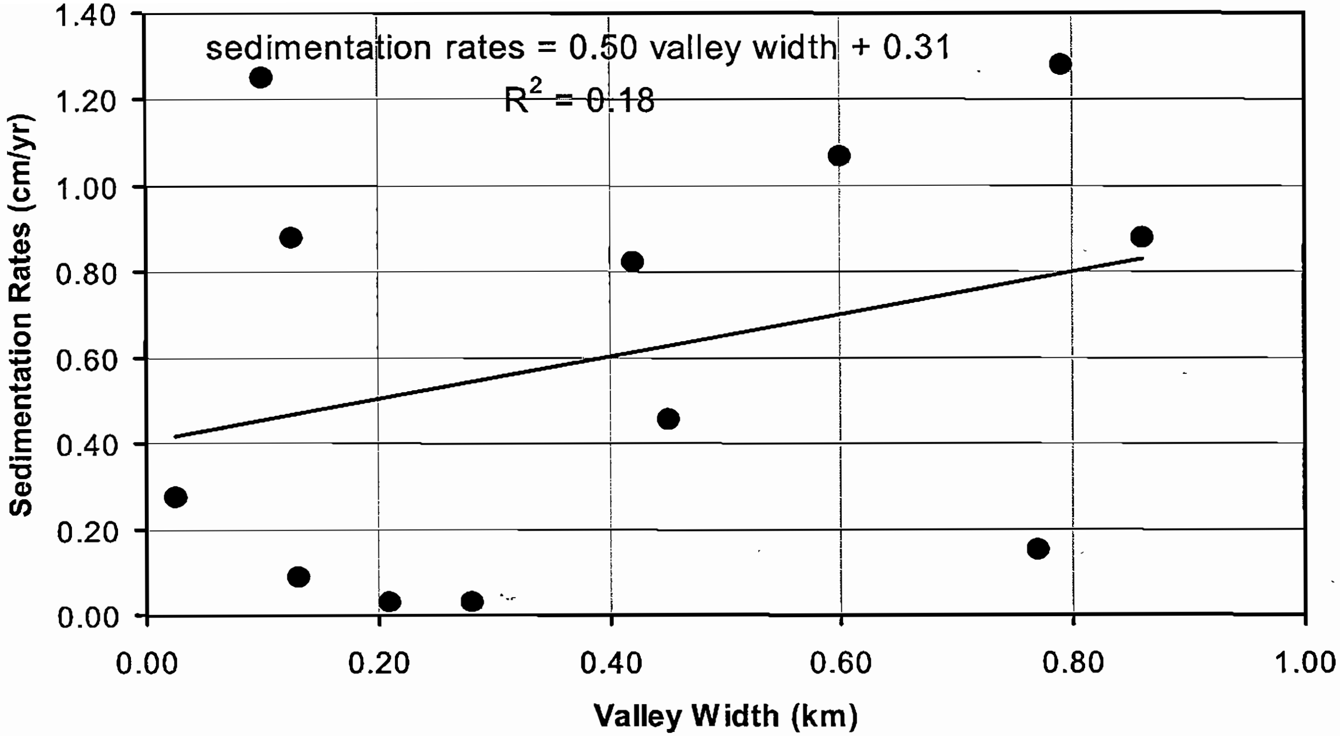

Figure 51B: Relationship between valley width and sedimentation rates 1916-1998.

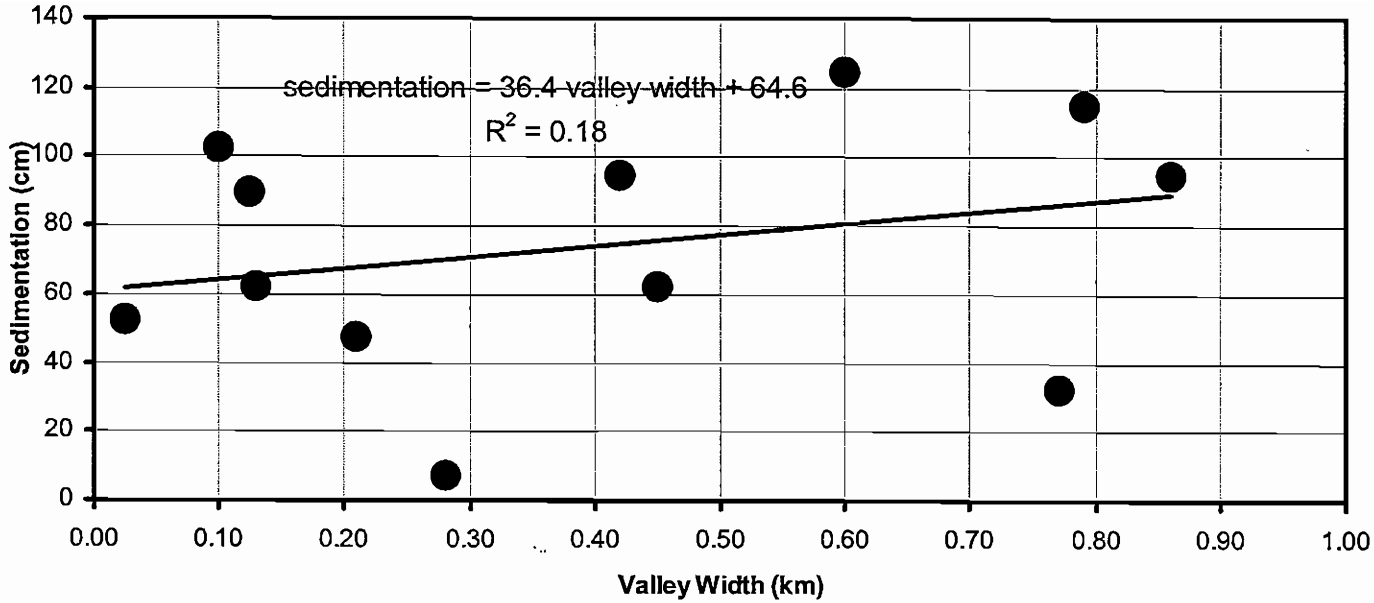

Figure 51C: Relationship between valley Width and overbank deposition in 1998.

History of Study Area					
1870	1886	1900	1916	1950	1998
-Construction of San Francisco Railroad	-Zinc mining begins in the Aurora Subdistrict	-Population of Aurora peaks -Agricultural development within Lawrence County Peaks	-Zinc production peaks	-Zinc mining ends	-Last year of study

Geomorphologic History of Study Area	
1886-1916	1916-1998
-Mean sedimentation rates of.82 cm/yr -Accumulation of a mean of 24.6 cm of overbank -Majority of sedimentation occurring in Lower Elm Branch -Large amounts of sediment occurring in Mid Honey reaches	-Mean sedimentation rates of 0.60 cm/yr -Accumulation of a mean of 49.4 cm of overbank with a mean total of 49.4 cm of overbank -Majority of overbank deposition occurring within the Mid-Honey reaches -Terracing occurring in Elm Branch

Figure 52: Geomorphic timeline of study area.

zinc continued to a climax in 1916 at which time, impacts of mining and land clearing had become well established. Between 1886 and 1916 maximum sedimentation rates of 0.82 cm/yr were the outcome of initial land clearing practices. These inflated sedimentation rates were the response to increases in flood frequencies and magnitudes as well as sediments from groundbreaking and land clearing sites. With flashier floods and increases in sediment sources, initial sediments were deposited in lower Elm Branch (or lower reaches of small tributaries) and in mid reaches of Honey Creek (middle main stream reaches). Soon after 1916, channels began to adjust to the increases in flooding causing lateral accretion and stream bank erosion to occur within the lower reaches of Elm Branch. This instability caused channels to widen and migrate laterally ultimately producing decreased mean sedimentation rates of 0.63 cm/yr with the majority of sedimentation being transported from lower reaches of small tributaries to mid Honey Creek locations.

From 1916 to 1998 mean depths of 49.4 cm of overbank sedimentation had been deposited to equal a mean total of 74.2 cm of deposition. In the later parts of this period mines were shut down with the effects of reclamation being evident in the upper reaches of Elm Branch. Little is known about the lower reaches of Honey Creek as amounts of overbank sedimentation decrease further and further downstream until site 1.0 where 2.5 cm of overbank were found. Chances are large increases in valley width have caused flood water and sediments to be spread out across the wide valley bottom to the degree that large amounts of deposition are displayed with shallow depths. This is supported by the fairly strong inverse relationships found between sedimentation and valley width during the 1916-1998 period.

CHAPTER 6

SUMMARY AND CONCLUSIONS

The purpose of this study was to assess the effects of mid to late 19th century zinc and lead mining and land clearing by: (1) determining the magnitude and spatial distribution of metal contaminants in floodplain sediments; and (2) using contaminant profiles as tracers in overbank deposits to determine patterns and rates of historical overbank sedimentation. Furthermore, a broader goal is to increase the understanding of how mining sediment tracers can be used for geomorphic evaluation of watershed sedimentation history. In order to accomplish these objectives vertical overbank sediment samples were collected at equally spaced cut banks throughout the Honey Creek watershed downstream from the mining complex. These samples were analyzed for geochemical and sedimentologic properties and used to identify the geomorphic characteristics of each site to find watershed trends.

Findings show that the Honey Creek watershed is heavily contaminated by zinc and lead from past episodes of mining (Figure 52). Mining contaminants are spatially-distributed in a longitudinal exponential decay trend in which lead and zinc concentrations decrease with increasing distance and drainage area away from the mine source. Using contaminant profiles related to mine history, relative dates were given to specific sediment layers in each cut bank. Overbank deposition depths, since 1886, were found to average 0.75 m throughout the watershed. Mean sedimentation rates were 0.83 cm/yr between 1886 to 1916 with decreasing rates of 0.60 cm/yr from 1916 through 1998. During active mining maximum amounts of sedimentation were deposited in the lower Elm section of the river while maximum depositional areas migrated downstream to mid Honey Creek sections after mining. Evidence of floodplain terracing and lateral channel accretion exists in the lower Elm Branch sites. This suggests that during the post-mining period sediment sources for overbank deposition in mid Honey Creek were from bank erosion within the lower Elm Branch or increased sediment delivery rates due to the lack of floodplain storage in the tributaries.

Management Implications

Understanding present magnitudes and distributions of mine contaminants in floodplains today are important in river and floodplain management (Eden and Bjorklund, 1996). Although mining has ceased, floodplains continue to store heavy metals such as zinc and lead releasing them by means of channel and bank erosion. Therefore, present-day contamination problems may be more controlled by preventing the reintroduction of metals stored within the floodplain by means of erosion and chemical weathering than by the waste disposal reclamation strategies during mining periods (Lecce and Pavlowsky, 1997). Long-term threats of contamination through means of sediment reworking are the concern of agricultural, soil and hydrologic scientists, fish and wildlife managers, landowners as well as city and environmental planning officials interested in preventing the release of contaminated sediments into active water systems.

Future Work

This study examines the distribution of mine contaminants and overbank sediments by evaluating the longitudinal and vertical changes of zinc and lead in channel and floodplain deposits. While these two aspects of floodplain formation are very important, cross-valley trends and changes in Ozarks floodplains remain unknown. This information is important in understanding the complete long-term threat of sediment pollution while increasing the precision of sedimentation rates throughout the entire floodplain.

Secondly, it is important to extend the area of this study downstream to include areas of more intense mining. This would include the middle and lower stretches of the Spring River near Joplin and Carthage, Missouri. This would allow for further understanding of storage and transport processes of mine contaminants in Ozarks floodplains. Also because these areas have been more extensively mined, contamination problems are potentially more severe.

Thirdly, by using similar methods to this study on other mined watersheds within the Ozarks a more precise understanding of how contaminants are stored and how overbank sedimentation rates vary throughout the Ozarks. How these studies compare and complement each other would greatly increase our understanding of the different processes involved in the transport and storage of contaminated sediments. Correlation of climatic data, especially precipitation data, with sedimentation rate and sediment transport processes would also enhance understanding of the geomorphic systems and contaminant processes.

Final Conclusions

This study has shown that mining and land clearing have had several effects on the floodplain formation in Honey Creek. These effects are as follows:

1. Overbank deposits are heavily contaminated with zinc and lead in Elm Branch, and to a lesser extent in Honey Creek. Maximum zinc levels are 574.9 times the background while mean levels of lead are 70.4 times the background in overbank deposits.

   Mean channel levels of zinc are163.2 times the background while mean channel levels of lead are 20.5 times the background.

   Zinc and lead concentrations in both channel and floodplain sediments decrease exponentially downstream from the mine sources because of dilution with uncontaminated sediments from nearby tributaries and removed by flood plain sedimentation.

2. Channel and floodplains responded immediately after land clearing and mining suggesting they have had impacts upon hydrologic influences in the Honey Creek watershed.

   Mean depths of overbank sedimentation for Honey Creek watershed were 74.2 cm with a range from 7.5 cm to 125.0 cm

   Mean sedimentation rates were 0.82 cm/yr from 1886 to1916 with a range of 0.0 cm/yr to 1.83 cm/yr. Mean sedimentation rates were 0.60 cm/yr with a range from 0.03 cm/yr to 1.28 cm/yr during 1916 to 1998.

3. The initial wave of sediment after mining and land clearing was deposited in the lower Elm (1886-1916 in a drainage area between 10 and 30 km^2). This stored sediment was later transported downstream through means of lateral erosion downstream to mid Honey creek areas.

Between 1916 and 1998 peak levels of deposition were found within middle Honey Creek (drainage area between <100 to 150 km^2) with lateral accretion and terracing occurring in lower Elm Branch.

4. Aluminum concentrations are inversely related to contaminated zinc concentrations, while uncontaminated zinc concentration are not related to Al in overbank deposits.

   Aluminum and Aluminum:Calcium ratios and their relationship with zinc concentrations provided a valuable geochemical difference between pre-mining soils and post-mining soils.

While large-scale reclamation steps have been made in preventing future lead and zinc contamination, high metal concentrations in floodplains continue to represent a long-term environmental threat. The release of floodplain contaminants is controlled by transport and storage processes such as bank erosion in channel and floodplain formation. At the watershed-scale, tributaries, headwaters, mid-stream and lower stream reaches all react to human impacts and changing hydrologic and climatic condition in different ways. While many of these hydrologic responses are understood some remain unknown. For this reason it is important for river managers to continue their attempts to understand the spatial and temporal controls on mining-sediment transport, including their relationships to a highly variable climatic environment.

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APPENDIX A

Concentrations and Percentages in Channel Sediments

CONCENTRATIONS AND PERCENTAGES IN CHANNEL SEDIMENTS

Site	Study No.	Reach	Al %	Ca %	Ca:Al ratio	Co ppm	Cu ppm	Fe %	Mn ppm	P ppm	Pb ppm	Zn ppm
24.3	27	Upper Elm	2.09	0.55	0.26	13	15	2.92	880	310	118	5330
24.3	28	Upper Elm	1.78	0.60	0.34	18	16	4.05	970	390	122	13400
24.3	29	Upper Elm	not/ss	not/ss	not/ss	not/ss	not/ss	not/ss	not/ss	not/ss	not/ss	not/ss
23.3	30	Upper Elm	0.32	2.94	9.19	8	8	1.58	700	260	310	7810
23.3	31	Upper Elm	0.35	2.87	8.20	11	9	1.90	1000	250	326	8720
23.3	32	Upper Elm	0.36	3.91	10.86	10	13	2.00	890	290	412	14800
21.5	39	Upper Elm	0.63	0.24	0.38	7	5	1.37	225	350	24	936
21.5	40	Upper Elm	0.8	0.35	0.44	9	8	1.50	355	610	28	1055
21.5	41	Upper Elm	1.05	0.47	0.45	8	8	1.29	180	360	50	2030
20.4	22	Upper Elm	0.55	0.20	0.36	8	3	1.16	450	190	30	814
20.4	23	Upper Elm	0.72	0.33	0.46	6	4	1.06	320	230	32	1085
20.4	24	Upper Elm	0.63	0.21	0.33	5	4	0.95	260	170	28	812
17.12	45	Control	1.17	0.68	0.58	37	9	3.44	3300	430	54	52
17.12	46	Control	1.01	1.10	1.09	29	7	2.80	2490	410	48	58
17.12	47	Control	1.36	1.26	0.93	40	10	4.08	3120	510	64	176
11.6	19	Middle Honey	1.24	0.55	0.44	11	7	1.72	945	420	22	148
11.6	20	Middle Honey	1.14	0.54	0.47	11	7	1.64	900	400	22	142
11.6	21	Middle Honey	1.24	0.57	0.46	11	8	1.60	945	430	20	154
6.5	16	Lower Honey	1.45	1.12	0.77	12	10	1.69	1000	550	22	138
6.5	17	Lower Honey	1.16	0.89	0.77	14	9	2.22	1155	550	24	144
6.5	18	Lower Honey	1.56	1.27	0.81	14	11	2.13	1235	610	24	154
4.3	33	Lower Honey	1.56	0.34	0.22	18	11	2.84	1565	420	26	256
4.3	34	Lower Honey	1.97	0.32	0.16	23	13	3.46	1895	480	30	136
4.3	35	Lower Honey	2.18	0.35	0.16	20	12	3.06	1645	450	30	234
1	36	Lower Honey	1.71	0.47	0.27	12	10	2.24	620	490	24	152
1	37	Lower Honey	1.58	0.59	0.37	11	10	1.82	690	460	22	158
1	38	Lower Honey	1.75	0.48	0.27	12	10	2.23	825	480	24	154

APPENDIX B

Concentrations and Percentages in Overbank Sediments

CONCENTRATIONS AND PERCENTAGES IN OVERBANK SEDIMENTS

Site (km)	Lat./Long	Drainage Area (km^2	Slope (m/m)	Valley Width (km)	Bankfull Width (m)	Max. Depth (m)	Sinuosity (m/m)	Soil Type
1.0 Lower Honey	N3704.624 W9351.317	174	0.005	1.1	25	4	1.19	Huntington Silt loam

Study No.	Depth(cm) min	Depth(cm) max	Depth(cm) mean	Al %	Ca %	Ca:Al ratio	Fe %	Mn ppm	P ppm	Pb ppm	Zn ppm
537.1	0	5	2.5	0.89	0.39	0.44	0.98	720	360	18	66
537.2	5	10	7.5	0.84	0.19	0.23	0.92	635	240	14	52
538	10	15	12.5	1.12	0.18	0.16	1.08	855	240	20	54
539	15	20	17.5	1.10	0.15	0.14	1.04	640	220	12	52
540	20	25	22.5	1.16	0.12	0.10	1.09	600	170	14	50
541	25	30	27.5	1.07	0.11	0.10	1.03	820	160	14	46
542	30	35	32.5	1.15	0.11	0.10	1.10	620	140	14	48
543	35	40	37.5	1.23	0.13	0.11	1.14	650	150	14	50
544	40	45	42.5	1.44	0.14	0.10	1.25	665	140	14	54
545	45	50	47.5	1.35	0.15	0.11	1.23	655	140	12	56
546	50	55	52.5	1.56	0.15	0.10	1.34	680	140	14	58
547	55	60	57.5	1.61	0.16	0.10	1.37	745	160	14	64
548	60	65	62.5	1.68	0.16	0.10	1.40	690	150	14	64
549	65	70	67.5	1.58	0.15	0.09	1.37	840	150	14	62
550	70	75	72.5	1.74	0.16	0.09	1.46	655	160	14	64
551	75	80	77.5	1.64	0.16	0.10	1.50	580	160	12	68
552	80	85	82.5	1.78	0.16	0.09	1.59	685	170	14	66
553	85	90	87.5	1.82	0.14	0.08	1.53	615	170	14	66
554	90	95	92.5	1.83	0.13	0.07	1.52	700	180	16	64
555	95	100	97.5	1.85	0.13	0.07	1.53	395	170	12	66
556	100	105	102.5	1.85	0.13	0.07	1.56	855	190	16	68
557	105	110	107.5	1.72	0.16	0.09	1.44	515	180	14	62
558	110	115	112.5	1.73	0.12	0.07	1.44	815	180	14	56
559	115	120	117.5	1.60	0.11	0.07	1.40	440	160	14	48
560	120	125	122.5	2.11	0.12	0.06	1.64	410	200	12	58
561	125	130	127.5	2.24	0.12	0.05	1.75	500	220	14	60
562	130	140	135.0	2.17	0.11	0.05	1.74	485	250	16	54
563	140	150	145.0	1.97	0.09	0.05	1.75	515	240	14	50
564	150	160	155.0	2.25	0.09	0.04	1.88	415	230	14	54
565	160	170	165.0	2.03	0.09	0.04	1.90	550	240	14	52
566	170	180	175.0	2.48	0.09	0.04	2.01	495	240	14	58
567	180	190	185.0	2.21	0.10	0.05	1.99	835	240	16	56
568	190	200	195.0	2.32	0.11	0.05	2.08	775	270	16	56
569	200	210	205.0	2.22	0.13	0.06	2.06	940	240	20	62
570	210	220	215.0	1.74	0.11	0.06	1.74	565	200	14	50
571	220	230	225.0	1.53	0.14	0.09	1.72	725	190	12	50
572	230	240	235.0	1.64	0.16	0.10	1.86	1005	220	16	56
573	240	250	245.0	1.84	0.16	0.09	1.96	730	230	14	58
574	250	260	255.0	2.24	0.20	0.09	2.48	915	300	18	76

Site (km)	Lat./Long	Drainage Area (km^2	Slope (m/m)	Valley Width (km)	Bankfull Width (m)	Max. Depth (m)	Sinuosity (m/m)	Soil Type
4.3 Lower Honey	N3703.615 W9349.840	167	0.022	0.77	23	2.3	1.63	Huntington Silt loam

Study No.	Depth(cm) min	max	mean	Al %	Ca %	Ca:Al ratio	Fe %	Mn ppm	P ppm	Pb ppm	Zn ppm	Sand %	OM %
514	0	5	2.5	1.13	0.34	0.30	1.18	1000	450	34	266	2.40	6.88
515	5	10	7.5	1.31	0.28	0.21	1.24	1025	410	24	276	1.51	4.31
516	10	15	12.5	1.01	0.16	0.16	1.08	935	350	64	292	1.16	3.37
517	15	20	17.5	0.85	0.14	0.16	0.94	900	330	16	90	1.16	3.03
518	20	25	22.5	1.08	0.14	0.13	1.12	985	330	20	104	0.91	2.99
519	25	30	27.5	1.07	0.12	0.11	1.13	975	270	12	62	0.99	2.56
520	30	35	32.5	1.42	0.16	0.11	1.27	970	240	24	94	1.08	2.69
521	35	40	37.5	1.44	0.13	0.09	1.27	1015	230	12	58	0.98	2.01
522	40	45	42.5	1.64	0.14	0.09	1.35	965	210	14	58	1.14	2.22
523	45	50	47.5	1.69	0.15	0.09	1.40	960	210	12	54	0.95	2.25
524	50	55	52.5	1.74	0.15	0.09	1.37	850	210	14	54	1.11	2.26
525	55	60	57.5	1.72	0.16	0.09	1.44	765	210	12	52	1.17	2.27
526	60	65	62.5	2.07	0.18	0.09	1.66	630	210	14	52	0.85	2.79
527	65	70	67.5	2.24	0.19	0.08	1.76	595	240	16	60	1.14	2.60
528	70	75	72.5	2.23	0.19	0.09	1.74	590	230	14	54	0.87	2.62
529	75	80	77.5	2.21	0.21	0.10	1.88	645	260	12	56	0.97	2.75
530	80	90	85.0	2.75	0.22	0.08	2.12	685	270	16	60	1.11	2.71
531	90	100	95.0	2.01	0.21	0.10	1.82	625	280	14	54	1.26	2.88
532	100	110	105.0	2.22	0.19	0.09	1.91	575	260	14	58	1.80	2.94
533	110	120	115.0	2.31	0.21	0.09	1.96	670	290	14	58	1.96	2.69
534	120	130	125.0	2.60	0.21	0.08	2.06	635	290	16	66	3.94	2.44
535	130	140	135.0	1.92	0.19	0.10	2.02	620	280	18	86	11.20	2.41
536.1	140	150	145.0	2.01	0.18	0.09	2.22	895	310	18	64	22.89	2.36
536.2	150	170	160.0	1.62	0.17	0.10	2.07	915	280	16	54	23.82	2.39

Site (km)	Lat./Long	Drainage Area (km^2	Slope (m/m)	Valley Width (km)	Bankfull Width (m)	Max. Depth (m)	Sinuosity (m/m)	Soil Type	Secondary Soil type
6.5 Lower Honey	N3703.351 W9348.362	159	0.002	0.45	18.5	2.7	1.22	Huntington Silt loam	Lanton Silt Loam

Study No.	Depth(cm) min	max	mean	Al %	Ca %	Ca:Al ratio	Cu ppm	Fe %	Mn ppm	P ppm	Pb ppm	Zn ppm
324	0	5	2.5	1.33	0.30	0.23	13	1.32	940	370	20	118
325	5	10	7.5	1.09	0.28	0.26	14	1.14	885	340	20	114
326	10	15	12.5	1.36	0.24	0.18	11	1.23	855	270	20	114
327	15	20	17.5	1.22	0.24	0.20	11	1.19	905	290	20	118
328	20	25	22.5	1.37	0.24	0.18	13	1.22	850	250	20	116
329	25	30	27.5	1.08	0.23	0.21	12	1.09	855	230	18	112
330	30	35	32.5	1.25	0.22	0.18	13	1.12	825	230	20	114
331	35	40	37.5	1.10	0.24	0.22	11	1.05	850	280	20	118
332	40	45	42.5	1.30	0.23	0.18	12	1.10	785	310	18	110
333	45	50	47.5	1.16	0.20	0.17	10	1.03	760	360	20	92
334	50	55	52.5	1.58	0.17	0.11	14	1.23	800	400	16	86
335	55	60	57.5	1.48	0.16	0.11	11	1.25	830	390	14	78
336	60	65	62.5	1.62	0.17	0.10	11	1.30	800	340	14	74
337	65	70	67.5	1.40	0.17	0.12	11	1.20	700	330	16	58
338	70	75	72.5	1.73	0.19	0.11	11	1.37	660	310	12	56
339	75	80	77.5	1.45	0.19	0.13	11	1.26	650	290	14	52
340	80	85	82.5	1.85	0.21	0.11	11	1.42	660	280	14	58
341	85	90	87.5	1.52	0.20	0.13	11	1.28	580	290	12	52
342	90	95	92.5	1.82	0.21	0.12	18	1.38	640	280	16	58
343	95	100	97.5	1.47	0.19	0.13	15	1.25	680	200	12	48
344	100	110	105.0	1.64	0.20	0.12	11	1.32	620	200	14	44
345	110	120	115.0	1.52	0.20	0.13	11	1.29	635	170	10	40
346	120	130	125.0	1.87	0.22	0.12	12	1.43	450	170	14	44
347	130	140	135.0	1.80	0.22	0.12	10	1.42	475	160	10	40
348	140	150	145.0	2.08	0.22	0.11	12	1.50	335	150	12	44
349	150	170	160.0	1.68	0.22	0.13	10	1.27	260	110	12	42
350	170	190	180.0	1.77	0.24	0.14	10	1.28	275	140	14	48
351	190	210	200.0	1.54	0.22	0.14	9	1.93	365	230	14	50

Site (km)	Lat/Long	Drainage Area (km^2	Slope (m/m)	Valley Width (km)	Bankfull Width (m)	Max. Depth (m)	Sinuosity (m/m)	Soil Type
8.1 Middle Honey	N3702.901 W9347.688	155	0.007	0.42	12.5	1.9	1.46	Huntington Silt loam

Study No.	Depth(cm) min	max	mean	Al %	Ca %	Ca:Al ratio	Fe %	Mn ppm	P ppm	Pb ppm	Zn ppm	Sand %	Om %
471	0	5	2.5	1.06	0.23	0.22	2.18	1080	490	28	122	65.85	3.72
472	5	10	7.5	1.14	0.23	0.20	2.31	1105	460	28	132	65.75	3.00
473	10	15	12.5	1.10	0.26	0.24	1.67	895	400	24	116	44.50	3.83
474	15	20	17.5	1.26	0.30	0.24	1.65	960	360	24	132	27.76	3.81
475	20	25	22.5	1.23	0.28	0.23	1.64	940	310	26	130	27.80	3.48
476	25	30	27.5	1.29	0.28	0.22	1.51	835	240	24	122	18.77	3.52
477	30	35	32.5	1.37	0.29	0.21	1.69	1005	250	26	126	23.71	3.28
478	35	40	37.5	1.36	0.28	0.21	1.55	890	250	24	126	17.04	3.10
479	40	45	42.5	1.58	0.28	0.18	1.89	1030	290	26	114	28.51	2.89
480	45	50	47.5	1.78	0.31	0.17	1.87	1000	270	26	114	24.47	3.31
481	50	55	52.5	1.81	0.33	0.18	1.71	945	260	26	124	10.39	3.42
482	55	60	57.5	1.73	0.35	0.20	1.53	845	240	24	148	4.56	3.62
483	60	65	62.5	1.68	0.35	0.21	1.57	875	250	24	156	7.06	3.11
484	65	70	67.5	1.42	0.32	0.23	1.65	925	260	26	160	22.02	2.90
485	70	75	72.5	1.23	0.23	0.19	2.51	1240	360	32	110	51.63	2.29
486	75	80	77.5	1.45	0.32	0.22	1.65	850	240	24	116	17.34	3.05
487	80	85	82.5	1.66	0.39	0.23	1.54	970	230	24	144	6.74	3.23
488	85	90	87.5	1.58	0.34	0.22	1.67	995	260	24	120	17.34	2.96
489	90	100	95.0	1.30	0.35	0.27	1.69	940	260	24	116	20.62	2.97
490	100	110	105.0	1.30	0.29	0.22	1.6	695	200	18	68	16.44	2.71
491	110	120	115.0	1.29	0.31	0.24	1.43	710	170	16	52	13.57	3.13
492	120	130	125.0	1.52	0.33	0.22	1.71	720	210	18	60	18.68	3.26

Site (km)	Lat./Long	Drainage Area (km^2	Slope (m/m)	Valley Width (km)	Bankfull Width (m)	Max. Depth (m)	Sinuosity (m/m)	Soil Type
9.9 Middle Honey	N3702.581 W9347.041	150	0.025	0.79	40	1.2	1.07	Huntington Silt loam

Study No.	Depth(cm) min	Depth(cm) max	Depth(cm) mean	Al %	Ca %	Ca:Al ratio	Fe %	Mn ppm	P ppm	Pb ppm	Zn ppm
575	0	5	2.5	1.66	0.40	0.24	1.97	1030	500	24	152
576	5	10	7.5	1.73	0.38	0.22	1.96	1055	480	22	156
577	10	15	12.5	1.64	0.31	0.19	1.85	995	410	22	132
578	15	20	17.5	1.53	0.28	0.18	1.74	885	350	22	124
579	20	25	22.5	1.69	0.33	0.20	1.87	990	380	22	136
580	25	30	27.5	1.70	0.32	0.19	1.89	955	390	22	132
581	30	35	32.5	1.50	0.26	0.17	2.12	990	400	24	124
582	35	40	37.5	1.54	0.27	0.18	3.18	1920	560	32	138
583	40	45	42.5	1.03	0.17	0.17	2.89	1740	480	36	94
584	45	50	47.5	1.34	0.25	0.19	2.79	1655	450	30	136
585	50	55	52.5	1.27	0.27	0.21	1.85	885	320	22	114
586	55	60	57.5	1.36	0.22	0.16	2.52	1390	380	28	212
587	60	65	62.5	1.17	0.16	0.14	3.59	1855	530	30	116
588	65	70	67.5	1.33	0.17	0.13	3.89	2480	570	40	110
589	70	80	75.0	1.20	0.13	0.11	4.44	1945	640	40	136
590	80	90	85.0	1.41	0.13	0.09	3.63	1785	530	36	116
591	90	100	95.0	1.16	0.12	0.10	3.61	1805	520	30	158
592	100	110	105.0	1.38	0.13	0.09	4.51	1980	640	48	204
593	110	120	115.0	1.09	0.18	0.17	4.26	2750	620	42	130

Site (km)	Lat./Long	Drainage Area (km^2	Slope (m/m)	Valley Width (km)	Bankfull Width (m)	Max. Depth (m)	Sinuosity (m/m)	Soil Type	Secondary Soil Type
13.0 Middle Honey	N3702.538 W9345.645	130	0.018	0.6	20.5	2.36	1.3	Huntington Silt loam	Clarksville Cherty silt loam

Study No.	Depth(cm) min	max	mean	Al %	Ca %	Ca:Al ratio	Fe %	Mn ppm	P ppm	Pb ppm	Zn ppm
449	0	5	2.5	1.11	0.29	0.26	1.24	750	300	24	188
450	5	10	7.5	1.15	0.33	0.29	1.29	790	310	26	200
451	10	15	12.5	1.08	0.28	0.26	1.25	790	260	26	180
452	15	20	17.5	1.17	0.28	0.24	1.30	805	270	28	200
453	20	25	22.5	1.19	0.24	0.20	1.28	790	210	24	194
454	25	30	27.5	1.24	0.23	0.19	1.28	775	200	26	204
455	30	35	32.5	1.24	0.21	0.17	1.27	745	180	26	186
456	35	40	37.5	1.34	0.23	0.17	1.35	850	190	26	204
457	40	45	42.5	1.38	0.24	0.17	1.35	855	190	26	196
458	45	50	47.5	1.32	0.24	0.18	1.32	845	190	24	170
459	50	55	52.5	1.11	0.20	0.18	1.22	730	180	22	134
460	55	60	57.5	1.29	0.24	0.19	1.30	840	190	24	176
461	60	65	62.5	1.34	0.24	0.18	1.33	885	210	24	164
462	65	70	67.5	1.28	0.24	0.19	1.29	860	200	26	208
463	70	75	72.5	1.21	0.25	0.21	1.32	910	210	26	220
464	75	80	77.5	1.18	0.26	0.22	1.30	900	210	32	308
465	80	85	82.5	1.09	0.25	0.23	1.35	955	230	40	514
466	85	90	87.5	1.19	0.24	0.20	1.36	960	240	58	922
467	90	100	95.0	1.35	0.25	0.19	1.42	975	280	58	920
468	100	110	105.0	1.43	0.26	0.18	1.39	630	250	28	190
469	110	120	115.0	1.60	0.28	0.18	1.47	650	220	20	88
470	120	130	125.0	1.56	0.28	0.18	1.56	565	230	16	66

Site (km)	Lat/Long	Drainage Area (km^2	Slope (m/m)	Valley Width (km)	Bankfull Width (m)	Max. Depth (m)	Sinuosity (m/m)	Soil Type
14.7 Middle Honey	N3702.495 W9344.464	111	0.007	0.86	9.7	2.44	1.27	Waben Cedargap Cherty silt loam

Study No.	Depth(cm) min	max	mean	Al %	Ca %	Ca:Al ratio	Fe %	Mn ppm	P ppm	Pb ppm	Zn ppm	Sand %	OM %
426	0	5	2.5	1.16	0.35	0.30	1.31	820	410	22	200	15.61	6.42
427	5	10	7.5	1.21	0.36	0.30	1.33	825	380	22	200	13.45	6.06
428	10	15	12.5	1.23	0.29	0.24	1.30	810	310	24	210	11.88	4.73
429	15	20	17.5	1.20	0.28	0.23	1.30	845	290	24	214	10.83	3.93
430	20	25	22.5	1.25	0.26	0.21	1.30	835	260	24	212	9.93	3.71
431	25	30	27.5	1.35	0.24	0.18	1.34	830	240	22	206	11.42	3.61
432	30	35	32.5	1.28	0.24	0.19	1.32	825	210	24	210	10.93	3.50
433	35	40	37.5	1.27	0.23	0.18	1.26	780	200	22	218	11.81	3.01
434	40	45	42.5	1.24	0.23	0.19	1.29	815	190	22	230	10.87	3.10
435	45	50	47.5	1.10	0.21	0.19	1.19	760	180	20	194	17.20	2.90
436	50	55	52.5	1.09	0.22	0.20	1.23	820	190	22	238	20.21	3.19
437	55	60	57.5	1.12	0.23	0.21	1.26	835	190	26	294	16.79	3.40
438	60	65	62.5	1.14	0.24	0.21	1.30	870	200	30	404	15.33	3.12
439	65	70	67.5	1.16	0.23	0.20	1.26	815	200	34	480	13.53	3.04
440	70	75	72.5	1.27	0.23	0.18	1.30	870	210	34	546	10.41	3.14
441	75	80	77.5	1.27	0.24	0.19	1.34	835	210	32	268	9.36	3.17
442	80	85	82.5	1.04	0.23	0.22	1.27	725	210	20	98	31.88	2.58
443	85	90	87.5	1.16	0.22	0.19	1.34	790	220	18	74	32.20	2.79
444	90	100	95.0	1.20	0.24	0.20	1.29	820	200	20	58	21.38	2.82
445	100	110	105.0	1.21	0.26	0.21	1.25	765	190	14	42	22.32	2.73
446	110	120	115.0	0.98	0.2	0.20	1.49	540	220	16	54	32.22	2.32
447	120	130	125.0	0.94	0.18	0.19	2.08	510	300	18	82	45.80	2.15
448	130	140	135.0	1.65	0.33	0.20	1.39	750	150	14	58	6.09	3.21

Site (km)	Lat./Long	Drainage Area (km^2	Slope (m/m)	Valley Width (km)	Bankfull Width (m)	Max. Depth (m)	Sinuosity (m/m)	Soil Type
16.0 Lower Elm	N3701.437 W9343.105	21	0.018	0.21	10.1	2.4	1.11	Huntington Silt loam

Study No.	Depth(cm) min	max	mean	Al %	Ca %	Ca:Al ratio	Fe %	Mn ppm	P ppm	Pb ppm	Zn ppm
392	0	5	2.5	1.08	0.14	0.13	1.43	765	240	26	330
393	5	10	7.5	1.25	0.16	0.13	1.37	755	230	26	300
394	10	15	12.5	1.27	0.17	0.13	1.31	750	230	26	288
395	15	20	17.5	1.35	0.20	0.15	1.30	785	230	20	248
396	20	25	22.5	1.33	0.20	0.15	1.28	800	230	22	222
397	25	30	27.5	1.35	0.20	0.15	1.22	785	230	18	194
398	30	35	32.5	1.49	0.20	0.13	1.29	785	240	16	154
399	35	40	37.5	1.44	0.18	0.13	1.24	685	210	14	106
400	40	45	42.5	1.49	0.17	0.11	1.30	710	200	16	88
401	45	50	47.5	1.44	0.15	0.10	1.25	585	190	14	74
402	50	55	52.5	1.53	0.15	0.10	1.37	660	190	14	64
403	55	60	57.5	1.67	0.16	0.10	1.49	645	200	16	66
404	60	65	62.5	2.00	0.16	0.08	1.68	630	190	16	64
405	65	70	67.5	2.03	0.15	0.07	1.70	520	200	16	62
406	70	75	72.5	1.85	0.14	0.08	1.60	380	180	12	60
407	75	85	80.0	1.84	0.14	0.08	1.73	470	190	16	56
408	85	95	90.0	1.76	0.13	0.07	1.79	425	180	18	60

Site (km)	Lat./Long	Drainage Area (km^2	Slope (m/m)	Valley Width (km)	Bankfull Width (m)	Max. Depth (m)	Sinuosity (m/m)	Soil Type
18.9 Lower Elm	N3701.220 W9342.757	16.0	0.02	0.13	5	1.7	1.05	Secesh Cedargap Silt Loam

Study No.	Depth(cm) min	max	mean	Al %	Ca %	Ca:Al ratio	Cu ppm	Fe %	Mn ppm	P ppm	Pb ppm	Zn ppm	Sand %	OM %
352	0	5	2.5	1.11	0.36	0.32	27	1.20	705	840	30	594	43.18	5.99
353	5	10	7.5	1.12	0.31	0.28	20	1.24	770	660	36	1125	37.82	4.44
355	10	15	12.5	1.26	0.33	0.26	14	1.26	685	460	36	1015	29.86	3.56
356	15	20	17.5	1.09	0.21	0.19	13	1.11	625	380	34	656	26.59	3.28
357	20	25	22.5	1.32	0.21	0.16	11	1.27	650	330	36	600	28.07	2.87
358	25	30	27.5	1.13	0.19	0.17	9	1.12	580	220	34	494	28.73	2.83
359	30	35	32.5	1.24	0.17	0.14	9	1.11	510	160	20	318	33.43	2.43
360	35	40	37.5	1.22	0.16	0.13	8	1.13	435	150	14	204	34.28	2.31
361	40	45	42.5	1.61	0.16	0.10	8	1.29	415	140	14	148	30.74	2.09
362	45	50	47.5	1.53	0.16	0.10	8	1.26	475	150	10	100	31.19	2.00
363	50	55	52.5	1.77	0.16	0.09	8	1.31	535	140	12	88	30.23	1.96
364	55	60	57.5	1.72	0.15	0.09	8	1.33	540	160	12	68	29.11	2.09
365	60	65	62.5	1.93	0.15	0.08	8	1.44	590	160	10	62	29.90	1.79
366	65	70	67.5	1.70	0.14	0.08	8	1.31	440	150	10	56	28.76	2.03
367	70	80	75.0	1.86	0.14	0.08	8	1.33	300	150	10	54	28.38	2.17
368	80	90	85.0	1.73	0.13	0.08	8	1.34	300	170	10	54	32.81	1.97
369	90	100	95.0	1.92	0.10	0.05	8	1.50	375	180	12	64	42.54	1.89
370	100	110	105.0	1.18	0.06	0.05	8	1.48	500	200	12	64	58.94	2.03
371	110	120	115.0	1.15	0.10	0.09	7	1.48	410	190	10	68	58.80	2.15
372	120	130	125.0	0.95	0.12	0.13	7	1.27	355	170	8	66	57.54	2.27
373	130	140	135.0	1.25	0.16	0.13	9	2.68	605	330	14	126	68.91	2.29
374	140	150	145.0	1.14	0.16	0.14	8	3.04	630	390	16	142	76.66	2.34

Site (km)	Lat./Long	Drainage Area (km^2	Slope (m/m)	Valley Width (km)	Bankfull Width (m)	Max. Depth (m)	Sinuosity (m/m)	Soil Type
20.4 Upper Elm	N3700.930 W9342.064	8	0.022	0.13	13.6	2.32	1.16	Secesh Cedargap Silt Loam

Study No.	Depth(cm) min	max	mean	Al %	Ca %	Ca:Al ratio	Fe %	Mn ppm	P ppm	Pb ppm	Zn ppm
375	0	5	2.5	0.72	0.22	0.31	0.96	370	220	40	1265
376	5	10	7.5	0.69	0.12	0.17	0.89	365	140	30	668
377	10	15	12.5	0.82	0.11	0.13	1.03	415	130	38	768
378	15	20	17.5	0.85	0.10	0.12	0.94	390	130	32	708
379	20	25	22.5	0.91	0.09	0.10	0.97	395	120	30	676
380	25	30	27.5	0.84	0.09	0.11	0.96	385	110	28	600
381	30	35	32.5	1.13	0.13	0.12	1.13	495	140	36	726
382	35	40	37.5	1.34	0.16	0.12	1.29	660	170	50	1055
383	40	45	42.5	1.05	0.12	0.11	1.10	485	140	46	948
384	45	50	47.5	1.09	0.13	0.12	1.18	620	150	60	1285
385	50	55	52.5	0.86	0.09	0.10	1.00	430	120	80	1440
386	55	60	57.5	0.9	0.08	0.09	1.03	270	110	88	1635
387	60	65	62.5	0.89	0.11	0.12	1.12	435	130	184	2790
388	65	70	67.5	1.06	0.34	0.32	1.52	505	230	344	6330
389	70	75	72.5	0.97	1.23	1.27	1.36	440	290	292	6080
390	75	85	80.0	1.46	0.28	0.19	1.63	695	190	60	3040
391	85	95	90.0	1.75	0.17	0.10	2.15	890	220	30	712

Site (km)	Lat./Long	Drainage Area (km^2	Slope (m/m)	Valley Width (km)	Bankfull Width (m)	Max. Depth (m)	Sinuosity (m/m)	Soil Type	Secondary Soil type
24.3 pper Elm	N3658.714 W9341.525	1	0.005	0.03	1	0.95	1.12	Secesh Cedargap Silt Loam	Dumps-orthents Complex

Study No.	Depth(cm) min	max	mean	Al %	Ca %	Ca:Al ratio	Fe %	Mn ppm	P ppm	Pb ppm	Zn ppm	Sand %	OM %
409	0	5	2.5	1.94	0.40	0.21	1.94	510	450	252	3140	4.50	8.39
410	5	10	7.5	1.72	0.31	0.18	1.94	495	430	168	2740	6.19	6.15
411	10	15	12.5	1.42	0.26	0.18	1.83	400	410	146	2700	18.36	5.66
412	15	20	17.5	1.58	0.24	0.15	2.13	530	450	204	5560	19.11	4.88
413	20	25	22.5	1.34	0.41	0.31	2.13	675	430	222	7710	16.93	4.90
414	25	30	27.5	1.49	0.37	0.25	1.93	580	420	230	7520	16.03	5.19
415	30	35	32.5	2.24	0.50	0.22	1.87	1160	310	84	3950	12.48	7.52
416	35	40	37.5	2.4	0.50	0.21	1.77	605	250	44	1420	9.78	7.95
417	40	45	42.5	2.34	0.47	0.20	2.09	515	230	38	812	12.33	7.56
418	45	50	47.5	2.62	0.48	0.18	2.43	445	210	34	388	13.96	7.25
419	50	55	52.5	2.86	0.48	0.17	2.44	510	180	30	280	12.41	6.96
420	55	60	57.5	2.72	0.46	0.17	3.50	5520	160	34	186	16.63	7.13
421	60	65	62.5	2.51	0.40	0.16	2.55	2780	120	30	128	16.80	5.75
422	65	70	67.5	2.32	0.36	0.16	2.35	540	130	30	140	16.30	4.76
423	70	75	72.5	2.21	0.34	0.15	2.18	245	130	30	156	17.39	4.64
424	75	80	77.5	2.26	0.33	0.15	2.54	225	130	30	112	17.82	4.30
425	80	85	82.5	2.31	0.33	0.14	2.57	205	130	32	110	16.91	4.13

Site (km)	Lat./Long	Drainage Area (km^2	Slope (m/m)	Valley Width (km)	Bankfull Width (m)	Max. Depth (m)	Sinuosity (m/m)	Soil Type	Secondary Soil type
23.3	N3659.422 W9341.503	3	0.02	0.1	9	1.1	1.02	Hepler Silt Loam	Dumps-orthents Complex

Study No.	Depth(cm) min	max	mean	Al %	Ca %	Ca:Al ratio	Fe %	Mn ppm	P ppm	Pb ppm	Zn ppm
493	0	5	2.5	0.53	6.81	12.85	1.42	785	470	434	31900
494	5	10	7.5	0.31	8.85	28.55	1.25	615	330	1355	44200
495	10	15	12.5	0.17	9.99	58.76	1.25	540	290	628	32900
496	15	20	17.5	0.22	9.20	41.82	1.28	590	300	804	36000
497	20	25	22.5	0.16	9.00	56.25	1.26	570	290	1430	49500
498	25	30	27.5	0.13	9.01	69.31	1.09	550	250	976	41700
499	30	35	32.5	0.15	9.15	61.00	1.13	590	240	1135	44100
500	35	40	37.5	0.33	8.48	25.70	1.67	625	430	1155	42400
501	40	45	42.5	0.25	7.83	31.32	1.72	575	530	262	37100
502	45	50	47.5	0.54	7.79	14.43	2.24	785	800	294	49400
503	50	55	52.5	0.08	9.32	116.50	1.00	400	220	192	38100
504	55	60	57.5	0.39	6.99	17.92	1.64	515	500	392	39300
505	60	65	62.5	0.51	6.57	12.88	1.80	560	520	892	38800
506	65	70	67.5	0.15	8.26	55.07	1.21	425	310	712	40200
507	70	75	72.5	0.14	7.07	50.50	1.31	370	360	512	40500
508	75	80	77.5	0.78	3.45	4.42	1.92	355	680	584	33100
509	80	85	82.5	1.40	2.10	1.50	1.89	175	410	870	16800
510	85	90	87.5	1.21	2.33	1.93	2.03	295	780	862	18300
511	90	95	92.5	1.00	2.77	2.77	2.00	625	760	1480	22000
512	95	100	97.5	0.30	1.76	5.87	1.23	140	160	558	17700
513	100	105	102.5	0.45	2.38	5.29	3.37	215	480	9590	58700

Site (km)	Lat./Long	Drainage Area (km^2	Slope (m/m)	Valley Width (km)	Bankfull Width (m)	Max. Depth (m)	Sinuosity (m/m)	Soil Type
21.2 Upper Elm	N3700.472 W9341.788	7	0.03	0.28	28.1	1.01	1.09	Secesh Cedargap Silt Loam

Study No.	Depth(cm) min	Depth(cm) max	Depth(cm) mean	Al %	Ca %	Ca:Al ratio	Fe %	Mn ppm	P ppm	Pb ppm	Zn ppm
594	0	5	2.5	0.71	0.20	0.28	0.90	660	280	16	178
595	5	10	7.5	0.72	0.11	0.15	1.10	1340	210	16	76
596	10	15	12.5	0.81	0.11	0.14	0.98	915	170	12	48
597	15	20	17.5	1.34	0.20	0.15	1.16	540	140	12	52
598	20	25	22.5	3.93	0.39	0.10	2.07	185	130	12	84
599	25	30	27.5	3.91	0.53	0.14	2.11	90	120	12	94
600	30	35	32.5	3.87	0.50	0.13	2.03	80	110	14	96
601	35	40	37.5	4.19	0.58	0.14	2.22	95	110	14	100
602	40	45	42.5	4.69	0.64	0.14	2.36	150	100	14	110
603	45	50	47.5	3.96	0.65	0.16	2.09	170	120	16	96
604	50	55	52.5	3.79	0.65	0.17	1.99	105	150	14	92
605	55	60	57.5	2.81	0.66	0.23	1.80	155	220	10	84
606	60	65	62.5	2.85	1.11	0.39	1.83	100	280	14	86