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Temporal Analysis of Floodplain Deposition Using Urban Pollution Stratigraphy, Wilson Creek, SW Missouri

Kathy A. Shade

TEMPORAL ANALYSIS OF FLOODPLAIN DEPOSITION

USING URBAN POLLUTION STRATIGRAPHY,

WILSON CREEK, SW MISSOURI

A Thesis

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Master of Natural and Applied Science

By

Kathy A. Shade

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TEMPORAL ANALYSIS OF FLOODPLAIN DEPOSITION USING URBAN POLLUTION STRATIGRAPHY, WILSON CREEK, SW MISSOURI

Department of Geography, Geology and Planning

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Master of Natural and Applied Sciences

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ABSTRACT

Alluvial sediments record both hydrologic changes and variations of sediment quality affecting watersheds. This study uses urban pollution signatures as temporal tracers to date alluvial deposits along Wilson Creek located within Wilson's Creek National Battlefield Park in southwestern Missouri. The creek drains Springfield, the third largest city in the state, which was settled in 1833. This study has three main objectives: (1) review historical documents to develop a pollution history for the watershed; (2) determine if there is a correlation between heavy metal and phosphorus concentrations in sediment cores and the timing of release of those elements into the creek system; and (3) evaluate stratigraphic relationships of pollutant trends to describe the history and rates of floodplain sedimentation. Samples were collected from thirteen core locations across a terrace-floodplain transect and analyzed for geochemistry, organic content, pH, Munsell color, and texture. ^{137}Cesium dating was used to identify the 1954 and 1964 layers and aerial photography was used to determine changes in stream location and morphology since 1936. Results show that (1) post-World War II urban pollution signatures are evident in the top 50 cm of floodplain deposits, with significant changes in concentrations with depth of Pb, Hg, Ag, Cu, Zn, and P; (2) some of these trends can be correlated with changes in land use patterns in Springfield and known industrial developments, toxic chemical releases, and wastewater treatment plant operations; (3) sedimentation rates averaged 0.8 cm/yr from 1861-1954, 2.5 cm/yr from 1954-1964, and 0.4 cm/yr from 1964-2002, with an overall average of 0.8 cm/yr.

KEYWORDS: floodplains, fluvial sediments, urban pollution, Wilson Creek, Missouri

This abstract is approved as to form and content

____

Dr. Robert Pavlowsky
Chairperson, Advisory Committee
Southwest Missouri State University

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CHAPTER ONE:

INTRODUCTION

All land surfaces are composed of drainage basins which collect and transport water and sediment from points of high elevation to lower elevation. In concert with the force of gravity, drainage basins form the basic units that concentrate energy from atmospheric processes for use in geomorphic work and changing the physical landscape (Derbyshire et al., 1979). Transfers of solid material, or sediment, take place as weathering releases material and water moving downhill carries that sediment as particles or solutes as far as it is able with the energy it has available. The ultimate destination for the transported load is a lake or ocean. However, this process is usually interrupted by the temporary or semi-permanent storage of those sediments on the channel bed or adjacent floodplain. At any given point in time, a river and its associated floodplain reflect only a snapshot of a dynamic, ever-changing system. In order to understand the dynamic morphology of the river channel and its floodplain over time, various methods can be used, including stratigraphic analysis, radiometric dating, and geochemical analysis. This study focuses specifically on using these methods to understand the timing and rates of overbank sedimentation on a small floodplain in southwest Missouri. In addition, emphasis is put on relating the influence of human activities to the formation and the composition of the landform.

Floodplains are flat belts of land adjacent to the river and represent the area which is inundated when flooding occurs and the river overflows its banks. Floodplain construction is thought to result from (1) lateral migration of the river producing point bar and in-channel deposition and (2) overbank sedimentation (Brakenridge, 1988; Derbyshire et al., 1979). According to Brakenridge, these processes are independent but may occur simultaneously. River meandering may occur without floods, and flooding may occur without migration of the river. Floodplains can develop in either case. Thus, floodplains typically include the following two assemblages of facies: channel bed/bar deposits and overbank deposits (Brakenridge, 1988). In the Ozark Plateaus of Missouri (the Ozarks), meandering streams are typically low sinuosity (about 1.1) and have gravel or cobble beds with either sand and gravel or mud (silt and clay) banks (Jacobson, 1995). Their floodplains are often wide, flat, and filled with substantial thicknesses of alluvial sediment (Jacobson, 1995). Since Ozarks streams are relatively straight, floodplain development in southwest Missouri is controlled primarily by overbank deposition.

High discharge events result in overbank deposition as the stream overflows its channel and deposits its suspended sediment load on the floodplain. This deposition is due to (1) reductions in flow velocity due to increase in flood width and (2) greatly increased roughness and decreased flow velocities related to terrestrial vegetation on the flooded surfaces (Brakenridge, 1988). Typical floodplain stratigraphy reflects a fining upward of the sediments, with larger particles (gravel and sand) near the bed and on lower point bar features and smaller particles (silt and clay) on higher surfaces or further from the channel. During the meandering process, the channel migrates away from the depositional side and finer grained material is deposited on top of the coarser sediments. Frequently inundated, low-lying floodplains have high sedimentation rates; deposition usually decreases with distance from the channel and fine sediment tends to accumulate in floodplain depressions or basins (Middelkoop and Van der Perk, 1998). Changes in the channel slope, shape, sediment load, or sediment source all affect the morphology of the stream. As these factors change, so does the carrying capacity and flood interval of the stream, thereby changing the sedimentation patterns on the floodplain. Thus, overbank deposits contain a record of geomorphic adjustments in the fluvial system.

The record contained in the overbank deposits is linked to climate and land use or cover changes within the watershed. Climate is the source of energy for the stream. The amount and frequency of rainfall determines the amount and timing of energy input into the system. The percentage of rainfall that reaches the ground surface will depend on the amount and intensity of rainfall as well as the extent of vegetation cover (Derbyshire et al., 1979). Additionally, changes in land use in the watershed may cause changes in runoff patterns, amounts, and retention time on surfaces. Accelerated landform development can occur in response to dramatic land use changes. For example, urbanization often involves the installation of a network of stormwater drains, providing additional channel flow (Derbyshire et al., 1979). Clearing of forested land for agriculture decreases vegetative cover and provides an easily erodable sediment supply (Jacobson, 1995; Jacobson and Gran, 1999). Long term effects include thick deposits of floodplain and channel sediments, enlarged channels, and higher recurrence intervals for overbank events for severely degraded tributary reaches. If the channel down-cuts in response to increased discharge without increased sediment supply, the channel capacity will increase and the frequency of overbank flow will in turn decrease. This will result in lower sedimentation rates on the floodplain (Derbyshire et al., 1979; Middelkoop and Van der Perk, 1998; Ruhlman and Nutter, 1999). Overbank deposits, and therefore floodplains, are a product of both climatic and land use changes. By studying the geomorphic record “preserved” in the floodplains sediments, we can understand the timing and rates of overbank sedimentation.

AGE-CONTROL ISSUE

In order to determine the rates of overbank sedimentation, it is necessary to identify “markers” that help determine the age of the sediments. The study of sediment cores has been used by many researchers to determine the record of various influences on aquatic systems, both natural and man-induced (Aston, 1998; Baudo, 1990; Brakenridge, 1988; Förstner, 1990; Jacobson, 1995; Lance et al., 1986; Mantei and Foster, 1991; Meade, 1982; Ritchie et al., 1974; Trimble et al., 1999; Van Metre et al., 1998; Walling and Bradley, 1988). In this study, stratigraphic analysis, radioactive isotope dating, and geochemical analysis will be combined to date cores from alluvial deposits in order to describe the morphology of the Wilson Creek floodplain.

Stratigraphic Analysis as a Tool

Floodplain stratigraphy analysis involves the mapping and interpreting floodplain deposits of different age. The basic goal is to reconstruct the sequence of depositional events. The boundaries of stratigraphic units are, by definition, based on a lack of continuity (Brakenridge, 1988). For example, a sharp color change from light brown to dark brown or abrupt change from gravel to silt would indicate a boundary between different depositional units. Other stratigraphic tools that rely on other indicators than the sediments/soils themselves are often used in conjunction with field observation and sediment analysis.

Buried soils. Active floodplains are not characterized by pedogenesis--soils don’t have time to form. However, if the floodplain was once stable and then becomes active, a buried soil may be present and separate the two accumulations into one older and one younger. The upper boundaries of buried soils are usually sharp, whereas the boundaries between soil horizons are commonly transitional (Brakenridge, 1988). By identifying buried soils, researchers can identify the timing of the change from a stable to depositional floodplain morphology.

Flood markers. Evidence of the maximum extent of flooding is usually left behind on the floodplain as debris or bent or flattened vegetation. These markers can aid in estimating the discharge of the stream as well as the area of the floodplain that was inundated during the flood. If significant materials, such as toppled trees, large trash, gravel splays or other ridges of debris are left behind, then subsequently buried by later floods, these can act as indicators of flood level and stream discharge. If the flooding is recent, additional indicators such as debris suspended in trees or shrubbery, or flattened or bent vegetation, may remain and can show the maximum extent of the previous flood.

Dendrochronology. Age of trees currently growing on the floodplain and the depth and pattern of their roots may indicate the sedimentation rate (Phipps et al., 1995). Analysis of tree rings may indicate periods of drought (low flow) and flooding. This can be an important aid in understanding channel flow for pre-settlement times when written records were not kept. Additionally, dating of tree rings found buried within the floodplain sediments can aid in dating surrounding layers (Brown, 1997; Herz and Garrison, 1998).

Surveys. Old land surveys, plat maps, and soil surveys can be useful in identifying changes to the floodplain surface, including channel migration, extent of floodplain and location of terraces. Changes in relative altitude of the floodplain surface can indicate whether the floodplain was depositional, stable, or erosional during the time span between survey records. By using these tools of stratigraphic analysis, a researcher can begin determine the timing of deposition to different layers of the floodplain sediments.

Radiometric Dating

Radiometric dating is another tool that can help date alluvial sediments. These methods are based on physical and chemical properties of selected unstable isotopes.

^{137}Cesium. Fallout from atmospheric testing of nuclear weapons, primarily between the late 1950s and the 1960s, produced radioactive isotopes that were dispersed around the globe. One of these, ^{137}Cs, has proven to be a useful tag in studying erosion rates of sediments and soil. ^{137}Cs does not occur naturally in the environment; it is produced only by nuclear fission. It strongly adsorbs to fine sediments, soil and organic material and movement by natural processes is very limited (Ritchie and McHenry, 1975). As such, it can serve as a permanent tag on those particles. ^{137}Cs is also relatively easy to measure, as it produces an energetic gamma ray emission as it decays. Its half life is only 30.2 years, and therefore is suitable for dating young deposits. Concentrations in the soil or sediments can be correlated to dates of the beginning, peak, and end of atmospheric nuclear weapons testing. Initial work in this area by Jerry Ritchie and Roger McHenry in the 1970s (McHenry and Ritchie, 1977; McHenry et al., 1973; Ritchie and McHenry, 1975; Ritchie et al., 1974) has led to hundreds of other studies using the ^{137}Cs isotope as a temporal tracer.

^{210}Lead. ^{210}Pb is another unstable isotope that has been used for dating of sediments. However, in addition to being a component of radioactive fallout from nuclear weapons testing, ^{210}Pb is also a natural product of the ^{238}U decay series. Therefore, dating deposits using ^{210}Pb requires computing the amount of *unsupported* ^{210}Pb, that is, the ^{210}Pb that cannot be accounted for by the natural decay of ^{226}Rn in the soils. Analysis of excess ^{210}Pb has been used successfully by researchers for dating vertical sediment cores in lakes (Applebee and Oldfield, 1978; Koide et al., 1973; Wise, 1980) and floodplains (Botrill et al., 1999), and for measuring rates of erosion (Wallbrink and Murray, 1993). Because ^{210}Pb dating correlates well with ^{137}Cs, and it is possible for ^{210}Pb excess to exist at depth, supported by local excesses of ^{222}Rn in the groundwater (Wallbrink and Murray, 1993), ^{210}Pb analysis was not used in this study.

^{14}Carbon. "Radiocarbon dating is the most important method for the construction of Lateglacial and Holocene alluvial chronologies since it covers the last 50,000 years and is the most widely used" (Brown, 1997). However, because of the long half-life of ^{14}C (5730 years), potential errors due to reworking of organic material, and rootlet contamination (Brown, 1997), radiocarbon dating is not practical for this study.

GEOCHEMICAL PROPERTIES OF ALLUVIAL SEDMENTS

Bulk Properties

Typical alluvial sediments of the Ozarks are primarily brown silty clay loams with small amounts of sand – a result of early Holocene erosion of late Quaternary loess (Brakenridge, 1988). In areas of the floodplain where natural levees have been breached, crevasse splays of gravel may also be present. As distance from the channel increases, fining of the sediments occurs. Lithographic contrasts between alluvia of different ages may be apparent due to weathering, changes in sediment source area, or changes in the dominant fluvial processes occurring (Brakenridge, 1988). Weathering begins as soon as sediments are deposited on the floodplain, although soil formation rarely occurs on active floodplains. Relative to their younger counterpart, older floodplains tend to have higher clay content, be more red or yellow in hue, and contain more abundant iron and manganese oxide stains throughout the profile (Brakenridge, 1988).

Metal and Phosphorus Sorption

Overbank sediments, in part because of their typically small grain size, act as significant reservoirs of metals and other pollutants in the watershed (Förstner, 1990; Horowitz, 1991; Mantei and Foster, 1991; Novotny and Chesters, 1989; Singh and Steinnes, 1994; Yong et al., 1992). In addition to small grain size, other important properties of sediments include large surface area, and surface charge (or cation exchange capacity). Most clay particles have a net negative surface charge, and most metal ions in the water column have a net positive charge. In addition, organic matter can sorb or contain P or metals and become concentrated in moist floodplain areas. Thus, geochemically active materials such as clay minerals, iron hydroxides, and organic matter are capable of sorbing cations from solution and releasing other cations back into solution. The most significant physical factor controlling the capacity to concentrate and retain trace elements, though, is grain size (Horowitz, 1991).

Anthropogenic pollutants, such as heavy metals and phosphorus, may be introduced into the atmosphere or aquatic environment from various sources: mining and smelting, power generation, solid waste incineration, industrial waste, residential street runoff, and agricultural runoff. In natural systems, more than 90% of the metal load is transported by particulate matter. A similar sequence of the ratios between dissolved and particulate matter has been found for polluted systems (Förstner, 1990). Thus, “because of their ability to sequester metals, sediments can reflect and record the effects of anthropogenic emissions" (Förstner, 1990).

Background vs. Pollution Source

Metals and phosphorus are natural components of rocks, and therefore of all sediments. However, since the beginning of industrialization, accumulations of metals from anthropogenic sources have stressed natural "regulatory" systems and in some cases built up to toxic levels in aquatic systems, including stream channel and floodplain sediments (Förstner, 1990). In order to determine whether or not a particular contaminant originated from a natural or anthropogenic source, Förstner (1990) evaluated studies that used dated sediment cores. He found that background levels of naturally occurring heavy metals appeared at consistently low concentrations up until the time of settlement and industrialization, approximately 200-300 years ago. At that point, fairly great concentrations of some heavy metals began to stand out, particularly in the sections representing the past 100 years. Therefore, sediment cores can indicate natural background levels and anthropogenic accumulations of pollutants over time.

Urban and Industrial Development Link to Metal and P Signatures

Because of this link between industrialization and metal and P concentration in sediments, various studies have used analysis of overbank sediments or lake sediments to determine a pollution history for a watershed (Chakrapani and Subramanian, 1993; Chillrud et al., 1999; Cooper and Gillespie, 2001; Li and Wu, 1991; Pierce Jr., 1992; Schwarz et al., 1999; Singh and Steinnes, 1994; Swennen and Van der Sluys, 2002; Van Metre et al., 1996). This study, however, will use the known history of urban development and pollution, combined with ^{137}Cs dating, in order to describe the overbank sedimentation of a floodplain. By using the chronology of the settlement, industrialization, and continued urban development of the Springfield area, sediment cores can be dated and the deposition patterns of the Wilson Creek floodplain can be understood.

PURPOSE AND OBJECTIVES

The purpose of this study is to use urban and industrial pollution history of the Springfield area to date alluvial sediments on the Wilson Creek floodplain and apply this toward understanding of the historical geomorphology of Ozarks streams.

Objectives of this study are:

(1) to review historical documents to develop a chronology of urban and industrial development, and therefore a pollution history, of the city of Springfield and the surrounding area. Wilson Creek and its tributaries have been the receiving waters for Springfield's industrial and residential waste since the settlement of southwest Missouri in the 1830s. By developing a chronology of development in the area, a better understanding of the historical geomorphology of Wilson Creek and potential sources of heavy metals and phosphorus can be determined;

(2) to develop a chronology of recent and historical floods in the watershed. Since deposition occurs only during high flow events, a flood history of the watershed will aid in understanding deposition patterns for the Wilson Creek floodplain of interest;

(3) to use historical and recent aerial photographs of the Wilson's Creek National Battlefield to identify changes in local land use and channel morphology. It is

hoped that by comparing available aerial photographs dating from 1936 to 1995, changes in the channel planform can be identified;

(4) to collect and analyze geochemical and stratigraphic information for the floodplain to determine if there is a correlation between heavy metal and phosphorus concentrations in sediment cores and the timing of release of those elements into the creek system; and

(5) to evaluate stratigraphic relationships of pollutant trends to describe the history and rates of floodplain sedimentation. Geochemical analysis, particle size analysis and other stratigraphic date will allow better understanding of the deposition patterns on the floodplain.

Currently, little is known about historical overbank sedimentation in Ozarks watersheds. While several studies have been done regarding sediment and water quality in Ozarks streams (Black, 1997; Carlson, 1999; Mantei and Coonrod, 1989; Mantei and Foster, 1991; Pierce Jr., 1992; Pulley et al., 1998; Shade, 2002; Trimble, 2001; USDI, 1969), only a few have attempted to describe the timing and rates of sedimentation of Ozarks streams. As concern for water quality in the Ozarks and the Wilson Creek/James River basin continues to increase, it would be helpful to better understand the history and effect of pollutants in Wilson Creek in addition to the impact of urbanization on the development of its channel and other features. By investigating the potential storage and release of pollutants in floodplain sediments, and effect of land use change on sedimentation rate, additional data will be available to make decisions regarding future growth in the Wilson Creek watershed.

EXPECTED RESULTS AND BENEFITS

It is expected that historical documents will show that there has potentially been significant contribution of contaminants to Wilson Creek and its tributaries from the industrial and residential development of Springfield. Flood records for the area will show that as land was cleared for agriculture and urban development progressed, and impervious areas increased, flood occurrences and their magnitude increased as well. Because aerial photographs are only available after 1936, it is unclear whether or not significant changes in the channel occur. Since it is expected that the floodplain area is an active depositional feature, any changes in the channel morphology will indicate increased deposition on the upstream side and limited erosion on the downstream side. A record of major chronic industrial pollutants and episodic toxic releases will be evident in the floodplain sediments. Finally, the pollutant trends, sedimentology, and radioactive dating of sediments will enable the determination of rates of sedimentation and history of the floodplain development.

Scientific benefits of this study include development of an additional method for analysis of floodplain geomorphology. It is hoped that testing and improvement of this method of using urban pollution history to date alluvial sediments will provide one more tool that can be applied to studying floodplains of other rivers and regions. Additionally, social or environmental benefits that will come from this study include a better understanding of floodplain storage and release of potential pollutants affecting a watershed, and the impact of land use changes on sedimentation rates.

THESIS ORGANIZATION

This thesis is organized into six additional chapters describing (1) previous relevant research; (2) physical characteristics of the study area; (3) history of development and urbanization of the study area; (4) methods of the study; (5) results and discussion; and (6) conclusions and suggestions for future study. Because of the volume of data collected and number of physical and chemical analyses performed, the comprehensive data tables are located in the appendices.

CHAPTER TWO:

REVIEW OF LITERATURE

This chapter will review relevant research that provides the framework for this study, as well as its potential limitations. It will focus on several different aspects of this study: stratigraphy and geomorphology research; methods of determining sedimentation rates; geochemical analysis; use of urban pollution studies in floodplain analysis; and research specific to the Ozarks area.

STRATIGRAPHY AND GEOMORPHOLOGY OF FLOODPLAINS

Floodplains in General

Because floodplain formation can be a complex process, describing the history of a floodplain feature or predicting future sedimentation trends is often a very difficult endeavor. The main obstacle involves our inability to directly observe the formation processes in historical or geological timescales. As our technology and knowledge about stream processes increases, so too does the recognition of how many variables are involved in river channel and floodplain development (Middelkoop and Van der Perk, 1998). Stream channel and floodplain morphology studies help researchers to understand and model the complex interactions between so many variables, such as sediment source, hydrology, land use, storage, and flood frequency; and recognize thresholds that control the response of the systems to changing environmental conditions (Alexander and Marriott, 1999; Brakenridge, 1988). As mentioned previously, most Ozarks floodplains are primarily controlled by overbank deposition rather than channel migration (Jacobson, 1995). Therefore, the focus of this review is on the properties and processes of overbank sedimentation.

One way to understand how landforms within a watershed develop is to look at sources of the sediment that are available to become deposited on the floodplain. Geochemical and physical characteristics of the sediments can help determine sediment source, time of deposition, and duration in storage on a floodplain. Bottril et al. (1999) studied recent and historical sediment deposits within a basin to “fingerprint” the sediments and statistically determine their source. While this was successful for recent sediments, they were unsuccessful in using this method with older deposits due to geochemical changes that occurred during storage in the floodplain (Botrill et al., 1999).

Determination of original sediment source, however, may not help us understand the true chronology of formation of floodplain features. Meade (1982), in a study of river sediments of the Atlantic drainage, concluded that “although the original source of sediment in a river basin is the soil that has been eroded off its uplands, the immediate source of most of the sediment that moves in a river at any given time may well be the storage sites that lie within reach of the river” (Meade, 1982). Therefore, sediments may be stored and released several times before they reach their final destination in a lake or ocean.

Change in overbank flows and flood frequency over the centuries also affects the rate and character of floodplain development. Ruhlman and Nutter (1999) found that in the Georgia Piedmont flooding occurs less frequently now than it once did. They believe this is the result of accelerated erosion and deposition due to past land use practices that led to channel expansion and therefore channel capacity. Now, since flooding is less frequent, interaction between the river and its floodplain is also decreased and therefore it is more stable (Ruhlman and Nutter, 1999).

Other studies have attempted to look at floodplain development using mathematical models with various levels of success. Because floodplain development is such a complex interplay of so many different variables, most computer models are good predictors of some processes, but often fail to predict others with any accuracy. Middelkoop and Van der Perk (1998) used a GIS-based model to simulate floodplain formation based on water flow and sediment concentration within the channel. Their model was able to predict sedimentation rates during individual flood events as well as average rates over longer time frames. However, some deposition patterns, such as ponding in small enclosed depressions was not taken into account and thus resulted in underestimation of sedimentation in some areas (Middelkoop and Van der Perk, 1998). Another model of overbank flow due to diffusion of sediment was able to accurately predict resulting topography as well as a decrease in grain size away from the channel (Pizzuto, 1987). Pizzuto's model, though, did not accurately predict the deposition of sand-sized particles that may have been moved as bedload or by processes other than diffusion.

Stratigraphy

Studying the stratigraphy of floodplains has many more challenges than studying the stratigraphy of rock formations. While sedimentary layers in rock formations are typically a product of hundreds of thousands or millions of years of deposition, floodplain layers may represent individual episodes of flooding or thousands of years of soil formation. Additionally, the complex stratigraphy of a floodplain represents both lateral and vertical movement of the river. Still, analyzing the stratigraphy, or layering of sediments, of a floodplain is one of the main tools in understanding the source of sediment, timing and duration of flood events, changing competence of the stream, and other various factors affecting erosion and deposition on the floodplain.

Vertical profiles of floodplain features may reveal evidence of layering as different flood events deposited varying amounts and types of sediment. Variations in natural stratigraphic markers such as grain size (Aslan and Autin, 1998; Brakenridge, 1988; Dinnin and Brayshay, 1999; Jacobson, 1995; Jacobson and Gran, 1999; Pizzuto, 1987), changes in vegetation (Cotton et al., 1999; Dinnin and Brayshay, 1999; Phipps et al., 1995), soil color, and fossil content may indicate the extent and boundaries of stratigraphic units. Additionally, other markers of anthropogenic origin such as heavy metals (Ji et al., 2002; Lecce and Pavlowsky, 1997; Li and Wu, 1991), radioactive isotopes (Ritchie et al., 1974; Walling, 1999; Wise, 1980), organic pollutants (Van Metre et al., 1996; Van Metre et al., 2000; Van Metre et al., 1998), and archeological artifacts (Aston, 1998; Brown, 1997) are useful in identifying depositional units of more recent sediments. In a study of Mississippi River floodplain soils, Aslan and Autin (1998) found that episodic depositional processes control the texture and chemical composition of alluvial soils in gradational settings. Predicting the effect of time on alluvial soil formation is complicated by this fact. Floodplains of similar age may have very different properties depending on various parent materials and changes in hydrologic condition (Aslan and Autin, 1998). In a previously mentioned study, Pizzuto's (1987) model confirmed field observations of the fining of sediments in both vertical layers and horizontally away from the channel (Brakenridge, 1988; Cerling and Spalding, 1982;

Middelkoop and Van der Perk, 1998; Pizzuto, 1987). However, results and/or interpretation of stratigraphic analysis may be greatly affected by sampling and laboratory techniques (Baudo, 1990) as well as natural processes such as bioturbation (Brown, 1997).

DETERMINATION OF SEDIMENTATION RATES

Understanding sedimentation rates in the study area is critical to understanding the geomorphic processes at work on the floodplain and vice versa. In this study, ^{137}Cs dating is used to determine absolute dates for the younger (post-1954) sediments, and the presence of a possible buried soil is used to date the pre-settlement layer. By knowing dates of certain layers, average sedimentation rates for those units can be determined. It is hoped that correlation with the pollution history of the Springfield area will show that other anthropogenic metals may also be used as markers for dating sediments in watersheds where a history of urban development is known.

As mentioned in the Introduction chapter, ^{137}Cs has been used as a tracer in numerous studies that have measured the erosion and deposition of soil and sediment (Botrill et al., 1999; Brown et al., 1981a; Brown et al., 1981b; Campbell et al., 1988; Cerling et al., 1990; Cerling and Spalding, 1982; Cygan et al., 1998; Lance et al., 1986; Loughran et al., 1987; McHenry and Ritchie, 1977; McHenry et al., 1973; Ritchie and McHenry, 1975; Ritchie and McHenry, 1990; Ritchie et al., 1974; Sobocinski et al., 1990; Van Metre et al., 1996; Van Metre et al., 2000; Van Metre et al., 1998; Wallbrink and Murray, 1993; Walling, 1999; Walling and Bradley, 1988; Wise, 1980). ^{137}Cs is a radioactive element that is produced by nuclear fission -- primarily from nuclear weapons testing. ^{137}Cs has a half-life of 30 years (Ritchie and McHenry, 1975). After washing out of the atmosphere, it is strongly and immediately adsorbed to soil and sediments. Once adsorbed, further movement of ^{137}Cs is only associated with physical movement of the soil particles (Ritchie et al., 1974). Because of its low mobility and since the dates of onset, peak and end of atmospheric testing of nuclear weapons are known, ^{137}Cs is a reliable tracer for sediment movement and/or storage. However, due to its relatively short half-life, its usefulness as a temporal tracer in long-term studies will diminish as it decays. This technique is most appropriate to a timescale of 10^1-10^2 years (Wise, 1980).

According to Campbell et al. (1988), characteristics of global ^{137}Cs fallout patterns that are important include: (1) the first appearance in soils in 1954, (2) a decrease from 1959-1961, (3) accelerating fallout from 1962 with maximum in 1964, and (4) atmospheric depletion from 1965-present (Campbell et al., 1988). Other studies may use slightly differing dates, e.g. Ritchie and McHenry (1975) show a peak in 1963 rather than 1964, and Wise (1980) has the peak from 1962-1964. In most cases, the date will vary only by one or two years, depending on location and time of peak atmospheric deposition. Since input of most atmospheric ^{137}Cs from ended in with the 1963 Test Ban Treaty, by the early 1970's the only subsequent change in concentrations of Cs was due to radioactive decay and surface soil movement (Wallbrink and Murray, 1993). By 1983, deposition from atmospheric fallout was below detection limits (Ritchie and McHenry, 1990).

While most studies have shown that once ^{137}Cs is bound to sediments it is immobile, one study found a high correlation of ^{137}Cs with dissolved organic carbon (DOC) and that the movement and release of ^{137}Cs was temperature dependent (Tegen and Dorr, 1996). Researchers also found that the seepage of ^{137}Cs decreases with time, hinting that microbial activity may be connected with its release. In their study, the release of ^{137}Cs into soil water (possibly bound to DOC) suggested that although when adsorbed onto inorganic sediments ^{137}Cs is immobile, when adsorbed onto organic matter it is not. However, after release of ^{137}Cs from organic matter, it is most likely adsorbed onto nearby sediments, not moving very far (Tegen and Dorr, 1996).

Because ^{137}Cs is such a widely used and accepted method of dating sediments, it will be used in this study. Additionally, it is hoped that patterns of correlation with other pollutants will emerge. As Springfield's pollution history is examined to determine dates of releases of other heavy metals, those pollutant concentration patterns may also be used as markers to date sediments on the Wilson Creek floodplain.

GEOCHEMICAL ANALYSIS

Geochemical analysis is used in this study to identify the geochemical substrate as well as adsorbed pollutants that have been accumulated and concentrated in the sediments. There are several factors that affect sediment-trace element chemistry. Identification of these geochemical factors is sometimes called partitioning. Examples of types of physical and chemical partitioning include surface area, surface charge, adsorption, precipitation, cation exchange, organometallic bonding, incorporation in crystalline minerals, interstitial water, carbonates, clay minerals, hydrous Fe and Mn oxides, sulfides, and silicates (Horowitz, 1991). Geochemical factors affecting partitioning include grain size, surface area, and geochemical substrate (Horowitz, 1991). One of the most significant factors controlling the ability of sediments to adsorb and concentrate trace elements is grain size (Chakrapani and Subramanian, 1993; Horowitz, 1991; Jenne, 1998; Novotny, 1995). This correlation results from both physical (surface area) and chemical (clay mineral or organic matter) properties (Horowitz, 1991; Ma and Rao, 1997; Novotny, 1995). Fe and Mn oxides in sediments also provide additional surfaces for trace element concentration (Chakrapani and Subramanian, 1993; Jenne, 1998; Ma and Rao, 1997; Mantei et al., 1996).

Sorption reactions can take place on time scales of microseconds to months; metal sorption reactions are rapid on clay minerals such as kaolinite and smectite and much slower on mica and vermiculite (Yong and MacDonald, 1998). Metals adsorbed to sediments are not fixed permanently, but may be recycled within the sedimentary media or back into the water column via biological and chemical agents (Chakrapani and Subramanian, 1993; Yong and MacDonald, 1998). Chakrapani and Subramanian also found that the surface sediments of dry bed cores showed lower concentrations due to weathering, leaching, and uptake by vegetation. Decreasing sediment pH may result in mobilization of metals back into the water column, however, sediments with increased ionic species would probably not increase in toxicity due to adequate buffering capability (Yaru and Buckney, 2000; Yong and MacDonald, 1998).

USE OF POLLUTION STUDIES IN FLOODPLAIN ANALYSIS

As humans interact with their environment, traces of that interaction are left behind. Mining, changes in land use practices, urban development, and waste disposal may leave evidence, or fingerprints, in the sedimentary record. Heavy metal and nutrient enrichment in the sedimentary environment can record anthropogenic contributions from various sources such as human and industrial wastes, mining activity, urban runoff, fossil fuel emissions, and agricultural practices (Aston, 1998; Baudo and Muntau, 1990; Ma and Rao, 1997). In addition to providing evidence of timing of sediment deposition, heavy metal enrichment in sediment and soil is of particular interest because of the toxicity of the typical metal pollutants.

Concentrations of certain elements, including the heavy metals Pb, Zn, Cd and Cu, tend to be associated with locations of past human activity and provide an additional tool by which archeologists might investigate the sedimentary record (Aston, 1998). In his study, Aston suggests that there are at least five ways that heavy metal concentration in the soil may be enriched by early human activities: (1) Human habitation (enrichment through human waste products), (2) stalled animals, (3) use of fires/hearths, (4) ancient metal working and (5) other processing such as leather-making or crop processing.

In modern communities, human, animal, and industrial wastes continue to affect water, and therefore sediment, quality. Excessive sewage sludge applications for agricultural use have resulted in the accumulations of heavy metals, particularly Pb, Cd, Cu and Zn (Krebs et al., 1998) and Cr, Cu, Ni and Zn (Chen). Chen found that in two rice-growing regions of China, areas as far as 30 m from the irrigation river could accumulate very high concentrations of Cd in the top 20 cm of the soil. Metal concentrations in the soil were related to the flow direction and distance from the chemical plant effluent. It was found in the Krebs study, however, that liming of the soils increased the pH and thereby reduced the solubility and plant uptake of the metals. Concentrations of heavy metals may range from 0-100 ppm in municipal solid wastes up to 10,000 ppm in sewage sludge and industrial wastes, such as those originating from electroplating, pulp and paper, and chemical industries (Yong et al., 1992). Other less studied, and usually less concentrated, elements such as Ag, As, Be, Co, Hg, Mo, Se, Sn, Te, Tl, and V are also found in these wastes and may be more hazardous than originally thought (Baudo and Muntau, 1990). Karst areas are particularly vulnerable to contamination from sewage effluent where there is the potential for rapid movement of contaminants through the soil/karst system and into the groundwater (Tennyson and Settergren, 1977).

Mining of metal ores and other mineral or rock deposits is another activity impacting the quality of sediments stored in the floodplain. For example, Lecce and Pavlowsky (1997) found that more than half the Zn released by mining activities from 1890-1940 in the Blue River, WI watershed remain stored in floodplain sediments. Overbank deposits were the primary sink, storing five times as much Zn as the point bar deposits. After storage, the Zn was able to be remobilized in areas where high stream power increased the rate of erosion and lateral channel migration (Lecce and Pavlowsky, 1997). In a study of the Upper Clark Fork River Valley, Nimick (1990) found contamination of floodplain sediments due to deposition of mine tailings by historic floods. Copper, arsenic, lead, and zinc in the floodplain were highly enriched (with Cu up to 1800 times background levels) and occurred primarily in the fine-grained overbank deposits. Additionally, those metals were in acid-extractable form and therefore potentially bioavailable with decreases in pH. Cattle grazing increased degradation of the actively eroding streambanks from 2.5% in ungrazed reaches to 16-21% in grazed reaches. When eroded into the river, the sediments may release the metals and concentrations in the water can reach toxic levels (Nimick, 1990).

Urban runoff is a major contributor to sediment contamination. It includes runoff from roads and other impervious surfaces, sewer system infiltrations, highway runoff and deicing. Urban runoff appears to be the most significant source of toxic metals to streams

(Novotny, 1995). As precipitation runs off various impervious surfaces in urban areas, pollutants are enriched as dissolved metals are adsorbed to the clay particles of soils and organic matter carried by overland flow. In Ontario, it was found that the most frequently detected elements in urban runoff were zinc, copper, nickel, and lead, and that the frequencies of detection of trace elements in sediments were higher than in water (Marsalek, 1986). Thus, a record of urban development will be reflected in sediments as they are deposited on the floodplain.

Atmospheric deposition of contaminants from fossil fuel combustion and other industrial processes appears in the sedimentary record as well. According to sediment core analysis dating back at least 50 years, lead in sediments increased from the late 1940s to the 1970s when it was banned in gasoline. Lead has declined since then, but has not yet returned to background levels (Grandon, 2001). Other atmospheric pollutants that are have been detected in sediments include Ag, As, Be, Co, Se, Sn, Te, Tl, V, and Zn that are emitted with Cd, Cu, Hg, Mn, Ni and Pb during fossil fuel burning and ore smelting (Baudo and Muntau, 1990).

OZARKS STUDIES

Land use changes associated with settlement of the area beginning in the 1830s had the potential to create stream instability due to land clearing for row cropping, timber harvest, railroad development, and urban growth. In 1995, Jacobson documented and discussed 70 years of stream-channel responses to land use change in the Ozarks. He notes that “beginning in the 1930s, residents of the Ozarks began to note that streams were becoming choked by gravel” (p. 227). According to local residents surveyed in the study, the responsibility lay with the logging practices of the timber boom and land use practices on marginal land (Jacobson, 1995). A period of intense row-cropping during the 1940s and 1950s may have been an additional source of disturbance (Jacobson, 1995). From another study in 1999, Jacobson concluded that in some cases, rather than being dispersed, gravel “packets” moved through streams as gravel waves and could result in channel instability and an increased rate of remobilization of fine sediment stored in floodplain deposits (Jacobson and Gran, 1999). Ozarks streams with low sinuosity were particularly affected by this pattern.

Mining in the Ozarks area has also had a profound impact on small streams and their watersheds, in most cases far beyond the active mining period. Near Aurora, Missouri, the Chat Creek watershed continues to be affected by lead and zinc mining tailings that are eroding from the floodplain, even though mining activity ended in 1930 (Trimble, 2001). In the nearby watershed of Honey Creek, floodplain storage of zinc and lead and subsequent erosion of those sediments is also producing ongoing contamination of the creek (Carlson, 1999).

Other studies of Ozarks streams have concentrated on industrial and sewage-born contaminants, primarily due to the concerns regarding quality of effluent discharge from the Southwest Wastewater Treatment Plant (SWTP). One study concluded that water quality in Wilson Creek, although poor, improved with distance downstream from the wastewater treatment plant, and “dilution from lower, less urbanized tributaries has apparently been responsible for the improved water quality” in the lower reach (Black, 1997). In another water quality study, seven-day chronic daphnid bioassays identified a toxic site in the Wilson Creek Watershed below the SWTP and above Wilson’s Creek National Battlefield (Pulley et al., 1998). They concluded that Cu alone could have accounted for all of the toxicity, however other toxicants were also present in elevated levels. A study of channel sediments both above and below the SWTP showed a marked increase in heavy metal concentrations below the plant outfall, particularly in P, Cu, and Pb (Shade, 2002) although a previous study showed that the SWTP may not be the only source of the contaminants (Pierce Jr., 1992).

SUMMARY

A review of the literature provides a theoretical framework and informs as to the possible limitations of this study. While significant studies have been conducted regarding floodplain geomorphology, dating of alluvial sediments, and heavy metal contamination due to human activity, none have combined all of these aspects and applied them to determine the geomorphologic history of floodplains in the western Ozarks. This study is an attempt to do so. Moreover, this study is also important in that it attempts to relate human activities to the composition and development of alluvial landforms.

CHAPTER THREE:

PHYSICAL DESCRIPTION OF STUDY AREA

This chapter focuses on the area of study at two different levels: the Wilson's Creek watershed area, including the majority of Springfield and area southwest of the city, and the much smaller floodplain site in Wilson's Creek National Battlefield Park where sediment samples were collected. Since water, sediment, and channel conditions at a given location are largely a product of watershed conditions, it is necessary to look at the larger area in order to understand the influences of various changes in the watershed on the sediment quality downstream.

REGIONAL LOCATION

The Wilson Creek watershed is contained entirely within the Springfield Plateau, the westernmost physiographic region of the Ozark Plateau (Figure 1). The watershed is located in southwest Greene and northern Christian counties in Missouri. Its headwaters originate on Jordan Creek in Springfield, the third largest metropolitan area in Missouri. Wilson Creek and its tributaries drain the majority of Springfield and the rural area south and west of the city. Cities of the watershed include Springfield, Brookline, Republic, Battlefield, and Clever (Figure 2). These cities are located on the edges of the watershed and none of them are entirely contained within its boundaries. The Wilson's Creek National Battlefield (WCNB) is located between the cities of Republic and Battlefield straddling the Green-Christian County line (Figure 3).

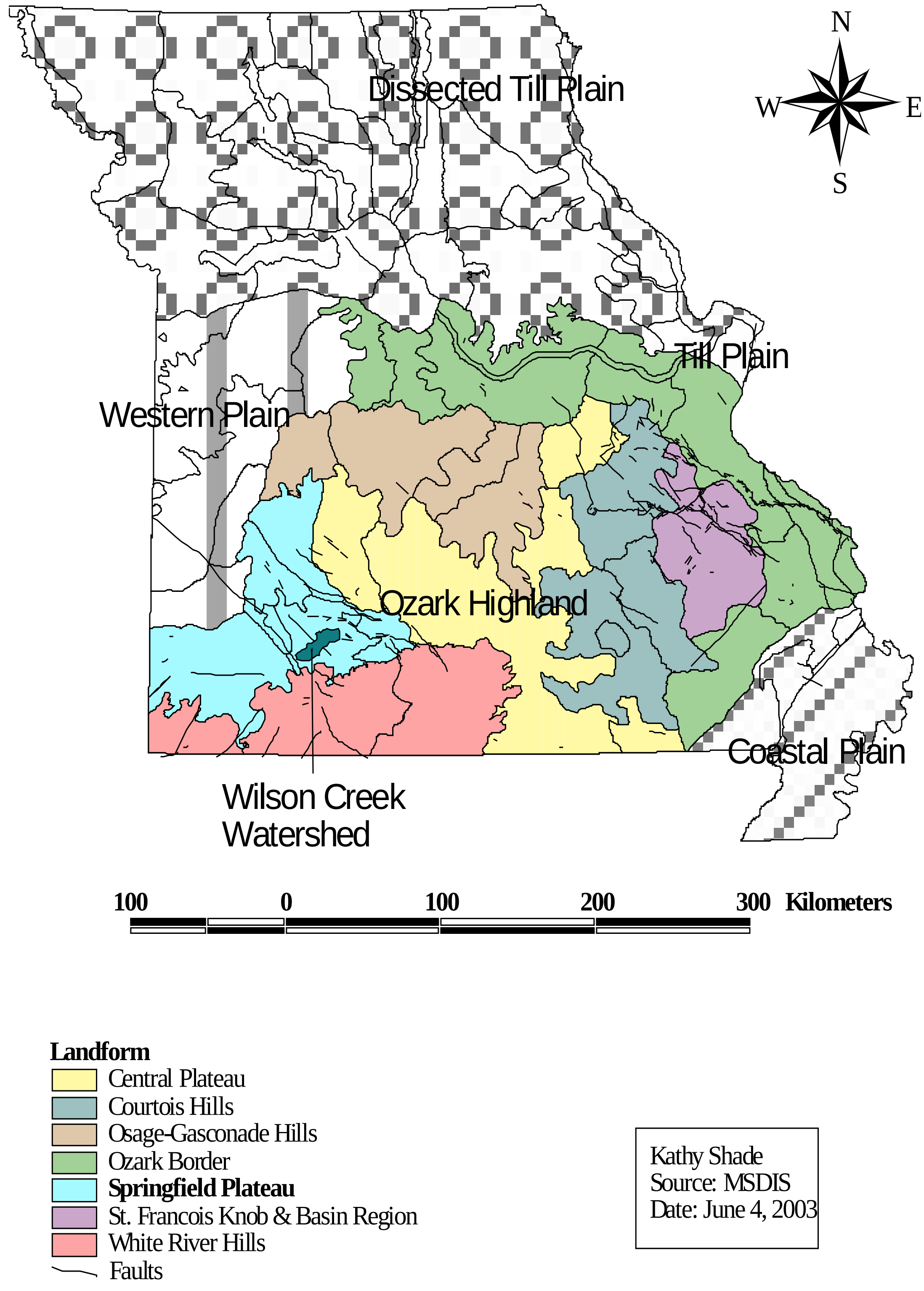


Figure 1. Physiographic regions of Missouri.

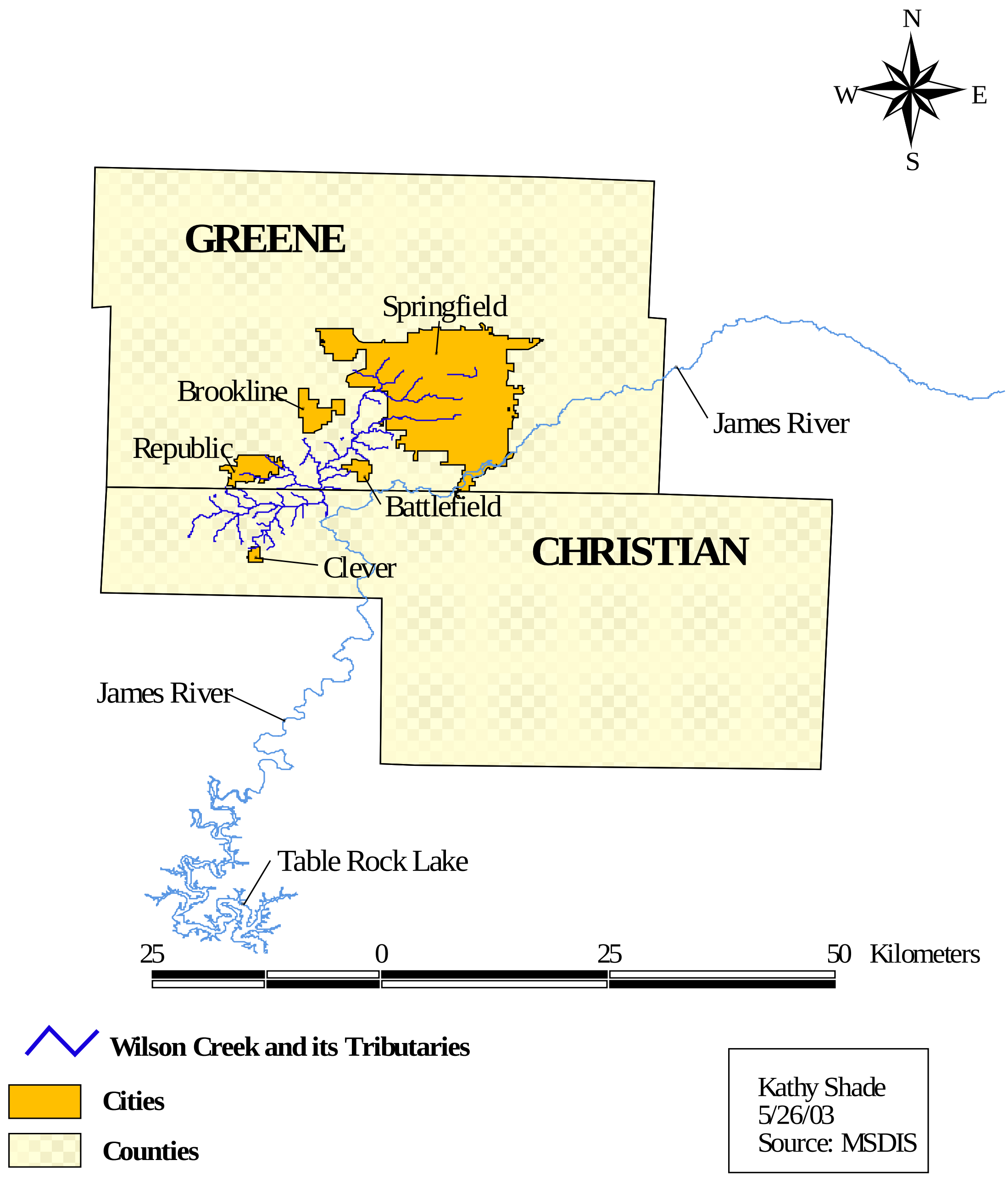


Figure 2. Cities of the Wilson Creek Watershed.

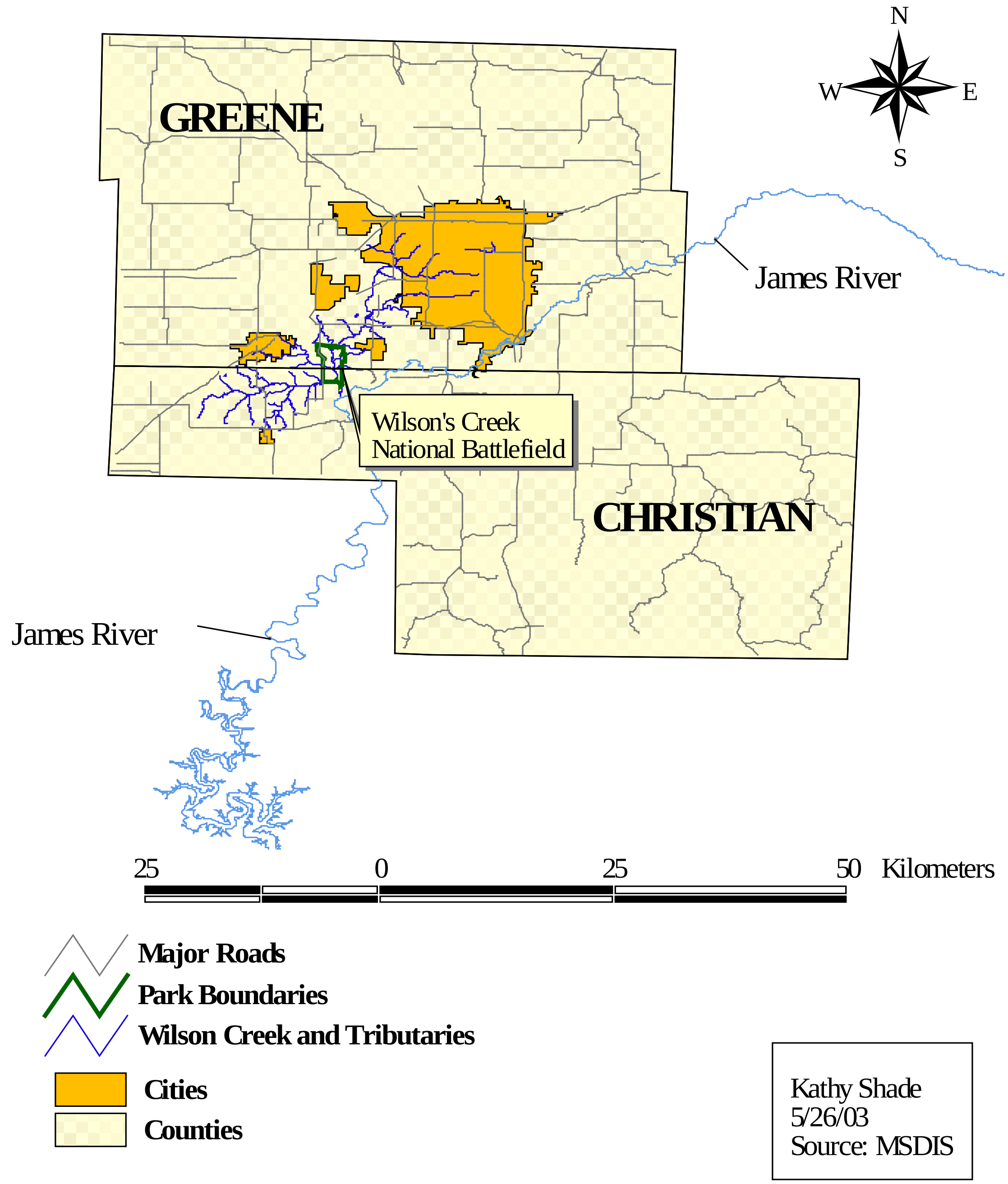


Figure 3. Location of the Wilson's Creek National Battlefield.

Wilson Creek is a 5th order stream and a James River tributary; its waters originate in Springfield and eventually flow into Table Rock Lake, the White River, and the Mississippi River (Figure 4). The watershed drains approximately 290 km^2, extending diagonally southwest from its headwaters in central Springfield to its mouth in north central Christian County. Its length of maximum order is 15.57 miles (approximately 25 km) (Kiner and Vitello, 1997). Wilson Creek itself flows west through urban central Springfield, curving to the south through suburban and agricultural areas before reaching the Southwest Wastewater Treatment Plant (SWTP). Named tributaries to upper Wilson Creek include Jordan Creek, Fassnight Creek, and South Creek, which all originate within the city of Springfield. The Wilson Creek - South Creek confluence is located on the SWTP grounds just above the effluent outflow pipe from the plant. Below the plant are the named McElhaney Branch, Shuyler Creek, and Terrell Creek as well as several smaller tributaries. Wilson Creek flows through the Wilson's Creek National Battlefield before reaching its confluence with the James River approximately 2 km south of the park. The drainage area at the study site is approximately 207 km^2.

GEOLOGY AND SOILS

Geology

The geology of the watershed is dominated by the Burlington-Keokuk limestone formation (Figure 5 and Figure 6). This formation is of Mississippian age and consists of nearly pure calcium carbonate. Other formations exposed within the watershed include the Pierson Formation, the Elsey Formation, the Warsaw Formation, Channel Sandstone, Terrace Deposits, and alluvium and colluvium. The rock units are nearly horizontal

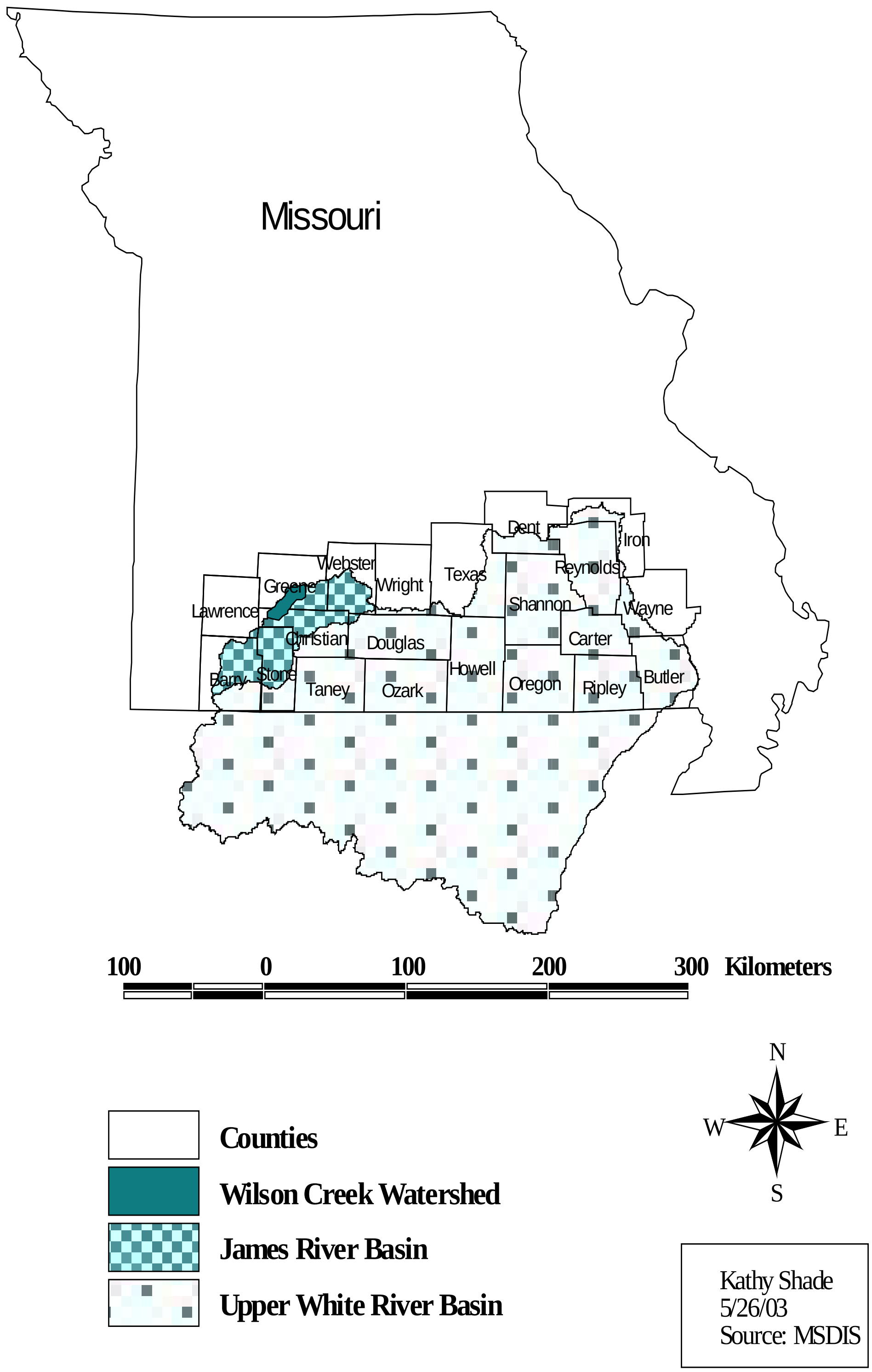


Figure 4. Location of the Wilson Creek Watershed.

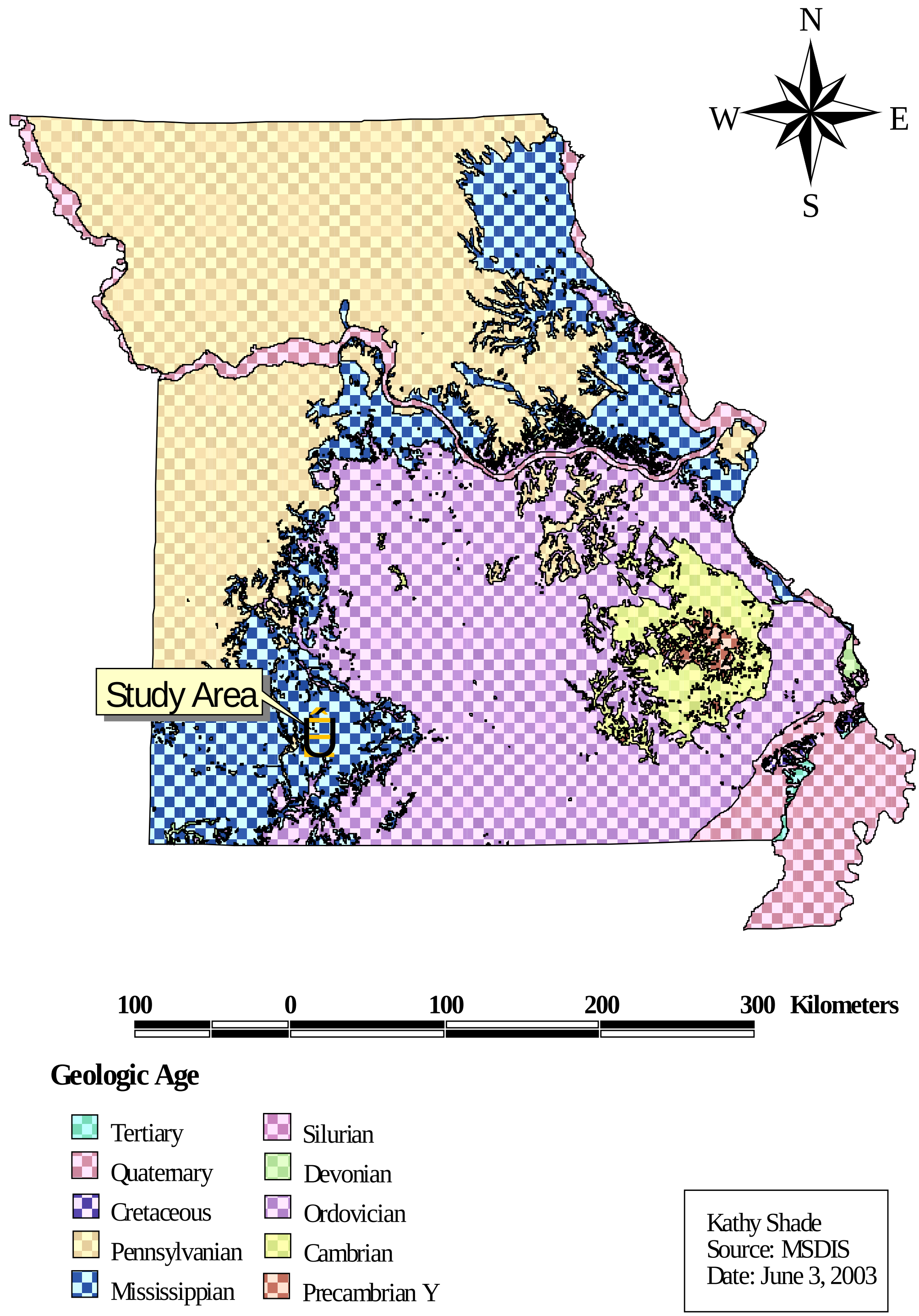


Figure 5. Geology of Missouri.

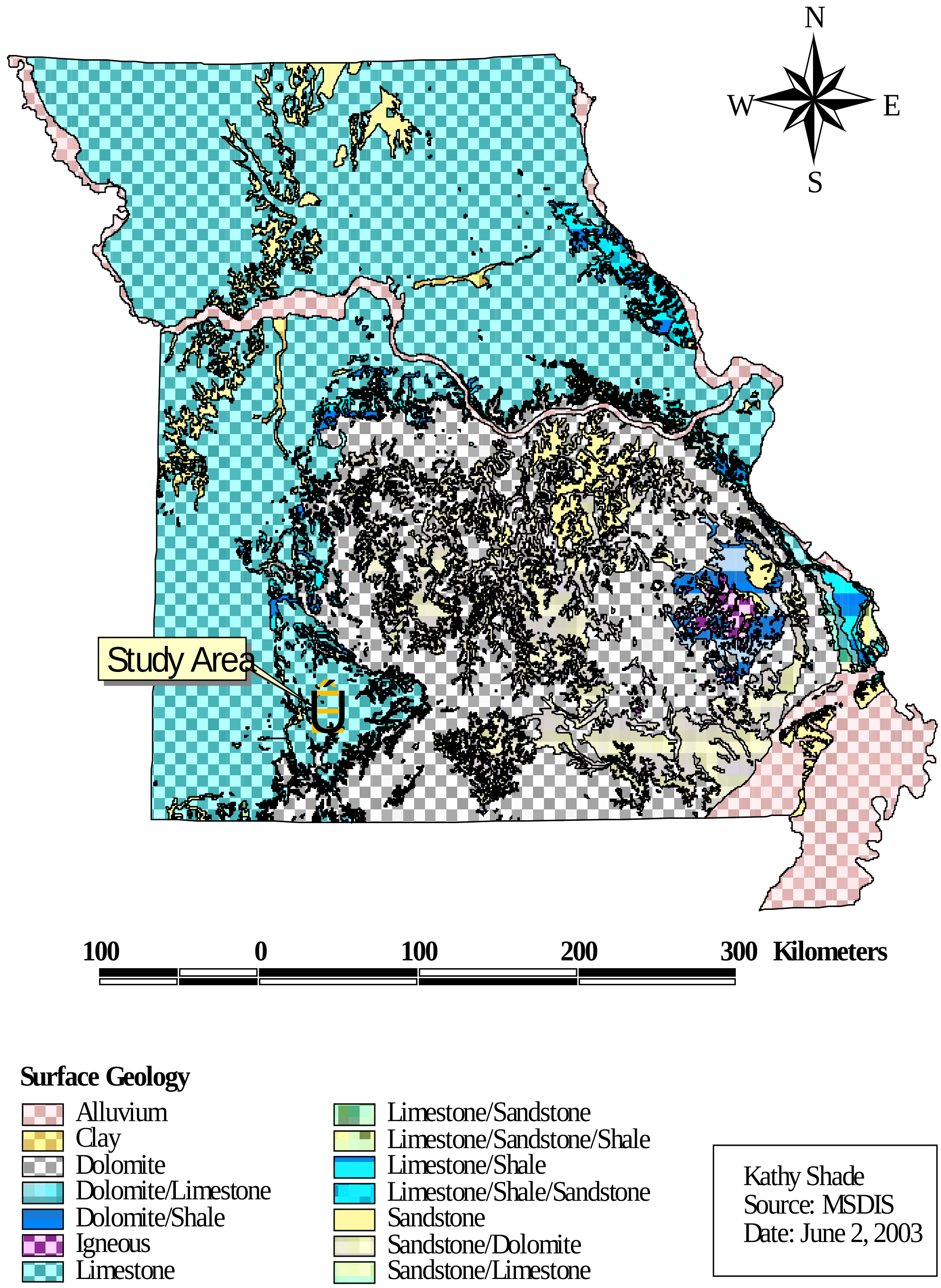


Figure 6. Surface Geology of Missouri.

with a slight dip to the west-southwest at approximately 40 ft/mile (7.6 m/km). Other geologic features within or near the study area include the Fassnight fault, the Sac-River-Battlefield fault, the Battlefield syncline and the Springfield Anticline. Other faults and joints may be present within the Precambrian basement rock below the previously mentioned formations (Shepard, 1915b).

Soils

Two major soil associations are found within the Wilson Creek watershed: Gerald-Craid-Eldon and Baxter-Newtonia soil association and Baxter-Bodine soil association (Scrivner et al., 1975). These southwestern Missouri soils form from cherty limestone with a thin loess mantle deposited on the ridgetops and level areas.

The Gerald, Craig and Eldon soils are dark-colored prairie soils that drain slowly and are often used for crops and forages. The Baxter soils developed on steep to rolling topography from cherty limestone and are light-colored with red cherty clay materials as close as two feet from the surface. These soils are not very fertile and are used for woodland and pasture. Newtonia soils are formed from loess over limestone and are dark to reddish brown. They are more productive than Baxter soils and are used for cropland, forages and pastures (Scrivner et al., 1975).

The Baxter-Bodine soil association is found in forested areas in southwestern Missouri. These soils form from cherty limestones and dolomites on steep to hilly topography and are usually well-drained. They are usually underlain by red cherty subsoils and are used primarily for woodland due to their stoniness (Scrivner et al., 1975).

Soils specifically near or on the Wilson Creek floodplain study area (Figure 7) include Peridge silt-loam (21B) in the Sharp cornfield area, Goss-Gasconade complex

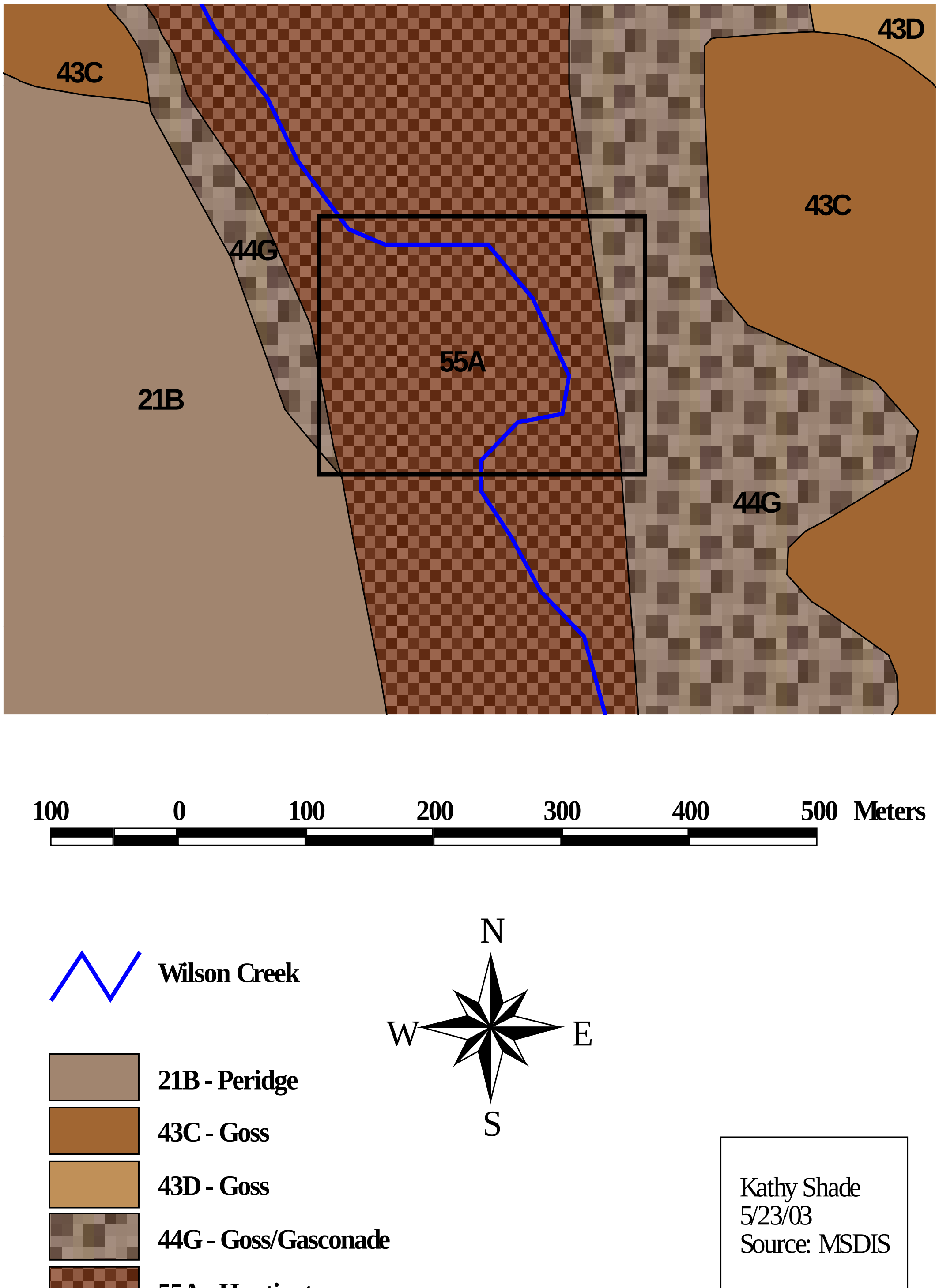


Figure 7. Soil Map of the WCNB Study Area.

(44G) along the ridge, and Huntington silt-loam (55A) along the Creek, including the floodplain (United States Department of Agriculture, 1985).

Peridge silt-loam is characterized by deep, gently sloping (2-5%) well-drained soils, typically located on high terraces and uplands around the heads and sides of drainageways. The surface layer is brown, very friable silt-loam; the subsoil extends to 64” or more and is yellowish-red friable silty clay loam over red firm silty clay loam. Most areas are used for hay, pasture and a few row crops; they are well suited to cool and warm season grasses and legumes (United States Department of Agriculture, 1985).

Goss-Gasconade soil is found on deep, gently to moderately sloping (2-50%) ridgetops and sideslopes on uplands adjacent to streams. The Goss typically has a surface layer of dark brown very friable cherty silt loam with a subsurface layer of brown then light yellowish brown very cherty silt loam. The subsoil extends to a depth of 64” or more and is light yellowish brown friable very cherty silty clay loam in the upper part and reddish brown to dark red firm or very firm very cherty silty clay loam in the lower part. Most areas of these soils are in woodlands, while some have been cleared for pasture. Goss-Gasconade soils are generally unsuitable for crops because of slopes and chert content of the soil (United States Department of Agriculture, 1985).

The Huntington silt-loam is a deep, nearly level (0-3% slope), well-drained soil found on floodplains subject to occasional (not frequent) flooding. The surface layer is typically dark brown, very friable silt-loam and about 11” thick, but up to 24” thick near the stream channel. The subsoil is brown friable silt loam up to 62” or more. In some places the surface layer may be grayish brown and the subsoil may have more clay. In other places the lower part of the subsoil and substratum are gravelly or sandy. Most areas are used for hay and pasture, some for row crops. This soil is well suited to cool and warm season grasses and legumes (United States Department of Agriculture, 1985).

CLIMATE AND HYDROLOGY

Climate

The climate of the study area is classified as a mid-latitude mild humid continental area with no dry season, distinct winter and summer seasons, and a hot summer. Total annual precipitation is about 102 cm, with most precipitation occurring in late fall, winter and early spring. The annual average high temperature for the study area is 55°F (13°C).

Hydrology

Maximum relief of the Wilson Creek watershed is 92.4 meters and the average slope of the creek is 0.0038 (Pavlowsky, 1999). Average annual precipitation is 102 cm and average annual runoff is 31 cm (Kiner and Vitello, 1997). The annual mean discharge at the mouth is about 2.5 m^3/s (U.S. Army Corps of Engineers, 1968). Discharges recorded at various USGS gages along Wilson Creek and its tributaries are listed in Table 1. Locations of the gages are shown in Figure 8. Because of the karst character of the study area, surface and subsurface waters are part of a continuous hydrologic cycle. Both influence the quality and character of the watershed.

Streams in the Wilson Creek watershed are of the typical Ozark type with gravel substrates, clear water, and characteristic Ozark flora and fauna (Bullard, 2001). There are numerous impoundments, primarily small farm ponds. Due to the karst topography and the cherty soils and poor clay materials, most ponds are leaky and streams lose substantial portions of their flow to groundwater (Bullard, 2001).

Table 1. Drainage area and discharge at USGS gages.

USGS Gage	Description	Period of Record	Drainage Area	Average Q for Period of Record	Max. Q for Period of Record
07052000	Wilson Creek at Scenic Dr. N 37º11'35", W 93º19'52" NAD27	10/01/32 to 9/30/39; 7/11/73 to 9/22/77; 6/4/98 to present	19.40 sq mi (50.2 km^2)	18.9 cfs (0.54 m^3/s)	6,750 cfs (191 m^3/s) 7/12/2000
07052050	N. F. Wilson Creek at Hwy 13 and 160 N 37º12'19", W 93º20'52" NAD27	6/26/73 to 9/30/77	5.12 sq mi (13.3 km^2)	6.5 cfs (0.18 m^3/s)	1,500 cfs (42 m^3/s) 5/20/1979
07052100	Wilson Creek near Springfield N 37º10'06", W 93º22'14" NAD27	9/21/72 to 8/30/82; 5/28/98 to present	35.3 sq mi (91.4 km^2)	20.5 cfs (0.58 m^3/s)	5,480 cfs (155 m^3/s) 7/12/2000
07052120	South Creek near Springfield N 37º09'16", W 93º21'51" NAD27	10/01/98 to present	10.5 sq mi (27.1 km^2)	2.62 cfs (0.07 m^3/s)	No data
07052150	Wilson Creek below Springfield N 37º08'49", W 93º22'26" NAD27	4/01/67 to 9/30/72	47.2 sq mi (122.2 km^2)	37.2 cfs (1.1 m^3/s)	3,700 cfs (105 m^3/s) 12/21/1967
07052152	Wilson Creek near Brookline N 37º09'07", W 93º22'18" NAD27	10/1/01 to present	39.5 sq mi (102.3 km^2)	67 cfs (1.6 m^3/s)	No data
07052160	Wilson Creek near Battlefield N 37º07'04", W 93º24'14" NAD27	3/1/68 to 9/30/70; 9/21/72 to 9/30/82; 8/3/99 to present	58.3 sq mi (151.0 km^2)	88.5 cfs (2.5 m^3/s)	7,240 cfs (205 m^3/s) 5/20/1979

Source: USGS Surface Water data for USA: Calendar Year and Peak Streamflow Statistics

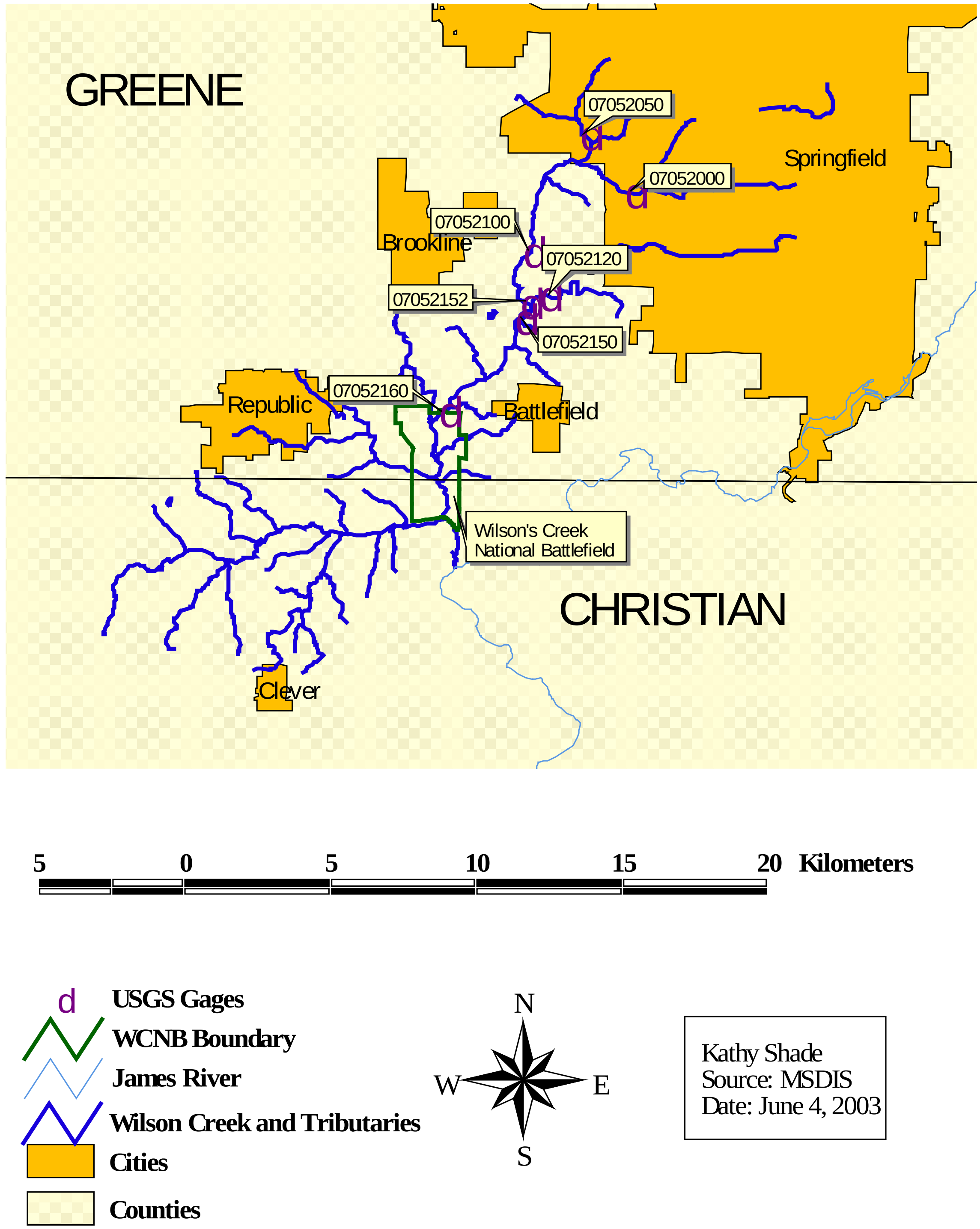


Figure 8. USGS gages in Wilson Creek watershed.

Channels of streams flowing through urban portions of Springfield have been straightened, lined with riprap and concrete, cleared of riparian vegetation, and in the case of Jordan Creek, re-routed through underground tunnels (Kiner and Vitello, 1997). Other modifications in the watershed include channelization associated with road and bridge construction, gravel removal, and alterations by landowners to control streambank erosion and other similar problems (Kiner and Vitello, 1997). These channel alterations create "flashy" storm discharges, especially in the urban areas, as is evident in Table 1.

KARST AND SUBSURFACE FLOW

Karst

The influence of the Burlington-Keokuk formation is most evident in the karst topography of the area. Conditions necessary for the formation of karst features are found throughout southwest Missouri (Thomson, 1987):

(1) A considerable thickness of rock (preferably in hundreds of feet) that is to some extent soluble. Massive, well-bedded, jointed or fractured limestones or dolomites are best suited;

(2) An area of moderate to heavy rainfall, in order for solution to take place; and

(3) Available relief for solution to take place, preferably in hundreds of feet.

As a result, features such as sinkholes, springs, caves, and faults are abundant in the watershed. Sections of Wilson Creek and its tributaries are directly affected by karst; springs, losing stream reaches, sinkholes, estavelles and caves are all included within the basin. Springs within the watershed influence the flow and temperature characteristics of the streams (Kiner and Vitello, 1997). Additionally, much of the watershed is affected by internal drainage and underground flow, making actual watershed boundaries and recharge areas difficult to assess. "In dry weather, [Wilson Creek] disappears a number of times along its course, exhibiting a more advanced stage of Karst topography than that described in another part of the county"(Shepard, 1915b). Since much of the normal storm flow is diverted to sinkholes and other internal drainage, stream channels have not been developed by storm runoff to the usual extent; during large floods the capacities of natural channels are exceeded frequently as a result of a smaller percentage of water draining into sinkholes and crevices within the channel (US Army Corps of Engineers, 1968).

Subsurface Hydrology

Groundwater may flow relatively freely through and between four limestone formations of the upper Springfield Plateau aquifer before encountering the Northview formation, a 10 to 30 foot thick relatively impermeable shale or siltstone layer that it dips slightly from northeast to southwest (Thomson, 1986). The Northview Shale acts as an aquitard and restricts flow, except where it is breached by wells or faults or fracture zones. Most residential and farm wells are drilled in the shallower aquifer at less than 300 feet (Bullard, 2001).

Below the Northview formation is the Ozark aquifer - a primarily dolomite formation of up to one thousand feet thick, capable of yielding flows of up to 2,500 gallons per minute. However, most of the City's drinking water comes from Fulbright Spring, the original source for the city, McDaniel Lake, Fellows Lake and the James River, all outside the Wilson Creek watershed (City Utilities, 2002). Deep wells are also located in the distribution system and are used as supplemental sources when needed

(City Utilities, 2002). A cone of depression exists under Springfield due to withdrawals by the City of Springfield (Kiner and Vitello, 1997).

SUMMARY

The Wilson Creek watershed and its associated landforms are strongly affected by several key aspects of the study area:

(1) The area is underlain by limestone bedrock, creating a karst landscape with its associated solution valleys, caves, sinkholes and underground channels;

(2) The headwaters of Wilson Creek and much of the watershed is located in primarily urban and residential areas;

(3) Karst landforms along with the urban nature of the watershed combine to create a stream prone to flashy discharge; and

(4) The sediment supply for the watershed is primarily fine-grained silty loess and limestone residuum, with 3-10 cm chert gravel from the limestone.

CHAPTER FOUR:

HISTORY OF URBANIZATION, WATER QUALITY AND LAND USE PRACTICES

SPRINGFIELD-GREENE COUNTY HISTORY

Pre-settlement

Before the war of 1812, "this portion of Missouri was known as 'the Osage country,' or country of the Osage Indians, who occupied it from time to time as they hunted in its forests, fished in its streams, and camped in its pleasant places" (Holcombe, 1883). The region consisted of oak/hickory forest dominated by oaks on the slopes of stream valleys and hills, as well as tall grass prairie on the level uplands (Rafferty, 1970). French voyageurs visited the area in the late 1700s searching for gold and silver, but finding nothing other than lead, did not stay (Holcombe, 1883). As other white settlers came in from points east, they found the land inhabited by the Delaware and Kickapoo Indians. From 1806 until 1829, a small village called Delaware Town was located just below the Wilson Creek confluence with the James River. Besides their principal villages at Delaware Town, according to Escott (1878), some suburban towns scattered along up and down the James and on the banks of Wilson Creek. In 1830, Congress ordered the removal of the Indians from the southwest portion of Missouri (Haswell, 1915c). Prior to 1830, Indian occupancy had discouraged the settlement of southwest Missouri, but after the removal of the Indians, immigrants flooded in (Haswell, 1915c).

Settlement of Greene County and Springfield Area

Greene County was created by a special act of the legislature on January 2, 1833 (Haswell, 1915d). The region designated as Greene County included all of what now constitutes the following counties: McDonald, Newton, Jasper, Barton, Dade, Lawrence, Barry, Stone, Christian, Greene and Webster and included parts of Taney, Dallas, Polk, Cedar, Vernon, Laclede, Wright and Douglas. It was bounded by the state's western and southern borders, the Gasconade River on the east, and the Osage Fork on the north (Holcombe, 1883). County boundaries were adjusted as new counties were created. Greene County was subdivided in 1834 with the creation of Henry County (originally called Rives), in 1835 with the creation of Barry County, again in 1851 as Stone County was formed, and finally in 1859 as Christian County took off a strip of territory "seven miles in width and running east and west across the Southern part of the county" (Holcombe, 1883).

The town of Springfield was incorporated on February 10, 1838, "By Act of the County Court", and Joel H. Haden, D. D. Berry, S. S. Ingram, R. W. Crawford and Joseph Jones, appointed Trustees (Escott, 1878). At the time of incorporation there were "something like two hundred and fifty inhabitants" and 19 businesses licensed to do business in the city, including grocers, merchants and saloons (Haswell, 1915a). By 1854, the population of Springfield was 550 (Young, 1915).

As the population of the area began to increase (Table 2, Figure 9), lumber was needed for construction, and agricultural land was needed for crops and forage to support the growing population (Rafferty, 1970). Road construction was underway, schools were built, and by 1850 citizens of Springfield were talking about the railroad coming to town.

Table 2. Population of Springfield and Greene County, Missouri.

Year	Springfield Population	Greene County Population
1840	411 [a]	5,372 [e]
1850	415 [b]	12,785 [e]
1860	2,000 [a]	13,186 [e]
1870	5,555 [a]	21,549 [e]
1880	6,522 [a]	28,792 [e]
1890	21,850 [a]	48,616 [e]
1900	23,307 [a]	52,713 [e]
1910	35,201 [a]	63,831 [e]
1920	39,631 [a]	68,698 [e]
1930	57,527 [a]	82,929 [e]
1940	61,238 [a]	90,541 [e]
1950	66,731 [a]	104,823 [e]
1960	95,865 [a]	126,276 [e]
1970	120,096 [c]	152,929 [f]
1980	133,116 [c]	185,302 [f]
1990	140,494 [c]	207,949 [f]
2000	151,580 [d]	240,678 [d]

Sources:
[a] History of Springfield: http://history.smsu.edu/FTMiller/LocalHistory/motimeline.htm
[b] Official Manual of the State of Missouri, 1963-1964
[c] Amonker, "The Changing Population of Missouri; Trends and Patterns," p. 259
[d] 2000 Census, Springfield News-Leader, March 16, 2001
[e] University of Virginia Geospatial and Statistical Data Center. United States Historical Census Data Browser. ONLINE. 1998. University of Virgina. Available http://fisher.lib.virginia.edu/census/. July 10, 2003
[f] USDC Bureau of the Census; MO Office of Administration

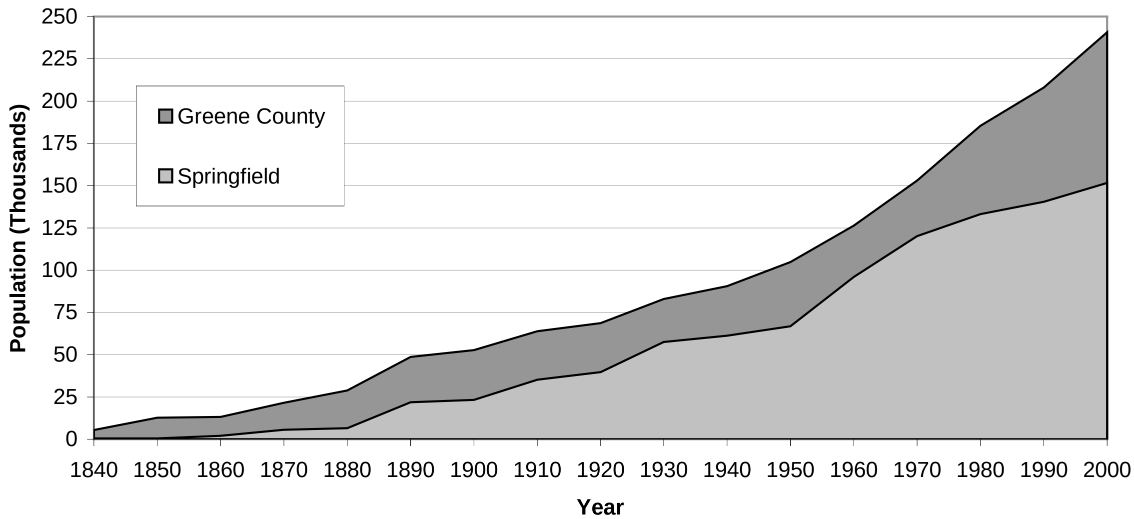


Figure 9. Population of Springfield and Greene County, Missouri, 1840-2000.

As a result of Springfield's rapid growth, most of the prairie habitat of the region has disappeared and the remaining forest lies in small stands and along riparian areas.

Springfield's boom was halted temporarily as the Civil War came to Missouri. The Battle of Wilson Creek was fought on August 9, 1861. Both armies were supplied with troops and goods from Greene County, as some merchants did their best to appear neutral and avoid the wrath of either side. The confederate and union armies traded control of the city back and forth until February of 1862. From that time until the close of the war in 1865, Federal troops remained in control of the city.

After the war, the railroad finally came to town, or at least near town. In 1870, the Atlantic and Pacific railroad was built over a mile and a quarter from the business center of Springfield, in the town of North Springfield, where the railroad had become owners of half of the town plat and been given right of way without cost. This would cause Springfield and North Springfield to eventually consolidate in 1887, but it would be well into the 20th century before "clubs of business men at either end of the town … learned to pull together for the mutual benefit" (Haswell, 1915b). Other railroads linked Springfield with population and trading centers. First regular train on the Springfield & Western Missouri Railroad came in 1878, and the Kansas City, Fort Scott & Memphis railway was completed from Kansas City to Springfield in 1881. By 1915, there were 108 manufacturing industries (not including the railroad shop) in the city with over 4,443 employees. The capital invested was $5,573,206, and the total value of products was $5,382,098 (Haswell, 1915b).

Mining in Greene County

Although it was known by the early 1800s that there were lead deposits in southwest Missouri, mining in Greene County effectively began after 1875 (Neumann, undated). Most mines in the Wilson Creek watershed were gravel mines, with few lead, zinc, iron, and clay mines (Figure 10). The only Greene County lead or zinc mining area within the Wilson Creek watershed was the Brookline mining area.

The Brookline Camp zinc-lead mines, located in S2,11 T28N, R23W include the Potter shaft and Armstrong, Old Silicate, and Deputy diggings. They were discovered in 1873, active to 1878, then again from 1891 to 1892. The productivity of this area was relatively insignificant, with only about 200 tons each of lead and zinc ores mined here through 1893 (Wharton, 1987).

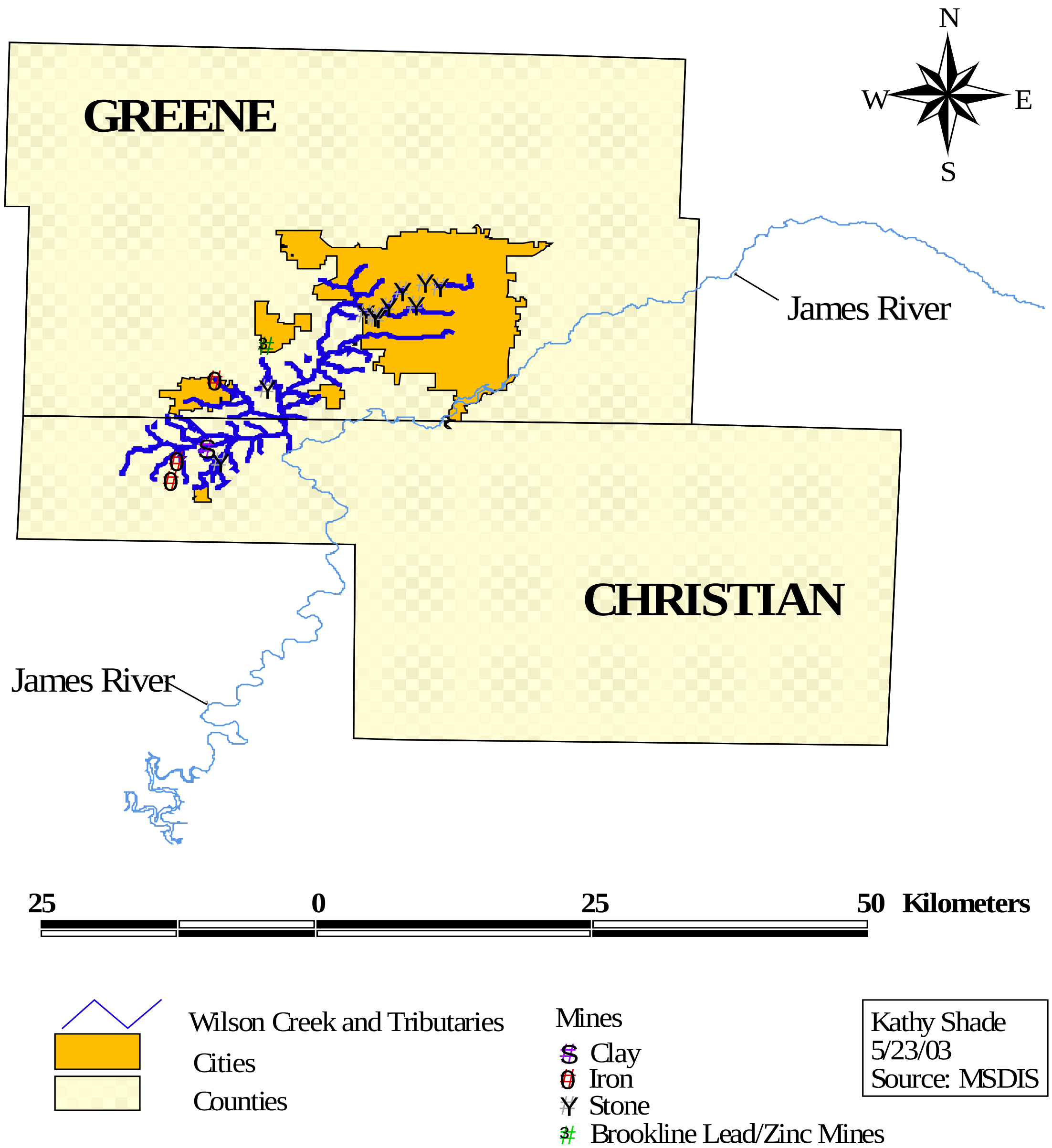


Figure 10. Mining in the Wilson Creek Watershed.

Manufacturing

By 1896, Wilson Creek and its tributaries within Springfield were the dumping ground for municipal waste from various industries located along the creeks. These ranged from (relatively) harmless mercantile businesses to those whose waste could seriously impact the stream. A partial listing of those businesses whose property was adjacent to the Creek in 1896 can be found in Table 3.

Table 3. Industries adjacent to Jordan/Wilson Creek in 1896.

Industry Name/Type
Chemical Dye Works
Foundry and Machine Shop
Coal & Wood Yard
Stone Quarry
Laundry
Tar Well
Railroad freight house
J. M. Jean Poultry Plant and Chicken Yard
Kansas City & Southern Lumber Co.
Springfield Gas Light Co.
Republican Printing Co.
Marblehead Lime Company Kilns
Kansas City, Fort Scott & Memphis Railroad Co. Shops

Source: Plat Book of Greene County, Missouri, 1904

Although Springfield's growth continued through the early 1900s, a great building boom began in the 1940s and continued through the 1980s. After World War II, companies such as Kraft Cheese, Paul Mueller, Lily-Tulip, Dayton Rubber Company, Minnesota Mining & Manufacturing (3M), Royal Typewriter, Zenith Radio Corporation and others brought jobs and money to Springfield. They also brought a need for better city services. By the early 1950s, "Springfield had overloaded its circuits almost to the point of blowing its communal fuse" (Dark, 1984) and it was obvious that a new power plant was required. City Utilities built a the James River Power Station in south Springfield, starting up towers #1 and #2 in 1955 and 1956, with #3 coming on in 1958, #4 in 1963, and #5 in 1970. Lake Springfield was built as a source of cooling water in 1955. The Southwest Power Station came online in 1974. A chronology of the growth of Springfield through the 1970s can be found in Table 4.

Urbanization

With more industry came more people, and more people built more houses. Urban land use increased by almost 20% from 1980 to 1995 with the most significant change coming from the conversion of rural and agricultural lands into residential and industrial uses (Black, 1997). Between 1984 and 1995, there was a 22% decrease in pasture and 59% increase in residential land use. The majority of growth in residential development occurred on the city's southwest side (Black, 1997). The 1995 distribution of land use within the watershed is shown in Figure 11. Approximately 55% is used as pasture and other agricultural lands; 22% is residential; 15% is used for commercial, industrial, and other urban developments; and 5% remains forested (Black, 1997).

Table 4. Chronology of development and urbanization of Springield, MO.

Year	Event	Source
10,000 BC	Prehistoric hunter-gatherers inhabited SW Missouri	CS
1700	Osage tribe dominated SW Missouri	CS
1821	First grist mill in SW Missouri (8 mi south of Springfield)	PP
1828	John Polk Campbell visits the area and stakes a claim	SO
1830	William Fullbright settled at what became known as Fulbright's Spring	SO
1831	Junius Campbell opens first store in Springfield	CS
1831	First log schoolhouse built	CS
1832	Kickapoo, Shawnee & Delaware tribes signed treaty that led to their removal to reservation in KS territory	CS
1832	Fulbright puts up mill near head of Little Sac	PP
1833	Entire southwest corner of the state established as Greene County	SO; CS
1833	First church built in Springfield	CS
1833	A one mile round race track was established in the southeast part of town, then prairie	HDSNS
1833	"Star showers"	HGC
1834	First post-office established at Springfield; J. T. Campbell appointed postmaster	HDSNS
1835	US Land office established	SO; HDSNS
1835	Springfield is named	CS
1835	John P. Campbell deeds land to Springfield "to lay off the public square and one tier of lots from said square"	PP
1837	Establishment of the *Ozark Standard*	PP
1838	Official incorporation of the city of Springfield	SO; CS
1838	Population of Springfield about 300	SO
1838	Andrew Jackson had Cherokees removed by Federal troops beginning October 1, 1838. They passed through Springfield on the Old Wire Road on the way to AR.	SO
1838	Current businesses: smithy, wagon shop, Captain Julian's carding machine, Wilson Hacknet's Hat Shop, Jake Painter-Gunsmith	SO
1840	Population of Greene county is 5,372	HDSNS
1842	"Classical academy" opens	SO
1842	18 mills for flour, cornmeal and commercial feed in operation	CS

Table 4 continued.

Year	Event	Source
1844	*Springfield Advertiser* established; printed until 1861	HGC
1845	Springfield branch of the State Bank of Missouri established	SO; CS; HGC
1845	Johnson & Wilson Co. had fall & winter dry goods, groceries, hardware, boots, shoes, books and stationery	CS
1845	J.D. Haden builds mill and distillery; sells whiskey by the barrel	CS
1845	Springfield Academy opens	CS
1845	Jake Painter gunsmith, maker of "Jake's Best" pistols opens	PP
1846	The war between the United States and Mexico breaks out; volunteers go to fight	HGC; SO
1848	Carleton College opens	SO; CS
1848	In November of this year came the "big sleet," as it was afterward known	HGC
1849	Constable elected	CS
1850	Five private schools in operation	SO
1850	Businesses include a drug store; cabinet and furniture makers; blacksmith; tinsmith; saddle, harness and wagon shops; 2 newspapers; tailors; milliners; shoe shops; gunsmith; livery stable; land office; bank; 10 lawyers, 5 doctors, one dentist and 4 clergymen	CS
1850	Population of Springfield is about 1200	CS
1850	January 14, the county was visited by one of the deepest snows known for many years	HGC
1850	Greene County population is 12,799	HGC
1850	Southwest Missouri High School opens	HGC
1853	In the summer and fall of 1853 occurred a severe drought	HGC
1853	There was considerable sickness in the county during and after the drought, and many children died of flux	HGC
1854	Springfield population of 550	PP
1854	Jamieson & Lair establish blacksmith shops	PP
1855	On the 4th and 5th of February the thermometer stood at 20 degrees below zero and the snow lay upon the ground to the unprecedented depth of 18 and 20 inches	HGC
1856	Southwest Missouri District Fair	SO; HGC
1856	Springfield population of 721	HGC

Table 4 continued.

Year	Event	Source
1857	Overland Mail delivery came through Springfield, traveling from the Mississippi River to San Francisco	SO
1857	Weather bureau established in Springfield	CS
1857	Cy M. Eversole and others of his family established the Eagle Mill on a farm southwest of the city	PP
1857	Famine in Southwest Missouri	HGC
1858	Regular mail delivery begins with the Butterfield Overland Mail coach	CS
1858	Springfield has a Police Chief and 2 officers	CS
1858	First foundry opened by Martin Ingram	PP
1858	Hancock Haden & Company established a small tobacco factory	PP
1858	W. H. Worrell opened a confectionery	PP
1860	Extension of the government telegraph line to Fort Smith	PP; HDSNS
1861	Bountiful crops this year	PP
1862	Keet-Rountree Dry Goods Company established	PP
1865	North Springfield has 400 homes, 30 businesses, 13 saloons	CS
1865	Springfield Grocer Company established	CS
1866	John McGregor opens hardware store	PP
1867	Springfield Public Schools established	CS
1869	Heer's department store opens on square	CS
1870	Atlantic and Pacific railroad reached North Springfield	PP; CS
1870	Greene County made an order incorporating the "Town of North Springfield"	HGC
1872	Springfield cotton mills established	PP
1872	Springfield Wagon Works established by Col. H. F. Fellows	PP; CS
1873	The Frisco Machine Shop erected	PP
1875	Springfield Gaslight Company established	PP
1876	City Carriage Shop established	PP
1876	Population of Springfield was 5,653; population of North Springfield was 1,038	HGC
1878	First telephone exchange	CS
1878	First regular train on the Springfield & Western Missouri Railroad.	HDSNS
1878	Springfield total population is 6878	HGC

Table 4 continued.

Year	**Event**	**Source**
1879	New steam elevator erected by Dr. E. T. Robberson	PP
1879	F. A. Heacker's Cigar and Tobacco Factory established	PP
1879	*Southwester* Job Office opens	PP
1879	Queen City Mills established	PP
1880	Hackney & Speaker open tin shop	PP
1880	Census of Springfield: 6524	HGC
1881	Mule-drawn streetcars in Springfield	CS
1881	The Kansas City, Fort Scott & Memphis Railway was completed from Kansas City to Springfield	PP
1883	Tornado hits Springfield	CS
1884	Eisenmayer Mill established	PP
1885	Electric streetcars in Springfield	CS
1887	Springfield and North Springfield merge	CS
1888	First free mail delivery	CS
1889	Springfield Ice and Refrigerating Company established	PP
1890	Population of Greene County is 21,850	PP
1891	St. John's Hospital established	CS
1894	First public high school (Springfield HS, now Central HS)	CS
1896	Welsh Packing Company established by A. Clas	PP
1900	Mill erected by the Meyer Company	PP
1903	Springfield Public Library opens	CS
1903	United Iron Works established	PP
1905	Springfield Bakery Company established	PP
1907	Doling Park established	CS
1908	Burge Deaconess Hospital (now Cox) established	CS
1910	Springfield Creamery Company established	PP
1913	Springfield Convention Hall opens	CS
1923	Phelps Grove Park served as zoo until 1923	CS
1925	Fassnight Park established	CS
1926	Highway 66 completed; gives Springfield a paved highway connection from Chicago to Los Angeles	CS
1929	Ozarks Empire Fair held at fairgrounds	CS
1932	US Medical Center for Federal Prisoners established	CS
1937	Last day of streetcars in Springfield	CS
1938	Silver Springs Park established	CS

Table 4 continued.

Year	Event	Source
1939	Kraft Cheese Company comes to Springfield	SM40
1940	Paul Mueller company begins	SM40
1945	Present Springfield-Branson Regional Airport opens in current location	CS; SM40
1945	Ozark Airlines first flight	SM40
1945	City of Springfield purchases Springfield Gas and Electric Companies and became City Utilities	SM40; CS
1945	Residential construction boom begins	SM40
1949	Assemblies of God purchases White City Baseball Park property on Boonville	SM40
1950	Paul Mueller company moves to Kansas & Phelps	SM40
1952	Lily-Tulip Cup expansion	SM40
1954	Carload of 105mm shells explode in Frisco West Railroad yards	CS
1955	Lake Springfield built for cooling James River Power Station	SM40
1955	James River Power Station unit #1 built	SM40
1955	Straightening of Glenstone Avenue	SM40
1956	James River Power Station unit #2 built	SM40
1957	James River Power Station online	CS
1957	City Utilities takes over Springfield City Water Company	SM40
1958	Springfield Convention Hall razed for parking lot	CS
1958	James River Power Station unit #3 online	SM40
1958	Hoerner Box opens at Battlefield and Scenic	SM40
1959	Royal McBee Typewriter factory built	SM40
1959	Dayton Rubber Company opens	SM40
1959	Chestnut Expressway expansion from Grant to Glenstone	SM40
1960	Kennedy Brick & Steel opens	SM40
1963	James River Power Station unit #4 online	SM40
1963	Litton Industries opens	SM40
1963	Loren Cook Company opens	SM40
1964	Clover Leaf Dairy Food opens	SM40
1965	Wilson's Creek Battlefield open to public	SM40
1966	Paul Mueller Company plant expansion to 306,000 sq ft	SM40
1966	Positronic Industries opens	SM40
1966	Springfield Tablet Manufacturing Company opens	SM40

Table 4 continued.

Year	Event	Source
1966	Zenith Radio Corporation opens	SM40
1967	Southwest Power Station construction begins	CS
1967	3M Corporation dedication	SM40
1967	Ralston-Purina Company opens	SM40
1968	MD Pneumatics opens	SM40
1969	Battlefield Mall opens	SM40
1970	James River Power Station unit #5 online	SM40
1971	General Electric Company comes to Springfield	SM40
1972	RT French Company opens	SM40
1974	Southwest Power Station online	SM40
1991	Tornado hits Springfield	CS

Sources:

CS	Boyle, Crossroads at the Spring
PP	Fairbanks & Tuck, ed., Past and Present of Greene County, Missouri
SM40	Dark, Springfield, Missouri: Forty Years of Growth and Progress
HGC	Holcombe, ed.,History of Greene County, Missouri
HDSNS	Escott, History and Directory of Springfield and North Springfield
SO	Dark, Springfield of the Ozarks

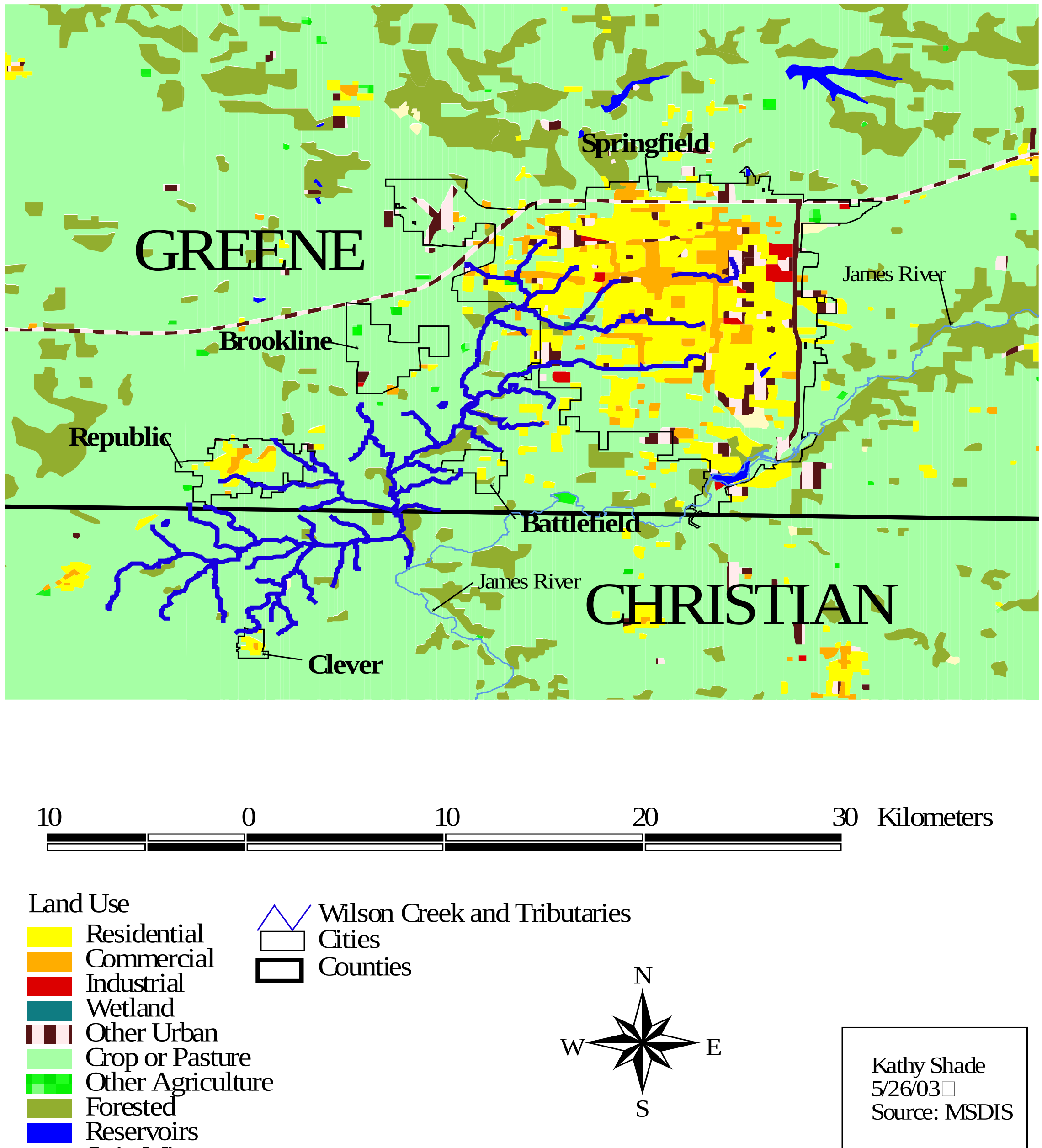


Figure 11. Land use in Greene County (1995).

WATER QUALITY ISSUES AFFECTING THE WILSON CREEK WATERSHED

Since the early 1900's, the quality of water in Wilson Creek has been a source of complaint by area citizens. The primary impacts on the watershed have come from industrialization/urbanization and clearing of the land for agriculture. Flooding, fish kills, noxious odors, and diseases have been concerns for many years.

Stormwater Runoff

With increasing urbanization producing more impermeable surfaces, flooding hazards in the urban parts of the watershed increased as well. Eventually, hazards were great enough to prompt the Army Corps of Engineers to prepare a study and compile floodplain information for Wilson Creek and its tributaries from Glenstone Avenue to the Greene-Christian County line (U.S. Army Corps of Engineers, 1968). Although systematic collection of flood data in the watershed was limited to records from a USGS gage on Wilson Creek near the city limits for the period 1932-1939 and records collected at another USGS gage near the SWTP from 1967-1968, historical information was available from located high water marks and interview of residents along the stream. Some historical documents also contained anecdotal information concerning past floods.

According to the 1968 report, the greatest flood heights at various locations in the area resulted from different storms. At the time of the report, the two largest floods were believed to be those of 1909 and 1932. In 1909, newspaper articles described water all over the Wilson and Jordan Creek bottoms. A photograph of the flooding in downtown Springfield is shown in Figure 12. In 1932, "chief damage was in the Jordan Valley, where everything was flooded, including homes and warehouses" (Leader and Press, 1932). Two people died in that flood. Other large floods occurred in 1900, 1933, and

1951. In 1951, “water was over the platform of the Frisco freight station and was waist deep at the Hoffman-Taft plant on West Bennett Street” (US Army Corps of Engineers, 1968). According to the Springfield Leader and Press (4 July 1951), “Most extensive damage was caused at Hoffman-Taft, Inc., pharmaceutical manufacturing plant…. Hundreds of drums of valuable chemicals were carried away by the flash flood.” The scene may have been similar to that in 1909 shown below:

Figure 12. Flooding along Jordan Creek in 1909 at the corner of Chestnut and Jefferson Streets.

Table 5 describes the significant floods documented by the Army Corps of Engineers occurring within Springfield from 1900 to 1968.

Table 5. Major and noteworthy floods at Springfield prior to 1968.

Year	Day and Month	Rainfall amount and duration
1900	June 17	3.0 inches / 24 hrs
1905	July 27	
1909	July 7	6.55 inches / 24 hrs
1915	August 20	
1924	April 14	
1924	June 20	
1925	September 20	
1927	April 15	
1931	August 6	
1932	June 26	3.4 inches / 2 hrs
1933	April 15	3.8 inches
1933	July 8	
1935	March 11	
1941	April 20	
1943	May 17-18	
1949	October 21	
1951	July 4	3.1 inches / 1 hr
1965	April 5	
1967	December 21	

Source: U.S. Army Corps of Engineers, 1968

According to the US Army Corps of Engineers report, “channel velocities have ranged up to 12 feet per second (3.7 m/s) during floods, and overbank velocities have reached about 4 feet per second (1.2 m/s)” and “rates of rise are known to have reached about 2 to 4 feet per second (0.6 to 1.2 m/s) at some locations in the past.”

Since the 1968 report, additional floods have been recorded on Wilson Creek near Battlefield (USGS gage 07052160). However, no gages on Wilson Creek were in operation during the period of 1982 to 1998. Therefore, the “great flood” of 1993 and any other flood during that period was not recorded by the USGS on Wilson Creek. Table 6 lists instantaneous peak discharges for floods in each year recorded from 1969-1982 and 1998-2002.

Table 6. Peak discharges at USGS gage 07052160 (Wilsons Creek near Battlefield).

Date	Discharge	Gage height
January 29, 1969	2390 ft^3/s (67.7 m^3/s)	7.25 ft (2.21 m)
April 30 ,1970	2420 ft^3/s (68.5 m^3/s)	7.28 ft (2.22 m)
November 11, 1972	3860 ft^3/s (109 m^3/s)	10.57 ft (3.22 m)
March 11, 1974	2820 ft^3/s (79.9 m^3/s)	9.13 ft (2.78 m)
June 17, 1975	2490 ft^3/s (70.5 m^3/s)	8.55 ft (2.60 m)
August 15, 1976	2130 ft^3/s (60.3 m^3/s)	7.95 ft (2.42 m)
September 27, 1977	4830 ft^3/s (137 m^3/s)	11.96 ft (3.65 m)
May 8, 1978	2010 ft^3/s (56.9 m^3/s)	7.72 ft (2.35 m)
May 20, 1979	7240 ft^3/s (205 m^3/s)	14.03 ft (4.28 m)
July 12, 2000	6160 ft^3/s (174 m^3/s)	13.75 ft (4.19 m)
February 24, 2001	2130 ft^3/s (60.3 m^3/s)	7.97 ft (2.43 m)
May 8, 2002	4620 ft^3/s (131 m^3/s)	12.06 ft (3.68 m)

Source: USGS, 2003

The Wilsons Creek near Battlefield gaging station is downstream from the SWWTP. "The left bank is high and is not subject to overflow; the right bank is low with some trees, and water will overflow at about a 6-ft. stage" (Richards and Johnson, 2002). None of the measured floods at the USGS gage on Wilsons Creek near Battlefield (07052160) exceed the USGS predicted peak discharge for even the 2-year flood (Table 7). This suggests that the flood events recorded are relatively frequent events and the Creek will overflow its banks on a nearly annual basis.

Table 7. Predicted peak flood discharge for the 2-, 5-, 10-, 25-, 50-, and 100-year flood events using equations for urbanized basins.

		Predicted peak flood discharge (cubic feet per second)					
Station Name	**Station Number**	**2-year**	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**
Wilsons Creek at Scenic Dr.	07052000	4,314	6,826	8,984	12,307	15,181	18,531
Wilsons Creek near Spfld.	07052100	6,600	10,517	13,928	19,144	23,715	29,803
South Creek	07052120	2,548	4,098	5,379	7,316	8,956	10,841
Wilsons Creek near Battlefield	07052160	9,481	15,172	20,191	27,839	34,619	42,630

Source: Richards and Johnson, 2002

In addition to flooding hazards, stormwater-induced problems include low dissolved oxygen levels (United States Department of the Interior, 1969), elevated heavy metals due to urban runoff (Proctor and Lance, 1973), and higher fecal coliform contamination (United States Department of the Interior, 1969).

Industrial Discharge

Point sources within the watershed contribute various pollutants to the Jordan and Wilson Creeks. A list of permitted point sources within the Wilson Creek watershed are listed in Table 8 and shown on Figure 13. Spills or leaks of materials from industrial sources, especially in older commercial and industrial parts of Springfield are a common problem. Fish kills documented by the Missouri Department of Conservation from 1980 to 1995 indicate spills of various pollutants, including oil, gasoline, sour milk, turkey blood, concrete, elemental mercury as well as sewage (Table 9).

Wilson Creek, Schuyler Creek, South Creek and Terrell Creek are classified for "Livestock and Wildlife Watering" and "Protection of Warm Water Aquatic Life and Human Health-Fish Consumption" beneficial uses by the Missouri Department of Natural Resources (MDNR, 1994). However, Wilson Creek has had health advisories listed on selected fish species. A level I advisory is issued for a species or area if contaminant levels are high enough that consumption of the fish species should be limited. A level III advisory is issued if the fish species should not be eaten due to contaminant concentration above levels of concern. Both level I and level III advisories were issued in 1991 due to chlordane contamination in Wilson Creek. Both advisories were lifted by 1995.

Table 8. Permitted point sources in the Wilson Creek Watershed.

Facility Name	Receiving Stream	Principal Contaminant(s)	Location (T R S)
Burlington Northern West	Wilson Creek	Pb	SE SE 29N 22W 9
Concrete Co. of Springfield	Jordan Creek	Concrete	SW SE 29N 22W 13
Dayco Products Inc.	South Creek	Zn	W NW 28N 22W 3
Drury HPER Gym and Pool	N Branch Jordan Cr.	Chlorine	NW SE 29N 22W 13
Gen. Council Assem. of God	Trib. to Jordan Creek	Printing press cooling water	NW SE 29N 22W 13
Kraft General Foods	Fassnight Creek	Phosphoric Acid, Nitrate	SE NW 29N 21W 29
Mid-America Dairymen	Jordan Creek	Nitric Acid, Phosphoric Acid	SW SE 29N 22W 14
Paul Mueller Company	Jordan Creek	Al, Mn, Cr, Cu, Ni, Zn	SE SE 29N 22W 15
Prairie View Heights Subdiv.	Trib. to Wilson Creek	Residential sewage	SE NE 28N 22W 17
SW Regional Stockyards	Trib. to Wilson Creek	Animal waste	SW SW 29N 22W 11
Springfield Ready-Mix Co.	Jordan Creek	Concrete	NE NW 29N 22W 23
Springfield SW WWTP	Wilson Creek	Cu, Cr, Cd, Pb, Ni, Hg, Ag, As, Zn	NE NE 28N 22W 7
Springfield Southwest PS	Trib. to Wilson Creek	Ba, Hg, V, Zn	SE SW NE 28N 23W 12
Springfield Southwest PS	Trib. to Wilson Creek	Ba, Hg, V, Zn	SE SW NW 28N 22W 7

Table 8 continued

Sweetheart Cup Company	Trib. to Jordan Creek	Ammonia; cooling water	SW NW 29N 21W 17
Syntex Agribusiness Inc.	Jordan Creek	Organics	NE SW 29N 22W 27
US Med. Ctr. for Fed. Prisoners	South Creek	Storm runoff/residential sewage	SW SE 29N 22W 34
Village Add. to Battlefield	Wilson Creek	Residential sewage	SE SE 28N 22W 18
Wilson's Creek Natl. Battlefield	McElhaney Branch	Storm runoff	NE SW 28N 23W 23

Source: Missouri Department of Conservation, 1996

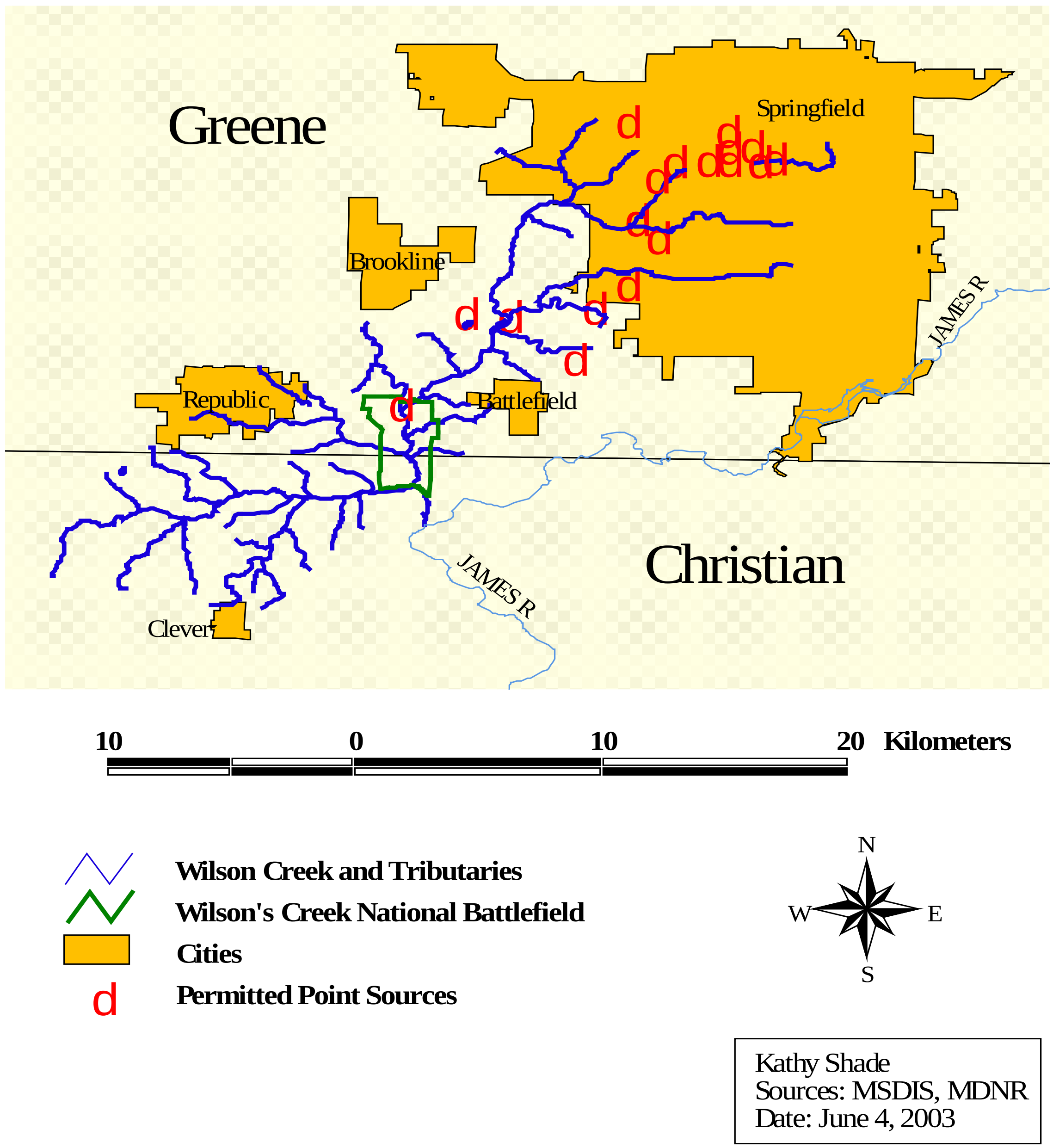


Figure 13. Permitted point sources in the Wilson Creek Watershed.

Table 9. Fish kill summary for the Wilson Creek Watershed, 1960-2003.

Date	Stream	Number Killed	Cause/Source
9-18-2002	Wilson Creek	<20	partially treated sewage
4-6-2002	Schuyler Creek	N/A	raw sewage
3-23-2002	Schuyler Creek Unnamed trib	N/A	raw sewage
3-28-2000	Jordan Creek	N/A	diesel fuel
12-30-99	Jordan Creek	N/A	unknown
9-22-97	Wilson Creek	215	low dissolved oxygen
6-23-97	Wilson Creek	41,940	raw sewage
3-14-96	Jordan Creek	N/A	undetermined
2-13-96	Jordan Creek	2,198	unknown
3-27-95	Jordan Creek	N/A	milk
8-1-94	South Creek	1,887	unknown
3-2-93	Jordan Creek	N/A	diesel fuel
5-17-93	Jordan Creek	21,164	sour milk
2-27-92	Jordan Creek	N/A	turkey blood
6-30-92	Wilson Creek/ James River	N/A	treated sewage effluent without disinfection
7-31-92	Jordan Creek	N/A	unused concrete
7-31-92	Jordan Creek	22,511	unknown
2-28-91	Jordan Creek	N/A	phosphoric acid
6-8-91	Schuyler Creek	4,909	sewage
6-18-91	South Creek	184	unknown
6-20-91	Jordan Creek	N/A	elemental mercury
1-8-90	Jordan Creek	4,162	industrial
1-25-88	Jordan Creek	10,675	unknown
3-6-87	Jordan Creek	3,273	unknown
9-23-87	Wilson Creek	N/A	sewage

Table 9, continued

10-14-86	Wilson Creek	5,539	sewage
3-30-85	Wilson Creek	N/A	sewage
4-10-84	Jordan Creek	N/A	sewage
8-12-84	Jordan Creek	19,604	unknown
12-17-84	Jordan Creek	300	sewage
3-1-83	Wilson Creek	N/A	sludge
6-2-82	Unnamed Trib to South Creek	N/A	oil spill
5-16-81	South Creek	60	unknown
10-18-79	Wilson Creek	N/A	low dissolved oxygen
4-9-75	Branch to Jordan Creek	N/A	diesel fuel
3-10-75	Fassnight Creek	N/A	#6 fuel oil
1-31-75	Jordan Creek	N/A	#6 fuel oil
4-20-72	Wilson Creek	100	low O_2 plus NH_3
7-19-63	Wilson Creek	300-400	chemicals
6-2-61	Wilson Creek	N/A	unknown
8-5-60	Wilson Creek and James River	15,000	domestic sewage
7-18-60	Wilson Creek and James River	4,000	domestic sewage

Source: Missouri Department of Conservation, 2003

Agricultural Runoff

Nutrient loading from agricultural sources continues to be a concern for watershed management throughout the White River Basin. Dairy cattle operations, poultry or turkey husbandry, sedimentation from erosion in disturbed watersheds, and pesticides, sludge or other fertilizer application all represent sources of nonpoint pollution in the Wilson Creek watershed. Following World War II, use of commercial fertilizers increased six-fold, plateauing in the 1980s. In the 1960s, pesticide use also increased, although the amounts and compounds used have changed (Grandon, 2001). In the USGS National Water Quality Assessment Program 10-year project to monitor urban and agricultural streams, they found that two-thirds of the agricultural stream samples contained five or more pesticides (Grandon, 2001).   In the study of water quality and toxicity of base flow and urban storm water in Wilsons Creek, researchers found that the greatest pesticide load was for diazinon (Richards and Johnson, 2002). Diazinon is primarily used on turf and for residential control of various insects.

Although it is often assumed that agricultural sources are the primary contributor of nutrients in the watershed, the Environmental and Energy Study Institute reported that phosphorus levels were generally as high in urban areas as in agricultural areas (Grandon, 2001). Fecal coliform bacteria concentrations were also found to be above recommended standards for water-contact recreation in both agricultural and urban streams (Grandon, 2001; Richards and Johnson, 2002).

Sewage Treatment

In addition to the previously mentioned historical issues with sewage disposal, seepage from septic systems is another unquantified source of nonpoint pollution within the watershed (Kiner and Vitello, 1997). The previously discussed karst features only enhance this problem by providing a faster and more direct route from septic tank to stream or groundwater. Karst makes the groundwater particularly susceptible to contamination because of “rapid transport through solution enlarged fractures to the groundwater system” (Waite and Thomson, 1993). Additionally, municipal sewage treatment plants discharging into the creek are significant point sources of pollution, especially the Southwest Wastewater Treatment Plant (SWTP). Most sewage discharges to streams affect less than 0.1 mile of the receiving stream, however, the effluent of the SWTP affects up to five miles of Wilson Creek (MDNR, 1994).

Southwest Wastewater Treatment Plant

With the rapid growth in Springfield came a need for treatment of sewage. Wilson Creek and its upper tributaries have been receiving Springfield's waste since the area was settled in the early 1800s. By the late 1800s, the need for sewage treatment was apparent.

The first documented sewers for the city of Springfield were built in 1894 and ran northwest to the Jordan Creek where a sand treatment facility was located. In 1910, a new sand-filter treatment facility was built further downstream (City of Springfield, 2001a).

By 1915, Shepard reports that "on account of receiving the sewage from the city of Springfield, the waters of this stream are very impure and turbid." In describing the springs of the city, he says "owing to their situation in a thickly-settled region, are all more or less contaminated with sewage, and Jones spring, especially, is unfit for domestic purposes" (Shepard, 1915a).

In 1922, the Southwest Treatment Plant moved again, this time constructing one of the first-ever activated sludge plants. It was located south of Bennett Street, and its effluent continued to be discharged into Wilson Creek. From 1937 to 1957, 68 miles of sewers were built (City of Springfield, 2001a).

The plant moved to its current location on Wilson Creek in southwest Springfield in 1959. It began with a flow capacity of 12 million gallons per day (MGD). Even after renovations in 1978, several malfunctions and storm overflows at the plant have raised serious concerns. As previously mentioned, numerous fish kills in Wilson Creek have been investigated since 1960, and several have been documented as sewage-related. A health advisory was issued in 1992 due to bacterial contamination of Wilson Creek after a malfunction at the SWTP, prompting additional renovations in 1993 (Figure 14).

Figure 14. Springfield's Southwest Wastewater Treatment Plant (used with permission).

The 1993 renovations included $30 million in improvements, enhancing treatment efficiency and reducing the phosphorus loading by 40% (City of Springfield, 2001b). Typical effluent quality is summarized in Table 10.

Table 10. Typical effluent water quality from the SWTP.

Waste Component	Concentration
Biological Oxygen Demand	< 2 mg/L
Total Suspended Solids	< 2 mg/L
Ammonia Nitrogen	< 0.1 mg/L
Dissolved Oxygen	> 20 mg/L
Fecal Coliform	< 10 colonies per 100 mL
Passes Whole Effluent Toxicity Test	
pH	7.10 std. units
Copper	15 μg/L
Chromium	< 10 μg/L
Zinc	40 μg/L
Cadmium	< 5 μg/L
Lead	< 20 μg/L
Nickel	< 10 μg/L
Mercury	< 0.2 μg/L
Silver	< 5 μg/L
Arsenic	< 20 μg/L
Cyanide	< 10 μg/L
Total Toxic Organics	Below detection limits

Source: City of Springfield, 2000

Even with significant upgrades, growth in and around the city continues to tax the system. High flows continue to be a concern, primarily due to serious infiltration/inflow problems in the sewage collection system (Bullard, 2001). The plant is currently being upgraded for the third time. Current capacity is an average of 42 MGD with a peak wet-weather flow of 65 million gallons; the $24 million expansion due to be completed in spring of 2005 will increase the peak flow of capacity to 80 million gallons (Penprase, 2003). The latest expansion will allow more flow through biological processes, increasing phosphorus removal by 25%. Although de-nitrification is not a part of this project, the city has already planned for potential nitrogen limits to be imposed and has secured a construction permit from MDNR for incorporation of the process in the future (Penprase, 2003).

Another problem related to wastewater treatment is the large volume of sludge produced. Before land application as fertilizer, sludge must meet specific chemical criteria regarding heavy metals. While cities with smaller industrial bases do not typically have much trouble meeting these criteria, Springfield aggressively addresses the issue. In 1985, the U.S. Environmental Protection Agency approved the City's Industrial Pretreatment Program (IPP) for the 5.6 MGD average flow from industrial users (City of Springfield, 2001a). The city's Publicly Owned Treatment Works (POTW) serves over 7,000 commercial-industrial customers. Springfield's IPP routinely monitors and inspects approximately 60 commercial customers each year to assure compliance with local, state and federal wastewater discharge standards (City of Springfield, 2001a). Despite the industrial discharge pretreatment and upgrades at the SWTP, the plant has still had some difficulty passing effluent toxicity tests due to problems with halogen and copper levels (Bullard, 2001). Lowering the dosage of ozone used for biological treatment has lowered the halogen level in the effluent and increased conformance with standards. Loading of copper has been reduced due to much lower emissions from a local industry (Bullard, 2001). Another potential problem for the SWTP has yet to be solved. Mercury levels below the SWTP are known to be elevated, nearly four times the state's acceptable amount of 0.5 parts per million. However, testing by plant personnel has shown that the SWTP only occasionally releases very small amounts and is probably not the source of the mercury (Barnes, 1995; Bullard, 2001). This problem, evident since 1991, continues to be investigated. Some suggest looking further west, to the nearby power station.

Springfield Southwest Power Station

The latest power-generation facility to come online is the Springfield Southwest Power Station in 1974 (Figure 15). The station is located southwest of the City of Springfield approximately two miles from the Wilson's Creek National Battlefield. It is a coal-fired unit that annually burns 650,000 tons of Powder River Basin coal (City Utilities, 1999). Coal and oil power plants are the largest sources of mercury emissions nationally, representing 33 percent of mercury emissions (Coequyt and Stanfield, 1999). According to the Environmental Working Group, a non-profit environmental research organization based in Washington, D.C., the Southwest Power Station released a total of 82 pounds of mercury into the air in 1998 (Coequyt and Stanfield, 1999).

These various sources -- some identifiable and recently regulated, some ubiquitous and virtually immeasurable -- all contribute to the contamination of the waters in the

Wilson Creek basin as well as those downstream. As pollutants in the water interact with the stream sediments, they leave behind a portion that continues to impact the area.

Figure 15. Springfield's Southwest Power Station (used with permission).

SUMMARY

Growth and development in Greene County and the City of Springfield since the settlement of the area in the early 1800s has presented many challenges to maintaining water quality in the Wilson Creek watershed. Land clearing, railroad construction, mining and manufacturing have all introduced various pollutants into the watershed. Commercial and residential development have changed land use patterns and increased sewage treatment requirements. Finally, urban and agricultural runoff have become significant yet elusive sources of nonpoint pollution. Significant events in the growth and urbanization are summarized in the following timeline (Table 11):

Table 11. Significant events in urbanization of Springfield

1820s	Settlement of Springfield/Greene County area
1830s	Green County and Springfield established; several small businesses open
1840s	Newspapers, groceries, and gunsmiths open; feed, flour and cornmeal mills built
1850s	More wagon shops, newpapers, blacksmith and tins shops open; drought, sickness, and huge snowfalls
1860s	Civil War and Battle of Wilson Creek; foundry opens; North Springfield grows; Heer's department store built on the square
1870s	Railroads arrive in Springfield; North Springfield incorporated; Frisco machine shop opens; Springfield Gaslight company established; Brookline mines open
1880s	Mule-drawn streetcars; railroad expansion; electric streetcars; Springfield and North Springfield merge
1900s	Meyer Company mill erected; United Iron Works established; Flood of 1909
1910s	Springfield Convention Hall opens; Springfield Creamery Co. established
1920s	Highway 66 completed; Phelps Grove and Fassnight Parks established; lime plant operating in Wilson Creek
1930s	Two large floods; US Medical Center for Federal Prisoners established; end of streetcars in Springfield; Kraft Cheese Company opens
1940s	Residential construction boom; Paul Mueller Co. opens; Springfield Airport opens in current location
1950s	Huge flood in 1951; Paul Mueller Co. moves; Lily-Tulip Cup expansion; 105mm shells explode in Frisco Railroad yards; Lake Springfield built; James River Power Station opens; Hoerner Box, Royal McBee, and Dayton Rubber Company open
1960s	Litton Industries, Loren Cook Co., Positronic Industries, Clover Leaf Dairy Food, Springfield Tablet Mfg. Co., Zenith Radio Corp., 3M, Ralston-Purina and MD Pneumatic companies open; Southwest Power Station construction begins; Battlefield Mall opens; large flood in 1967 and 1969
1970s	James River Power Station unit #5 online; General Electric Co. and RT French Co. open; Southwest Power Station online; huge floods in 1972 and 1979; smaller floods in 1970 and 1977; upgrade of SWTP
1980s	City Utilities/SWTP begins Industrial Pretreatment Program for industrial and commercial customers; major residential growth in SW Springfield
1990s	Tornado hits Springfield; Flood of 1993; more growth in SW Springfield; upgrade of SWTP
2000s	Major floods in 2000 and 2002; upgrade of SWTP

CHAPTER FIVE:

METHODS

The alluvial floodplain/terrace feature on Wilson Creek was sampled in order to examine the floodplain development and sedimentation patterns as well as the spatial and temporal distribution of pollutants in the floodplain sediments. It was expected that this feature would best reflect variations in overbank sedimentation due to lateral and vertical accretion processes. This required field methods, such as surveying and sample collection, as well as laboratory methods, such as geochemical analysis, sedimentological analysis, and radiological dating. These methods were aided by using GPS, mapping, and data analysis software.

FIELD METHODS

Survey of Study Area

The study area is located at the southern end of the Wilson's Creek National Battlefield Park, latitude N 37º05.6' and longitude W 93º 24.3'. A survey was conducted according to Ritchie et al. (1988) in order to select appropriate sites to collect samples while keeping the number of pits to a minimum. As the site was surveyed, GPS coordinates (latitude and longitude) of all relevant locations were collected using a Garmin GPS 12 hand-held unit.

The survey was conducted starting 135 m from the creek on the west floodplain and bisecting the feature, heading approximately due east. Surveying continued east across Wilson Creek. An Oakfield probe was used every 5 meters along this "east-line transect" to determine depth of refusal. Refusal was considered to be the point at which gravel or very tight clay prohibited pushing the probe any further. Sites for collecting sediment samples from pits or cores were chosen based on apparent changes in elevation of the floodplain surface or depth to refusal. In order to better map the surface of the floodplain, surveys were also conducted perpendicular to the 55 m and 100 m mark on the transect to both the north and south until the N-S transects intersected the creek. The study site is shown below in Figure 16, and the survey area is shown in Figure 17.

Figure 16. View along east-line transect toward Wilson Creek.

Initial Sample Collection

As a result of the survey, six locations along the East-line transect were chosen for pit sampling: 55, 70, 91, 110, 120, and 130 meters from the western terrace boundary. Pits were dug to refusal (depth ranged from 60 to 190 cm) and samples were collected

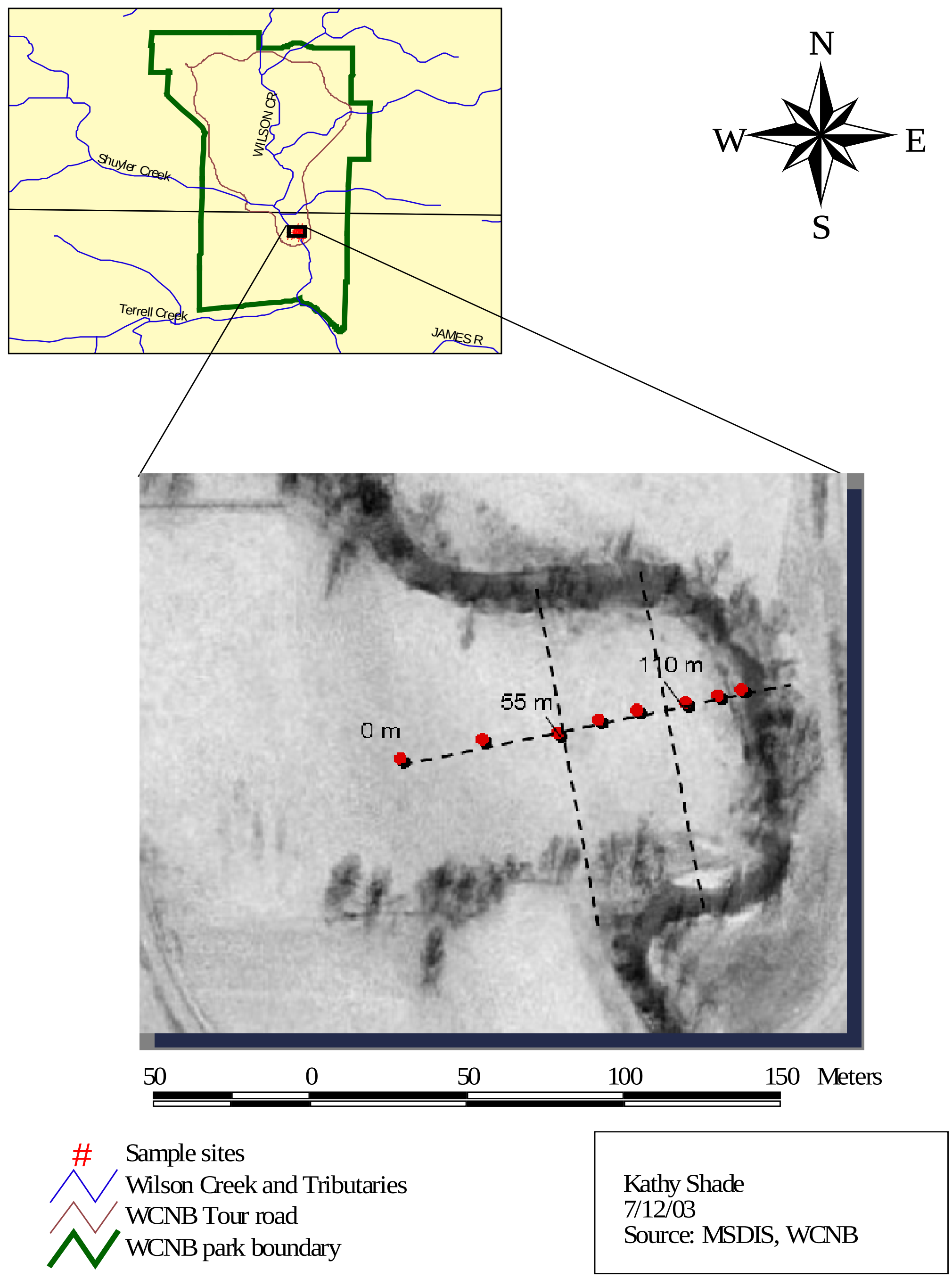


Figure 17. Sample sites on the Wilson Creek floodplain.

from the edge of the pit in 3 to 10 cm increments. In the 55 m pit an AMS 2”x 12”split core sampler was used from 120 cm down to 190 cm as the limits on pit diameter prohibited collection of samples from the wall at that depth. All samples were immediately bagged in Ziploc® plastic bags labeled with date, site, pit location and depth for transport to the SMSU Geomorphology Research Laboratory. After sampling, pits were refilled with soil that was originally removed from the pit.

Eight additional locations were chosen to sample by taking cores collected with an Oakfield soil sampling tube: 0, 5, 10, 15, 20, 35, 45, and 65 meters from the western terrace boundary. Cores collected ranged from 10 to 220 cm in depth. Finally, surface samples (0-10 cm) of soils were collected 30 and 60 meters west of the 0-meter mark on the east-line transect. The location of all pits, cores and key survey points were recorded by obtaining a GPS position using the Garmin GPS 12.

Sampling for ^{137}Cesium Analysis

Samples for ^{137}Cs analysis were collected from four additional pits that were dug 1 to 2 m north of the existing pits/cores at 25, 55, 110 and 130 meters. A control pit was dug on level upland soil just south and west of the floodplain. Samples of approximately 1.5 kg were collected in 5 cm depth intervals from pits dug to a maximum depth of 50 cm. Samples were bagged as above.

Background Samples

Samples from upland soil approximately 260 m southwest of the floodplain (N37º05.501’, W93º24.437’) were collected to determine background levels of metals and phosphorus. One pit was sampled in 5 cm increments to a depth of 35 cm. Additionally, sediment samples were collected from the bank of Wilson Creek upstream

(N 37º05.628’, W93º24.359’), downstream (N37º05.567’, W93º24.244’), and at the intersection of the East-line transect at the creek (N37º05.614’, W93º24.267’). Samples were also collected from a cutbank and the dry channel of McElhaney Branch, a tributary to Wilson Creek immediately north of the WCNB and 3 kilometers north of the study site (N37º07.107’, W93º24.567’). This stream is unaffected by urban runoff, industrial inputs, and municipal sewage effluents.

LABORATORY METHODS

Sample Preparation

All samples were air dried in their original bags for several days, then oven-dried at 50-60 ºC for a period of 24-48 hours. Samples were disaggregated by mortar and pestle and sieved to 2 mm or less and placed in clean, labeled plastic bags. The remaining portion (> 2mm) was retained in separate bags, but excluded from further testing.

Five-gram samples to be processed for chemical analysis were measured and bagged in clean, labeled plastic bags and shipped to ALS Chemex, Inc. in Sparks, Nevada. One-kilogram samples for ^{137}Cs analysis were measured and bagged in clean, labeled plastic bags and shipped to the USDA Agricultural Research Service (ARS) Hydrology and Remote Sensing Laboratory (HRSL) in Beltsville, Maryland. Remaining portions of the samples were retained for particle size analysis, Munsell color determination, soil water pH testing, and organic matter analysis.

Geochemical Analysis

After collection and preparation, 255 five-gram samples were sent to ALS Chemex, Inc. for ultra-trace level geochemical analysis. Included in that total were 80 triplicates to be used for quality assurance and same-site comparisons. Each sample was tested for a total of 34 elements by aqua regia digestion and Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES). The aqua regia digestion uses a 3:1 mixture of hydrochloric and nitric acids. Nitric acid breaks down organic matter, oxidizes sulphide material, and reacts with concentrated hydrochloric acid to generate aqua regia:

$$3\ HCl + HNO_3 = 2\ H_2O + NOCl + Cl_2$$

Most base metals and their sulfates, sulfides, oxides and carbonates are dissolved, while common rock-forming elements, such as aluminum, calcium, magnesium, and potassium are only partially dissolved. This method is economical and is appropriate for soils, sediments and weakly mineralized rock or drill samples (ALS Chemex, 2003; Kebbekus and Mitra, 1998; Walsh et al., 1997). A list of all elements tested and their detection ranges can be found in Table 12. Because trace analysis of mercury requires greater analytical sensitivity, a procedure using conventional cold vapor atomic absorption spectroscopy with a detection limit of 10 parts per billion was used for Hg analysis.

^{137}Cs Dating

Fifty-four samples from the four selected east-line transect pits and the upland soil control pit were analyzed for ^{137}Cs activity by Dr. Jerry Ritchie at the United States Department of Agriculture Agricultural Research Service Hydrology and Remote Sensing Laboratory (USDA ARS HRSL) at the Beltsville Agricultural Research Center in Beltsville, Maryland (Figure 18). Samples were dried at 90° C for 48 hours and weighed. This weight was used to calculate dry bulk density of the volumetric samples. The samples were passed through a 2-mm screen. One-liter Marinelli Beakers were

Table 12. Elements selected for geochemical analysis.

Elements and Ranges (ppm unless specified otherwise)					
Ag	(0.2 - 100)	Fe	(0.01% - 15%)	S	(0.01% - 10%)
Al*	(0.01% - 15%)	Ga*	(10 - 10,000)	Sb	(2 - 10,000)
As	(2 - 10,000)	Hg **	(0.01 - 100)	Sc*	(1 - 10,000)
B*	(10 - 10,000)	K*	(0.01% - 10%)	Sr*	(1 - 10,000)
Ba*	(10 - 10,000)	La*	(10 - 10,000)	Ti*	(0.01% - 10%)
Be*	(0.5 - 100)	Mg*	(0.01% - 15%)	Tl*	(10 - 10,000)
Bi	(2 - 10,000)	Mn	(5 - 10,000)	U	(10 - 10,000)
Ca*	(0.01% - 15%)	Mo	(1 - 10,000)	V	(1 - 10,000)
Cd	(0.5 - 500)	Na*	(0.01% - 10%)	W*	(10 - 10,000)
Co	(1 - 10,000)	Ni	(1 - 10,000)	Zn	(2 - 10,000)
Cr*	(1 - 10,000)	P	(10 - 10,000)		
Cu	(1 - 10,000)	Pb	(2 - 10,000)		

* Digestion will be incomplete for most sample matrices.

**Hg by AAS (0.01 - 100 ppm)

Source: ALS Chemex, 2003

Figure 18. USDA ARS HRSL counting facility.

filled with approximately 1000 g of the sieved soils and sealed for gamma ray analysis. Gamma-ray analyses were made with a Canberra Genie-2000 Spectroscopy System with Windows-based software/hardware package that receives input into three 8192 channel analyzers from three Canberra high purity coaxial germanium crystals (HpC >30 % efficiency). The system is calibrated and efficiency determined using an analytic mixed radionuclide standard (10 nuclides) whose calibration can be traced to U.S. National Institute of Standards and Technology. Counting time for each sample provides a measurement precision of ± 4 to 6 %. Estimates of radionuclide concentrations of the samples are made using Canberra Genie-2000 software. ^{137}Cs concentration is expressed in Becquerels per gram ($Bq\ g^{-1}$) (Ritchie, 2003).

Sedimentology

One hundred and four samples from selected pits and cores were analyzed for sand, silt and clay content using the hydrometer method based on Stokes' Law (Gee and Bauder, 1986). Approximately 40 grams of each sediment sample was weighed and placed in 250 ml beakers. Fifty milliliters of deionized water, 10 ml of acetic acid, and 5-10 ml of H_2O_2 were added to each beaker. Sample mixtures were stirred and allowed to digest for a minimum of four hours, usually overnight. They were then heated on a hot plate to 90º C for one hour in order to complete the digestion of organic matter. If the liquid above the sediment was clear or light yellow, the digestion was considered complete. However, if the liquid was dark green or brown, the procedure was repeated. After the H_2O_2 digestion, samples were dried to 110º C in a convection oven to remove all water. Samples were cooled in a desiccator for at least one hour and then reweighed.

Two hundred-fifty mL of a dispersant solution of sodium hexametaphosphate was added to the samples and stirred, allowed to sit overnight, then mixed in a blender for 15 minutes to insure dispersal of all particles. Samples were then put into one-liter graduated cylinders and diluted to a volume of one liter with deionized water. After sitting overnight to allow temperature of the samples to come to equilibrium, they were mixed with a plunger and allowed to settle. Hydrometer readings were taken at appropriate times to determine the 63 μm, 2 μm, and 1 μm fractions corresponding to sand (>63 μm), silt (63 μm-2 μm), clay (2 μm-1 μm) and very fine clay (<1 μm) fractions (Table 13). The samples were wet-sieved to isolate the >63 μm fraction, which was dried and weighed. The silt and clay fractions were discarded. The mass of the recovered sand fraction was used to correct the hydrometer readings for the sand portion (Gee and Bauder, 1986).

Munsell Color

All samples were analyzed for color using Munsell Soil Color Charts (1975). Soil samples were prepared as described above (Sample preparation) and individually compared to the Munsell Soil Color Charts in a fluorescent-lighted lab. Outdoor light, though recommended (Natural Resource Conservation Service, 1993), was not used because the soil samples were to be analyzed on different days and the lighting conditions were not guaranteed to be the same. Two researchers independently determined colors and compared random results to check for agreement. Munsell colors for all dried samples were determined and recorded.

Table 13. Hydrometer settling times.

Temp. (ºC)	Hydrometer settling time (hh:mm:ss)						
	63 µm	32 µm	16 µm	8 µm	4 µm	2 µm	1 µm
23.5	00:00:27	00:01:43	00:06:54	00:27:35	01:50:20	07:21:21	29:25:25
24.0	00:00:26	00:01:42	00:06:49	00:27:16	01:49:05	07:16:18	29:05:13
24.5	00:00:26	00:01:41	00:06:44	00:26:57	01:47:50	07:11:19	28:45:14
25.0	00:00:26	00:01:40	00:06:40	00:26:39	01:46:36	07:06:22	28:25:29
25.5	00:00:26	00:01:39	00:06:35	00:26:21	01:45:22	07:01:29	28:05:58
26.0	00:00:25	00:01:38	00:06:31	00:26:03	01:44:10	06:56:40	27:46:40
26.5	00:00:25	00:01:37	00:06:26	00:25:45	01:42:48	06:51:54	27:27:35
27.0	00:00:25	00:01:36	00:06:22	00:25:27	01:41:38	06:47:11	27:08:44

Source: Pavlowsky, 1997

Soil Water pH

Soil water pH was determined according to the methods of the Soil Science Society of America (Thomas, 1996). Before testing of the soil, a hand-held pH meter was calibrated using a two-buffer standardization, at pH 7 and pH 4. Ten grams of a previously prepared sample was weighed out and placed in a 50-mL beaker. Ten mL of deionized water was added and mixed well with a glass rod. The soil-water mixture was allowed to stand for two hours, then mixed again using a glass rod. After 10 minutes, the suspension was swirled and the pH measured for at least 30 seconds or until stable for at least 10 seconds. The pH was read and recorded. Between pH readings, the electrodes were rinsed with deionized water and calibration was checked with both buffer solutions after approximately every 10 readings.

Organic Matter

The amount of organic matter was determined by Loss on Ignition (LOI) in the SMSU Geomorphology Research Lab. Approximately five grams of each previously-prepared sample was weighed and placed in clean, dry crucibles. Samples were then dried in a convection oven at 105º C for two hours to remove atmospheric moisture. Samples were placed in a desiccator to cool for one hour and then weighed. After weighing, samples were ignited in a muffle furnace at 600º C for six hours to burn off any organic matter. After the burning, samples were again cooled in a desiccator for one hour and then weighed. The organic matter (OM) content was determined by the loss on ignition (LOI) according to the following formula:

$$\frac{(\text{2 hr-dried sed. mass}) - (\text{Post-6 hr burn sed. mass})}{(\text{2 hr-dried sediment mass})} \times 100 = \text{\% OM LOI}$$

DATA ANALYSIS

Computer-Based Analysis

Various software programs were used to store sample data, perform calculations, do statistical analysis, and visually display numeric and spatial data. *Microsoft® Excel 2002* software was used to store survey and sample data and perform calculations, including organic matter % LOI; percent sand, silt and clay; means and variances of triplicate samples; and Pearson correlations of metals from the geochemical data. Graphs of survey data were constructed using the charting capabilities of *Excel*.

Graphical and spatial data were also processed electronically. *LogPlot 2003* software was used to import data from *Excel* in order to create plots of core data, including Munsell color, pH, sedimentology, and geochemical data. GPS locations and geochemical data were imported into *ArcView GIS 3.2a* software for mapping and visualization of spatial distribution of trace elements. All maps were created using *ArcView GIS* software with data imported from *Excel*, MSDIS and MDNR.

Normalization of Geochemical Data

Geochemical data reported by ALS Chemex was imported into an Excel spreadsheet for analysis. In order to compensate for the differing grain size and geochemical makeup of the matrix, all concentrations except Al and Fe were normalized to the Al and organic matter concentrations according to Horowitz (1991) using the following formula:

$$\text{Normalized concentration} = \frac{\text{Reported metal concentration}}{(\ \%\ \text{Al}\ ) * (\ \%\ \text{LOI}\ )}$$

Aluminum tends to stay in the solid phase – sediments and soils – and is not influenced by human inputs or pollutant loads. By normalizing to Al – a conservative rock-forming element that correlates with clay content – correction is made to account for geochemical matrix and grain-size differences that tend to concentrate trace elements on the smallest particles. The additional normalization to LOI corrects for the concentration/collection effect of the organic matter particles.

Calculation of Enrichment Factor

In order to determine how each of the suspected pollutants was enriched compared to background levels, the normalized concentration was divided by the normalized background concentration (defined as the average concentration for samples below 1 m depth). Therefore, the enrichment factor is a ratio that shows how many times greater the sample concentration is over the background level of that contaminant (Förstner, 1990; Horowitz, 1991).

Quality Assurance

Particle-size analysis. Six samples from the sites were tested in triplicate for particle size analysis for same-site comparison and quality assurance. Those six samples represented collections from surface and deep pit locations, as well as near-channel and high floodplain locations. Results of the triplicate analysis (Table 14) showed that the standard deviation was less than one percent, and the coefficient of variation for all samples averaged less than 4%.

Table 14. Variations in triplicate analysis of particle size for six selected samples.

	Recovered Sand	Adjusted silt	Adjusted clay
Mean	9.0%	64.9%	26.1%
St. Dev.	0.5%	0.9%	0.8%
CV	6.6%	1.3%	3.2%

Organic Matter. A same-bag triplicate analysis was performed for all ten samples collected from the 55- meter pit on 11/19/02. Results of that analysis are shown in Table 15. Results of this analysis were extremely close, with an overall standard deviation of 0.04% and coefficient of variation of less than 1%.

Table 15. Results of triplicate analysis of organic matter LOI for ten selected samples.

Sample 1	Sample 2	Sample 3	Mean	Std. Dev.	C.V.
9.58%	9.59%	9.51%	9.56%	0.045%	0.5%
8.00%	7.93%	7.88%	7.93%	0.060%	0.8%
6.06%	6.14%	6.07%	6.09%	0.044%	0.7%
5.21%	5.30%	5.26%	5.26%	0.043%	0.8%
4.83%	4.84%	4.85%	4.84%	0.009%	0.2%
4.86%	4.75%	4.74%	4.78%	0.068%	1.4%
4.79%	4.80%	4.79%	4.79%	0.008%	0.2%
4.85%	4.94%	4.94%	4.91%	0.051%	1.0%
5.33%	5.32%	5.39%	5.35%	0.037%	0.7%
5.32%	5.37%	5.40%	5.36%	0.040%	0.8%
		Overall	5.89%	0.04%	0.7%

Geochemical analysis. Forty samples were selected from three pits for same-bag blind triplicate analysis as part of the QA/QC procedures. Each of the forty samples from the 55m, 91m, and 120m pits were split into three bags after sieving and analyzed separately. As can be seen from Table 16, most coefficients of variation were extremely small, with all but one less than 7%. The largest CV was for silver (19%), where concentrations were very close to the detection limit of the testing facility.

Table 16. Variations in geochemical analysis for forty selected samples.

	Ag ppm	**Al %**	**Cu ppm**	**Fe %**	**Hg ppb**	**Mg %**	**Mn ppm**	**P ppm**	**Pb ppm**	**Zn ppm**
Mean	0.6	1.2	19.7	1.6	231.9	0.1	1253.4	632.3	48.6	109.9
St.Dev.	0.07	0.08	0.76	0.04	11.98	0.01	34.07	16.13	1.33	2.89
CV	18.7%	6.9%	3.6%	2.9%	6.4%	5.6%	2.7%	2.6%	3.1%	2.7%

Complete results of triplicate analysis may be found in Appendix A (particle size), Appendix B (organic matter) and Appendix C (geochemical analysis).

CHAPTER 6

RESULTS AND DISCUSSION

This section describes and discusses the important geomorphological and geochemical findings of the study in the following sections: (1) landform characterization, including morphology, stratigraphy and aerial photography record; (2) core analysis, including sedimentology, cesium profiles, geochemical profiles, and geochemical relationships; and (3) urban pollution and dating of alluvial deposits.

LANDFORM CHARACTERIZATION

The landform being studied is a small alluvial floodplain located near the southern boundary of the Wilson's Creek National Battlefield Park. It is approximately 100 m north of the southern loop of the park tour road, and 900 m from the southern park boundary. Elevation is 1080 ft (329 m) at the channel bank. The old Missouri Pacific Railroad bed runs parallel to the Creek approximately 50 m to the east.

Morphology

The survey results of the study area, including the surface survey and probes for depth to refusal, are shown in Figure 19 (East-line survey), Figure 20 (100m survey), and Figure 21 (55m survey). At the intersection of the East-line transect and the creek, the channel width is approximately 20 m. Water depth at the time of the survey was 0.38 meters, and bankfull depth is approximately 1.0 m. Within the park boundary, valley slope is 0.54%, and sinuosity of the Creek is 1.2. The slope of the Creek at the study site (around the bend) is 0.33%, while the valley slope is 0.50%.

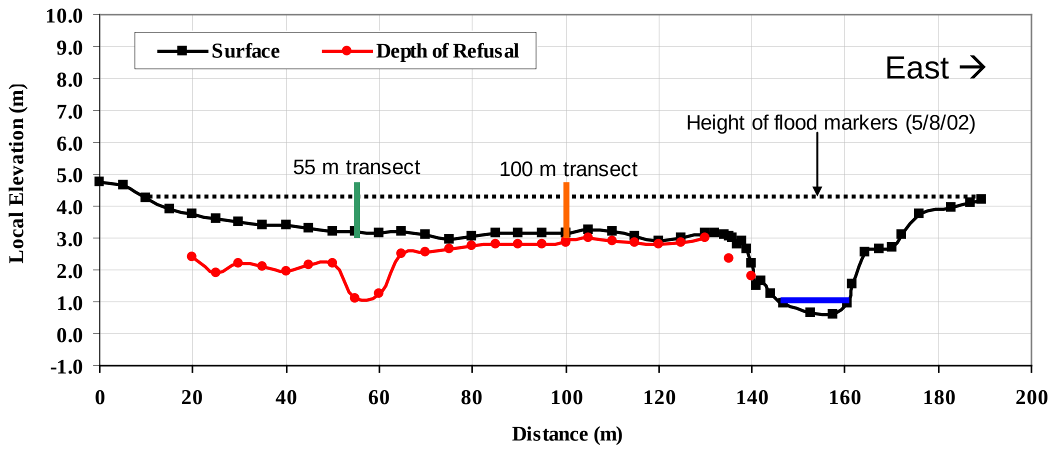


Figure 19. East-line survey.

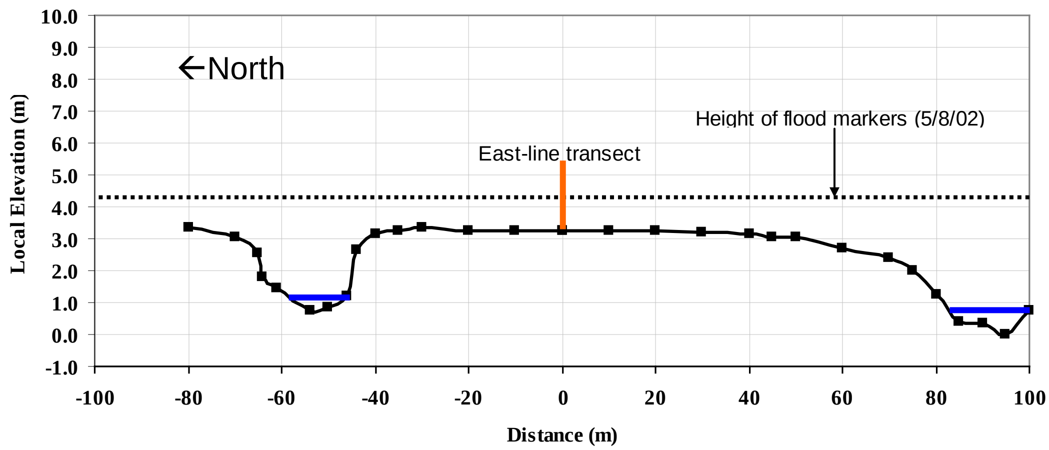


Figure 20. 100m-transect survey.

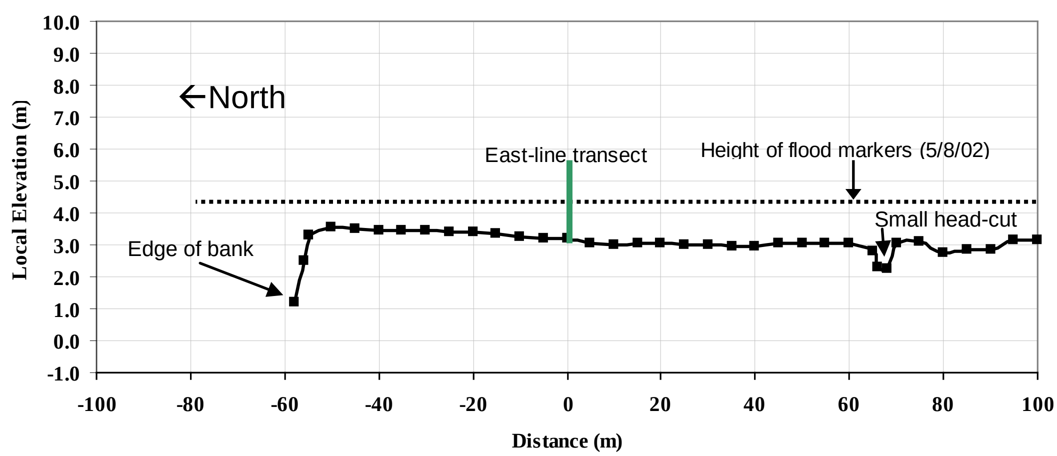


Figure 21. 55m-transect survey.

The East-line survey indicates a slightly sloped (3.4%) colluvial footslope, and a relatively flat (0.27 %) alluvial floodplain. There is a slight depression approximately 20 meters west of the channel bank, with some gravel apparent on the surface. This depression continues both north and south across the feature, perhaps indicating a periodic breach of the bank during seasonal flooding.

The 100 m-transect survey indicates a flat floodplain on the north side with the crest of the overbank levee approximately 15 m from the channel bank. Since the north side of the floodplain is the upstream, erosional side of the channel, this was an expected result. The south side was more convex and gently sloping, with an overall slope to the water's edge of 3.1%. This is the typical shape of the depositional side of a floodplain (Willis, 1989). There was no clear mark that indicated a bankfull depth on this side of the creek.

The 55m-transect survey reached from the bend in the creek at the north to just above the creek at the south. This portion of the floodplain is flatter, with a gentle slope from N to S of only 0.2%. There is a small tributary approximately 65 meters from the east-line transect that runs W to E across the southern edge of the feature, and a small headcut, approximately 0.5 m deep, where the survey-line intersects the tributary.

Channel maximum cross-sectional area of the channel from bank to bank (134 m to 178 m) at the study site where the east-line transect intersects the creek is approximately 51 m^2. Using Manning's equation with a hydraulic radius (R) of 0.73 m, estimated roughness coefficient (n) of 0.045, and slope of 0.33%, the mean velocity at maximum capacity is 1.2 m/s (3.80 ft/s). Average discharge at channel capacity is approximately 60 m^3/s (2100 ft^3/s).

At the time that the initial survey was conducted (5/30/02), flood markers such as debris in trees, a ridge of debris at the high water mark on the ground, and bent and broken branches were apparent. According to these markers, the water reached approximately 3.7 meters above the channel bed. Therefore, nearly the entire study area of the floodplain (up to approximately 140 m from the center of the channel) was flooded and received sediment during a recent flood on May 8, 2002.

During the May 2002 flood, the cross-sectional area of the flooded channel was approximately 171 m^2. Using Manning's equation with R of 0.74 m, n of 0.055, and slope of 0.33%, the mean velocity at maximum capacity is 0.86 m/s (2.8 ft/s). Maximum discharge during the flood was approximately 147 m^3/s (5157 ft^3/s) at the study site -- slightly higher than the 131 m^3/s (4620 ft^3/s) discharge at the upstream USGS gage.

Stratigraphy

The probe for depth to refusal indicated a gravel layer approximately 15-20 cm below the surface near the natural levee at the channel bank, gradually tapering to a depth of 40 cm about 60 meters from the channel. From this point westward, refusal was due to very tight clay rather than gravel. Clay continued to be the reason for refusal up to the 20 meter mark, at which point probes were no longer used.

Six original pit/core locations were sampled on 5/26/02 based on the results of the initial survey. Four additional locations were sampled using the Oakfield probe, and three surface samples (0-10 cm) were taken on 6/30/02. Pits for ^{137}Cs sampling were sampled 11/19/02, and an upland comparison pit was samples on 2/12/03. Locations of the sample sites are shown in Figure 22 and Figure 23, and identification information for all samples can be found in Appendix D. Diagrams of the stratigraphy of each pit and core are presented in Figure 24.

The floodplain alluvium primarily consisted of brown silt at the surface down to depths of 10-100 cm with increasing depth away from the channel. From the terrace boundary (0 m) to the 45 m core, the soil appeared to be a combination of hillslope colluvium with some fluvial deposition. The 55 m pit was the deepest (190 cm) and nearly all silt and clay with very little sand or gravel. Refusal at the bottom of the pit was due to very dense reddish clay. This may be an indication of an old channel that has been filled in with fine-grained material. From the 65 m core to the 130 m pit, there is an increasing amount of gravel, with depth to refusal decreasing towards the channel. This likely indicates the location of an old gravel bar that has since been covered by finer material as the channel shifted to the east. The red clay at the bottom of the 25 m to 55 m pits/cores indicates that this soil has had time to weather and therefore is probably older than those to the east.

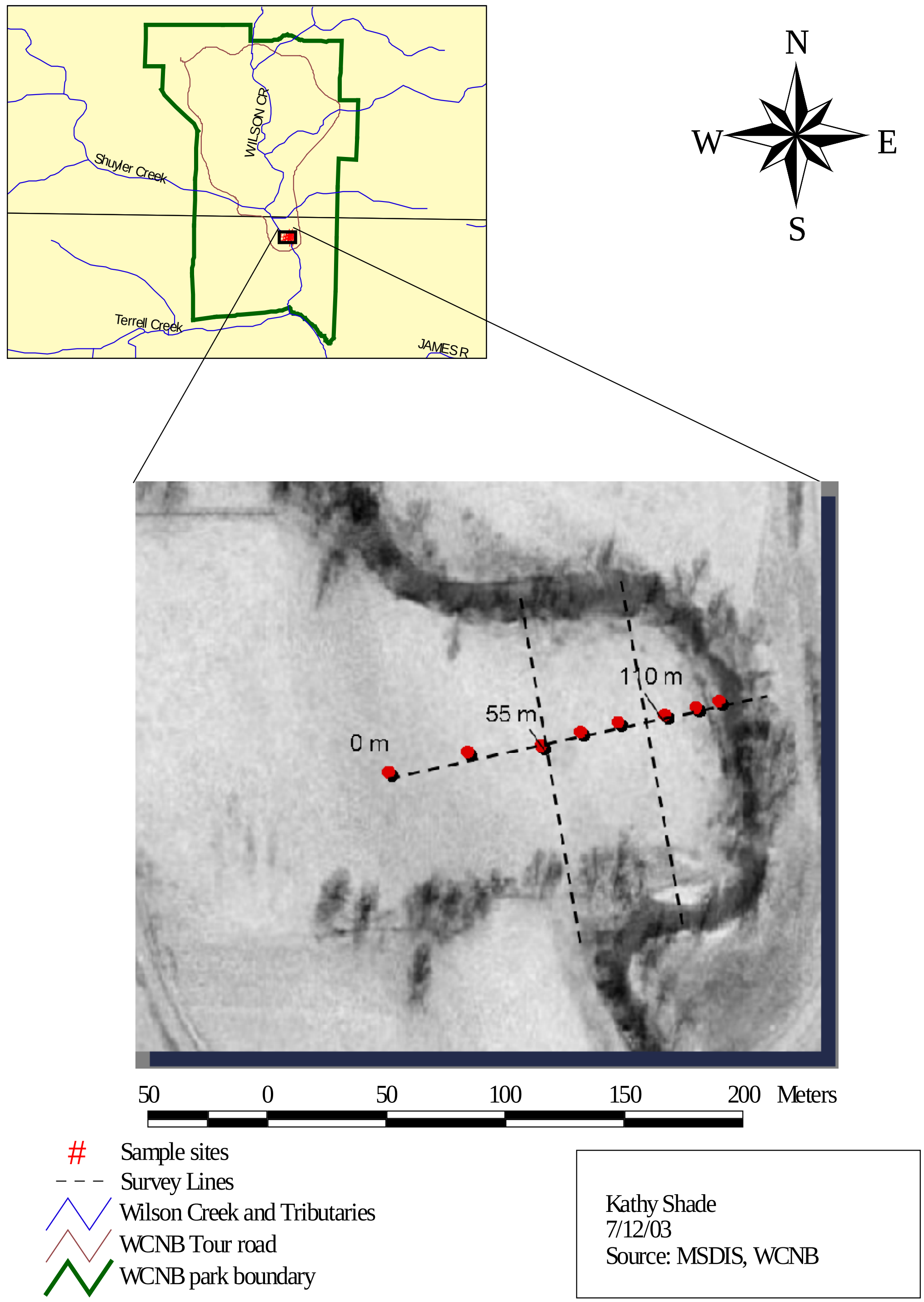


Figure 22. Initial samples sites on Wilson Creek floodplain.

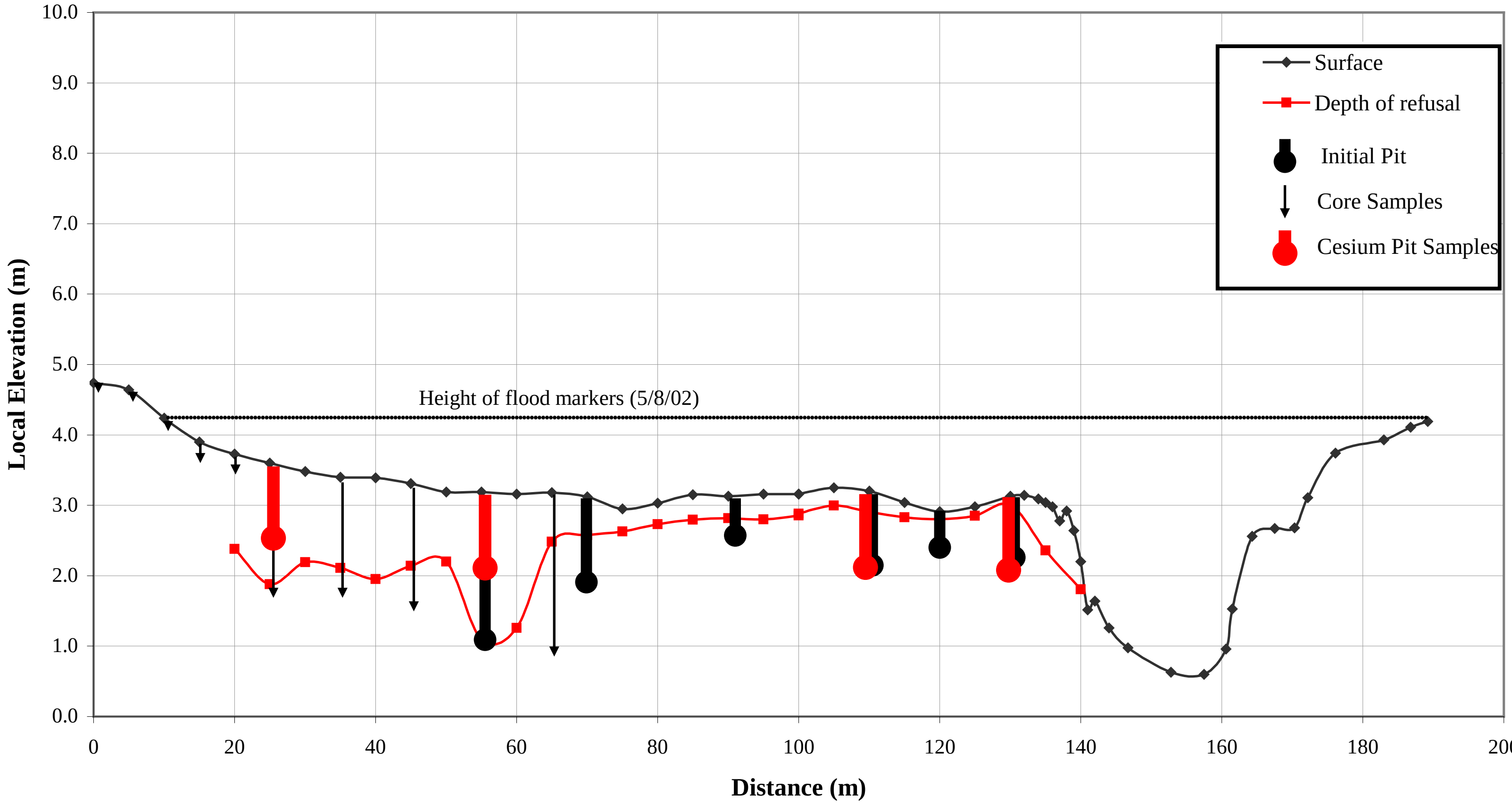


Figure 23. Location of all sample pits and cores.

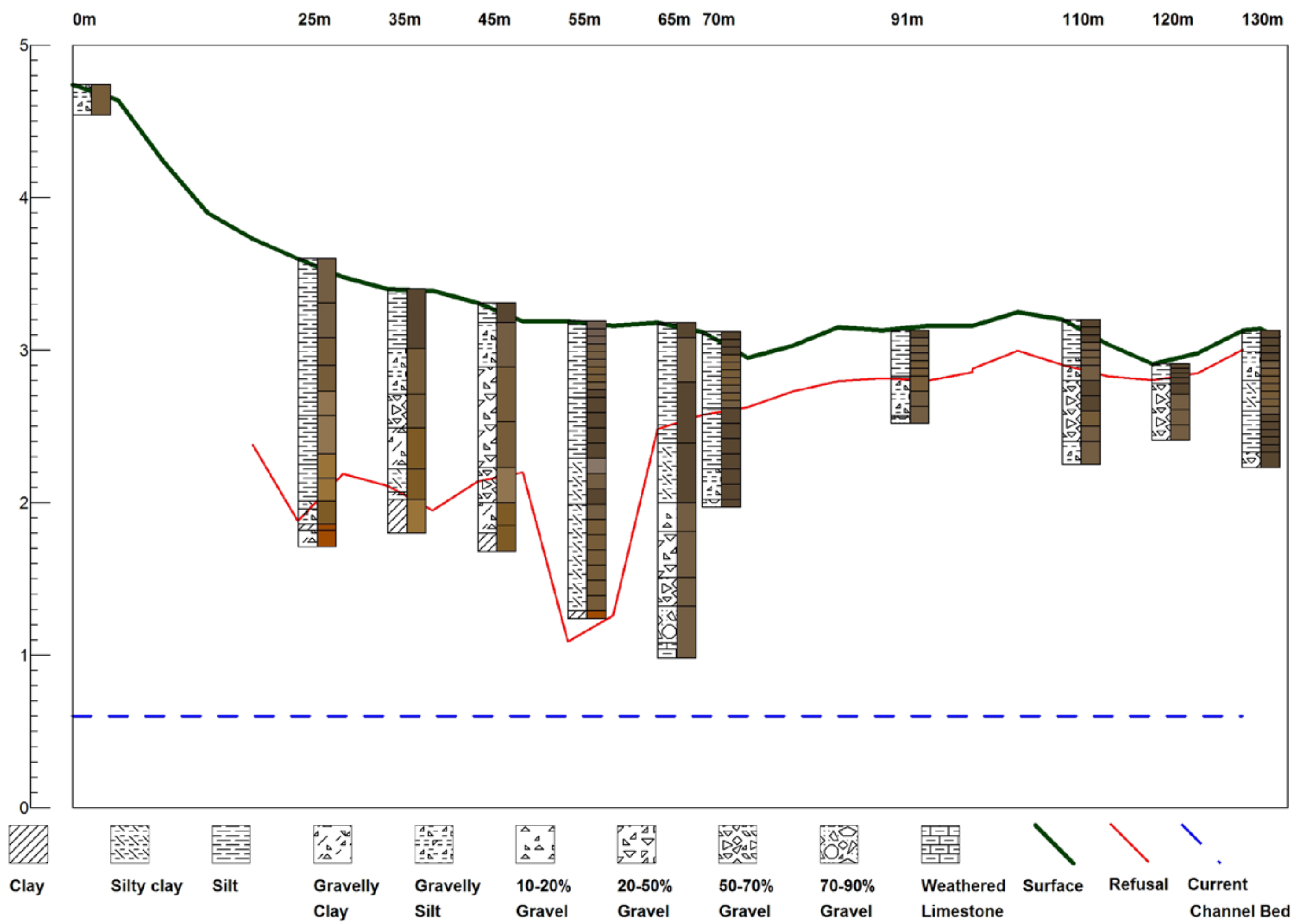


Figure 24. Pit stratigraphy.

From stratigraphic data, six general deposition units can be identified, and are pictured in Figure 25:

1. Hillslope colluvium/alluvium
2. Weathered alluvium
3. Weathered gravelly alluvium
4. Buried soil unit
5. Historical gravel
6. Post-WW II alluvium

Residuum or very weathered limestone is found at the bottom of the 25m - 65m pits, but core sample sizes were not adequate for geochemical analysis. These units will be further defined by using additional information from the aerial photos, geochemical analysis and cesium profiles.

Aerial Photography Record

Aerial photos from 1936, 1941, 1968 and 1995 were analyzed to determine if and/or how the channel of Wilson Creek had changed during that interval. Photos of the channel of Wilson Creek near the study area in are shown in Figure 26. In the earliest three photographs, photos were taken during the summer and fall, while deciduous trees still had their leaves. Identifying the exact location of the channel in these photos is difficult due to the tree cover. However, it is apparent that the channel has not moved significantly since the first photo in 1936.

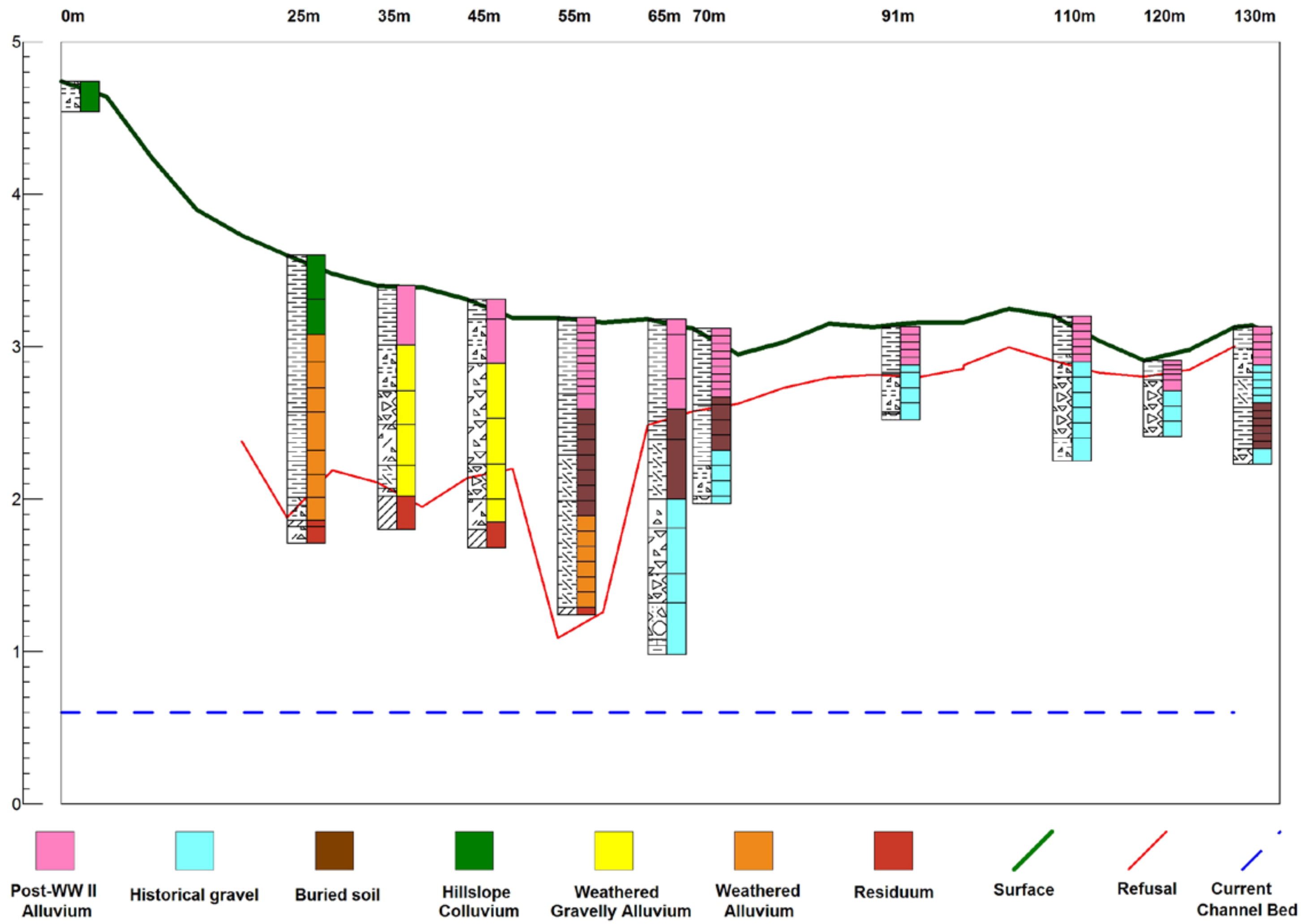


Figure 25. Geomorphic map of deposition units

Figure 26a. Study site in 1936. Note the gravel splay or bar deposits near the channel. A buffer is well established by 1936, indicating channel was probably in this location by 1910 or earlier.

Figure 26b. Study site in 1941. Gravel is more apparent in this photo than in 1936. Some trees have been removed above the floodplain.

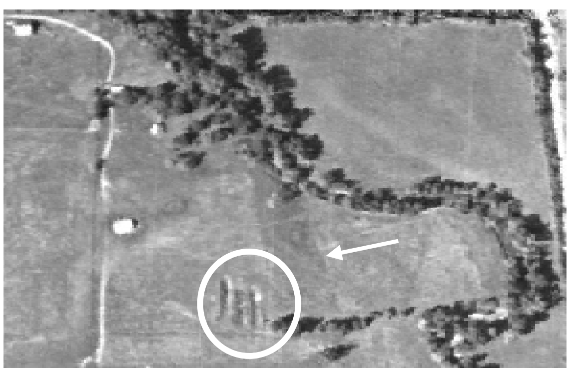


Figure 26c. Study site in 1968. All trees have been removed from above the floodplain. Archeological research was conducted in the 1950's and may be responsible for the disturbance near the bottom center of the photo.

Figure 26d. Study site in 1995. Disturbance is still slightly visible.

Photos courtesy of Wilson's Creek National Battlefield

Other changes (or lack thereof) can be seen in the photographs. Most of the trees originally on the slope between the corn field and floodplain in the 1936 photo have been removed by 1941, and by 1968 they are completely gone. Without the tree line as a buffer, slope wash and colluvial sedimentation would increase during this time. There appears to be increased erosion of the upstream bank as the corner appears to be a sharper angle. Additional deposition in the lower bend appears to be slightly increased as well, as the lower bend appears somewhat less acute. Since the trees in the photo obscure the exact location of the channel, however, it is difficult to precisely measure the change.

Land use in the immediate area has changed since the National Park Service began management of the Battlefield area. The upland area to the west of the floodplain was primarily used for row crops and/or pasture prior to 1959 and would have been a source of erosion and deposition down slope. Since the area became designated as a National Battlefield, there has not been row cropping in this region. The floodplain itself remains uncultivated. In the 1968 photo there is a series of small ridges that are still evident in the 1995 photo. There is still evidence of overturned soil and rock in this area today. Records of archeological studies indicate that some sites near the floodplain were investigated in the early 1950s. These may be remnants of those digs.

Finally, a gravel splay is evident in the 1936 and 1941 photo that may indicate where the natural levee of the channel was breached during a flood event. This appears to correspond to the 120m pit location on the current floodplain. This may explain the slight depression that has filled in with finer grained material over the past 50-60 years and the resulting concentration of pollutants in this location.

Discussion and Summary

Survey, stratigraphy, and aerial photo analysis show that this feature is likely the result of a large gravel bar getting wedged in the channel at approximately 65 m and forcing the channel to shift to the east side of the bar. The presence of a darker silty layer in the 65 and 70 meter pits may indicate a buried soil on top of the gravel bar. Lighter, redder, more fine-grained soils further from the current channel (55 m and 25m pits) indicate older, more weathered deposits. Aerial photos indicate this feature has remained relatively stable over the past 70 years. A gravel splay in the 1936 and 1941 photos may aid in dating deposits in the 120m pit.

CORE ANALYSIS

Sedimentology

Analysis results for all Munsell color, soil water pH, organic matter content, and particle size analysis are presented in Appendix E. Results for four representative pits/cores can be found in Figure 27 (25 m), Figure 28 (55 m), Figure 29 (110 m), and Figure 30 (130 m).

Munsell color for the dried, sieved soil was typical of the Huntington silt loam soil type. The hue was primarily 10YR and ranged from yellowish brown (10YR 5/6) to dark brown (10YR 3/3 or 7.5YR 4/2). In the upland soil sample and the core farthest from the channel (25 m), the darkest colors were in the top 10-20 cm where the organic matter was content was the highest. Soil got lighter and redder with depth, indicating soil forming processes have occurred and clay content increased with depth, and therefore age. However, in the cores closer to the channel color alternated from a dark brown top layer to a dark yellowish brown intermediate layer, then another dark layer beginning at a depth of 40-50 cm and with a thickness ranging from 20 to 60 cm. In the 55-m core there was an additional dark layer at a depth of 110-120 cm. These dark layers indicate higher organic content and, combined with other geochemical markers, may indicate the presence of a buried soil.

As expected, soil water pH was relatively neutral, with a range of 6.4 to 7.8 for all samples. Because of the limestone residuum soils in the area, the soil is naturally somewhat buffered. In general, the soil water pH is lower when the organic matter was higher with a few exceptions. There is no decrease in pH with organic (1) near the water table or gleyed deposits and (2) in “redder” more weathered deposits.

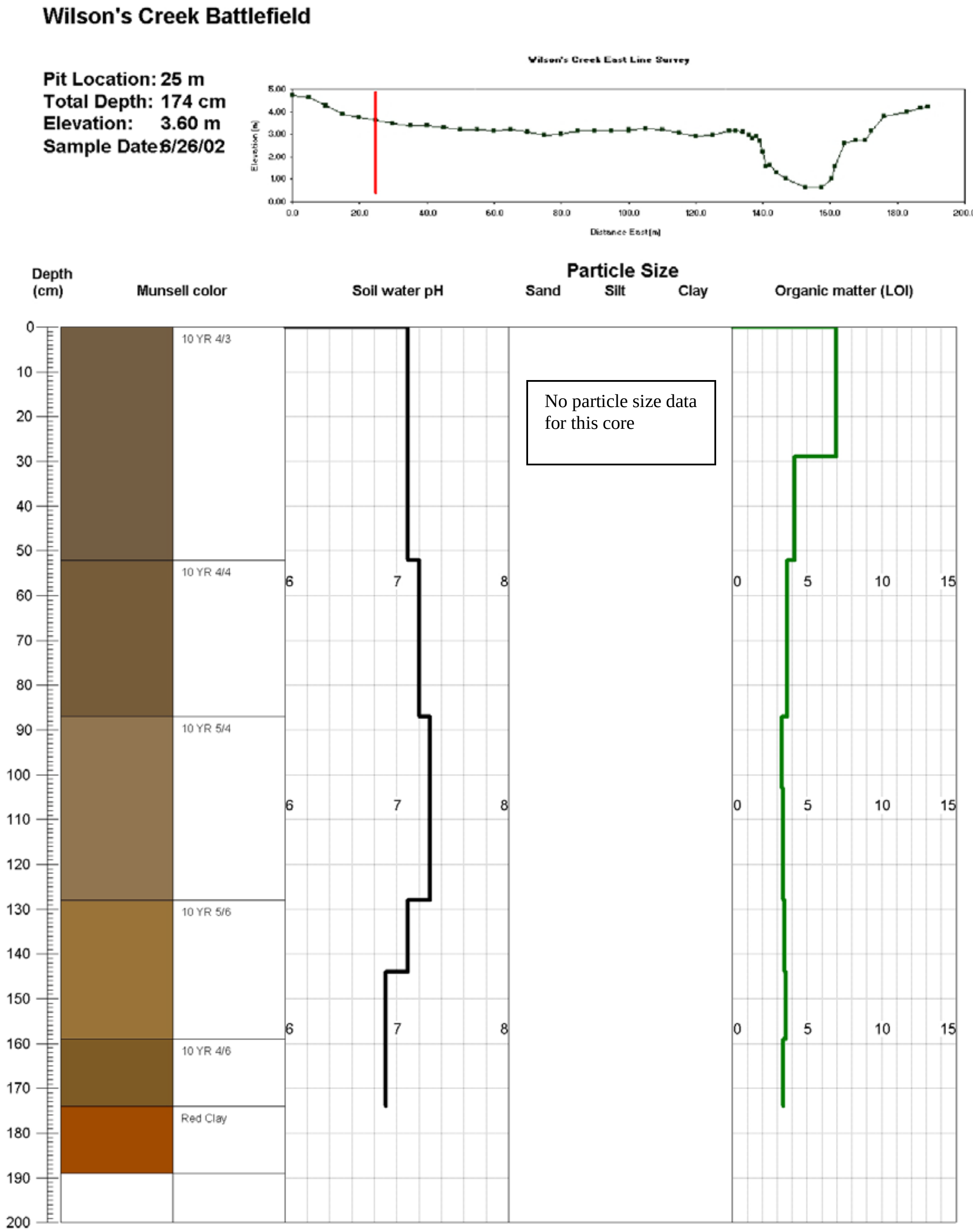


Figure 27. 25m Munsell color, pH, particle size, and organic matter LOI.

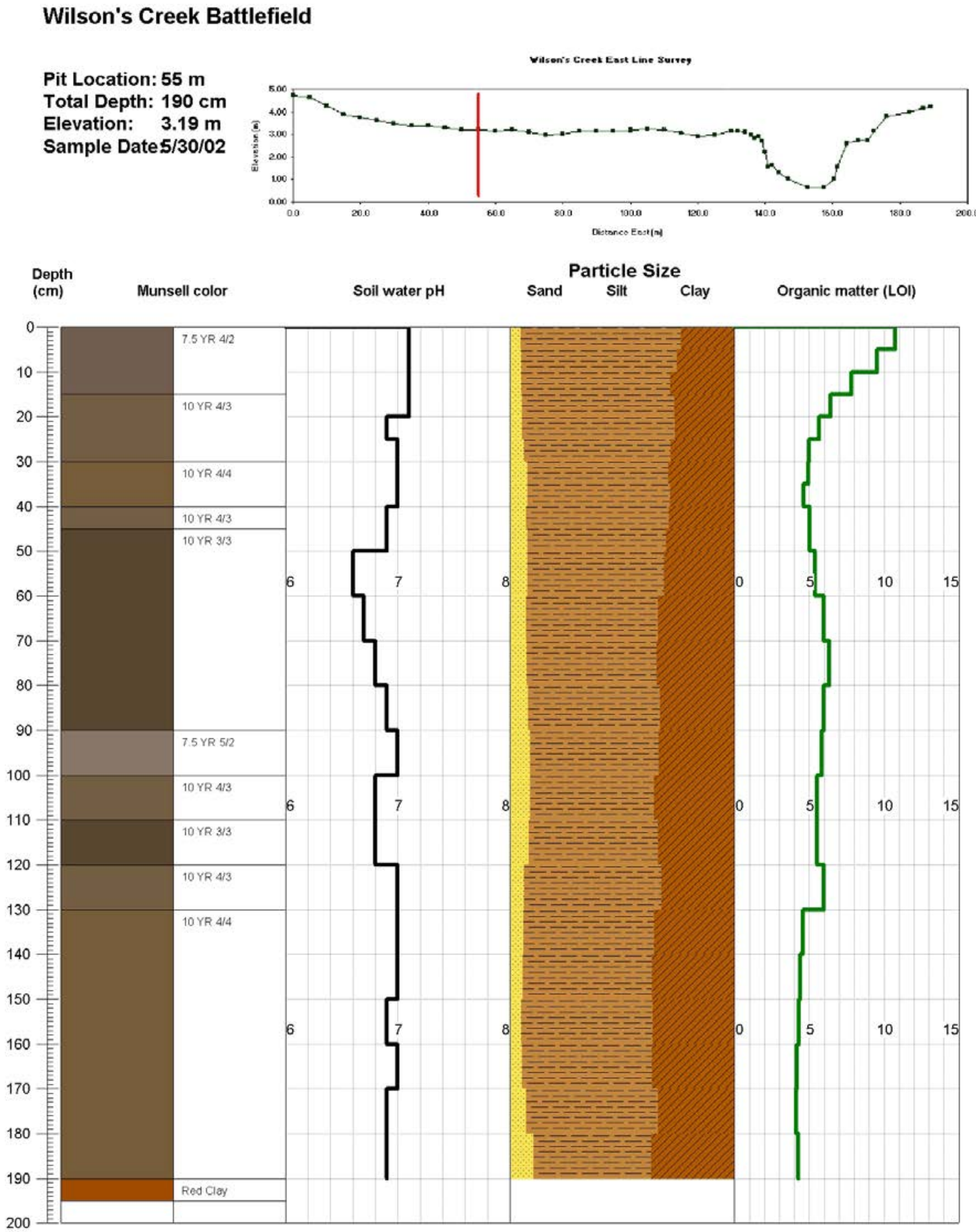


Figure 28. 55m Munsell color, pH, particle size, and organic matter LOI.

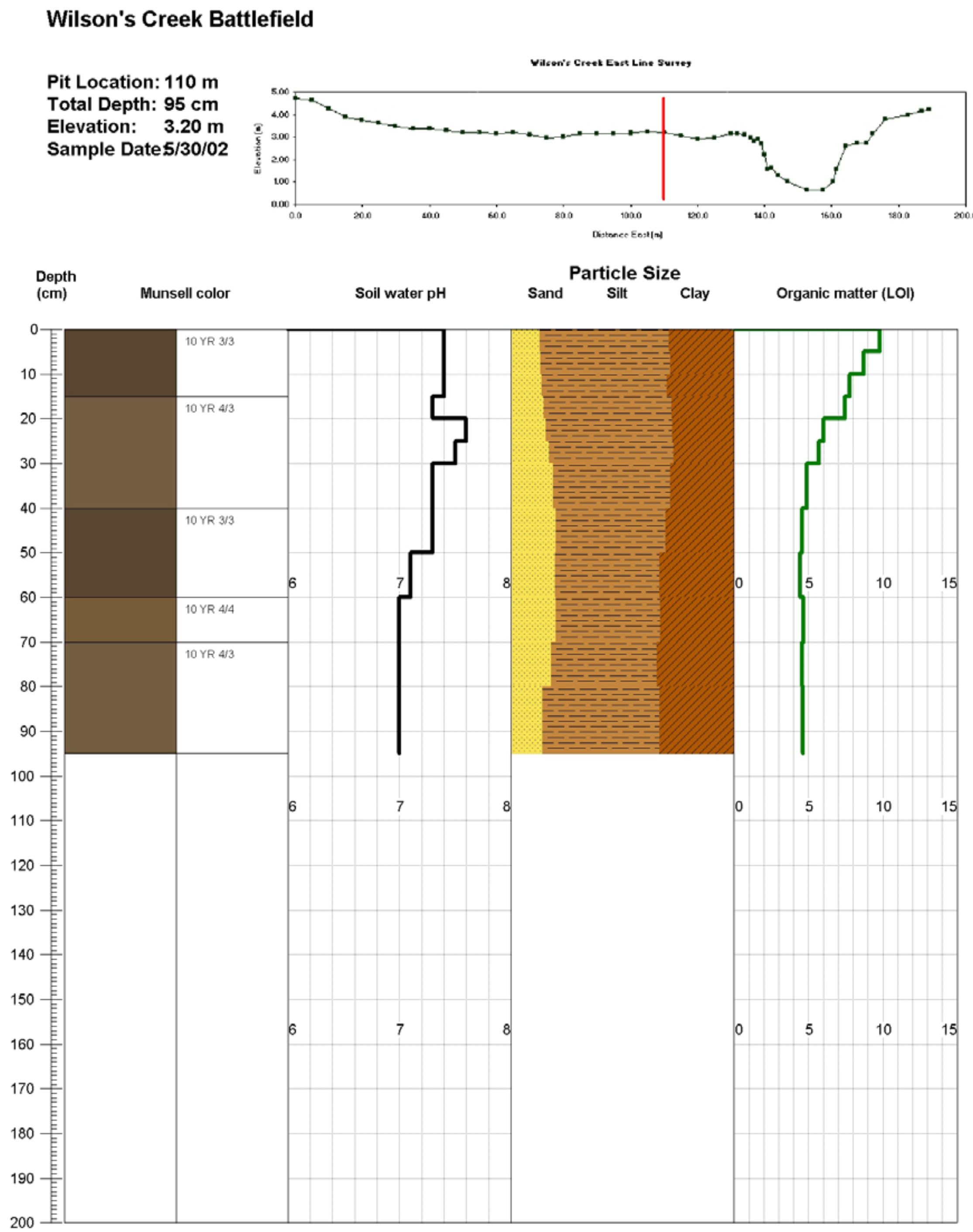


Figure 29. 110m Munsell color, pH, particle size, and organic matter LOI.

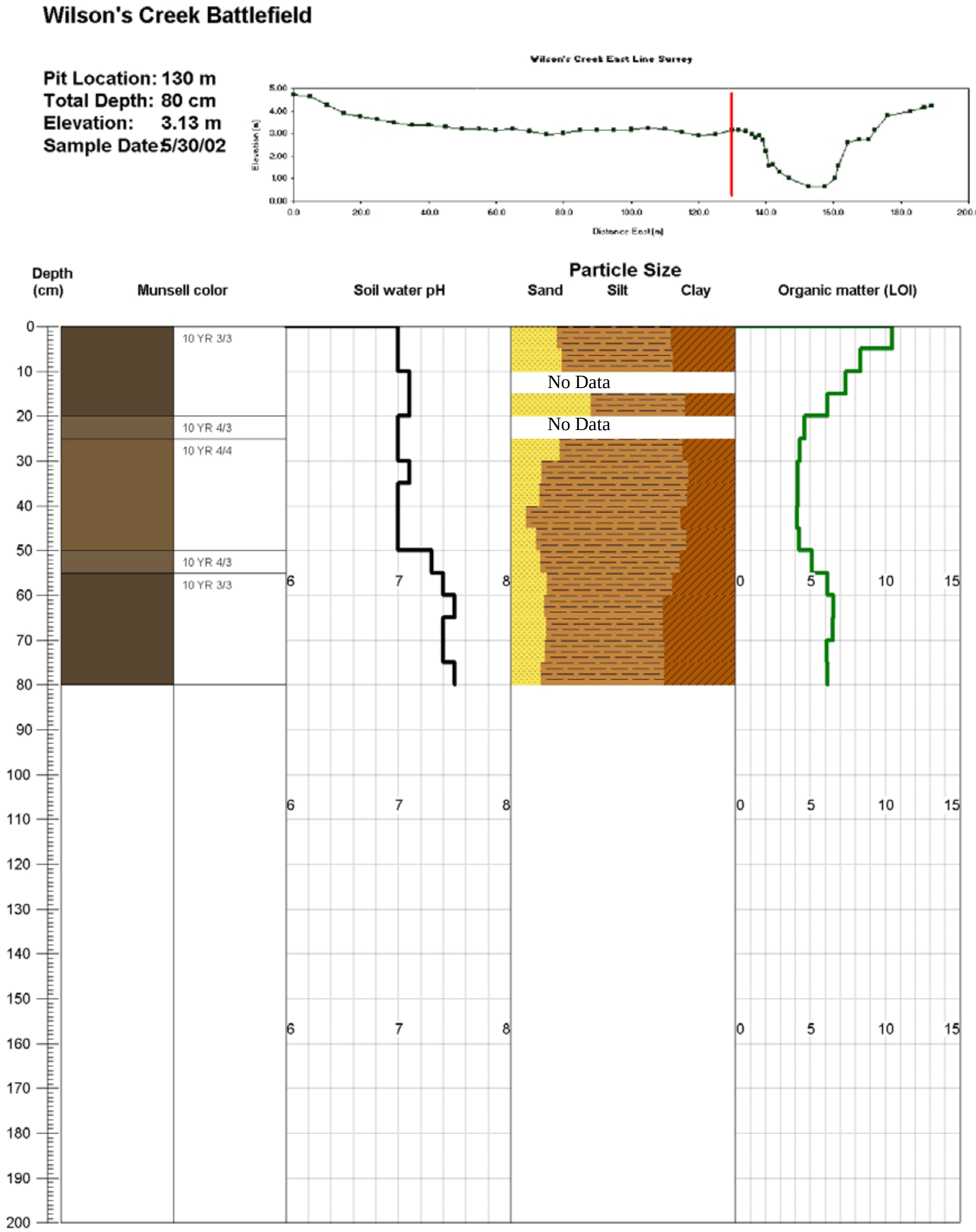


Figure 30. 130m Munsell color, pH, particle size, and organic matter LOI.

Organic matter (OM) content was also typical for the Huntington silt loam soil, ranging from 11.1% at the surface to 2.7% at depth. The average OM content at depths of one meter or more was 4.4%. Seasonal differences of the near-surface soils were slight. The average OM content for 0-50 cm for the May 2002 samples was 6.6%; the average OM content for the same depth in November was 5.7%.

Cesium Profiles

Selected pits (25m, 55m, 110m, and 130m) and the upland soil were sampled for the purpose of having the sediment analyzed for ^{137}Cs activity in order to have another basis for dating the soil profiles. Results of the ^{137}Cs analysis are presented in Table 17 and are illustrated in Figure 31 and Figure 32.

Results indicate the beginning of ^{137}Cs deposition at a depth of approximately 40 cm near the channel and approximately 35-40 cm away from the channel. This indicates the 1954 layer representing the onset of ^{137}Cs fallout from atmospheric nuclear weapons testing (Ritchie, 2003). The peak of fallout occurred in 1964 (Ritchie, 2003), and this corresponds to the peak ^{137}Cs deposition at a depth of approximately 10 cm near the channel and 5-10 cm away from the channel. Upland soils samples showed a ^{137}Cs profile for a typical undisturbed soil, with most of the ^{137}Cs concentrated in the top 13 cm.

Because of the strong sorption of the ^{137}Cs to fine-grained sediments, mobility of the ^{137}Cs is extremely minimal. Since the ^{137}Cs stays adsorbed to the sediments, sedimentation rates can be estimated based on those dated layers. Figure 32 shows the 1954 and 1964 layers. Rates of sedimentation based on the location of these dated layers are shown in Table 18.

Table 17. Cesium-137 activity in sample pits.

Location	Depth (cm) from	to	^{137}Cs Activity (Bq/kg)	Comments (Ritchie, 2003)
25m pit	0	8	13.443	
	8	15	13.823	1964 layer
	15	20	9.177	
	20	25	4.828	
	25	30	1.876	
	30	35	1.104	
	35	40	1.021	1954 layer
	40	45	0.000	
	45	50	0.000	
55m pit	0	5	16.417	
	5	10	19.367	1964 layer
	10	15	14.202	
	15	20	6.060	
	20	25	1.633	1954 layer
	25	30	0.000	
	30	35	0.000	
	35	40	0.000	
	40	45	0.000	
	45	50	0.000	
110m pit	0	5	13.048	
	5	10	15.884	
	10	15	19.006	1964 layer
	15	20	16.328	
	20	25	13.765	
	25	30	6.934	
	30	38	3.108	
	38	50	Not enough sample	1954 layer (?)
130m pit	0	5	9.810	
	5	10	12.261	
	10	15	17.817	1964 layer
	15	30	11.206	
	30	35	3.152	
	35	40	0.868	1954 layer
	40	45	0.000	
	45	50	0.000	
Upland Soil Pit	0	5	18.775	1964 layer
	5	13	12.320	
	13	20	3.749	1954 layer
	20	25	0.810	
	25	30	0.000	
	30	35	0.000	

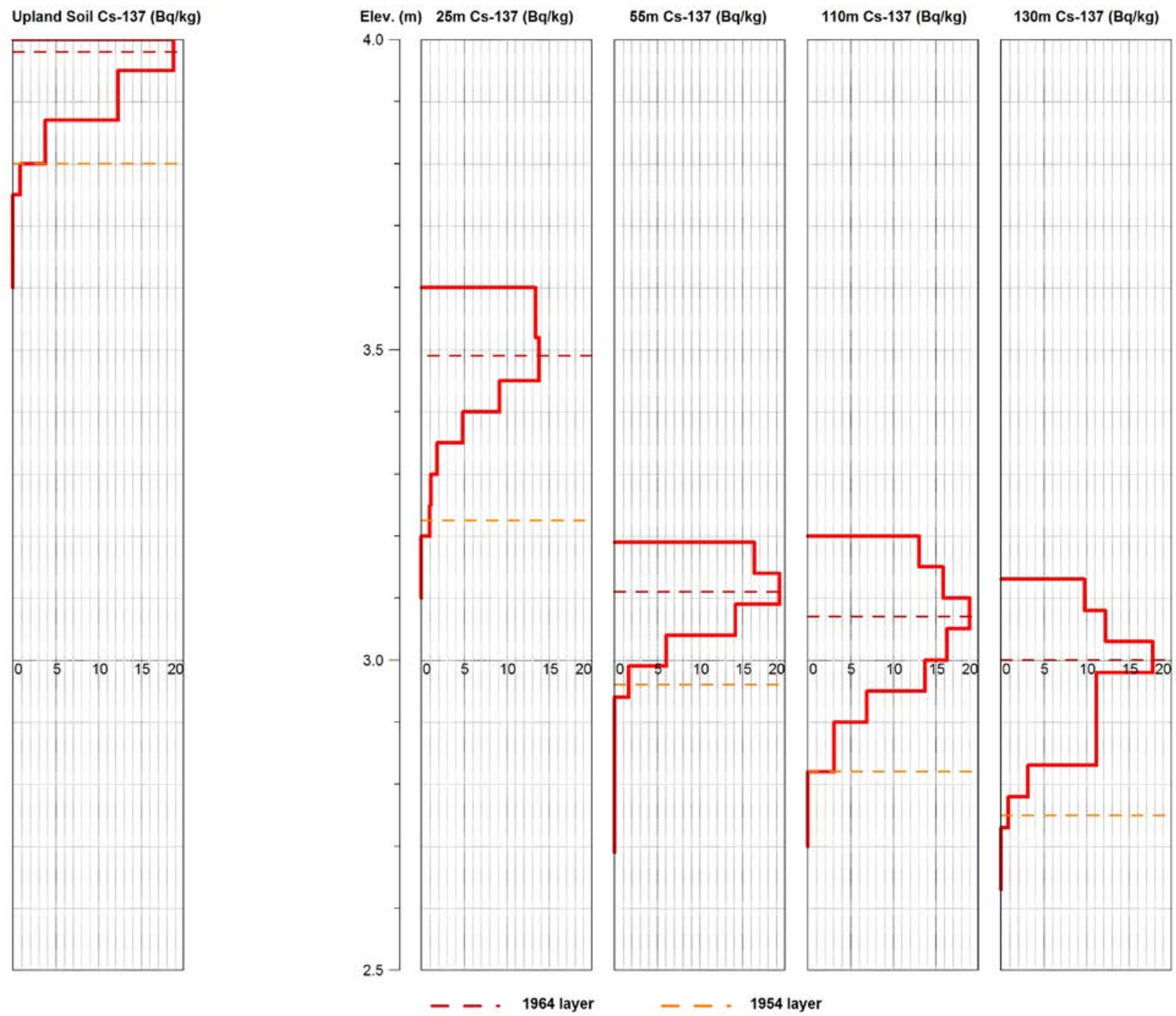


Figure 31. ^{137}Cs activity in selected pits.

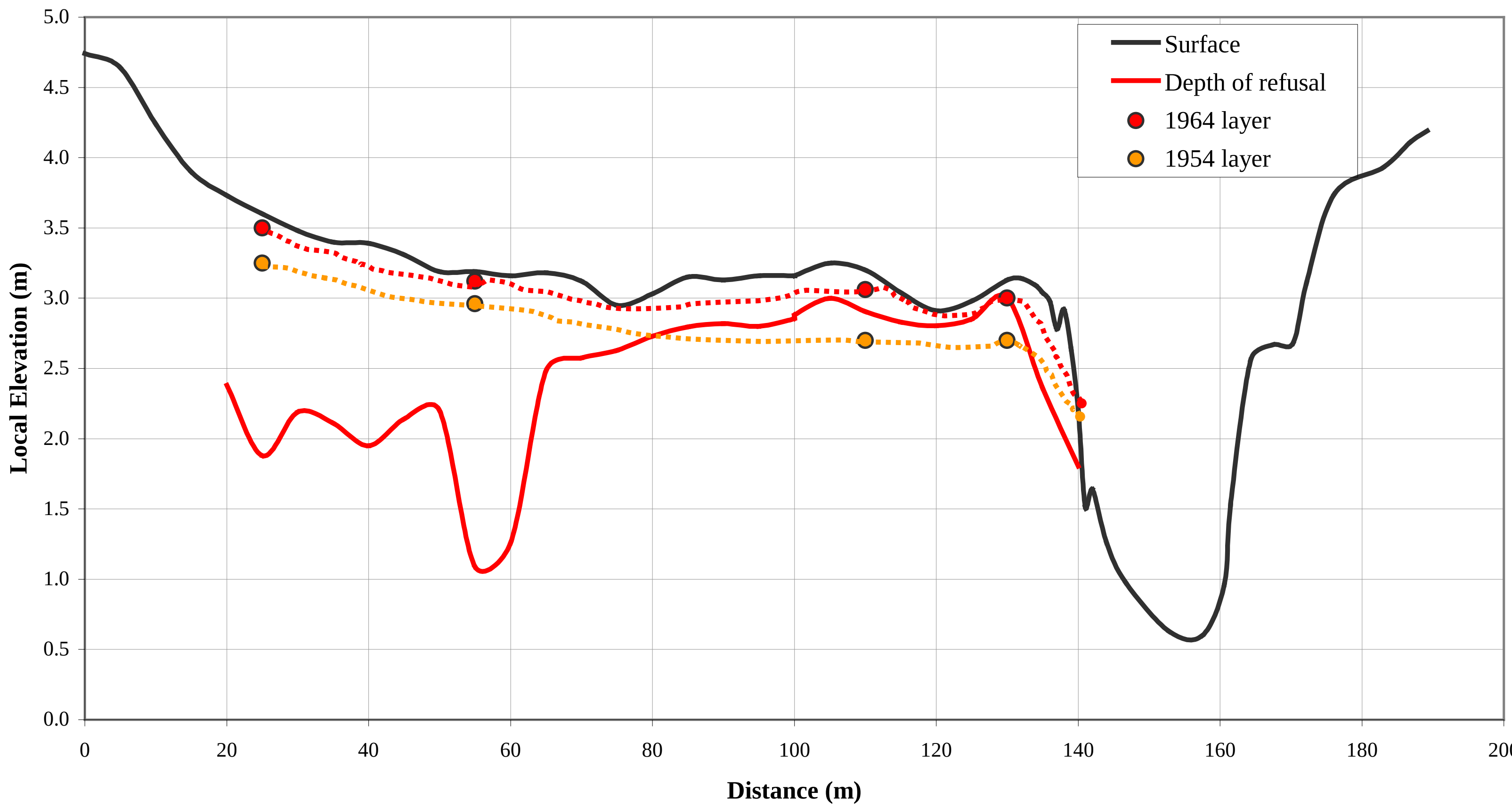


Figure 32. 1964 and 1954 layers as indicated by ^{137}Cs activity.

Table 18. Sedimentation rates for 1964-2002 and 1954-1964.

Depth to Cs-137 layer (cm)			Sedimentation rates (cm/year)		
Pit	**1964**	**1954**	**1954-1964**	**1964-2002**	**1954-2002**
25 m	15	40	2.5	0.4	0.8
55 m	10	25	1.5	0.3	0.5
110 m	15	40	2.5	0.4	0.8
130 m	15	40	2.5	0.4	0.8
Average	14	36	2.3	0.4	0.8

As shown in the table above, sedimentation rates from 1954-1964 were significantly higher (5-6 times) than from 1964-2002, with rates decreasing away from the channel and increasing at the 25 m pit. Interestingly, there were no significant floods recorded during this time period. This indicates that deposition on the floodplain may be controlled more by smaller annual floods rather than larger, more news-worthy floods. Hillslope erosion was also significant from 1954-1964 as indicated by the high sedimentation rates at the 25 m pit. Disturbances evident in aerial photos show possible sources of sediment from the hillside where tree removal and digging for archeological research would have turned up significant amounts of soil and subjected it to sheet erosion processes.

Geochemical Profiles

Chemical analysis was performed for selected metals and phosphorus at ALS Chemex, Inc. Although samples were analyzed for 34 metals, only 9 metals and phosphorus were selected for analysis and discussion in this study. Complete results of the chemical analysis can be found in Appendix F.

Geochemical substrates. Results of geochemical analysis for selected rock-forming minerals (Al, Fe, Mg, and Ca) in the representative pits, the upland soil samples, and the cutbank samples from McElhaney Branch are presented in Figure 33. The results are summarized in Table 19-Table 24. These results indicate that Al, Fe, and Mg are fairly consistent throughout each of the profiles, averaging 1.16% 1.56% and 0.10% respectively with a CV of less than 20%. Individual pits vary slightly less. However, Ca varied widely (CV of 76.7%), only generally decreasing with depth. In all samples analyzed for particle size, Al concentration correlated closely with % clay (Figure 34) with R^2 values of 0.61 to 0.86. Since each pit was not tested for particle size, %Al will be used as an indicator of clay content when normalizing concentrations by particle size.

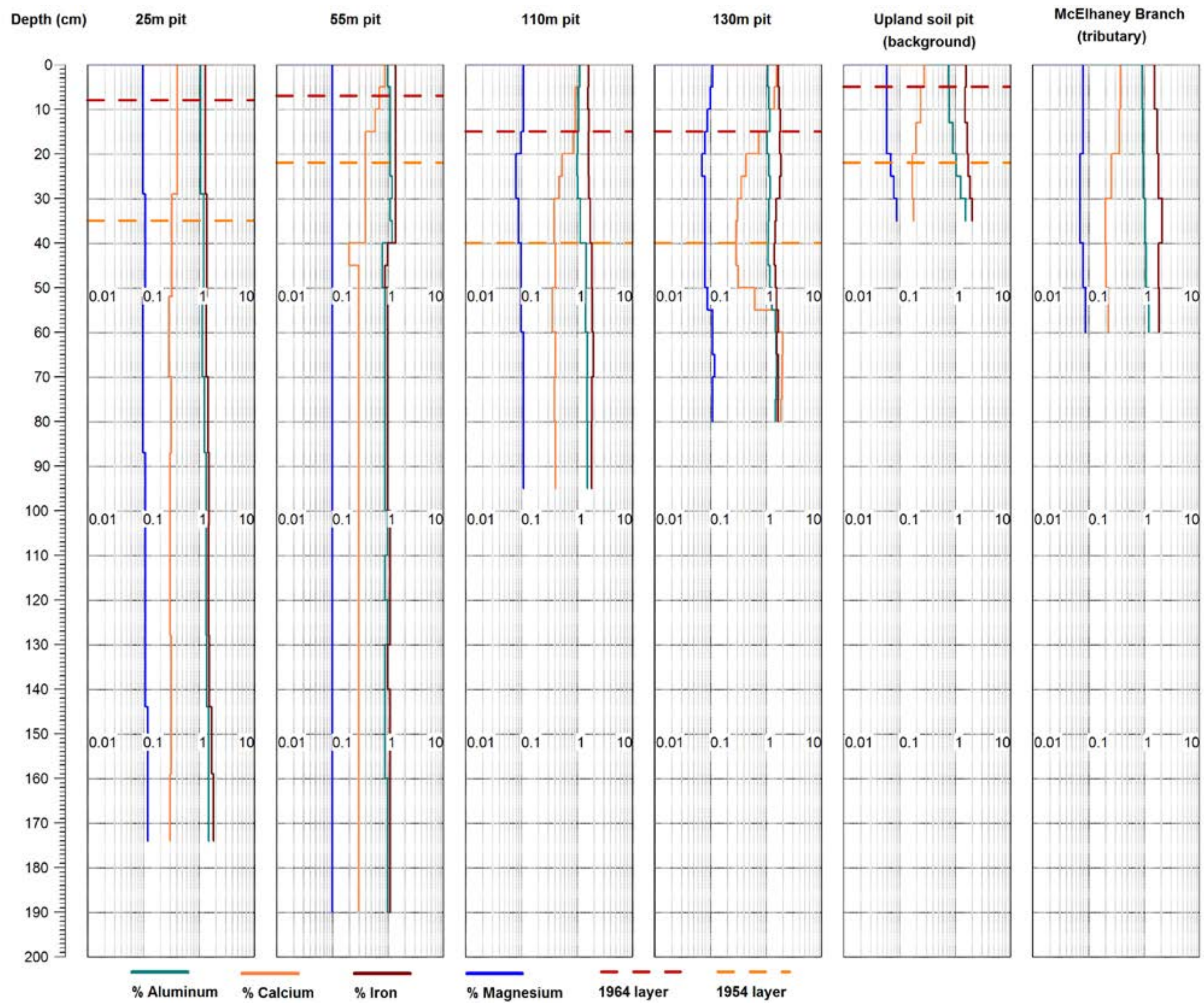


Figure 33. Results of geochemical analysis of major rock-forming elements.

Table 19. Geochemical substrate analysis for 25m core.

			Raw Concentration			
	Depth (cm)		Al	Ca	Fe	Mg
Pit/Core	**from**	**to**	**%**	**%**	**%**	**%**
25m core	0	29	1.08	0.41	1.31	0.10
	29	52	1.22	0.33	1.40	0.11
	52	70	1.15	0.29	1.37	0.10
	70	87	1.28	0.32	1.47	0.10
	87	103	1.37	0.31	1.52	0.11
	103	128	1.38	0.31	1.51	0.11
	128	144	1.39	0.32	1.56	0.11
	144	159	1.50	0.32	1.70	0.12
	159	174	1.51	0.31	1.83	0.12
		n	9	9	9	9
		Min	1.08	0.29	1.31	0.10
		Mean	1.32	0.32	1.52	0.11
		Median	1.37	0.32	1.51	0.11
		Max	1.51	0.41	1.83	0.12
		Std. Dev.	0.15	0.03	0.16	0.01
		CV	11.3%	10.5%	10.8%	7.2%

Table 20. Geochemical substrate analysis for 55m core.

			Raw Concentration			
	Depth (cm)		Al	Ca	Fe	Mg
Pit/Core	**from**	**to**	**%**	**%**	**%**	**%**
55m pit/ core	0	5	1.03	0.85	1.42	0.11
	5	10	1.07	0.75	1.43	0.10
	10	15	1.08	0.60	1.44	0.10
	15	20	1.08	0.44	1.43	0.09
	20	25	1.09	0.41	1.43	0.09
	25	30	1.17	0.37	1.43	0.09
	30	35	1.15	0.36	1.41	0.09
	35	40	1.18	0.36	1.45	0.09
	40	45	0.81	0.24	0.97	0.07
	45	50	0.78	0.26	0.94	0.06
	50	60	0.89	0.28	0.99	0.09
	60	70	0.91	0.30	0.99	0.09
	70	80	0.93	0.32	1.00	0.08
	80	90	0.93	0.33	1.01	0.08
	90	100	0.94	0.32	1.03	0.08
	100	110	0.96	0.31	1.07	0.08
	110	120	0.94	0.30	1.08	0.07
	120	130	0.96	0.30	1.06	0.08
	130	140	0.87	0.32	1.03	0.08
	140	150	0.95	0.26	1.07	0.08
	150	160	0.95	0.26	1.09	0.08
	160	170	0.95	0.27	1.10	0.09
	170	180	0.96	0.26	1.10	0.09
	180	190	1.01	0.26	1.13	0.08
		n	24	24	24	24
		Min	0.78	0.24	0.94	0.06
		Mean	0.98	0.36	1.17	0.08
		Median	0.96	0.31	1.08	0.08
		Max	1.18	0.85	1.45	0.11
		Std. Dev.	0.10	0.16	0.19	0.01
		CV	10.6%	42.9%	16.4%	11.4%

Table 21. Geochemical substrate analysis for 110m pit.

			Raw Concentration			
	Depth (cm)		**Al**	**Ca**	**Fe**	**Mg**
Pit/Core	**from**	**to**	**%**	**%**	**%**	**%**
110m pit	0	5	1.12	1.14	1.62	0.11
	5	10	1.08	0.94	1.59	0.11
	10	15	1.07	0.95	1.64	0.11
	15	20	1.04	0.88	1.61	0.10
	20	25	1.02	0.54	1.62	0.08
	25	30	1.03	0.48	1.64	0.08
	30	40	1.15	0.39	1.73	0.09
	40	50	1.46	0.41	1.87	0.10
	50	60	1.45	0.36	1.91	0.10
	60	70	1.55	0.41	1.98	0.11
	70	80	1.52	0.40	1.86	0.11
	80	95	1.57	0.41	1.83	0.11
		n	12	12	12	12
		Min	1.02	0.36	1.59	0.08
		Mean	1.26	0.61	1.74	0.10
		Median	1.14	0.45	1.69	0.11
		Max	1.57	1.14	1.98	0.11
		Std. Dev.	0.23	0.28	0.14	0.01
		CV	18.3%	46.3%	8.0%	11.5%

Table 22. Geochemical substrate analysis of 130m pit.

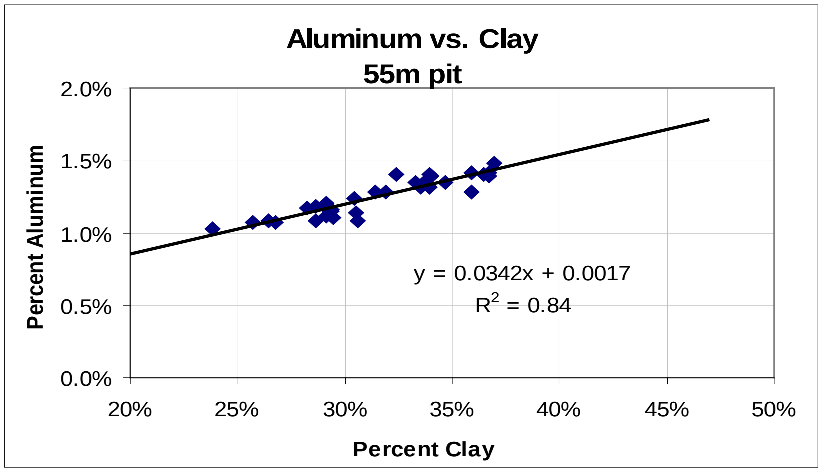
			Raw Concentration			
	Depth (cm)		Al	Ca	Fe	Mg
Pit/Core	from	to	%	%	%	%
130m pit	0	5	1.08	1.56	1.68	0.11
	5	10	1.14	1.42	1.73	0.10
	10	15	1.18	1.19	1.83	0.09
	15	20	1.06	0.75	1.76	0.08
	20	25	1.13	0.44	1.86	0.07
	25	30	1.21	0.36	1.76	0.08
	30	35	1.13	0.31	1.54	0.08
	35	40	1.12	0.29	1.46	0.08
	40	45	1.09	0.29	1.42	0.08
	45	50	1.18	0.32	1.51	0.08
	50	55	1.30	0.63	1.55	0.09
	55	60	1.51	1.59	1.67	0.11
	60	65	1.52	2.03	1.59	0.11
	65	70	1.56	1.98	1.67	0.12
	70	75	1.53	1.94	1.67	0.11
	75	80	1.51	1.86	1.65	0.11
		n	16	16	16	16
		Min	1.06	0.29	1.42	0.07
		Mean	1.27	1.06	1.65	0.09
		Median	1.18	0.97	1.67	0.09
		Max	1.56	2.03	1.86	0.12
		Std. Dev.	0.19	0.70	0.13	0.02
		CV	15.0%	65.9%	7.7%	16.9%

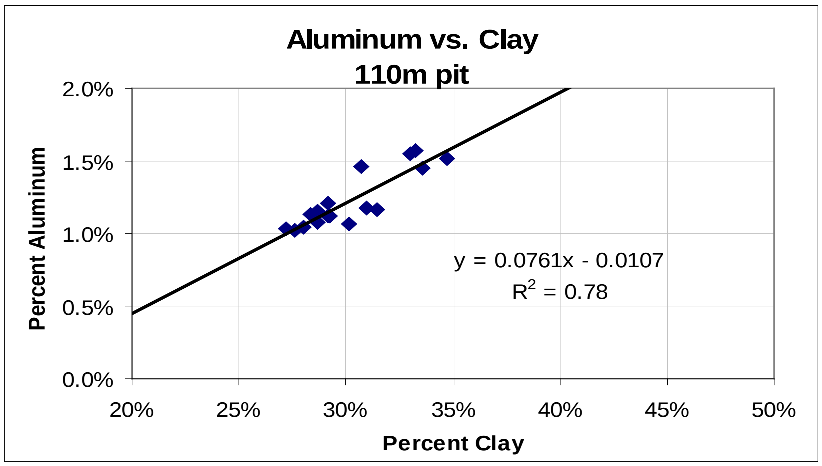
Table 23. Geochemical substrate analysis for upland soil and McElhaney Branch pits.

	Depth (cm)		Raw Concentration			
Pit/Core	**from**	**to**	**Al %**	**Ca %**	**Fe %**	**Mg %**
Upland soil	0	5	0.77	0.28	1.59	0.06
	5	13	0.78	0.24	1.54	0.06
	13	20	0.91	0.2	1.66	0.06
	20	25	1.06	0.17	1.74	0.07
	25	30	1.27	0.17	1.88	0.08
	30	35	1.55	0.18	2.04	0.09
		n	6	6	6	6
		Min	0.77	0.17	1.54	0.06
		Mean	1.06	0.21	1.74	0.07
		Median	0.99	0.19	1.70	0.07
		Max	1.55	0.28	2.04	0.09
		Std. Dev.	0.306	0.045	0.189	0.013
		CV	29.0%	21.6%	10.8%	18.1%
McElhaney Branch	0	10	0.93	0.38	1.55	0.08
	10	20	0.94	0.36	1.73	0.08
	20	30	0.99	0.26	1.82	0.07
	30	40	1.06	0.20	2.14	0.07
	40	50	1.10	0.21	1.83	0.08
	50	60	1.23	0.23	1.86	0.09
		n	6	6	6	6
		Min	0.93	0.20	1.55	0.07
		Mean	1.04	0.27	1.82	0.08
		Median	1.03	0.25	1.83	0.08
		Max	1.23	0.38	2.14	0.09
		Std. Dev.	0.114	0.078	0.192	0.008
		CV	10.9%	28.5%	10.6%	9.6%

Table 24. Summary of geochemical analysis for all samples.

		Raw Concentration			
		Al	**Ca**	**Fe**	**Mg**
		%	**%**	**%**	**%**
All samples	n	171	171	171	171
	Min	0.77	0.17	0.94	0.06
	Mean	1.16	0.59	1.56	0.10
	Median	1.12	0.36	1.55	0.10
	Max	1.57	2.03	2.93	0.15
	Std. Dev.	0.217	0.486	0.289	0.016
	CV	18.7%	82.6%	18.5%	17.2%





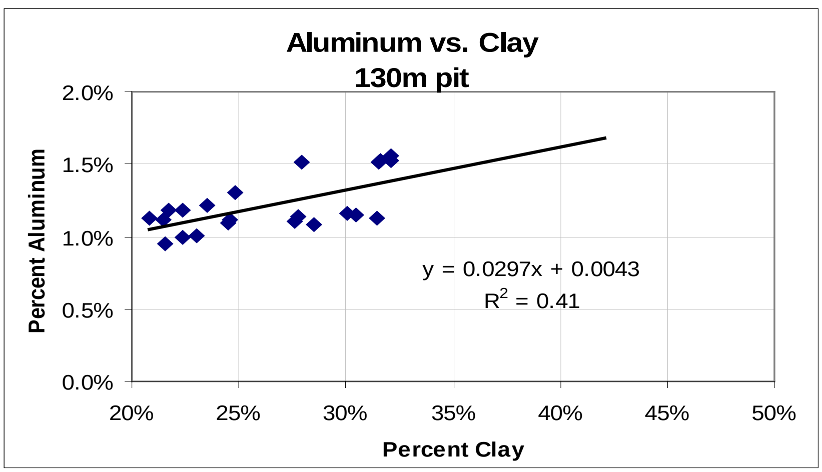


Figure 34. % Aluminum vs. % clay in selected pits.

Pollutants. Reported concentration values for Ag, Cu, Hg, Pb, Zn and P have been normalized to Al concentration to account for grain-size differences and OM to account for concentrating effects of the organic matter particles (Horowitz, 1991). These normalized values then are divided by background levels (Table 25) of those elements and the result expressed as an enrichment ratio. Results of geochemical analysis for selected anthropogenic metals and phosphorus (Ag, Cu, Hg, Pb, Zn and P) are summarized in Table 26-Table 30. A diagram of enrichment levels for Ag, Hg, and P is shown for all pits/cores in Figure 35.

Table 25. Background levels of selected pollutants.

Pollutant	Background Concentration
Ag	0.15 ppm
Cu	15 ppm
Hg	18 ppb*
Pb	23 ppm
Zn	64 ppm
P	331 ppm

* Hg background for upstream cutbank samples averages 30-50 ppb (Rodgers, 2003)

As expected, results show that the concentrations for anthropogenic metals are highest near the channel and slightly below the surface, decreasing with distance from the channel and with depth. The exception to this is an apparent pollution sink at the 120 m mark where the surface is concave and fine-grained sediments would tend to concentrate as they settle in this depression and are less likely to be washed away by sheet erosion processes.

Table 26. Geochemical analysis for selected metals and phosphorus in 25m core.

			Raw Concentration						Enrichment Ratio					
	Depth (cm)		Ag	Cu	Hg	Pb	Zn	P	Ag	Cu	Hg	Pb	Zn	P
Pit/Core	**from**	**to**	**ppm**	**ppm**	**ppb**	**ppm**	**ppm**	**ppm**						
25m core	0	29	0.1	16	70	26	70	520	0.59	0.94	3.44	1.02	0.97	1.40
	29	52	0.1	15	20	20	56	410	0.87	1.29	1.44	1.15	1.14	1.61
	52	70	0.1	14	10	18	50	310	1.05	1.45	0.87	1.24	1.22	1.47
	70	87	0.1	15	10	18	54	270	0.95	1.40	0.79	1.12	1.20	1.16
	87	103	0.1	14	5	16	54	240	0.98	1.35	0.40	1.03	1.23	1.06
	103	128	0.1	13	5	18	52	230	0.95	1.21	0.39	1.12	1.15	0.98
	128	144	0.1	13	10	18	56	250	0.92	1.17	0.76	1.09	1.20	1.04
	144	159	0.1	16	10	22	60	280	0.83	1.31	0.69	1.20	1.16	1.05
	159	174	0.1	15	10	26	62	300	0.87	1.29	0.72	1.49	1.26	1.18
		n	9	9	9	9	9	9	9	9	9	9	9	9
		Min	0.1	13	5	16	5	230	0.59	0.94	0.39	1.02	0.97	0.98
		Mean	0.1	15	17	20	17	312	0.89	1.27	1.06	1.16	1.17	1.22
		Median	0.1	15	10	18	10	280	0.92	1.29	0.76	1.12	1.20	1.16
		Max	0.1	16	70	26	70	520	1.05	1.45	3.44	1.49	1.26	1.61
		Std. Dev.	0.0	1	20	4	20	95	0.129	0.151	0.946	0.143	0.085	0.223
		CV	0.0%	7.8%	123%	18.1%	123%	30.3%	14.5%	11.9%	89.5%	12.3%	7.3%	18.3%

Table 27. Geochemical analysis for selected metals and phosphorus in 55m pit/core.

			Raw Concentration						Enrichment Ratio					
	Depth (cm)		Ag	Cu	Hg	Pb	Zn	P	Ag	Cu	Hg	Pb	Zn	P
Pit/Core	**from**	**to**	**ppm**	**ppm**	**ppb**	**ppm**	**ppm**	**ppm**						
55m pit/ core	0	5	0.7	23	293	59	143	887	2.95	0.91	9.78	1.57	1.35	1.61
	5	10	0.9	22.3	287	57.3	137	840	3.78	0.96	10.37	1.65	1.39	1.66
	10	15	0.6	20.3	307	56.0	123	740	3.09	1.05	13.36	1.94	1.51	1.76
	15	20	0.6	18.7	290	48.7	109	590	3.77	1.18	15.43	2.06	1.63	1.72
	20	25	0.6	17.7	257	45.3	101	520	4.36	1.26	15.44	2.17	1.71	1.71
	25	30	0.4	18.0	180	35.3	87	410	3.05	1.35	11.36	1.77	1.55	1.41
	30	35	0.4	16.0	137	34.0	82	387	2.89	1.24	8.93	1.77	1.51	1.38
	35	40	0.5	16.0	147	36.0	87	397	3.81	1.29	9.93	1.94	1.67	1.47
	40	45	0.3	10.7	120	23.6	57	274	3.68	1.14	10.80	1.69	1.44	1.35
	45	50	0.1	10.2	60	17.3	47	293	0.75	1.14	5.63	1.29	1.24	1.50
	50	60	0.1	9.3	37	15.7	44	302	0.62	0.85	2.81	0.95	0.94	1.26
	60	70	0.1	9.5	27	14.0	42	318	0.68	0.76	1.80	0.75	0.81	1.18
	70	80	0.2	9.8	13	13.8	44	317	1.30	0.74	0.84	0.69	0.78	1.09
	80	90	0.2	9.5	10	13.3	44	297	1.37	0.75	0.67	0.70	0.82	1.08
	90	100	0.2	9.7	10	13.4	43	270	1.39	0.78	0.67	0.72	0.81	0.99
	100	110	0.2	10.8	13	13.3	44	253	1.43	0.89	0.93	0.74	0.87	0.96
	110	120	0.2	9.3	10	13.0	42	231	1.47	0.79	0.71	0.74	0.84	0.90
	120	130	0.2	9.3	33	15.4	44	234	1.33	0.71	2.15	0.79	0.81	0.82
	130	140	0.2	10.0	70	18.8	50	253	1.73	1.10	6.50	1.38	1.31	1.29
	140	150	0.1	9.2	10	13.0	39	169	0.71	0.96	0.88	0.91	0.97	0.82
	150	160	0.1	9.0	10	13.3	40	175	0.91	0.96	0.90	0.95	1.02	0.86
	160	170	0.2	9.5	10	13.3	42	187	1.73	1.05	0.93	0.99	1.11	0.95

Table 27, continued

Pit/Core	Depth (cm) from	to	Raw Concentration Ag ppm	Cu ppm	Hg ppb	Pb ppm	Zn ppm	P ppm	Enrichment Ratio Ag	Cu	Hg	Pb	Zn	P
	170	180	0.1	9.0	10	13.4	41	186	0.75	0.99	0.93	0.99	1.08	0.94
	180	190	0.1	9.5	10	13.6	43	203	0.69	0.97	0.86	0.93	1.04	0.95
		n	24	24	24	24	24	24	24	24	24	24	24	24
		Min	0.1	9.0	10	13.0	39	169	0.62	0.71	0.67	0.69	0.78	0.82
		Mean	0.3	12.8	98	25.4	66	364	2.01	0.99	5.53	1.25	1.18	1.24
		Median	0.2	9.9	35	15.5	44	295	1.45	0.97	2.48	0.99	1.10	1.22
		Max	0.9	23.0	307	59.3	143	887	4.36	1.35	15.44	2.17	1.71	1.76
		Std. Dev.	0.2	4.8	111	16.4	34	206	1.247	0.190	5.300	0.505	0.316	0.315
		CV	84.5%	37.3%	113%	64.7%	51.5%	56.6%	51.5%	51.5%	51.5%	40.3%	26.9%	25.4%

Table 28. Geochemical analysis for selected metals and phosphorus in 110m pit.

			Raw Concentration						Enrichment Ratio					
	Depth (cm)		Ag	Cu	Hg	Pb	Zn	P	Ag	Cu	Hg	Pb	Zn	P
Pit/Core	**from**	**to**	**ppm**	**ppm**	**ppb**	**ppm**	**ppm**	**ppm**						
110m pit	0	5	1.2	26	360	74	174	1040	4.88	1.04	12.12	1.98	1.65	1.91
	5	10	1.2	25	380	74	164	930	5.68	1.17	14.90	2.31	1.81	1.99
	10	15	1.4	25	510	74	170	910	7.52	1.32	22.69	2.62	2.13	2.21
	15	20	1.2	23	390	70	150	850	6.89	1.30	18.55	2.65	2.01	2.21
	20	25	0.6	20	340	60	124	580	4.35	1.43	20.41	2.86	2.10	1.90
	25	30	0.6	18	280	52	106	480	4.56	1.35	17.62	2.60	1.88	1.65
	30	40	0.2	15	150	36	84	350	1.59	1.17	9.88	1.88	1.56	1.26
	40	50	0.2	13	50	26	70	320	1.33	0.85	2.76	1.14	1.09	0.97
	50	60	0.2	11	30	22	66	260	1.39	0.75	1.72	1.00	1.07	0.82
	60	70	0.2	13	20	24	68	290	1.23	0.79	1.02	0.97	0.98	0.81
	70	80	0.2	12	20	22	68	300	1.28	0.76	1.06	0.93	1.02	0.87
	80	95	0.2	13	30	22	70	320	1.22	0.78	1.52	0.88	1.00	0.88
		n	12	12	12	12	12	12	12	12	12	12	12	12
		Min	0.2	11	20	22	66	260	1.22	0.75	1.02	0.88	0.98	0.81
		Mean	0.6	18	210	46	110	553	3.49	1.06	10.36	1.82	1.52	1.46
		Median	0.4	17	210	44	95	415	2.97	1.10	11.00	1.93	1.60	1.45
		Max	1.4	26	510	74	174	1040	7.52	1.43	22.69	2.86	2.13	2.21
		Std. Dev.	0.5	6	180	23	44	297	2.415	0.261	8.426	0.785	0.466	0.576
		CV	80.0%	32.1%	85.0%	49.9%	40.6%	53.7%	69.1%	24.6%	81.4%	43.2%	30.6%	39.5%

Table 29. Geochemical analysis for selected metals and phosphorus in 130m pit.

			Raw Concentration						Enrichment Ratio					
Pit/Core	Depth (cm) from	to	Ag ppm	Cu ppm	Hg ppb	Pb ppm	Zn ppm	P ppm	Ag	Cu	Hg	Pb	Zn	P
130m pit	0	5	1.6	29	460	88	200	1340	6.28	1.12	14.97	2.27	1.83	2.38
	5	10	1.4	30	340	88	198	1240	6.55	1.38	13.18	2.71	2.16	2.63
	10	15	1.4	28	400	88	186	1150	7.16	1.41	16.95	2.96	2.22	2.66
	15	20	1.0	23	390	76	160	950	6.84	1.55	22.11	3.42	2.56	2.94
	20	25	0.6	21	360	64	132	700	5.12	1.77	25.45	3.59	2.63	2.70
	25	30	0.2	19	320	56	120	540	1.71	1.60	22.66	3.15	2.39	2.09
	30	35	0.2	17	260	46	100	380	1.89	1.58	20.35	2.86	2.20	1.63
	35	40	0.2	18	270	44	112	330	1.91	1.69	21.35	2.76	2.49	1.43
	40	45	0.2	17	290	42	98	330	1.98	1.66	23.79	2.74	2.27	1.48
	45	50	0.2	16	230	40	104	340	1.77	1.40	16.89	2.33	2.15	1.36
	50	55	0.1	15	140	32	92	360	0.67	0.99	7.75	1.41	1.44	1.09
	55	60	0.1	14	60	26	78	420	0.48	0.66	2.38	0.82	0.87	0.91
	60	65	0.1	13	30	20	68	430	0.45	0.57	1.11	0.59	0.71	0.87
	65	70	0.2	13	30	22	68	420	0.88	0.56	1.09	0.63	0.70	0.83
	70	75	0.1	13	40	22	70	420	0.48	0.61	1.58	0.69	0.78	0.91
	75	80	0.1	12	30	22	66	380	0.48	0.57	1.19	0.70	0.74	0.83
		n	16	16	16	16	16	16	16	16	16	16	16	16
		Min	0.1	12	30	20	66	330	0.45	0.56	1.09	0.59	0.70	0.83
		Mean	0.5	19	220	49	116	608	2.79	1.20	13.30	2.10	1.76	1.67
		Median	0.2	17	260	43	102	420	1.83	1.39	15.93	2.52	2.16	1.45
		Max	1.6	30	460	88	200	1340	7.16	1.77	25.45	3.59	2.63	2.94
		Std. Dev.	0.5	6	150	25	47	355	2.600	0.463	9.302	1.102	0.751	0.775
		CV	113%	32.1%	66.3%	52.1%	40.4%	58.3%	93.2%	38.7%	69.9%	52.4%	42.7%	46.4%

Table 30. Geochemical analysis for selected metals and phosphorus in upland soil.

			Raw Concentration						Enrichment Ratio					
	Depth (cm)		Ag	Cu	Hg	Pb	Zn	P	Ag	Cu	Hg	Pb	Zn	P
Pit/Core	from	to	ppm	ppm	ppb	ppm	ppm	ppm						
Upland soil	0	5	0.1	20	40	38	41	370	1.00	1.98	3.33	2.51	0.96	1.68
	5	13	0.1	13	30	29	31	340	1.42	1.82	3.52	2.71	1.03	2.18
	13	20	0.1	14	40	36	38	230	1.63	2.25	5.40	3.86	1.45	1.70
	20	25	0.1	13	30	25	32	190	1.54	1.98	3.84	2.54	1.15	1.33
	25	30	0.1	15	30	31	38	170	1.29	1.90	3.19	2.62	1.14	0.99
	30	35	0.1	15	30	29	39	160	0.96	1.42	2.39	1.83	0.87	0.70
		n	6	6	6	6	6	6	6	6	6	6	6	6
		Min	0.1	13	30	25	31	160	0.96	1.42	2.39	1.83	0.87	0.70
		Mean	0.1	15	33	31	37	243	1.31	1.89	3.61	2.68	1.10	1.43
		Median	0.1	15	30	30	38	210	1.35	1.94	3.43	2.58	1.08	1.51
		Max	0.1	20	40	38	41	370	1.63	2.25	5.40	3.86	1.45	2.18
		Std. Dev.	0.0	3	5	5	4	90	0.28	0.27	1.00	0.66	0.20	0.54
		CV	0.0%	17.4%	15.5%	15.5%	11.1%	37.1%	21.2%	14.4%	27.7%	24.6%	18.2%	37.6%

Table 31. Geochemical analysis for selected metals and phosphorus in cutbank of McElhaney Branch.

			Raw Concentration						Enrichment Ratio					
	Depth (cm)		Ag	Cu	Hg	Pb	Zn	P	Ag	Cu	Hg	Pb	Zn	P
Pit/Core	from	to	ppm	ppm	ppb	ppm	ppm	ppm						
McElhaney Branch	0	10	0.1	14	50	43	72	500	0.70	0.96	2.89	1.97	1.17	1.58
	10	20	0.1	14	50	61	77	480	0.73	1.00	3.01	2.92	1.31	1.58
	20	30	0.1	13	40	53	66	400	1.04	1.33	3.45	3.63	1.60	1.89
	30	40	0.1	13	40	64	70	380	1.22	1.56	4.04	5.13	1.99	2.09
	40	50	0.1	12	30	50	77	370	1.16	1.37	2.89	3.82	2.09	1.94
	50	60	0.1	13	30	45	83	380	1.03	1.31	2.55	3.04	1.99	1.76
		n	6	6	6	6	6	6	6	6	6	6	6	6
		Min	0.1	12	30	43	66	370	0.70	0.96	2.55	1.97	1.17	1.58
		Mean	0.1	13	40	53	74	418	0.98	1.26	3.14	3.42	1.69	1.81
		Median	0.1	13	40	52	75	390	1.03	1.32	2.95	3.34	1.80	1.83
		Max	0.1	14	50	64	83	500	1.22	1.56	4.04	5.13	2.09	2.09
		Std. Dev.	0.0	1	0.9	8	6	57	0.22	0.23	0.53	1.06	0.39	0.21
		CV	0.0%	5.7%	22.4%	16.1%	8.2%	13.6%	22.3%	18.3%	16.8%	31.0%	23.0%	11.4%

Table 32. Geochemical analysis for selected metals and phosphorus in all samples.

		Raw Concentration						Enrichment Ratio					
	Depth (cm) **from to**	**Ag** **ppm**	**Cu** **ppm**	**Hg** **ppb**	**Pb** **ppm**	**Zn** **ppm**	**P** **ppm**	**Ag**	**Cu**	**Hg**	**Pb**	**Zn**	**P**
All samples	n	171	171	171	171	171	171	168	168	168	168	168	168
	Min	0.1	9	5	13	31	160	0.4	0.6	0.4	0.6	0.7	0.7
	Mean	0.4	16	175	17	94	545	2.9	1.2	9.4	1.9	1.5	1.6
	Median	0.2	15	70	15	76	420	1.7	1.2	4.5	1.6	1.3	1.5
	Max	1.6	30	650	42	239	2590	10.2	2.4	41.5	7.8	2.9	3.8
	Std. Dev.	0.4	6	175	6	48	334	2.4	0.4	9.6	1.1	0.5	0.6
	CV	110%	35.5%	100%	35.4%	51.0%	61.3%	84%	31%	102%	56%	37%	37%

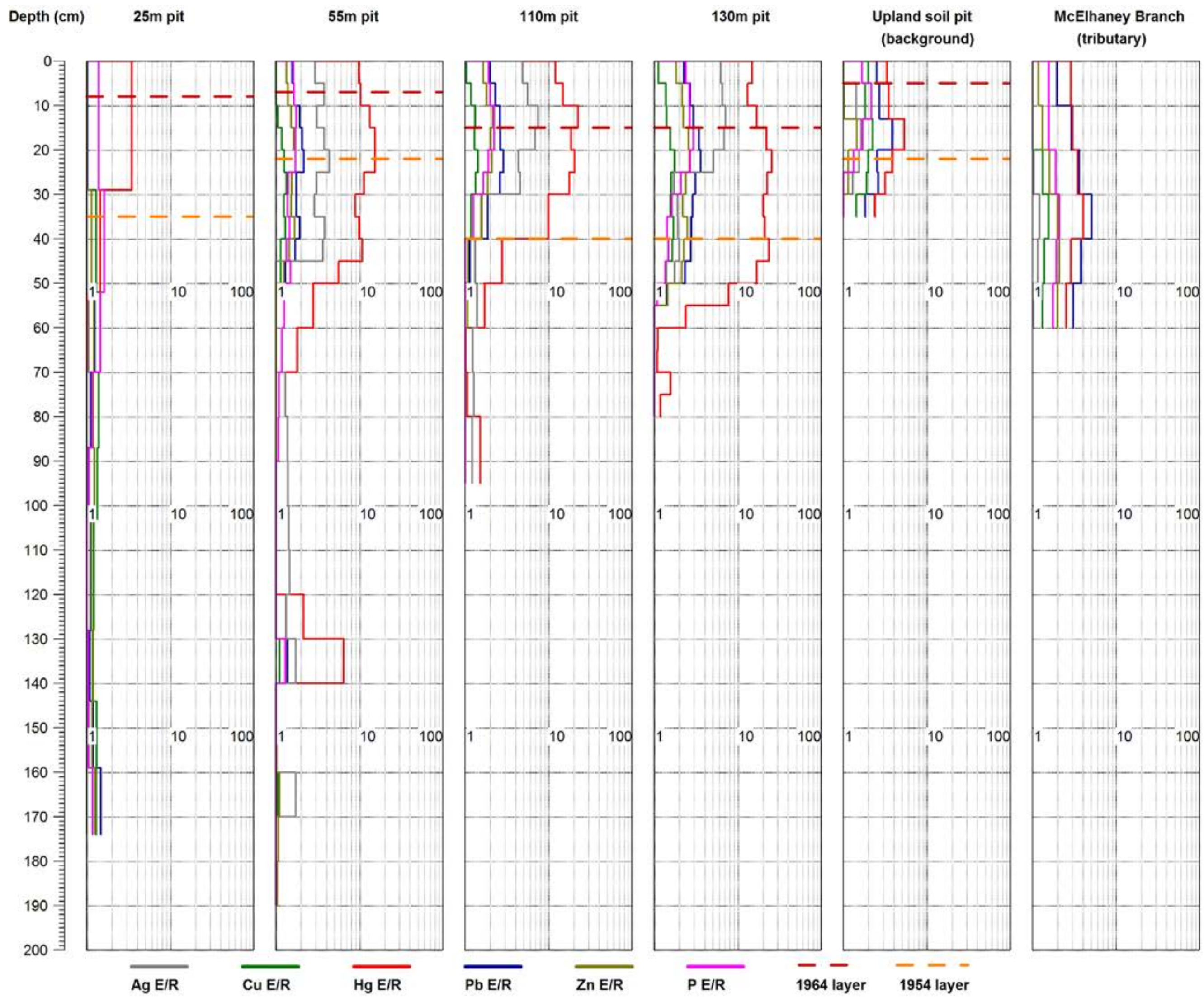


Figure 35. Results of geochemical analysis of selected metals and phosphorus.

Peak concentrations for most metals are at depths of 10-30 cm, depending on distance from the channel, with very little anthropogenic metal or phosphorus enrichment in the 25 m core.

Greatest total enrichment of metals and phosphorus was near the channel, whereas the highest peak of metal enrichment was in the 120 m pit, in a slight depression approximately 15 meters from the channel. There was very little enrichment in metals in the 25 m core. This is to be expected if the metals are carried by fluvial sediments. One exception to this is mercury. However, since the nearby Southwest Power Plant is a known source of aerial Hg (Coequyt and Stanfield, 1999), it is expected that some Hg enrichment would occur whether or not flood waters reached that location. Different patterns of enrichment are shown for silver, mercury and phosphorus. As mentioned previously, most other anthropogenic metals are highly correlated with silver, and their patterns are very similar.

Upland soil and McElhaney branch samples showed some enrichment over background levels, primarily in Hg and Pb, both metals which are often carried as particulates in the air. Both Hg and Pb concentrations were highest at depths of 13-20 cm.

Discussion and Summary

Based on physical, radiological and geochemical analysis of sediment cores, pollutants are being deposited and stored on the floodplain at a higher rate and concentration than on upland soils that are not impacted by flood events.

Sedimentation rates as indicated by ^{137}Cs dating show that rates have decreased since 1964 and are primarily influenced by smaller annual floods. Although sedimentation generally decreases away from the channel, aerial photos suggest that there may have been other disturbances responsible for hillslope deposition in the 1954-1964 time frame.

As expected, most pollution is concentrated in sediments closer to the channel and nearer to the floodplain surface (<50 cm). In young sediments, there is a strong association between anthropogenic pollutants, while those associations diminish in the older sediments and those away from the influence of regular flooding.

URBAN POLLUTION AND DATING OF ALLUVIAL DEPOSITS

Pollution/Land Use Chronology

Over the past 170 years, land use within the Wilson Creek watershed has shifted from upland prairie and forested bottomland to 55% pasture and other agricultural lands, 22% residential use, and 15% commercial/industrial developments; only 5% remains forested (Black, 1997). During that time, population increased from 300 residents at the founding of Springfield to 151,580 residents at the 2000 census. The growth and development of the infrastructure necessary to support that population has significantly impacted water and sediment quality in the Ozarks. A chronology of the urbanization of Springfield was included previously in Table 4 on page 52.

Note from the table that there were building "booms" from 1840-1850, 1870-1890, and 1940-1970. With such growth in commercial/industrial land use, railroad construction, and residential development, sources of sediment were plentiful. Industries in the downtown area used the Jordan, Fassnight, and Wilson Creeks as their waste removal channels. Additionally, in 1959 the SWTP added an additional source of contamination by releasing (mostly) treated sewage effluent into Wilson Creek. After several fishkills and complaints about noxious odors, Springfield began to try to address water quality issues in Wilson Creek in earnest. Plant upgrades since 1993 have reduced contaminants in the effluent and seem to have reduced contamination in sediments.

Correlation with Stratigraphic Markers and Geochemical Profiles

In order to determine the strength of associations between the rock-forming elements as well as the pollutant metals, Pearson product-moment correlations were run for all samples within each defined depositional unit. The results of that analysis can be found in

Table 33-Table 39. As expected, three rock-forming metals are strongly associated in most units. Al, Fe, and Mg are correlated in the Post-WW II silt/loam, Weathered gravelly alluvium, Hillslope colluvium, Upland soil and McElhaney Branch units. Exceptions are the Historical Gravel and Weathered Gravelly Alluvium deposits. This may be due to oxide coatings on gravels and extensive weathering in those deposits.

Results indicate a strong correlation between pollutant metals and phosphorus in the Post-WW II unit as well as the Historical Gravel unit. Ag, Cu, Hg, Pb, Zn and P are strongly associated in both of these units, indicating that these pollutants are probably deposited together – perhaps having a common source. However, moving away from the channel and into older units, the associations between pollutants become weaker. In Weathered Alluvium, Buried Soil, and the Weathered Gravelly Alluvium unit, few associations are apparent among the pollutants. On the Hillslope, most pollutant metals except Hg and Pb are associated, suggesting a separate source for these metals. In the upland soil, Pb, Zn, and Hg occur together. Figure 36 and Figure 37 summarize these associations in selected units. Enrichment patterns for Hg, Ag and P are shown in Figure 38, Figure 39, and Figure 40.

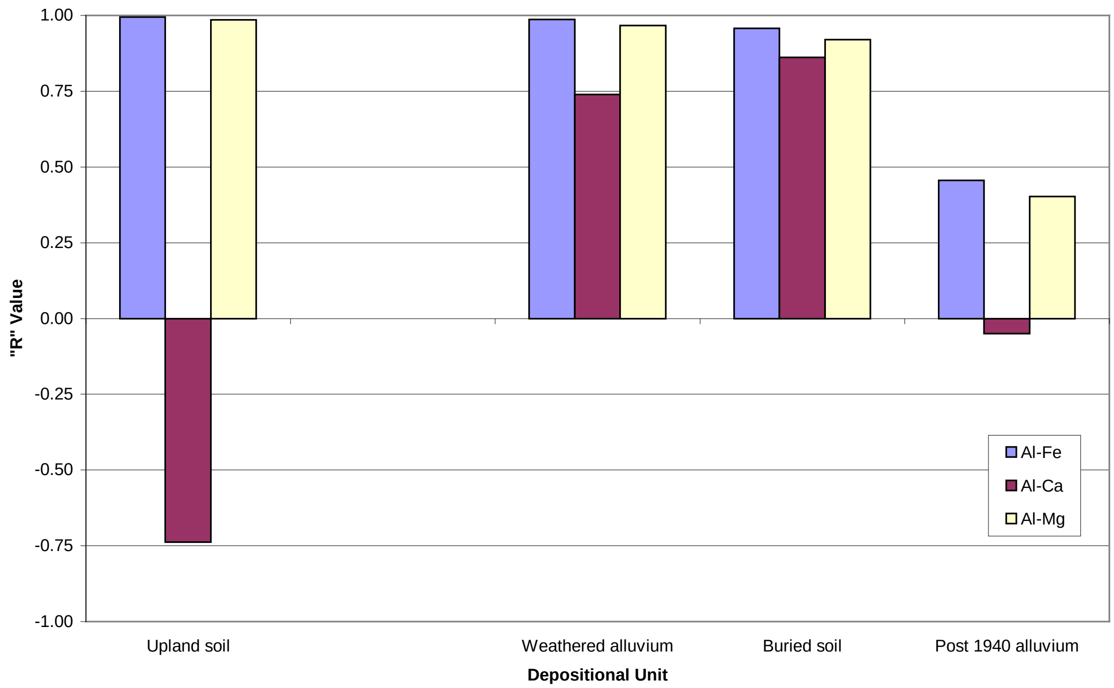


Figure 36. Aluminum correlation with rock-forming elements.

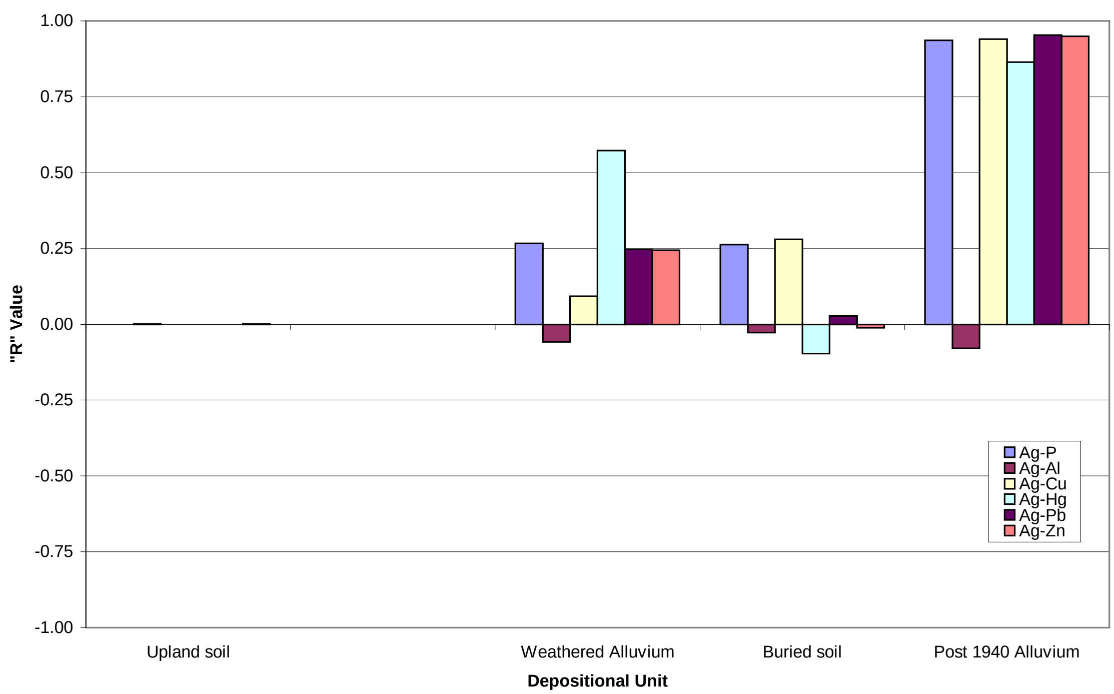


Figure 37. Silver correlation with pollutant metals and phosphorus.

Table 33. Pearson correlation for Post-World War II silt/loam unit.

	Al	**Ca**	**Cu**	**Fe**	**Hg**	**Mg**	**P**	**Pb**	**Zn**
Ag	-0.079	**0.908**	**0.941**	**0.590**	**0.864**	**0.454**	**0.937**	**0.954**	**0.949**
Al		-0.050	-0.001	**0.455**	-0.105	**0.403**	-0.057	-0.096	-0.031
Ca			**0.901**	**0.515**	**0.671**	**0.487**	**0.966**	**0.886**	**0.936**
Cu				**0.659**	**0.849**	**0.440**	**0.951**	**0.972**	**0.980**
Fe					**0.642**	0.240	**0.600**	**0.690**	**0.667**
Hg						**0.328**	**0.768**	**0.887**	**0.850**
Mg			n=68				**0.451**	**0.325**	**0.444**
P								**0.954**	**0.949**
Pb			**sig. at p=0.05**						**0.978**

Table 34. Pearson correlation for Historical Gravel unit.

	Al	**Ca**	**Cu**	**Fe**	**Hg**	**Mg**	**P**	**Pb**	**Zn**
Ag	-0.050	**-0.551**	0.064	-0.010	**0.469**	-0.036	0.327	**0.548**	**0.512**
Al		**0.783**	**-0.427**	**0.977**	**-0.841**	**0.970**	**0.512**	**-0.768**	**-0.770**
Ca			-0.044	**0.756**	**-0.771**	**0.731**	**0.372**	**-0.745**	**-0.733**
Cu				**-0.372**	**0.660**	**-0.462**	0.094	**0.670**	**0.645**
Fe					**-0.777**	**0.910**	**0.529**	**-0.683**	**-0.676**
Hg						**-0.836**	-0.177	**0.983**	**0.978**
Mg			n=27				**0.368**	**-0.785**	**-0.810**
P								**0.548**	**0.512**
Pb			**sig. at p=0.05**						**0.979**

Table 35. Pearson correlation for Hillslope unit

	Al	**Ca**	**Cu**	**Fe**	**Hg**	**Mg**	**P**	**Pb**	**Zn**
Ag	**0.678**	**0.571**	0.258	0.254	0.243	**0.614**	-0.263	-0.297	**0.526**
Al		0.184	**0.572**	0.128	-0.080	**0.918**	**-0.680**	**-0.781**	0.288
Ca			0.356	-0.178	**0.809**	0.216	0.401	0.322	**0.926**
Cu				-0.190	0.156	**0.522**	-0.180	-0.276	**0.593**
Fe					-0.381	0.136	-0.228	0.016	-0.306
Hg						-0.071	0.379	**0.498**	**0.769**
Mg			n=26				**-0.460**	**-0.653**	0.288
P								-0.297	**0.526**
Pb			**sig. at p=0.05**						0.226

Table 36. Pearson correlation for Weathered Gravelly Alluvium unit.

	Al	Ca	Cu	Fe	Hg	Mg	P	Pb	Zn
Ag	0.049	0.309	0.039	0.247	0.000	0.104	0.570	0.320	0.120
Al		**0.859**	0.165	**0.961**	0.000	**0.933**	0.706	**0.922**	**0.924**
Ca			0.409	**0.939**	0.000	0.674	**0.812**	**0.803**	**0.753**
Cu				0.307	0.000	-0.084	0.434	0.111	0.051
Fe					0.000	**0.864**	**0.860**	**0.927**	**0.916**
Hg						0.000	0.000	0.000	0.000
Mg		n=8					0.651	**0.946**	**0.911**
P								0.320	0.120
Pb		**sig. at p=0.05**							**0.867**

Table 37. Pearson correlation for Weathered Alluvium unit.

	Al	Ca	Cu	Fe	Hg	Mg	P	Pb	Zn
Ag	-0.058	**0.404**	0.093	-0.014	**0.573**	0.007	0.267	0.247	0.245
Al		**0.739**	**0.906**	**0.986**	**-0.424**	**0.967**	**0.666**	**0.748**	**0.893**
Ca			**0.820**	**0.742**	0.217	**0.738**	**0.778**	**0.767**	**0.906**
Cu				**0.923**	-0.249	**0.899**	**0.862**	**0.792**	**0.915**
Fe					-0.371	**0.966**	**0.740**	**0.827**	**0.924**
Hg						-0.366	0.114	0.131	-0.006
Mg		n=23					**0.705**	**0.771**	**0.892**
P								0.247	0.245
Pb		**sig. at p=0.05**							**0.916**

Table 38. Pearson correlation for Upland Soil unit.

	Al	Ca	Cu	Fe	Hg	Mg	P	Pb	Zn
Ag	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Al		-0.738	-0.185	**0.995**	-0.548	**0.986**	**-0.854**	-0.430	0.251
Ca			0.654	-0.719	0.579	-0.674	**0.968**	0.636	0.200
Cu				-0.110	0.594	-0.121	0.476	0.728	0.779
Fe					-0.478	**0.979**	**-0.851**	-0.361	0.332
Hg						-0.612	0.486	**0.906**	0.576
Mg		n=6					-0.788	-0.457	0.235
P								0.509	-0.033
Pb		**sig. at p=0.05**							0.736

Table 39. Pearson correlation for McElhaney Branch unit.

	Al	**Ca**	**Cu**	**Fe**	**Hg**	**Mg**	**P**	**Pb**	**Zn**
Ag	0.661	**0.842**	0.642	0.565	0.774	0.604	**0.839**	0.704	0.620
Al		**0.814**	**0.815**	**0.971**	0.741	**0.917**	0.722	0.772	**0.865**
Ca			0.798	**0.838**	**0.835**	0.611	**0.974**	**0.869**	**0.815**
Cu				**0.835**	**0.968**	0.811	**0.841**	**0.981**	**0.993**
Fe					0.738	**0.828**	0.757	0.809	**0.892**
Hg						0.741	**0.902**	**0.982**	**0.940**
Mg			n=6				0.557	0.714	**0.834**
P								0.704	0.620
Pb			**sig. at p=0.05**						**0.969**

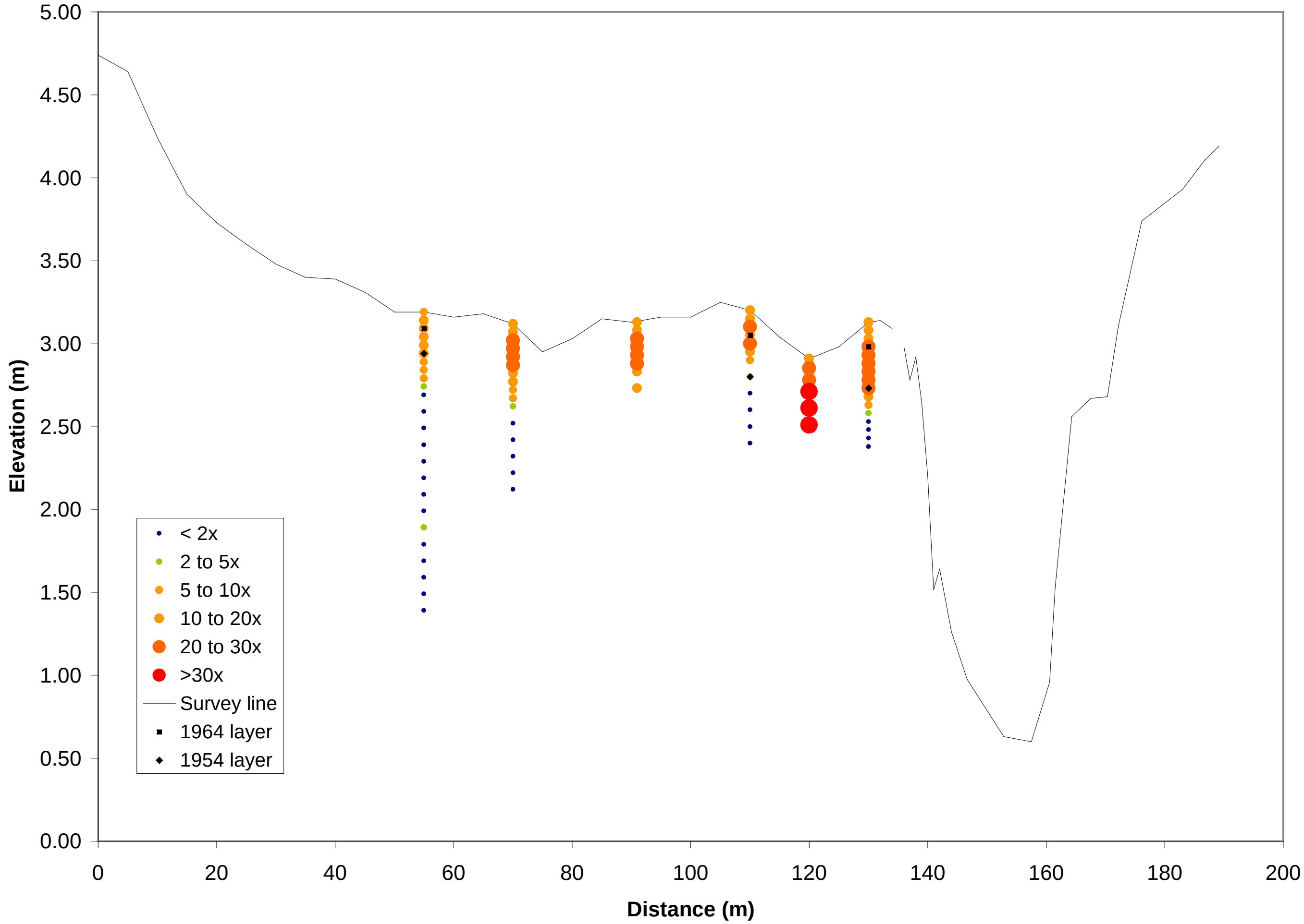


Figure 38. Mercury enrichment pattern

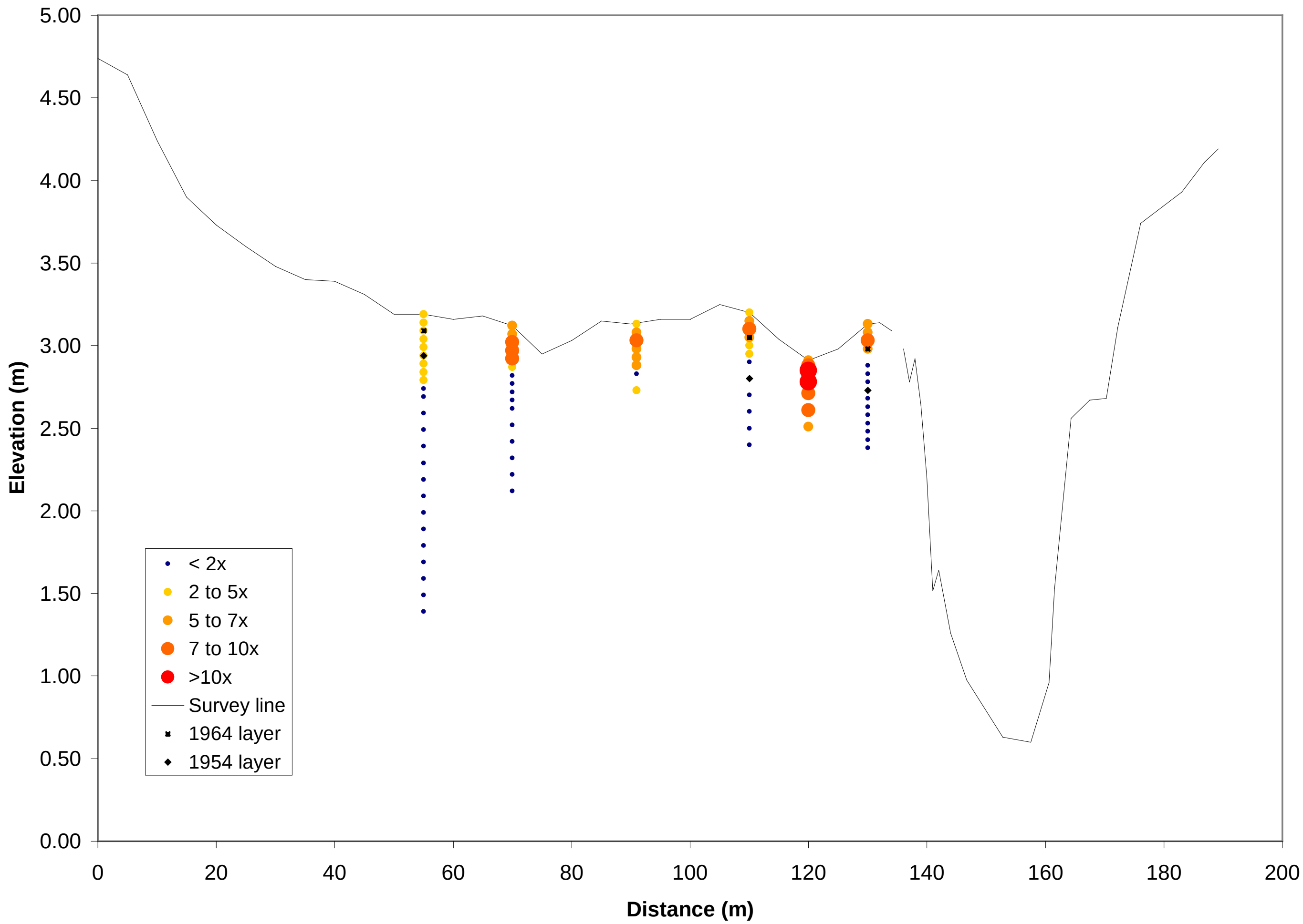


Figure 39. Silver enrichment pattern.

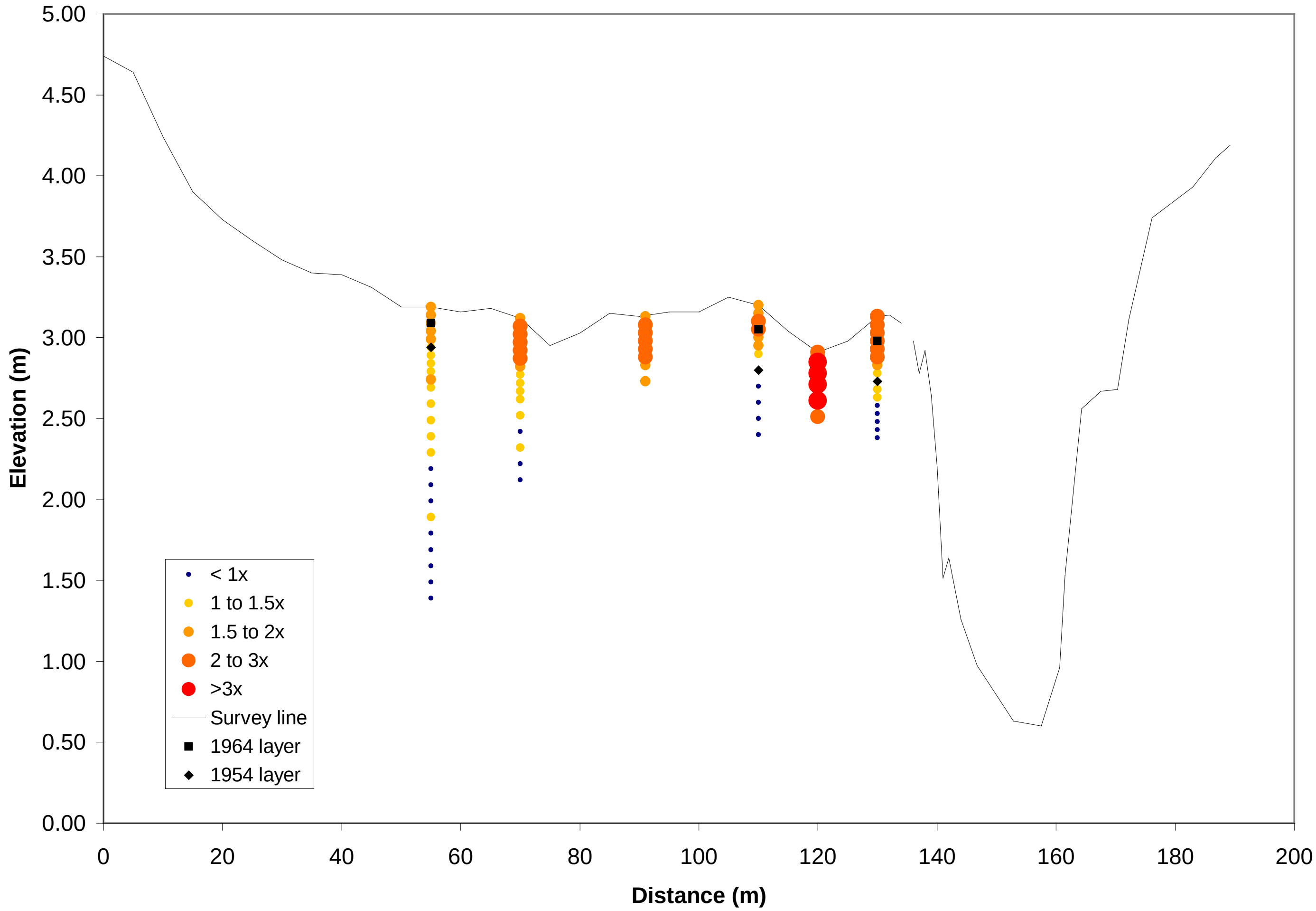


Figure 40. Phosphorus enrichment pattern.

Sedimentation Rates

Anthropogenic metals concentrations can act as markers to aid in dating the sediments and therefore calculating sedimentation rates. The first appearance of possible pollutants was the appearance of Hg and Pb in the 55 m pit, very close to an increase in organic matter with a corresponding darker soil color at 1.8 m elevation. This may be interpreted as the boundary of a pre-settlement buried soil. In that case, the most likely source of the Pb and Hg is the Battle of Wilson's Creek in 1861. This layer is only approximately 20 cm thick. Pb and Hg return to background levels in the next 50 cm of soil, from 2.0 m to approximately 2.5 m.

The next appearance of anthropogenic metals is Hg again at an elevation of approximately 2.5 m, followed by an increase in Zn, Pb, Cu and Ag. These appear approximately 20 cm below the 1954 layer that was identified by Cs dating techniques. These may be a result of the rapid industrial development during the 1940s and early 1950s. At this time, the SWTP has not yet been built, and many industrial wastes were disposed of in Jordan and Wilson Creeks.

Metal enrichment peaks for most metals occurs in the layers between 1954 and 1964. During this time, the SWTP came online and began handling treatment of wastewater from both industrial and residential customers. Enrichment levels for Hg were as high as 41 times the background level in the 120 m pit. Hg concentrations peaked earlier and dropped off sooner than other metals. This may be a function of having a different source or slightly different downward mobility in the sediments. Ag, on the other hand, peaked later and persisted slightly longer than Cu, Pb and Zn. Again, perhaps this is due to a different source or different mobility in the soil. Identifying exact sources of each of the pollutants is difficult. Toxic release reports were not required of industries until the 1980s, so knowing exactly what might have been released into the stream prior to government regulation is difficult.

Atmospheric pollutants, such as Pb and Hg, were also a factor. It is apparent that atmospheric sources did contribute some pollutants because even in the upland soil, Pb was enriched by a factor of nearly four and Hg was enriched by a factor of 5 times background levels. If it were possible to separate the atmospheric contributions from Hg and Pb in the floodplain sediments, it may be possible to estimate dates based on power plant emissions and the removal of Pb from gasoline. However, due to the location of the floodplain and multiple potential sources of those metals, it would be difficult, if not impossible.

With the addition of possible identification of the 1861 layer, sedimentation rates can be estimated for older layers of the feature. An updated calculation of sedimentation rates is presented in Table 40. From 1861 to 1954, it appears that sedimentation rates were higher in the 55 m pit than near the channel. This may be due to filling in of the old

Table 40. Sedimentation rates for 1861-2002

	Depth to Cs-137 layer (cm)			**Sedimentation rates (cm/year)**			
Pit	**1964**	**1954**	**1861**	**1861-1954**	**1954-1964**	**1964-2002**	**1861-2002**
25 m	15	40	N/A	N/A	2.5	0.4	N/A
55 m	10	25	140	1.0	1.5	0.3	1.0
110 m	15	40	100	0.7	2.5	0.4	0.7
130 m	15	40	80	0.6	2.5	0.4	0.6
Average	14	36	107	0.8	2.5	0.4	0.8

channel and shifting sedimentation patterns as the floodplain was adjusting to the new channel location.

Limitations of Urban Pollution Dating

Urban pollution dating, when combined with additional tools, can aid in dating floodplain sediments. However, because floodplain geomorphology is so complex and the time scale of human development is so short, the are limitations to how useful it can be. Short term changes can be measured, especially if there has been a specific instance of a known toxic release of chemicals. However, since records of regular industrial discharge have only been kept for the past 20 years at the most, urban pollution signatures are not useful for studying old features.

In studying younger features, pollution source determination is an obstacle to having an accurate pollution history. Many anthropogenic metals and nutrients are released from multiple sources – some are documented and some are not. Atmospheric releases from industries such as power plants or manufacturing may or may not be regulated and therefore may or may not be reported. Nonpoint pollution from stormwater runoff, agriculture and turf maintenance makes determination of input even more difficult. Combined with radiometric dating, however, urban pollution dating may provide some additional useful information.

Discussion and Summary

A chronology of pollution/land use for the watershed will enable researchers to better and attribute changes in stream morphology and sediment quality. Knowing the timing of events that have the potential to impact the stream and the sediment quality can aid in explaining patterns that might otherwise might not be recognized.

Events in the urbanization and development that have impacted the Wilson Creek floodplain include the initial land clearing for agriculture and the railroads, as well as burst of industrial, commercial and industrial development as Springfield grew from a settlement to the third largest city in the state. Key periods of growth occurred in the mid and late 1800s and from 1940-1970. This last period of growth probably introduced large amounts of sediments into the system and helps account for the significant increase in sedimentation rates during this period. The construction of the SWTP near Wilson Creek also likely influenced the sediment supply as well as introduced additional pollutants into the system.

Urban pollution dating as a tool, however, is limited by the amount of specific information available regarding the release of contaminants. With specific information about amount and type of material released, it may be possible to more accurately date sedimentary layers. However, until government regulations required the documentation of this information, accurate data is difficult to find.

CHAPTER 7

CONCLUSIONS

This study correlates periods of floodplain sedimentation with contaminated sediments related to urban and industrial sources since the post-World War II period and applies this toward understanding the historical geomorphology of Ozarks streams. Historical documents are used to develop a chronology of urban and industrial development as well as a flood history of the watershed. Aerial photographs are used to identify changes in local land use and stream morphology since 1936. Samples were taken from pits and cores along a transect across the floodplain for stratigraphic, geochemical and radiometric analysis. Various computer software was used for analysis and plotting of the data in order to evaluate relationships between pollutant trends and deposition patterns on the floodplain.

GEOMORPHOLOGICAL IMPLICATIONS

Key findings of this study regarding the geomorphology of the floodplain are:

(1) The floodplain feature and channel location have been relatively stable over the past 70 years. Aerial photos indicate that the channel has been in place and relatively unchanged since the early 1900s;

(2) This meander bend and floodplain appear to be the result of a stalled gravel wave or bar, and the channel was at one time approximately 80 m west of the current channel. Floodplain stratigraphy and geochemical analysis indicate a large gravel deposit covered by post-WWII fine-grained alluvial deposits west of the current channel;

(3) Floodplain deposition is primarily controlled by small, regular floods (< 2 year interval) rather than infrequent high magnitude floods. Historical and recent newspaper accounts and gage data indicate that this floodplain is inundated every 1 to 3 years; and

(4) The floodplain, while relatively stable, is still depositional in nature. According to radiometric dating, gravel splays that were evident on the surface in 1941 have been covered by approximately 20-30 cm of fine-grained material, with evidence of recent deposition from the May 2002 flood. Using ^{137}Cs dating and assuming a buried soil represents the battlefield surface in 1861, overbank sedimentation rates were approximately 0.8 cm/yr from 1861-1954, 2.5 cm/yr from 1954-1964, and 0.4 cm/yr from 1964-2002, with an overall average rate of 0.8 cm/yr.

While most Ozarks streams are relatively straight and primarily controlled by overbank deposition, large gravel waves resulting from landuse changes may produce changes in stream morphology and channel migration that would not normally occur. This appears to be the case on this floodplain of Wilson Creek.

POLLUTION CONTROL IMPLICATIONS

It is well documented that floodplain sediments can act as major storage areas for pollutants transported from upstream sources. This study found that this floodplain is indeed storing pollutants originating from upstream point and non-point sources, with the onset of major pollutants beginning in post-World War II. Key findings of this study regarding pollution control implications are:

(1) Stored pollutants may represent a source of contamination downstream, however most metals stored in the floodplain appear to be relatively immobile due to the

neutral pH of both the soil and stream. Sediments do not appear to be a toxicity hazard at this time;

(2) Phosphorus storage on the floodplain does not seem to be an issue – it is either very mobile and washes out, or plant uptake recycles much of the P. Enrichment of P is only 2-3 times background levels;

(3) Hg levels in some cores were enriched up to 45 times background levels for this floodplain, or approximately 20 times historical background levels for upstream reaches. However, the source of the Hg is still unknown. It is likely a combination of both aerial and fluvial deposition; both the Southwest Power Plant and Southwest Wastewater Treatment Plant have permits to discharge Hg; and

(4) Upgrades at the Southwest Wastewater Treatment Plant and Industrial Pretreatment Programs appear to be reducing both the phosphorus and heavy metal pollutant load in recent sediments.

Although the floodplain is acting as a sink for both metal and phosphorus pollution, concentrations of most metals and P have decreased in recent years and do not appear to pose toxic risk to the immediate environment.

LIMITATIONS OF STUDY

This study successfully used what is known about the pollution history and urban growth in Springfield to help interpret historical floodplain development. However, the study was limited by the following factors:

(1) Records of pollutant input are limited for early industrial discharge. Until governmental regulations required reporting of toxic discharges, most industrial

waste was discharged to Wilson Creek or its tributaries in the downtown Springfield area without record. Additionally, many wastes that were unacceptable for municipal sewage treatment were dumped directly into the creeks;

(2) Complex sedimentation patterns on the floodplain and a lack of old dateable artifacts limit interpretation of pre-1954 deposits. While a possible buried soil representing the 1861 battlefield surface was located, no war artifacts or buried wood were found to confirm that date;

(3) Only one transect was sampled because of the need to preserve the National Park environment. More sample locations would help to more accurately describe the geomorphology of the floodplain;

(4) The gravel layer impeded digging to old sediments, especially near the channel. This restricted collection of samples and therefore limited geochemical and stratigraphic information; and

(5) Gages on the Wilson Creek and tributaries were limited in location and duration of operation. There is not a complete record of flooding history. Additionally, the remote location of the study area meant that large floods prior to installation of USGS gages were not directly recorded.

Although these conditions exist and did limit sample collection and interpretation of data, a great deal of information and knowledge was gained about the floodplain’s geomorphology and it geochemical characteristics.

SUGGESTIONS FOR FURTHER STUDY

There is a great deal of potential for future research related to this study. Some possible future studies might include:

(1) additional research regarding historical pollution sources, especially sources of Hg and Ag;

(2) additional sampling of the floodplain feature to more accurately describe patterns of floodplain deposition;

(3) research regarding sediment distribution for different flood magnitudes; and

(4) research regarding conditions for and impact of release of contaminants from storage on the floodplain

SUMMARY

This study provides information regarding the development and contaminant storage potential of floodplains associated with Wilson Creek and the impact of human activities in the Wilson Creek watershed. It is evident that past land use changes as well as direct channel alteration have impacted the Wilson Creek channel and floodplain near the study area. Additionally, pollutants generated and released into the stream by industrial and urban sources are stored in the top 50 cm of the floodplain sediments where they are potentially bioavailable and subject to erosion. Both sedimentation rates and pollutant concentrations in the sediments were highest during the post-World War II period when the industrial growth and urbanization of Springfield was at its peak. Future development in the watershed may have additional impacts.

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