



MSU Graduate Theses

Summer 2001

Spatial Distribution Of Phosphorus In Fluvial Sediments From The James River Basin, SW Missouri

Briain Fredrick

As with any intellectual project, the content and views expressed in this thesis may be considered objectionable by some readers. However, this student-scholar's work has been judged to have academic value by the student's thesis committee members trained in the discipline. The content and views expressed in this thesis are those of the student-scholar and are not endorsed by Missouri State University, its Graduate College, or its employees.

Follow this and additional works at: <https://bearworks.missouristate.edu/theses>



Part of the [Geographic Information Sciences Commons](#), [Hydrology Commons](#), and the [Sedimentology Commons](#)

Recommended Citation

Fredrick, Briain, "Spatial Distribution Of Phosphorus In Fluvial Sediments From The James River Basin, SW Missouri" (2001). *MSU Graduate Theses*. 2119.
<https://bearworks.missouristate.edu/theses/2119>

This article or document was made available through BearWorks, the institutional repository of Missouri State University. The work contained in it may be protected by copyright and require permission of the copyright holder for reuse or redistribution.

For more information, please contact BearWorks@library.missouristate.edu.

Spatial Distribution of Phosphorus in Fluvial Sediments from the

James River Basin, SW Missouri

A Thesis

Presented to

The Graduate College of

Southwest Missouri State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science in Resource Planning

By

Brian S. Fredrick

August 2001

Spatial Distribution of Phosphorus in Fluvial Sediments from the James River Basin, SW Missouri

Department of Geography, Geology and Planning

Southwest Missouri State University, August 2001

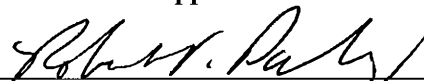
Master of Science in Resource Planning

Brian Fredrick

ABSTRACT

Degraded water quality in the James River Arm of Table Rock Lake, southwest Missouri has raised concerns about sources and transport of nutrients, especially phosphorus, in the James River Basin. Sections of the James River Basin have been identified as having excessive nutrient problems on the Missouri Department of Natural Resources 303d list and ranked fifth in the state for water quality improvements. Understanding the sources and transport patterns of phosphorus in the James River is necessary to evaluate contamination problems and the effectiveness of management efforts to reduce phosphorus inputs to the lake. This study uses bed sediments to monitor the concentrations and spatial patterns of phosphorus in the James River Basin. Fine-grained sediments were collected from eighty sites located by a Global Positioning System (GPS) during a two-week period in the summer of 1999. These samples were dried and put through a 2 mm sieve, evaluated for sand and organic matter, and analyzed for "acid extractable" total phosphorus and metals. A Geographic Information System (GIS)-based approach was used to delineate the drainage area above each site and determine the land use characteristics of the each sub-watershed. Sediment-Phosphorus concentrations in the James River Basin average 366 ug/g and ranged from 100 ug/g to 1,960 µg/g. The highest concentrations are found immediately below wastewater treatment plant outfalls. The lowest concentrations were found at sites where the land cover of the contributing drainage area was mostly forested. The spatial distribution of phosphorus is described by a multivariate regression equation ($r^2=0.78$) consisting of three predictors: (1) dilution factor related to the loading of wastewater treatment plant effluents; (2) organic matter content of the sediment; and (3) percent forested land cover in the drainage area of the sampling site. There is a strong positive relationship between phosphorus in bed sediments and phosphorus in overlying water column data in the basin. The results of this study could be used to better understand the influence of point and nonpoint sources of phosphorus in watersheds on phosphorus contamination problems in rivers and lakes.

This abstract is approved as to form and content



Chairperson, Advisory Committee
Southwest Missouri State University

**Spatial Distribution of Phosphorus in Fluvial Sediments from the
James River Basin, SW Missouri**

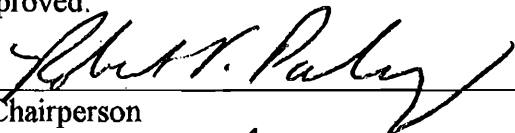
By

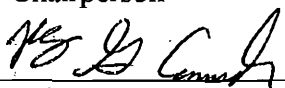
Brian Fredrick

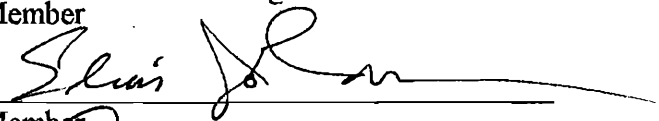
A Thesis
Submitted to the Graduate College
Of Southwest Missouri State University
In Partial Fulfillment of the Requirements
For the Degree of Master of Science

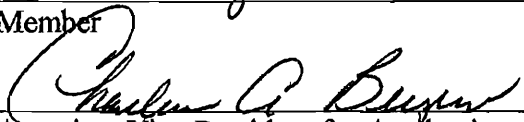
August 2001

Approved:


Chairperson


Member


Member


Associate Vice-President for Academic
Affairs and Dean of the Graduate College

ACKNOWLEDGMENTS

I would like to acknowledge the following people
for their support provided during this study:

I would first like to thank my committee members Dr. Robert T. Pavlowsky, Dr. Rex G. Cammack, and Dr. Elias Johnson from the Department of Geography, Geology, and Planning Southwest Missouri State University. This study would not have been possible without the knowledge and support that I received from these individuals through coursework, advisement, and personal instruction. Their professional guidance during this study is greatly appreciated. I would also like to thank Dr. Pavlowsky and the Graduate College for providing the funding for trips to professional meetings and laboratory analysis.

I also want to acknowledge the support of local agencies that helped me gain an understanding of water quality in the Ozarks. I would like to thank Adam Coulter and Loring Bullard from the Watershed Committee of the Ozarks. The experience of working with watershed scientists and managers that are involved with the issues of conserving and preserving water resources in the Ozarks was invaluable. I would also like to thank Norman Youngsteadt with City Utilities of Springfield who during several field courses provided information on aquatic biomonitoring and the effects of urbanization on stream ecosystems. In addition, thanks to Tom Holtz and the City of Springfield, Department of Public Works, Southwest Treatment Plant for providing water quality data. I would like to thank Gary Krizanich, James Vaughn, and Jeri Davis from the United States Geological Survey for providing land use/land cover data and the water quality database for the Frazer Bridge location.

I would also like to mention fellow graduate students and friends that I took courses with, worked on projects with, and shared the experience of graduate school with. Thanks to Kenny Legleiter, Jason White, Jimmy Trimble, Marc Owen, and Susan Burroughs for helping me with laboratory analysis and field work. I would also like to thank Paul Cushing for being a great friend that also helped with fieldwork and assisted in the maintenance of laboratory equipment. I would especially like to thank my mother and family for their support and understanding over the last few years and before.

TABLE OF CONTENTS

	Page Number
Abstract	ii
Acceptance Page	iii
Acknowledgments	iv
List of Tables	vii
List of Figures	viii
 Chapter One - Introduction	1
Phosphorus Sources and Transport	1
Phosphorus Contamination in the James River Basin	6
Purpose and Objectives	7
Benefits of This Study	9
 Chapter Two – Sources and Transport of Phosphorus in Rivers	11
Sources of Phosphorus in Watersheds	11
Transport of Phosphorus in Rivers	12
Sediment Composition	16
Texture	17
Organic Matter	18
Summary	18
 Chapter Three – Study Area	20
Geology and Soils	21
Nonpoint Sources of Pollution in the James River Basin	23
Land use	23
Point Sources of Pollution in the James River Basin	25
Waste Water Treatment Plants	25
Water Quality Problems	28
 Chapter Four – Methods	31
GPS Data Collection	31
Sample Collection	32

TABLE OF CONTENTS CONTINUED

	Page Number
Chapter Four Continued	33
Sample Processing	33
Sediment Texture Analysis	36
Organic Matter	36
Geochemical Analysis	37
Geographic Information Processing	37
Watershed Delineation	37
Land Use/Land Cover	38
Point Source Loading Index	40
Chapter Five – Results	42
Sediment-Phosphorus Concentrations	42
Sediment-Phosphorus Background Levels	44
Spatial Distribution of Sediment-Phosphorus	47
Lake Bottom Sampling	49
Sampling Error	51
Within-Site Variability	51
Temporal Variability	56
Land Use and Sediment Composition Effects	60
Pearson Correlation Matrix Analysis	60
Multivariate Regression Modeling	66
All Sample Sites	67
Sites Affected by both Point and Nonpoint Sources	68
Sites Affected by Nonpoint Sources	69
Sediment and Water Column Relationship	70
Regression Trend	73
Water Quality Assessment	74
Chapter Six – Summary and Conclusions	76
Literature Cited	81
Appendix	89

LIST OF TABLES

	Page Number
Table 3.1 Wastewater Treatment Plant in the James River Basin	27
Table 3.2 Sections of the James River or tributaries that are listed on the Missouri Department of Natural Resources (EPA) 303 (d) list	30
Table 4.1 Re-classified NLCD land use/land covers	39
Table 5.1 Summary of Sediment-Phosphorus Concentrations and Sediment properties	43
Table 5.2 Concentrations of Sediment-Phosphorus from other studies	44
Table 5.3 Preliminary Sediment Phosphorus Contamination Thresholds	46
Table 5.4 Within Sample Site Variance of Sediment Phosphorus	52
Table 5.5 Within Sample Site Variance of Percent Sand	53
Table 5.6 Within Sample Site Variance of Percent Organic Matter	54
Table 5.7 Analysis of Site Triplicate samples	55
Table 5.8 Pearson Correlations for All Sediment Sampling Locations	61
Table 5.9 Pearson Correlations for Sediment Sampling Locations affected by Point and Nonpoint sources	62
Table 5.10 Pearson Correlations for Sediment Sampling Locations affected by nonpoint sources	63
Table 5.11 Pearson Correlations Between Sediment Phosphorus and other Spatial, Geomorphic, and Geochemical Parameters	65
Table 5.12 Water column samples provided by the USGS and the City of Springfield	71
Table 5.13 Spatially joined table of water column phosphorus and sediment phosphorus	73

LIST OF FIGURES

	Page Number
Figure 3.1 Map of Missouri showing location of the James River	21
Figure 3.2 Map of the geology of the James River Basin	22
Figure 3.3 Map of land use in the James River Basin as of 1976	24
Figure 3.4 Map of land use in the James River as of 1999	25
Figure 3.5 Land use change James River over the last twenty-five years	26
Figure 3.6 Locations of wastewater treatment plants ranked according to the annual contribution of phosphorus in the James River Basin.	27
Figure 3.7 Sections of the James River listed on the 303(d) list.	29
Figure 4.1 Sediment Sample Locations in the James River Basin	32
Figure 4.2 Map of USGS Gauges that were recording flow data during the time of the Study	34
Figure 4.3 Discharge at the USGS gauge at Kinser Bridge near Springfield, MO (07052500) before and during the study	35
Figure 4.4 Discharge at the USGS gauge at Galena, MO (07050700) before and during the study	35
Figure 5.1 Locations and concentrations of soil and source samples	45
Figure 5.2. Spatial distribution of phosphorus concentrations	47
Figure 5.3 Downstream variations of main channel and tributary phosphorus concentrations	48
Figure 5.4 Locations of Lake Bottom Samples and Sediment-Phosphorus concentrations	50
Figure 5.5 Comparison of between-site the variability of sediment-phosphorus and sediment properties	56

FIGURES CONTINUED

	Page Number
Figure 5.6	Sites that were sampled in August of 1999 and March of 2001 57
Figure 5.7	Temporal comparison of sediment-phosphorus concentrations and sediment properties 59
Figure 5.8	Sediment phosphorus concentrations compared to predicted phosphorus concentrations for all sample sites 67
Figure 5.9	Sediment phosphorus concentrations compared to predicted phosphorus concentrations for sample sites affected by point and nonpoint sources 68
Figure 5.10	Sediment phosphorus concentrations compared to predicted phosphorus concentrations for sample sites affected by nonpoint sources 69
Figure 5.11	Nine locations where water column total phosphorus and sediment total phosphorus were compared 72
Figure 5.12	Relationship between water column total phosphorus and sediment phosphorus 74
Figure 5.13	Predicted water column total phosphorus (mg/L) using sediment phosphorus ($\mu\text{g/g}$) 75

CHAPTER 1

INTRODUCTION

Phosphorus Sources and Transport

In recent years, increased attention has been focused on the problem of excessive phosphorus being introduced to rivers. Identification of phosphorus sources and quantification of phosphorus pollution trends in large and multiple-use drainage basins present unique challenges to water resource managers (Emmerth *et al.*, 1996). Phosphorus, a naturally occurring element, is essential in aquatic ecosystems but excessive amounts are a major cause of water pollution when concentrations exceed critical levels (Hearn, 1985; Litke, 1999; Hem, 1985). According to the Clean Water Act, water pollution is defined as any anthropogenic alteration of the physical, biological, or chemical integrity of water (33 U.S.C. 7401 *et seq*). Determining the spatial distribution of natural and anthropogenic phosphorus sources in watersheds and the pathways of phosphorus transport in rivers is vital when attempting to understand phosphorus pollution problems. Therefore, an assessment of the levels of phosphorus in streams and lakes to identify phosphorus sources and understanding their linkages to both proximal and downstream pollution effects is needed before water quality control measures that address water pollution problems can be implemented.

Phosphorus occurs naturally in bedrock, is released from the decomposition of organic material, and has been detected in small concentrations in rainfall (Grobler and Silberbauer, 1985). Besides naturally occurring sources, anthropogenic sources of phosphorus are generally divided into two types: point and nonpoint. Phosphorus derived

from point and nonpoint sources differ in their spatial, hydrologic, and chemical characteristics.

A point source represents a specific location such as a pipe, drain, or wastewater outfall from which phosphorus is released. Examples of point sources include publicly owned wastewater treatment plants, agricultural animal production facilities, and industrial production plants. Primarily, wastewater treatment plants collect and treat human as well as cleaning and washing waste from households. Often, industrial facilities will send process water to wastewater treatment plants for treatment, this practice is known as indirect discharging. Indirect dischargers of phosphorus include manufacturers of organic chemicals and plastics, metal finishers, pulp and paper mills, and commercial establishments like restaurants, offices, and hotels (USEPA, 1995).

Phosphorus releases from a point source occurs at an almost constant rate and typically represents a higher percentage of the phosphorus being released during base flow conditions in a receiving stream (Baker, 1984). Although there is some daily variability in concentrations of phosphorus in wastewater treatment plant effluents, the total amounts released by these types of sources on an annual basis are relatively consistent (Pocernich and Litke, 1997). Phosphorus released from wastewater treatment plants is predominately in a dissolved inorganic form (Baker, 1984). This form of phosphorus is also referred to as orthophosphorus or soluble reactive phosphorus. This form is highly available to the environment and can be sorbed by sediment and soil particles. Since the 1970's, point source pollution has been increasingly brought under control due to government regulations, as point source levels decrease, the true impact of nonpoint source pollution is being recognized (Rosich and Cullen, 1981; Arnold, 1996).

Nonpoint sources are diffuse sources of phosphorus coming from the land or water use activities within the watershed such as septic tanks, agricultural practices, and urban runoff. The accumulation of phosphorus-containing materials on land surfaces within a watershed are eroded and washed off the surfaces (during rainfall events) and transported to the receiving stream by storm runoff (Novotny, 1981). This terrestrial-derived source of phosphorus is associated with episodic, often localized, erosion events (Pionke *et al.*, 1996). It is possible for up to 93% of the total phosphorus entering a body of water to come from nonpoint sources (Juracek, 1998).

The loading rates of nonpoint pollution to water bodies are associated with the amounts and intensity of rainfall and the runoff storm events produce. It has been estimated that 50 to 85% of the phosphorus originating from nonpoint sources is transported during stormwater events (Field and Pitt, 1990; Line, 1995). Amounts of phosphorus from this diffuse type of pollution can vary with discharge and vary seasonally making estimates of nonpoint sources of phosphorus more difficult to estimate than point sources. The amount of phosphorus contributed by point sources is accounted for in nutrient management plans with a higher degree of confidence than amounts of phosphorus from nonpoint sources due to the variable and episodic nature of nonpoint source inputs (EPA, 1983). Nonpoint sources of phosphorus are also variable because the export of phosphorus within the watershed is a function of land use, geology, and geomorphology (Uttormark *et al.*, 1974; Dillon and Kirchner, 1975; Minns and Johnson, 1979; Beaulac and Reckhow, 1982; Yaksich *et al.*, 1983). Sediment is also a major nonpoint source pollutant; both for its effects on aquatic ecology and because of the fact that many pollutants tend to adhere to eroded soil particles (EPA, 1992).

Phosphorus occurring in rivers is dissolved and suspended in the water column and adsorbed onto sediment that is deposited in the channel bed, banks, and floodplains throughout the river system. The forms of phosphorus transported in rivers can vary due to chemical and physical properties of the water and sediment. For the purposes of this study, the two general forms of phosphorus that are considered are total phosphorus, which occurs in the water column as dissolved and particulate phosphorus and sediment phosphorus which is attached to and incorporated within sedimentary deposits (Stumm and Morgan, 1981; Sonzogni *et al.*, 1982; Baker, 1984). The adsorption of phosphorus onto stream bottom and suspended sediments is considered the main factor affecting the mobility of phosphorus in aquatic systems (Stone *et al.*, 1989).

Total phosphorus is transported by the river suspended in the water column. Dissolved phosphorus is in solution and can pass through a 0.45 μm filter. Dissolved phosphorus that occurs in surface waters is comprised mostly of orthophosphate, which is immediately bioavailable phosphorus for algal uptake. Phosphorus may be adsorbed onto sediment particles or desorbed into solution depending on ambient pH, presence of competing anions, and redox potential (Edzwald *et al.*, 1976; Kuo, 1974; Li *et al.*, 1972; Taylor, 1971). Dissolved phosphorus that has precipitated onto the surface of soil particles, attached to clay minerals, or adsorbed onto the surface of clays is considered particulate phosphorus (Sonzogni, 1982). Particulate phosphorus is associated with eroded soil and organic matter particles and is not readily available for uptake by aquatic plants and animals. Particulate phosphorus that is incorporated into sediment that is deposited throughout the river system is a long-term source of bioavailable phosphorus (Sharpley and Smith, 1991; Sharpley, 1993).

In general it is believed that approximately 95 percent of phosphorus in streams tends to adhere to sediment particles (Hem, 1985). Therefore, to understand pollution problems associated phosphorus, the characteristics of the sediment that is being transported through the drainage basin must be considered as a medium for the transport of phosphorus. Sediment that is deposited in bed, bank, and floodplain material can act as a sink for sediment that is enriched with phosphorus. This phosphorus attached to sediment can also be a source of pollution whereas there is the potential for remobilization of sediment phosphorus by erosion, weathering, re-suspension, biological uptake, and chemical desorption. Sediment phosphorus concentrations generally vary with grain size and organic matter. Sediments with higher percentages of clay-sized particles and increased organic matter content tend to have higher concentrations of phosphorus (Syers, 1973). In addition, elevated sediment phosphorus concentrations may also be associated with iron, aluminum, and manganese oxides which coat the sediment surface (Bortleson and Lee, 1974; McCallister and Logan, 1978). Hence, even in non-polluted streams, sediment phosphorus concentrations can vary greatly due to natural variations in sediment composition and abundances of phosphorus-absorbing substrates.

Understanding the relationship between sources of phosphorus and the spatial distribution of sediment phosphorus concentrations throughout a river system can help determine the areas within a watershed that are contributing excessive amounts of phosphorus. Using sediment as an environmental monitoring tool is ideal for understanding the sources and distribution of pollution sources throughout watersheds (Combest, 1991). Sediment samples can provide time-integrated, highly informative data of high local representatively (Hakanson *et al.*, 1983). Sediment surveys can be used for

understanding the movement of phosphorus in watersheds and managing phosphorus contamination in rivers by examining the spatial, physical, and geochemical properties of sediment.

Phosphorus Contamination in the James River Basin

Reduced water clarity and quality in the James River Arm of Table Rock Lake, located in southwest Missouri, over the past decade has raised concerns about phosphorus sources in the James River Basin. Nutrient amounts entering Table Rock Lake, especially phosphorus, through the James River are unknown (Leyland, 1999; Knowlton, 1990). The Missouri Unified Watershed Assessment Report ranks the James River Basin as the fifth most impaired river in the state (Missouri Unified Watershed Assessment Steering Committee, 1998). This report identifies and ranks watersheds in the state that are impaired by different types of pollution and sources of pollution. The James River Basin has been identified in this report as being impaired by several pollutants, including phosphorus. The sources of nutrients are related mostly to nonpoint pollution (Missouri Unified Watershed Assessment Steering Committee, 1998). Although the actual inputs of phosphorus to Table Rock Lake from different sources within the James River Basin has not been determined, studies have shown that the James River Arm of Table Rock Lake is the most impaired arm of the lake compared to other areas of the lake (MDNR, 1998). Inputs of phosphorus from the James River and its tributaries to Table Rock Lake need to be examined. Sections of the James River and some main tributaries have been placed on the Missouri Department of Natural Resources/Environmental Protection Agencies 303(d) list. These sections have been placed on the list due to several

impairments including nutrients that have been identified as originating from point and nonpoint sources.

In the report published by the Lakes of Missouri Volunteer Program, the James River arm of Table Rock Lake was considered the most degraded arm of the lake. The average chlorophyll, nitrogen and phosphorus concentrations in the James River arm would be considered excessive for any region of the state or country (MDNR, 1998). The highest concentrations are found closest to the James River inflow point and decrease down lake. Information is needed that can describe the sources and transport patterns of phosphorus in the James River Basin. This information can be used to address and understand the problems related to phosphorus transport in the James River Basin. Very few studies have been conducted in the James River that examine the sources and transport patterns of phosphorus. By describing the geography and transport patterns of sediment phosphorus in the James River Basin, the sources of phosphorus can be assessed spatially. Thus, efforts can be made to reduce the inputs of phosphorus and monitor the affects of these reductions. While strategies are currently being implemented to reduce phosphorus concentrations from wastewater treatment plants, there continues to be a gap in knowledge concerning inputs of phosphorus from nonpoint sources.

Purpose and Objectives

There are no watershed-scale studies that examine the spatial relationships between potential sources of phosphorus and phosphorus contamination trends in the water and sediment in the James River Basin. In order to assess problems associated with excessive phosphorus inputs to Table Rock Lake, point and nonpoint sources of

phosphorus need to be examined. There needs to be an understanding of how sources of phosphorus are distributed throughout the watershed. Once the phosphorus is in the river system, the patterns of contamination need to be explained in order to identify the areas within the watershed that are contributing or storing excessive amounts of phosphorus. After it has been determined where the excess phosphorus is coming from within the watershed, management strategies can be implemented that focus on the sources within those areas that have the greatest downstream influence on phosphorus pollution problems.

This study addresses the phosphorus contamination problem in the James River by examining the geography of phosphorus sources and spatial distribution of phosphorus contamination in sediments throughout the basin. While a basin-scale monitoring strategy is used, the focus of this study will be on identifying the influence of nonpoint sources on phosphorus contamination as distinct from phosphorus releases from wastewater treatment plants. Although the amounts and locations of phosphorus inputs from wastewater treatment plants are well known, little is known about the effect of nonpoint phosphorus sources on water quality.

The main objectives of the study are to:

- Determine the spatial distribution of potential and known phosphorus sources, sediment properties, and sediment phosphorus concentrations in the James River Basin.
- Develop a multivariate regression model, driven by spatial and geochemical variables, that predicts the concentrations of phosphorus in bed sediments.

- Evaluate the relationship between sediment phosphorus values derived from this study and total phosphorus levels in the water column collected from previous monitoring efforts.

This sediment survey will be used to locate areas within the James River Basin that are contributing excessive amounts of phosphorus. It will identify the influence of sediment composition, wastewater treatment plant loadings, and land use on the dependant variable of sediment phosphorus in regression equations. Point and nonpoint sources of phosphorus will be linked to sediment quality, thus adding to the understanding of the relative contribution of point and nonpoint sources of phosphorus throughout the James River Basin.

Benefits of This Study

The expected benefits of this study include adding to the scientific knowledge of how phosphorus sources are related to sediment phosphorus concentrations in rivers (Chalmers, 1998; 1985; Van Metre and Callender, 1996). This study will also provide environmental managers in the region with information about how sources of phosphorus in watersheds are linked to downstream pollution problems. The model for sediment phosphorus used in this study may be used as a predictive tool to provide information for water quality assessments in adjacent watersheds in the region. In addition, the results of this study will help to better understand the different characteristics of point and nonpoint sources of pollution. Further, techniques used to assess the spatial patterns of phosphorus could be modified to identify spatial trends of other pollutants such as heavy metals.

This study will provide new information on sediment phosphorus in the James River and has the potential to be repeated for long term monitoring purposes in the future due to the geographic database that was developed during the course of sampling and analyses. Comparing future sediment phosphorus concentrations to the sediment phosphorus concentrations detected in this study could provide environmental managers in the region with useful information concerning the effectiveness of management strategies implemented to reduce phosphorus level in the James River Basin.

CHAPTER 2

SOURCES AND TRANSPORT OF PHOSPHORUS IN RIVERS

The erosion and transportation of sediment in rivers has been the focus of many studies (Pye, 1994). Fewer studies have examined the spatial distribution of phosphorus attached to fluvial sediments. In a study conducted by the USGS in the Winooski River Watershed, Vermont the average phosphorus concentrations in bed sediments were estimated to be 20 percent higher in urban and agricultural areas than in forested areas (Chalmers, 1998). Sediment phosphorus concentrations in the Cuyahoga River, Ohio also correlated with anthropogenic sources of phosphorus. In addition, a sediment survey conducted in the Trinity River, Texas determined phosphorus concentrations were enriched in urban and agricultural streambed sediments relative to those of undisturbed streambed sediments and soils. They concluded that this enrichment was attributed to the effects of agricultural practices, urbanization, and wastewater discharge on the main stem of the river (Van Metre and Callender, 1996). A companion study, similar to this sediment survey, was recently conducted on the Kings River in northwest Arkansas that examines how geology and the spatial distribution of poultry operations influence sediment phosphorus concentrations (White, 2001).

Sources of Phosphorus in Watersheds

Point sources are discrete, continuous sources of pollution that originate from a concentrated point such as a pipe from a factory or a wastewater treatment plant. Nonpoint source pollution is diffuse by nature and is a function of land use in the watershed. Both of these types of pollution sources are combined and constitute the total

amount of phosphorus entering the river. Management strategies that focus on the sources of phosphorus separate these sources and attempt to estimate contribution from each. The assessment of nutrient loadings from different sources to surface waters is important for the implementation of control measures to prevent or reverse nutrient pollution problems (Vighi, *et al.*, 1991).

An estimation of nonpoint sources of phosphorus is fundamental to the management of water quality in lakes and reservoirs (Juracek, 1998). Nonpoint sources include sediment, animal wastes, pesticides and other materials from agriculture, municipal dumps, and urban runoff. This diffuse form of pollution, now the nation's leading threat to water quality, is derived from contaminants washed off the surface of the land by stormwater runoff, and carried either directly or indirectly into waterways or ground water (EPA, 1994). Nonpoint pollution can reflect the combined influence of several pollutants and account for a large percentage of the total amount of pollution entering a body of water. This makes it extremely difficult to trace the source and identify which pollutant came from which source. Nonpoint nutrient loading is the leading cause of water quality problems in the nation's lakes and reservoirs (U.S. EPA, 1995).

Transport of Phosphorus in Rivers

Phosphorus is transported through river systems either bound to sediment or suspended in the water column as dissolved and particulate phosphorus. As dissolved phosphorus is transported in a river and its tributaries, the phosphorus can adsorb to the sediment. Sediment enriched with phosphorus that is deposited throughout the river

system can be a source of phosphorus to the overlying water column (Mortimer, 1941; Holdren and Armstrong, 1980). Fine-grained sediment can be re-suspended and transported in the water-column supported by turbulence. Eventually, this sediment and phosphorus may be deposited in lakes and reservoirs and can act as an internal loading source of phosphorus to the overlying water (Boström *et al.*, 1982; Imboden, 1974). The spatial nature of fluvial sediment that is enriched with phosphorus can be understood partially by understanding how sediment is transported in rivers.

The interaction between climate and the physical, chemical, and mechanical weathering of parent material creates soil (Leeder, 1982). As water moves through the drainage basin, weathered material is eroded from land surfaces in the watershed and transported by the river as sediment (Leopold *et al.*, 1964). The soil is delivered to stream channels through various erosional processes, including sheetwash, gully and rill erosion, aeolian processes, landslides, and human excavation. In addition, sediments are often released by stream channel and bank erosion. This erosion and transport of soil particles is a natural process that can also be accelerated by human activities. Increased soil tillage and reductions in protective soil surface cover provided by grasses, specific crops, and crop residues increase sediment and associated phosphorus transport dramatically (Sharpley *et al.*, 1989). The James River Basin Inventory and Management Plan reports that bottom sediments are primarily of surface soil erosion origin with 89% coming from sheet and rill erosion, 3% from streambank erosion, and 7% construction/urbanization (Kiner and Vitello, 1997).

The geomorphic and hydrologic variables that affect the transport of sediment also control the spatial variability of sediment-phosphorus concentrations. One of the

most complex and challenging problems in geomorphology is understanding how sediment moves through river systems (Wolman, 1977). Most of the sediment in rivers is transported during bankfull events (Leopold, 1995). Suspended sediment may travel from the place of erosion to points downstream without intermittent stages of deposition (Ritter, 1995). This sediment is then transported and deposited, at varying rates, throughout the basin depending on flood frequency and geomorphic variables such as aggradation, degradation, and channel sinuosity (Graf, 1994; Graf, 1996). As the phosphorus that has been attached to the sediment is transported through the river, it may be retained temporarily as streambed deposits or semi-permanently as over bank deposits. Sediment-Phosphorus concentrations at any location in a river vary temporally due to the episodic transport of sediment through river systems.

Several factors affect the transport of sediment from upland areas of drainage basins to the main channel and outlet. Not all of the sediment eroded from the uplands is eventually transported to the drainage basin outlet. The process of erosion and the delivery of sediments to the exit of a basin is never a spatially uniform process (Morris *et al.*, 1997). The overall process of sediment erosion, delivery to stream channels and episodic downstream movement has been referred to as sediment routing (Jacobson *et al.*, 1999). As phosphorus is transported to a lake, it may be retained temporarily or permanently in stream channels and wetlands and be altered by physical, chemical, and biological processes (Wagner *et al.*, 1996). The sediment that is stored in the stream bed consists of mostly cohesionless grains and is more mobile in the river system compared to floodplain material which is more cohesive because of finer material that is eroded from cut-banks and re-released into the active channel by hydraulic action and mass

failure (Knighton, 1998). Point bars and floodplains also act as temporary sinks and sources for sediment and the pollutants that could be adsorbed onto the sediment.

Land use conversion practices result in long-term changes in sediment yield and pollution levels. Examples include natural to commercially harvested forest, from forest to agriculture, or from agriculture to urban use (Morris *et al.*, 1997). These land cover changes produce a nonpoint source character via accelerated sediment erosion over long time-scales. Sediment yields can fluctuate through time by activities that have reduced or destroyed vegetation cover or disturbed the soil. The increased impervious surface that is associated with urbanization changes the hydrology in a watershed and can increase the peak and total runoff (Leopold, 1968; Hollis, 1975). As runoff increases, peak discharges in the river channel increase. This increase in discharge in the channel causes channel widening that can erode floodplain deposits and release stored sediment (Trimble, 1997).

The low energy environment of the lake creates an area of deposition that acts as a sink for sediment phosphorus. Continuous accumulation of sediment will leave some phosphorus too deep within the substrate to be reintroduced to the water column. Lakes and reservoir sediments also serve as sediment phosphorus sources. When conditions in the bottom of the lake are optimal (i.e. low pH, low dissolved oxygen, and high temperature), the phosphorus is readily desorbed from the sediment and made available to aid in increased algae growth. Phosphorus that is readily desorbed from upper layers of bottom sediments can act as an internal source of phosphorus to the overlying water column (Smith, 1990; Holtan *et al.*, 1988).

Sediment Composition

Sediment delivery is dependant on drainage basin size and particle size distribution of the sediments being transported (Walling, 1983). During erosion, transport, and deposition, these sediments in rivers and receiving bodies of water undergo sorting by size and physiochemical transformations (Holtan, 1988). Sediment composition has an influence on the ability of phosphorus to be adsorbed to streambed deposits. This study examines two components of sediment composition, texture and organic matter. These two components commonly help to explain the concentrations of phosphorus adsorbed onto the sediment in sediment-based pollution monitoring studies (Edzwald, 1976; Stone and Mudroch, 1989).

It is generally accepted that the sorption capacity of phosphorus increases with decreasing grain-size due to the increase in surface area of the soil or sediment particles (Holtan, 1988; Boström, 1982). This positive correlation between decreasing grain-size and increased phosphorus sorption is also due to iron and aluminum oxides on the surface of the clay (Stuanes, 1982). The nature of the sorption processes of phosphorus is quite complex but the literature provides explanations of how phosphorus can be associated with sediment (Baker, 1984; Chalmers, 1998). The need for speciation of phosphorus stems from the importance of understanding the availability of phosphorus needed for biological processes. In general, total particulate phosphorus is separated into: physical and chemical-sorbed phosphate; aluminum-bound phosphorus; iron and manganese bound-phosphorus; calcium-bound phosphorus; reductant soluble phosphorus; organic phosphorus and inert phosphorus (Holtan, 1988).

These sorption processes are dependant on other physical and chemical variables such as temperature and pH. The way that phosphorus is sorbed onto sediment is important because this determines the temporal availability of phosphorus for biological uptake. Physical and chemically sorbed phosphorus, also known as liable phosphorus, is considered readily available as a nutrient for algae growth. Aluminum/iron bound phosphorus tends to remain adsorbed until temperature, pH, and oxygen conditions are optimum for desorption to take place. These two fractions of phosphorus are important environmentally because of the depositional setting and residence time of the sediment as it moves through the river system and is deposited in receiving bodies of water.

Texture

To assess the capacity of sediment to absorb phosphorus, understanding the relationship between the affinity of this pollutant to the sediment and grain size is essential. The absorption capacity of sediment commonly increases with decreasing grain size (Horowitz, 1991). Grain-size distributions in soil and riverine sediment are similar as compared to lacustrine sediments that are composed of higher fractions of silt and clay (Van Metre, 1996). Although, some studies have shown that heavy metal concentrations do not increase with decreasing grain size and that pollutants can be associated with iron and manganese coatings and sand-sized particles (Feltz, 1980; Gibbs, 1977). The absorption of aluminum is associated with clay and silt-sized sediment.

Organic Matter

Most of the phosphorus in soils is adsorbed to soil particles or incorporated into organic matter (Smith, 1990; Craig *et al.*, 1988; Holtan *et al.*, 1988). The percent organic matter is related to phosphorus concentrations found in sediment. Organic matter is mostly made up of decaying plant material and can increase phosphorus concentrations in sediment. Studies have shown that there is a significant positive relationship between percent organic matter and concentrations of phosphorus in river sediment (Svendsen *et al.*, 1993).

Summary

The spatial distribution and sources of pollution in watersheds is a concern of environmental managers. One way to monitor pollution is to examine the spatial and geochemical properties of the bed sediment throughout the watershed. The characteristics of the contributing drainage area can be used to characterize the geochemistry of sediment at any given location. Organic matter and grain size can affect the concentration of phosphorus adsorbed onto the sediment.

Determining the spatial distribution of phosphorus adsorbed onto sediment in the James River Basin will assist in the assessment of sources of pollution. The relative influence of wastewater treatment plants and land use practices can be understood by comparing levels of pollution found in sub watersheds. This study attempts to develop a model that will predict the spatial distribution and levels of phosphorus pollution in watersheds. The concentration of phosphorus found in the sediment samples combined

with information on point sources, land use practices, and sediment composition is used to develop the model.

CHAPTER 3

STUDY AREA

The James River is one of the major river systems emptying into Table Rock Lake and is part of the White River Basin that is located in southwest Missouri and northern Arkansas (Figure 3.1). It drains 2,500 square kilometers at the United States Geological Survey gage at Galena, Missouri (USGS 07052500 James River at Galena, MO). The basin drains from seven counties, Webster, Greene, Christian, Barry, Stone, Douglas, and Lawrence. The largest urban area in the basin is Springfield, Missouri, which is located on the northern edge of the basin. Other rapidly growing communities in the basin include Nixa and Ozark located in Christian County, Missouri. The James River flows one hundred miles in a southwest direction from eastern Webster County into Table Rock Lake. Major tributaries to the James River include Wilson Creek, Pearson Creek, Finley Creek, Crane Creek, and Flat Creek. Minor tributaries to the James River include Turnbo Creek, Wildcat Creek, Panther Creek, Sawyer Creek, Turners Creek, Galloway Creek, and Railey Creek.

Table Rock Lake is a 174 square kilometer Army Corps of Engineers reservoir located in southwest Missouri. The lake is in the White River system and is downstream of Beaver Lake, which is in northwest Arkansas. The three major contributing rivers to Table Rock are the Kings River, Long Creek, and the James River. The lake was built in 1959 for the purpose of flood control and generation of electricity. The lake is a valuable recreational resource used by people from the region for fishing and recreational boating.

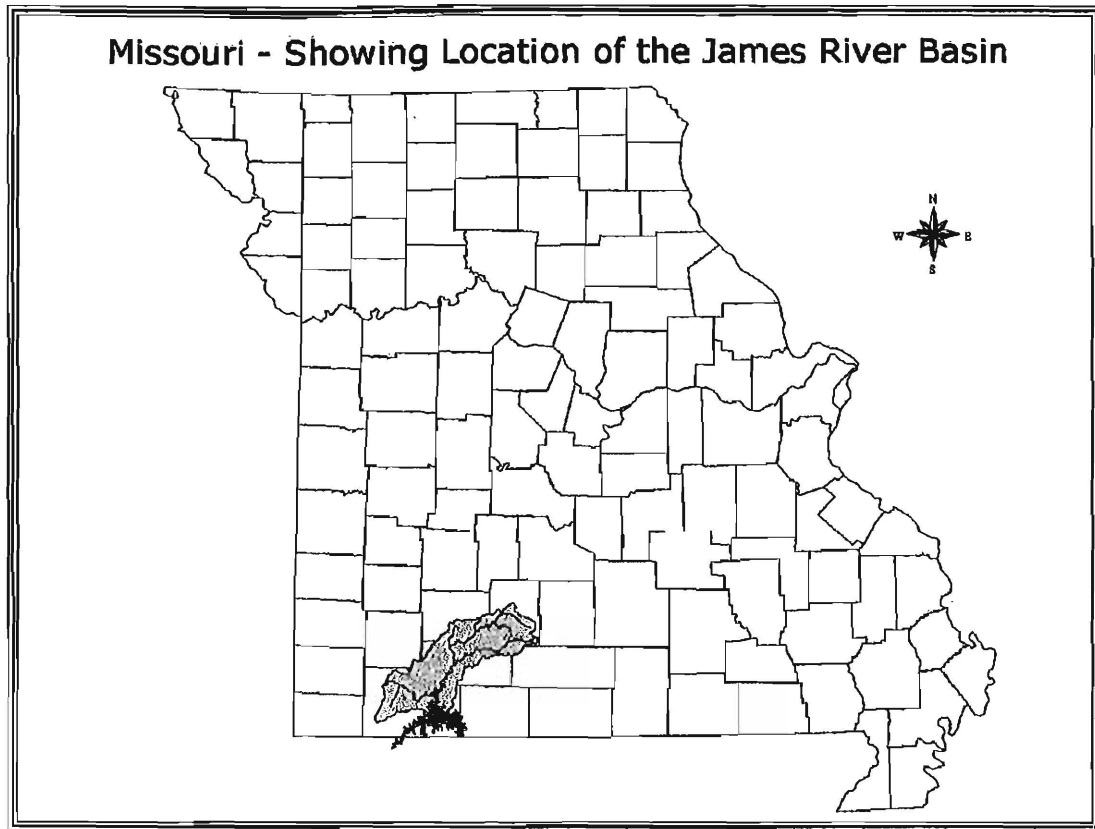


Figure 3.1. Map of Missouri showing location of the James River Basin.

Geology and Soils

The James River Basin is situated on the Springfield Plateau in the Ozarks physiographic region. The basin is dominated by near horizontal sedimentary rocks that include limestone, dolomite, shale, and some sandstone (Figure 3.2). From oldest to youngest, the geologic formations in the James River Basin are Cotter Dolomite, Bachelor Formation, Compton Formation, Northview Formation, Pierson Formation, Reed Springs and Elsey Formations, Burlington-Keokuk Limestone, and Pennsylvanian Sandstone. The rock layer that is most frequently exposed at the surface is the Burlington-Keokuk limestone. This carbonate bedrock is susceptible to chemical

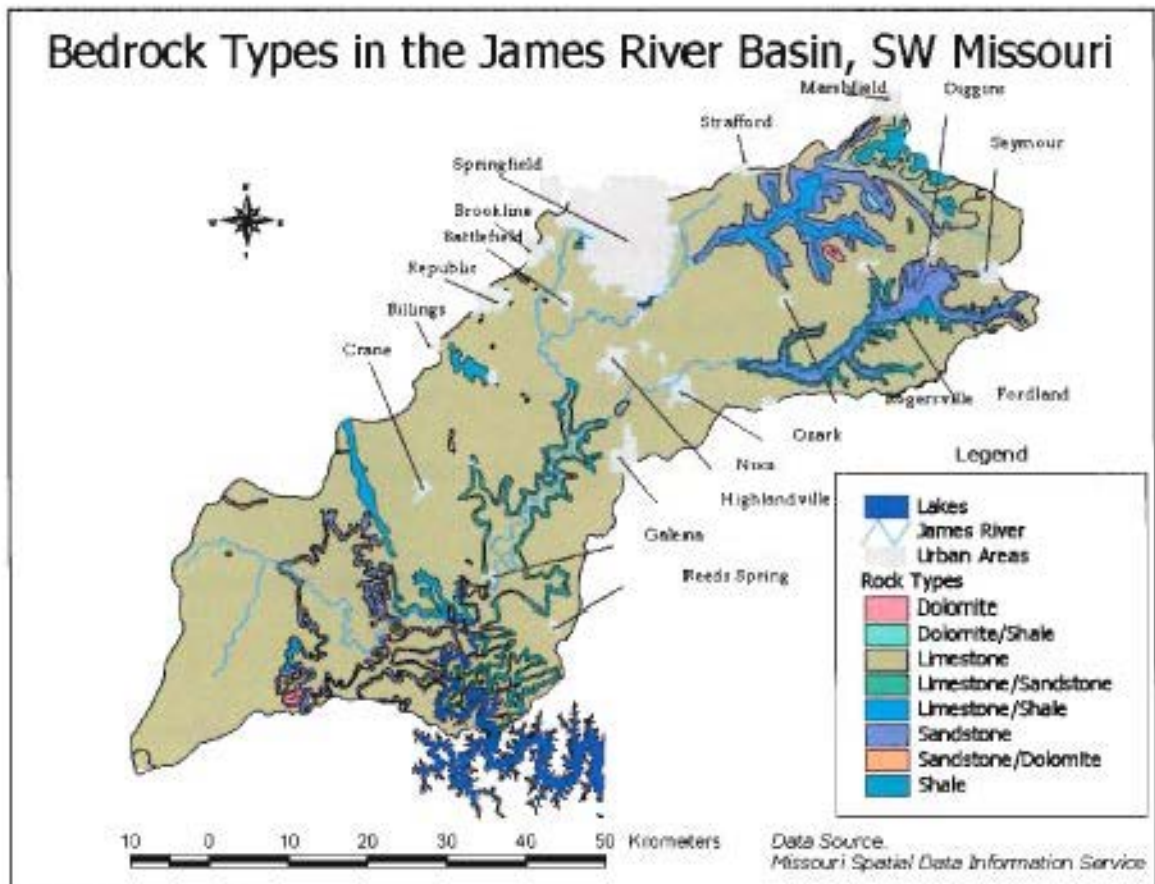


Figure 3.2 Map of the geology of the James River Basin.

weathering and the upper portions of the basin have typical characteristics found in a karst environment (Beveridge, 1978). Sinkholes and losing streams are common in the upper portions of the basin (Kiner and Vitello, 1997). These sinkholes and losing streams are scattered over the karst areas on uplands and act as conduits to the underlying ground water. Surface water that enters these sinkholes and losing streams percolates downward through the permeable soils and fractures in the bedrock. Because of this sometimes rapid infiltration, pollutants derived from the surface adjacent to sinkholes and losing streams can rapidly enter ground water.

The soils in the basin are mostly thin cherty residual soils with remnant caps of wind-blown glacial loess of Pleistocene age. Six major soil complexes are found in the basin: (1) Viration-Wilderness; (2) Eldon-Pembroke; (3) Peridge-Wilderness-Goss-Pembroke; (4) Nixa-Clarksville; (5) Needleeye-Viration-Wilderness; and (6) Gasconade-Opequon-Clarksville (Allgood *et al.*, 1979). The soils in the region are thin, relatively impermeable, or both, which during intense rainstorms can produce runoff that bypasses the underlying karst drainage system, resulting in fast-rising floods (Jacobson, 1995).

Nonpoint Sources of Pollution in the James River Basin

Land Use

According to The James River Basin Management Plan, land use in the James River Basin is approximately 63% agriculture, 30% forested, and 7% urban (Kiner and Vitello, 1997). Agricultural and mining land-use activities can increase the concentrations of nutrients, bacteria, dissolved solids, sulfate, and trace elements in the surface and ground water of the study unit. Increases in population density can result in increased discharges of nutrients, trace elements, bacteria, suspended sediment, and organic compounds (Adamski, 1995). Elevated concentrations of nutrients are usually related to areas of increasing urbanization and areas of agricultural land use (Spahr *et al.*, 1997).

A comparison of land use change between 1976 (Figure 3.3) and 1999 (Figure 3.4) shows forested land cover has been decreasing and urban land areas have been increasing. According to the EPA, as of 1976 agriculture land use in the James River Basin was 59%. Classified land use data from 1999 determined that 63% of the land use

Land Use in 1976 (Source : EPA)

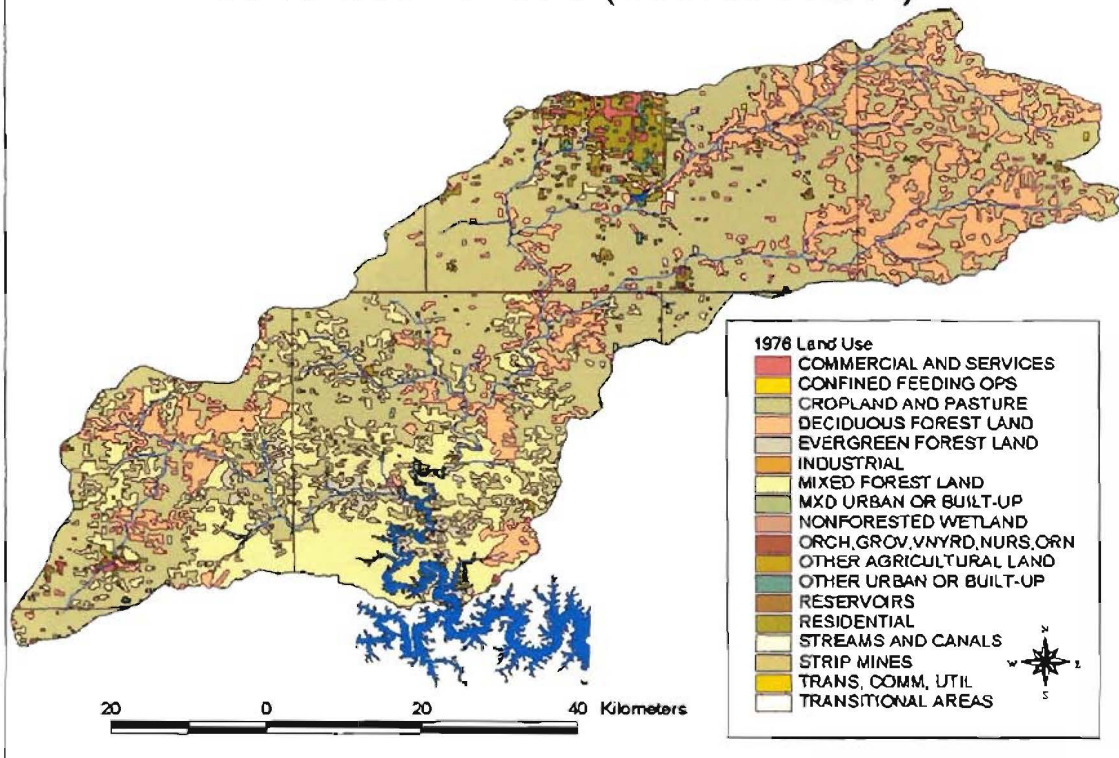


Figure 3.3 Map of the Land use in the James River Basin as of 1976. Data obtained from MSDIS (Missouri Spatial Data Information System). Land use percentages were calculated by summing the areas of the polygons for each land use.

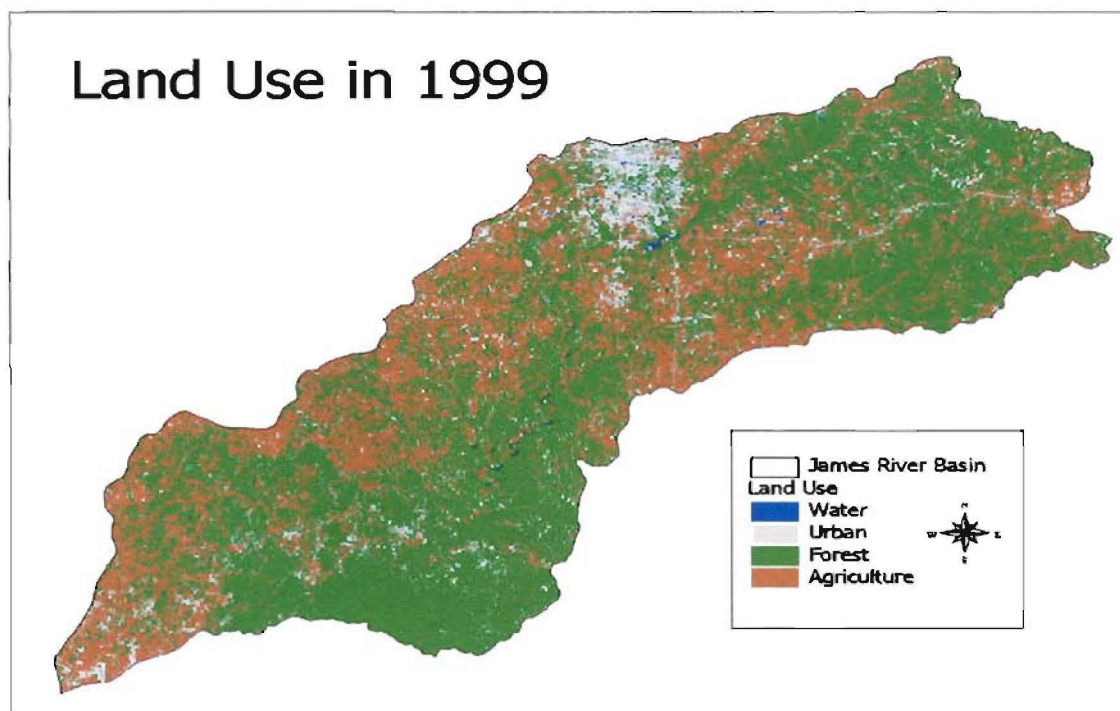


Figure 3.4 Map of the Land use in the James River Basin as of 1999. Data obtained from MORAP (Missouri Resource Assessment Program). Land use percentages were calculated by summing classified pixels for each land use.

in the James River Basin was agricultural. Over the last twenty-five years, urban and agricultural land use has increased and forested land area has decreased (Figure 3.5).

Point Sources of Pollution in the James River Basin

Waste Water Treatment Plants

To date, most of the management efforts to control the amounts of phosphorus being released in the James River Basin have focused on sewage treatment plant effluents and other point sources. There are thirteen wastewater treatment plants in the James River Basin. Each wastewater treatment plant within the basin has a different permitted design flow. Primary treatment removes only 10% of the phosphorus in the waste

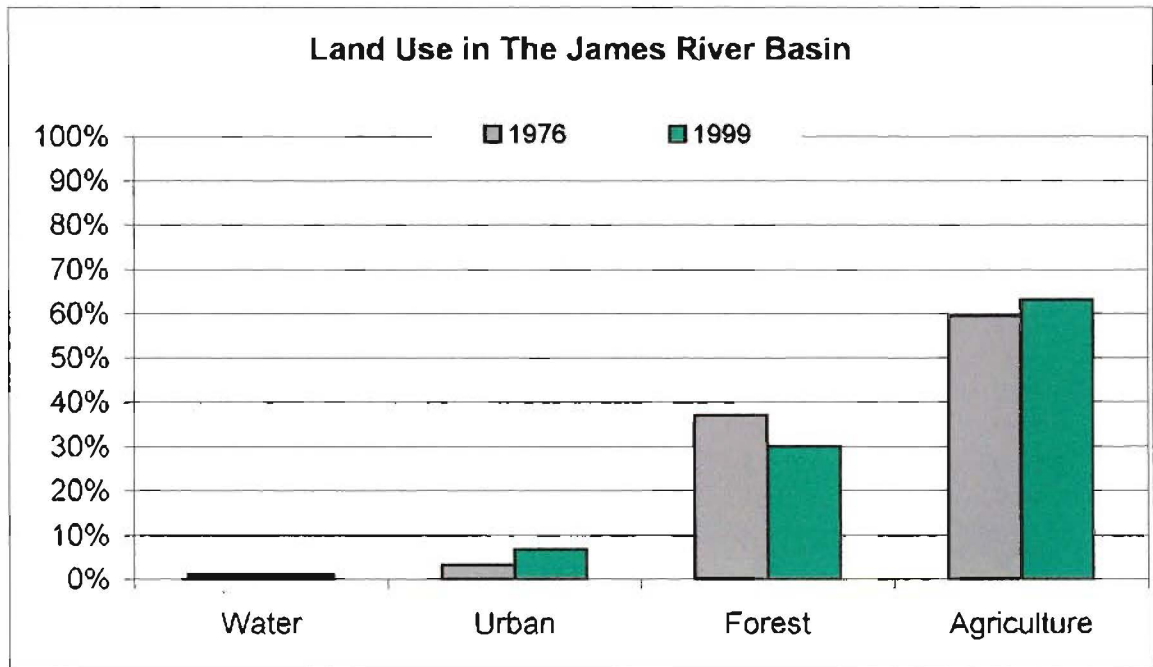


Figure 3.5 Land use change in the James River Basin over the last twenty-five years.

stream; secondary treatment removes only thirty percent. The remainder is discharged to the water body (Smith, 1990). The wastewater treatment plant located in Springfield has the highest permitted discharge compared to the other facilities in the basin (MDNR, 1999).

There are 13 wastewater treatment plants in the James River Basin (Table 3.1). This information was used to calculate the loadings in metric tons per year. The loadings are compared graphically using graduated point symbols (Figure 3.6). The graduated point symbols on the map depict annual loading for each wastewater treatment plant in the basin.

Table 3.1 Wastewater Treatment Plants in the James River Basin.

Facility	Permitted Flow (MGD)	Total Phosphorus (ppm)	Total Phosphorus (lb/year)	Total Phosphorus (Mg/year)
Springfield	42.50	3.88	501,972	227
Nixa	1.84	5.27	29,622	13
Ozark	0.75	8.13	18,561	8
Cassville	0.70	3.94	6,417	2.9
Crane	0.30	2.80	2,557	1.15
Seymour	0.25	3.49	2,667	1.2
Rogersville	0.11	3.52	1,200	0.54
Fordland	0.10	2.21	673	0.30
Sparta	0.09	4.26	1,225	0.55
Fremont	0.09	4.30	1,178	0.53
Hills				
Exeter	0.08	3.31	832	0.37
Clever	0.07	4.86	1,036	0.46
Galena	0.06	2.18	398	0.18

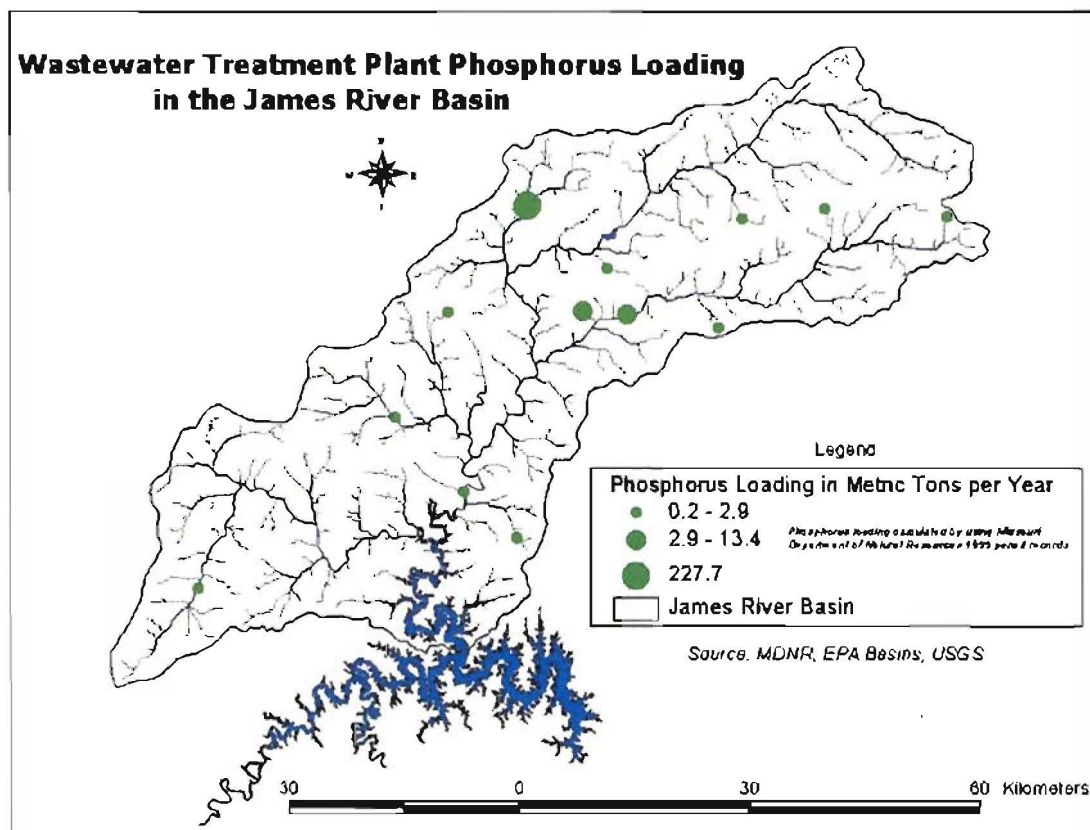


Figure 3.6 Locations of wastewater treatment plants ranked according to the annual contribution of phosphorus in the James River Basin.

Water Quality Problems

Surface water problems in the James River watershed have been documented by DNR since 1965. The USGS performed a comprehensive water quality study on the James River in 1969 (Kerr, 1969). The data indicated elevated levels of nutrients in the James, particularly when values were compared above and below the confluence with Wilson Creek. The wastewater discharge also accounts for about 27% of the daily phosphorus loading to Table Rock Lake (Watershed Committee of the Ozarks, 1997). Due to accelerated eutrophication of Table Rock Lake, especially in the James River arm, a phosphorus limit was adopted by the Missouri Clean Water Commission of 0.5 mg/L for all point sources that discharge over 22,500 gallons/day to the Table Rock Lake Basin. Increased algae blooms in the James River have been observed, but have not been documented quantitatively. Many sections of the James River have been placed on the Missouri Department of Natural Resources 303(d) list (Figure 3.7). Sections that are included on this list have been targeted for TMDL (Total Maximum Daily Load) implementation (Table 3.2).

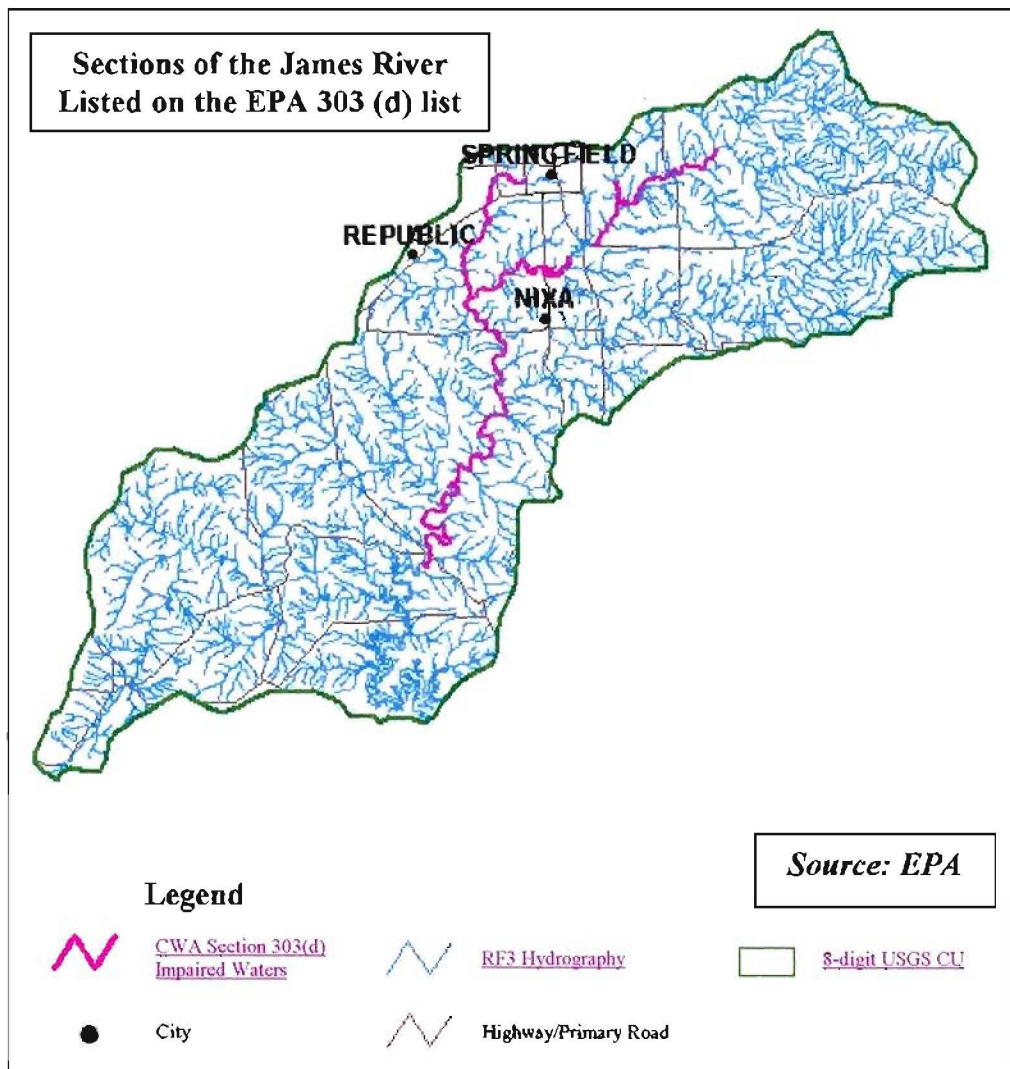


Figure 3.7 Sections of the James River listed on the 303(d) list. Source: United States Environmental Protection Agency. 303 (d) list.

Table 3.2 Sections of the James River or tributaries that are Listed on the Missouri Department of Natural Resources (EPA) 303 (d) list.

Waterbody	Parameter of Concern	Targeted for TMDL before April, 2000	Potential Sources of Impairment
James River <i>Main Stem</i>	NUTRIENTS	NO	URBAN POINT & NPS
James River <i>Main Stem</i>	NUTRIENTS	NO	URBAN POINT & NPS
James River <i>Main Stem</i>	NUTRIENTS	NO	URBAN NPS
Pearson Creek <i>Tributary</i>	UNKNOWN TOXICITY	NO	SOURCE UNKNOWN
Wilson Creek <i>Tributary</i>	UNKNOWN TOXICITY	YES	SOURCE UNKNOWN

Source: United States Environmental Protection Agency. 303 (d) list.

CHAPTER 4

METHODS

The approach used to determine phosphorus contamination associated with various sources within the James River Basin was a sediment survey of eighty sites in the James River and its tributaries. Results of the survey are combined with Geographic Information Systems (GIS) based land use/land cover variables to develop a spatial regression model to predict phosphorus concentrations at the watershed scale. This study helps to understand and estimate the relative effects of nonpoint and point sources on phosphorus loading in the James River and its tributaries.

GPS Data Collection

A handheld Global Positioning System (GPS) receiver was used to determine a position at eighty different sampling locations throughout the basin. The sample locations are located in the main channel of the James River and on some of the main tributaries. Locations were chosen based on their position relative to confluences of major and minor tributaries, locations of wastewater treatment plants, and access points. The sampling points were accessed using a kayak and on foot. The positions were logged in the field using a Garmin® 12xl GPS receiver. Each point was attributed with a waypoint number from 1-80. The GPS unit was connected to a PC with a serial connector and downloaded from the receiver at the end of each day of sampling. Garmin PCX5® software was used to interface with the GPS unit. The GPS file containing the points was exported from PCX5 software as a DXF file. The DXF file was then imported

into the GIS. The GIS was used to graphically display the sediment sampling sites that were taken throughout the James River Basin and its tributaries (Figure 4.1).

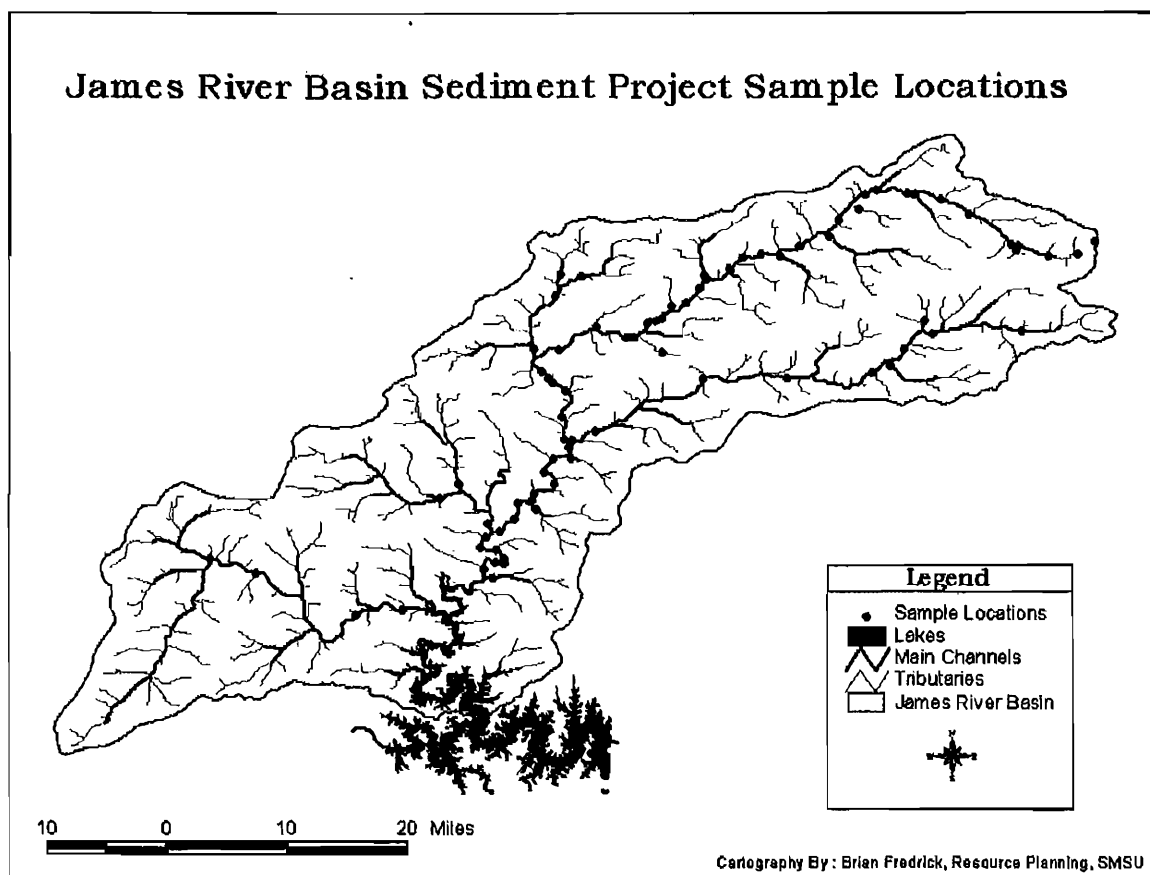


Figure 4.1 Sediment Sample Locations in the James River Basin.

Sample Collection

During a two-week period in August of 1999, samples were taken starting at the headwaters of the James River and ending at Galena, Missouri. Galena is located approximately 6 kilometers upstream from the 915 feet elevation that marks the conservation pool of Table Rock Lake. Samples were taken at low energy depositional areas at the end of point bars. Typically, this is the area along the sides of the active

channel where there is lower hydraulic energy and fine-grained sediments are deposited. Three samples spaced approximately 3 meters apart were taken at each location. Fine-grained sediment was collected from the top (≈ 2 cm) of the deposit. The three samples were taken at this spacing to be representative of the depositional setting.

Samples were taken at low flow and there were no significant rainfall events during the sampling period. The sampling was done at this time of year to minimize the chances that the sediment in the channel would be transported and redistributed at any time during the sampling period. Two gaging stations maintained by the USGS in the basin that record mean daily discharge were used to monitor discharge during the sampling period (Figure 4.2). Mean daily discharge for the two gaging stations spanning the dates prior and during the sampling period did not fluctuate significantly (Figure 4.3 and 4.4).

Sample Processing

The samples were collected in the field, stored in plastic bags, and taken to the Geomorphology Laboratory at Southwest Missouri State University (SMSU), Department of Geography, Geology, and Planning. The samples were placed in a drying oven at sixty degrees Celsius until completely dry. The sediment samples were disaggregated using a mortar and pestle and the gravel fraction ($> 2\text{mm}$) was removed by dry sieving. Five grams of each sample were sent to a private laboratory, Chemex Labs, Sparks, Nevada.

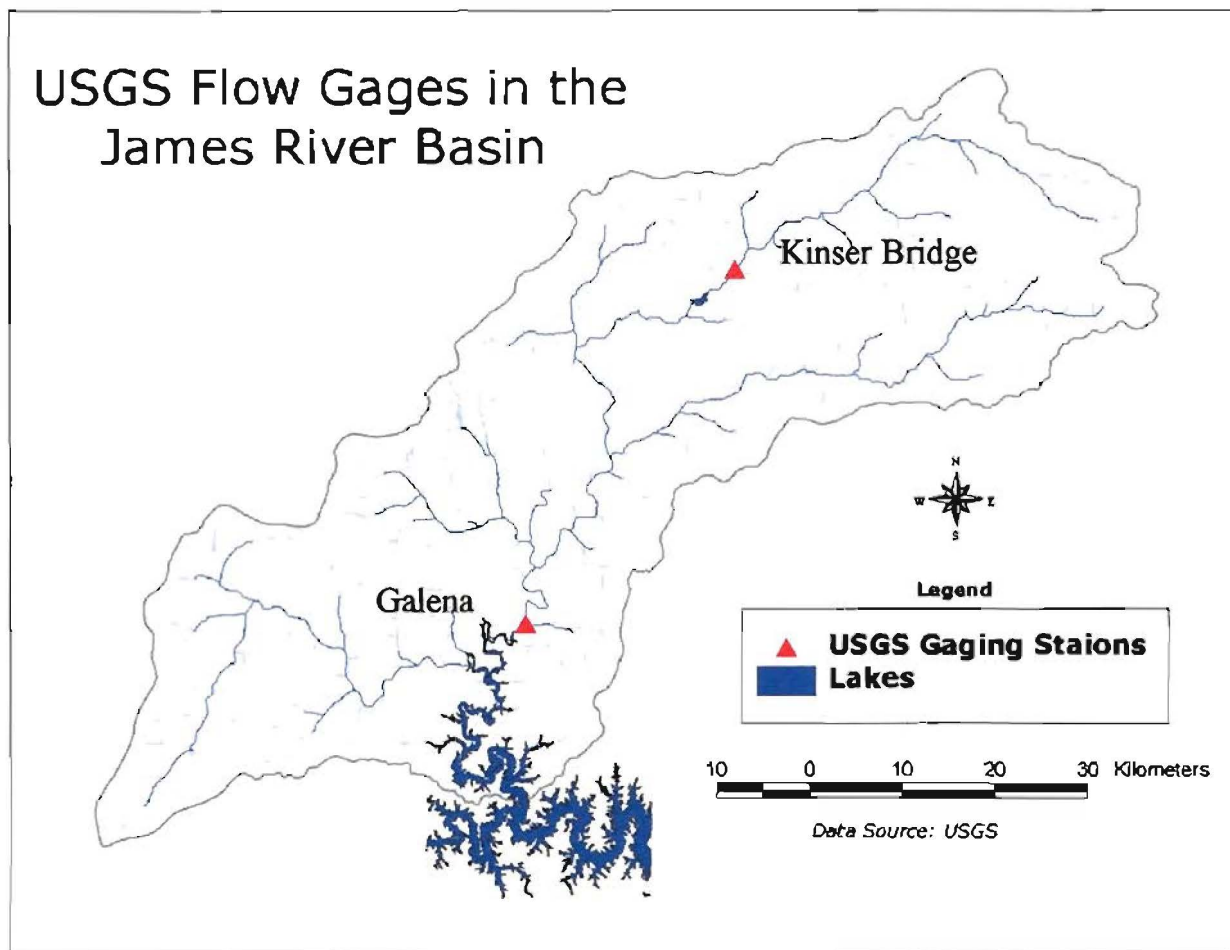


Figure 4.2 Map of USGS Gages that measure continuous flow that were used to measure flow conditions during the time period of sampling.

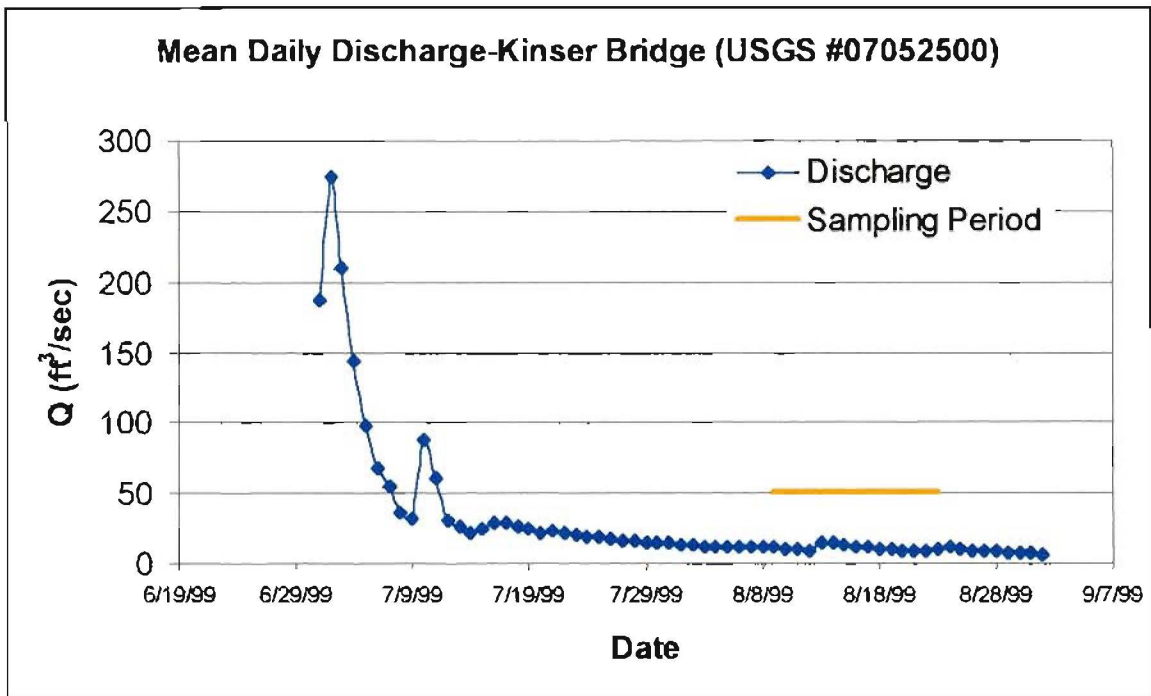


Figure 4.3 Discharge at the USGS gage at Kinser Bridge near Springfield, MO (07052500) before and during the study. Recording dates: 1921-2001. Mean daily discharge 986 cf/s.

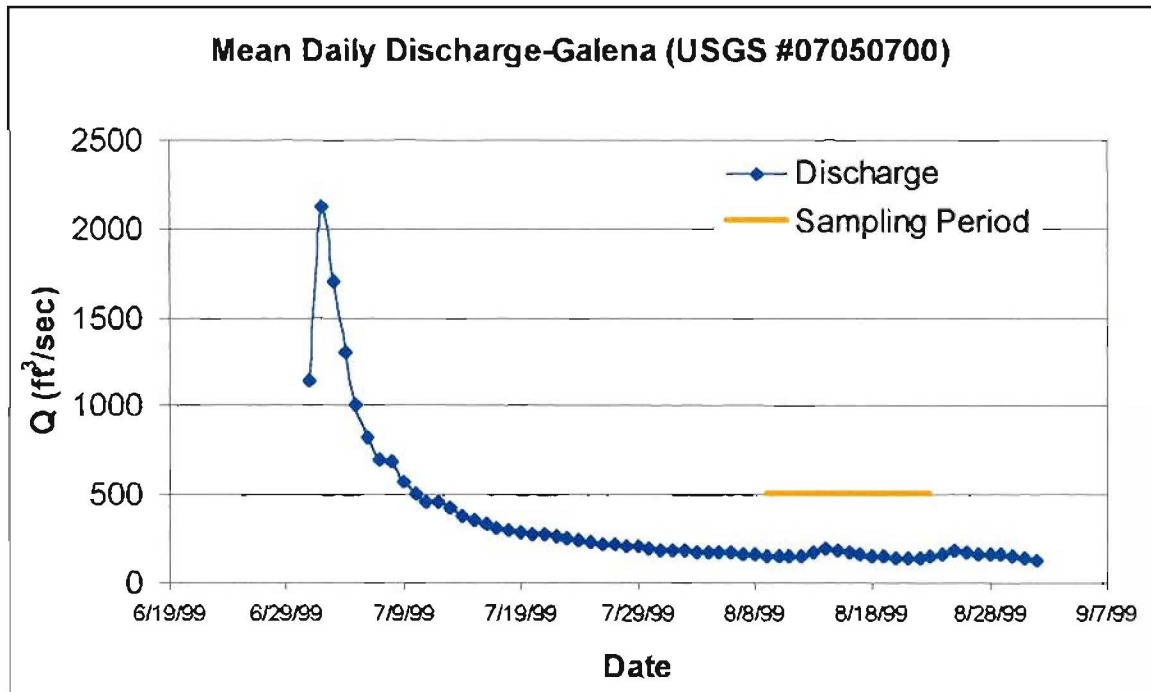


Figure 4.4 Discharge at the USGS gage at Galena, MO (07050700) before and during the study. Recording dates: 1955-2001. Mean daily discharge 236 cf/s.

Sediment Texture Analysis

The samples were dispersed and fractionated to determine the sand content (Buol, 1989). The percent sand was determined for the sediment samples in the Geomorphology Laboratory at SMSU. Thirty grams of each sample, a sub-sample, that had been sieved through a 2 mm sieve were weighted and put into 250 ml beakers. A solution of hydrogen peroxide and acetic acid was added to the beakers and the samples were heated to 90 degrees Celsius for four hours to digest the organic matter. After the digestion, the samples were cooled and dispersed for 12 hours using 125 ml of sodium hexametaphosphate solution (45.7 g/l). The samples were then stirred and poured into a mixer and mixed for 15 minutes. After thorough mixing, the samples and solution were poured into a 63 μ m sieve. The silt and clay fraction was rinsed through the sieve and the remaining sand fraction was put into a numbered 250 ml beaker that had been weighed. The sand fraction was then placed into a 60 degree Celsius drying oven until completely dried. After the sand fraction had completely dried, the beaker containing the sand was weighed and the weight of the beaker was subtracted to determine the weight of the sand. The percent sand was calculated by taking the remaining weight of the sand in grams and dividing by 30 grams (the weight of the sub-sample).

Organic Matter

The percent organic matter was also determined for each sample in the Geomorphology Laboratory at SMSU. The method used was the loss on ignition at 500° Celsius (Dean, 1974).

Geochemical Analysis

The geochemistry of each sample was determined by using the inductively coupled plasma-atomic emission spectroscopy (ICP-AES). The concentrations of 32 elements were extracted from the samples by using the Aqua Regia (3:1 HCl: HNO₃) method (Chemex, 1999). This method determined the concentration of acid extractable phosphorus and other metals. A total of 32 elements were analyzed including; aluminum, antimony, arsenic, barium, beryllium, bismuth, cadmium, calcium, chromium, cobalt, copper, gallium, iron, lanthanum, lead, magnesium, manganese, mercury, molybdenum, nickel, phosphorus, potassium, scandium, silver, sodium, strontium, thallium, titanium, tungsten, uranium, vanadium, and zinc.

Geographic Information Processing

A Geographic Information System (GIS) was used to manage, store, and process the data used in this study. Several data sources and formats were acquired to perform the necessary analyses. Geographic data providers included the United States Geological Survey, Missouri Spatial Data Information Service (MSDIS), and the Missouri Resource Assessment Program (MORAP).

Watershed Delineation

In order to understand the characteristics of the drainage area above each sediment sample location, the drainage area above each sample location was delineated using Geographic Information Systems. Fifty-meter resolution digital elevation models (DEM) were used to determine the boundaries of the drainage areas. DEM's were acquired, from the USGS, for every county in the basin. The county DEM's were merged

together and clipped down to best fit the boundary of the basin. The DEM's were processed for use in the GIS by filling sinks, calculating flow direction, and flow accumulation. The watershed for each sample location was delineated from the GPS location for each site. After all of the watersheds (polygons) were created, they were intersected with a land use/land cover grid to assess the co-occurrence of land cover types in each watershed. A table was created for each polygon that listed the number of pixels for each land use/land cover type. The number of pixels in each class was divided by the total number of pixels in each polygon to calculate the percent land use for each watershed.

Land Use/Land Cover

Three major types of land use were used to determine the relative effects of each land use on sediment quality. The Department of the Interior, USGS, provided an Anderson level II raster dataset. This land cover data set was produced as part of a cooperative project between the USGS and the U.S. Environmental Protection Agency (USEPA) to produce a consistent land cover data layer for the conterminous U.S. based on 30-meter Landsat Thematic Mapper (TM) data. National Land Cover Data (NLCD) was developed from TM data acquired by the Multi-resolution Land Characterization (MRLC) Consortium. The MRLC Consortium is a partnership of federal agencies that produce or use land cover data. Partners include the USGS (National Mapping, Biological Resources, and Water Resources Divisions), USEPA, the U.S. Forest Service, and the National Oceanic and Atmospheric Administration. The original data set had been classified into twenty separate land use/land cover classes. This data was re-

classified into four land use classes by reassigning the values of the original data with values from one through four that corresponded with the four land use classes used in this study (Table 4.1).

Table 4.1 Re-classified NLCD land use/land covers.

Water
11 Open Water
12 Perennial Ice/Snow
Urban
21 Low Intensity Residential
22 High Intensity Residential
23 Commercial/Industrial/Transportation
31 Bare Rock/Sand/Clay
32 Quarries/Strip Mines/Gravel Pits
33 Transitional
Agricultural
61 Orchards/Vineyards/Other
71 Grasslands/Herbaceous
81 Pasture/Hay
82 Row Crops
83 Small Grains
84 Fallow
85 Urban/Recreational Grasses
Forested
41 Deciduous Forest
42 Evergreen Forest
43 Mixed Forest
51 Scrubland
91 Woody Wetlands
92 Emergent Herbaceous Wetlands

Point Source Loading Index (PSLI)

An additional variable was used in this study to model the contribution of point sources of phosphorus. The Point Source Loading Index (PSLI) compensates for the dilution and deposition of phosphorus downstream of the wastewater treatment plant (wwtp) as a function of the upstream contributing area and proximity of the wwtp outfall to the sampling site. The advantage of the PSLI is that it includes the total drainage area of the sample site from which sediment is being delivered. Additionally, it places the wwtp spatially in the drainage area of the sample site. As you move downstream in a river, the drainage area subsequently increases and the contribution of pollutants coming from the wwtp is mixing with the water and sediment from the upstream drainage area. Further, phosphorus is being removed by deposition and biologic uptake.

The formula for the PSLI is as follows:

$$PSLI = \sum \left[(Ad_{wwtp} * \text{permitted load}) / Ad_{\text{sample site}}^2 \right]$$

Where:

PSLI = Point Source Loading Index (Mg P/km²/yr);

Σ Is the sum of the wastewater treatment plant loadings in the drainage area of the sample site (Mg/yr);

Ad_{wwtp} is the drainage area of the wastewater treatment plant (km²);

$Ad_{\text{sample site}}$ is the drainage area of the sample site (km²).

The drainage area and load for each wastewater treatment plant are constant. The load is calculated by multiplying the permitted flow (liters/day) by the permitted concentration (mg/l). This load is then multiplied by 365 to determine the loading in metric tons per year. As the drainage area of the sample site increases or decreases relative to the drainage area of the wwtp, the loading that is multiplied by this ratio is affected accordingly. For example, as the A_d of the wwtp/ A_d of the sample site ratio approaches one, the more that sample site is affected by the “full” loading of the wastewater treatment plant. The PSLI was also used to determine the sample sites that were not affected by point sources of pollution. If a site did not have a PSLI or “0” value then that site did not have a point source in its drainage area and is affected only by nonpoint sources of pollution.

CHAPTER 5

RESULTS

Sediment phosphorus concentrations in the James River are examined in this chapter. Levels of phosphorus contamination are considered relative to sediment-phosphorus concentrations found in other studies. The phosphorus levels found in soil and floodplain deposits throughout the watershed are categorized and used to rank streambed sediment phosphorus contamination levels. Sampling errors are estimated using statistics to account for the cumulative error associated with site selection, sampling media, sediment composition variability, and sample analysis is examined. The sediment-phosphorus concentrations are described spatially and longitudinally. In addition, sediment-phosphorus levels in the James River arm of Table Rock Lake are examined. Pearson correlation matrix will be utilized to understand the relationship between sediment-phosphorus concentrations and spatial, geochemical, and sediment composition variables. Multivariate regression models are developed by using variables from the Pearson correlation to predict the sediment-phosphorus concentrations. Water-column total phosphorus data is related spatially to sediment-phosphorus concentrations. Regression trends were used to estimate water-column total phosphorus by using sediment-phosphorus.

Sediment-Phosphorus Concentrations

Concentrations of sediment phosphorus found in the sediment samples varied throughout the basin depending on land use, proximity to point sources, and sediment composition. The highest mean concentrations of sediment-phosphorus in the James

River generally were found in urbanized streams and below wastewater treatment plant outfalls (Table 5.1). The highest sediment phosphorus concentration (1,960 µg/g) in the basin was found in the sample taken in Wilson Creek immediately downstream of the wastewater treatment plant in Springfield. The lowest mean concentration of sediment-phosphorus for any area within the basin was in the Flat Creek and Crane Creek watersheds.

Table 5.1 Summary of Sediment-Phosphorus Concentrations and Sediment properties.

Sites Classified by Reach Location	SEDIMENT-PHOSPHORUS (PPM)					
	<i>N</i>	<i>Mean</i>	<i>Median</i>	<i>Min</i>	<i>Max</i>	<i>CV%</i>
Upper James River	17	279	240	110	610	55
Upper James River Tributaries	7	266	240	110	540	54
Lower James River	32	348	305	140	990	50
Flat Creek and Crane Creek	7	213	220	100	300	36
Finley Creek	10	371	230	130	1360	102
Wilson Creek-WWTP affected	2	1665		1370	1960	
Urban and Mixed Streams	5	602	560	420	880	28
<u>All Sample Sites</u>	<u>80</u>	<u>366</u>	<u>275</u>	<u>100</u>	<u>1960</u>	<u>82</u>
	PERCENT SAND					
	<i>N</i>	<i>Mean</i>	<i>Median</i>	<i>Min</i>	<i>Max</i>	<i>CV%</i>
Upper James River	17	47	57	5	82	62
Upper James River Tributaries	7	45	42	3	79	73
Lower James River	32	74	82	11	98	31
Flat Creek and Crane Creek	7	76	81	45	95	21
Finley Creek	10	67	88	1	94	55
Wilson Creek-WWTP affected	2	66		58	75	
Urban and Mixed Streams	5	22	23	6	34	47
<u>All Sample Sites</u>	<u>80</u>	<u>61</u>	<u>74</u>	<u>1</u>	<u>98</u>	<u>49</u>
	ORGANIC MATTER LOI (%)					
	<i>N</i>	<i>Mean</i>	<i>Median</i>	<i>Min</i>	<i>Max</i>	<i>CV%</i>
Upper James River	17	4.0	3	1	11	71
Upper James River Tributaries	7	4.9	5	1	12	77
Lower James River	32	2.6	2	1	8	71
Flat Creek and Crane Creek	7	2.1	2	1	4	50
Finley Creek	10	4.3	2	1	18	130
Wilson Creek-WWTP affected	2	4.2		3	5	
Urban and Mixed Streams	5	7.0	6	3	11	41
<u>All Sample Sites</u>	<u>80</u>	<u>3.6</u>	<u>2</u>	<u>1</u>	<u>18</u>	<u>82</u>

Sediment-Phosphorus Background Levels

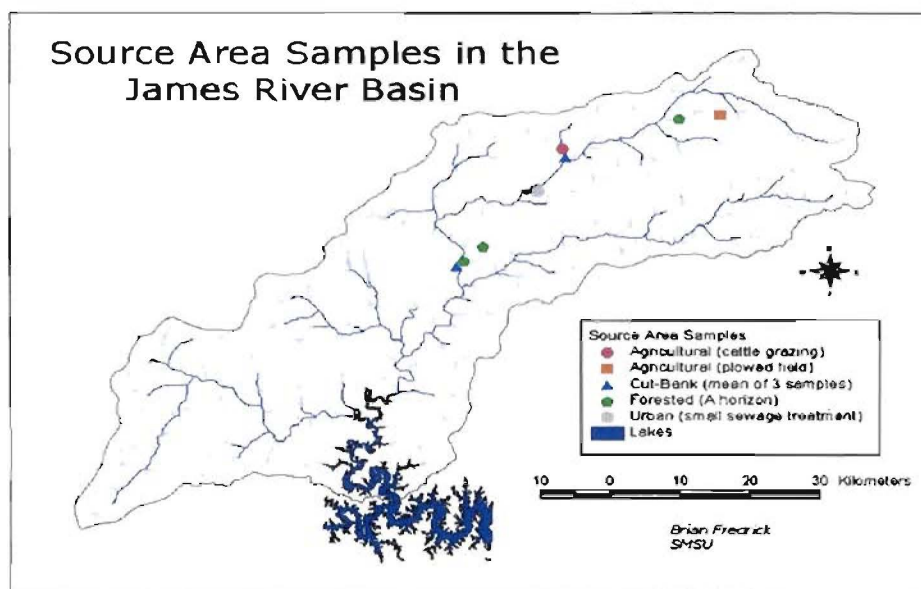
Sediment-phosphorus concentrations from other studies were summarized to put the sediment-phosphorus concentrations from the James River into context. The mean sediment-phosphorus in the James River was less compared to sediment surveys conducted in the region and other rivers around the US (Table 5.2).

Table 5.2 Concentrations of Sediment-Phosphorus from other studies. * <2mm grain size, all other studies used <0.63 grain size.

River	Number of Samples	Mean(ppm)	Min(ppm)	Max	Reference
Kings River, AR	91	209	7	1,280*	White, 2001
Chat Creek, MO	67	1,188	220	3,080*	Trimble, 2001
Winooski River, VT	59	957	652	1,180*	Chalmers, 1998
Housatonic River, NY/MA/CT	7	1,700	1,300	2,800	Harris, 1997
Connecticut River, CT/MA/NH/VT	26	2,250	1,100	5,100	Harris, 1997
Thames River, CT/MA	6	3,100	1,800	4,100	Harris, 1997
Illinois River, IL/IN/WI	372	1,502	400	4,000	Colman, 1991
Puget Sound, WA	17	1,540	900	2,800	MacCoy, 1998

In order to understand background concentrations of phosphorus within the study area, samples were taken from soil “A” horizons and floodplain deposits throughout the basin. This was done to compare concentrations of phosphorus in the bed sediment relative to source areas. Samples were collected from these areas and analyzed using the same methods as the sediment samples. Soil A-horizon samples were taken from forested, agricultural, and urban areas. Cutbank sediment was collected from two locations along the main stem of the James River (Figure 5.1). Forested areas and cutbank samples had the lowest concentration 170-360 (µg/g). Urban and agricultural

areas had increased concentrations of 540-1420 ($\mu\text{g/g}$). The urban area sample was taken down slope of a detention basin near the parking lot of a church that had a small sewage treatment system. Therefore, the urban concentration is not necessarily representative of soil phosphorus concentrations from other urban land uses, but reflects the phosphorus levels associated with wastewater treatment plants. In general, background sediment-phosphorus levels tend to be < 400 ppm, but A-horizons with high natural organic matter levels may approach 600 ppm.



Source Area	Phosphorus ($\mu\text{g/g}$)
Forested	170
Forested	360
Agricultural (row crop)	540
Agricultural (pasture)	1200
Urban (near parking lot with small sewage treatment facility)	1420
Cut Bank 1 (0.5 meter from top of floodplain surface)	310
Cut Bank 1 (1 meter from top of floodplain surface)	220
Cut Bank 1 (slump near wetted perimeter)	210
Cut Bank 2 (0.5 meter from top of floodplain surface)	310
Cut Bank 2 (1 meter from top of floodplain surface)	270

Figure 5.1 Locations and concentrations of soil and source samples.

The source area samples were categorized according to concentration ranges in order to understand the contamination trends of source materials within the basin (Table 5.3). These are relatively broad categories used to derive working sediment criteria for this study. Hence, more work is needed to more precisely define pollution thresholds. Of the source areas that were sampled, forested soils and riverbank, deposits had the lowest phosphorus levels and are categorized as being low background. The agricultural areas had higher background phosphorus levels and were categorized as high background and some were above the contamination threshold. The sample of soil that was taken adjacent to the small wastewater treatment plant and detention basin was considered to be in the heavy contamination category.

Table 5.3 Preliminary Sediment Phosphorus Contamination Thresholds.

General Sed-P Pollution Categories
Low OM Background= <400 ppm
High OM Background= 400-700 ppm
Contamination threshold= >700 ppm
Heavy Contamination= >1000 ppm

Spatial Distribution of Sediment-Phosphorus

Of the eighty sample sites within the James River Basin, three would be considered heavily contaminated compared to source levels of phosphorus. Three of the sites would be above the contamination threshold but not heavily contaminated compared to background levels. Fourteen of the sites would fall into the high background category compared the source areas. The remaining sixty sites (75% of the total sites) were less than 400 ppm and would be considered low background compared to source areas (Figure 5.2).

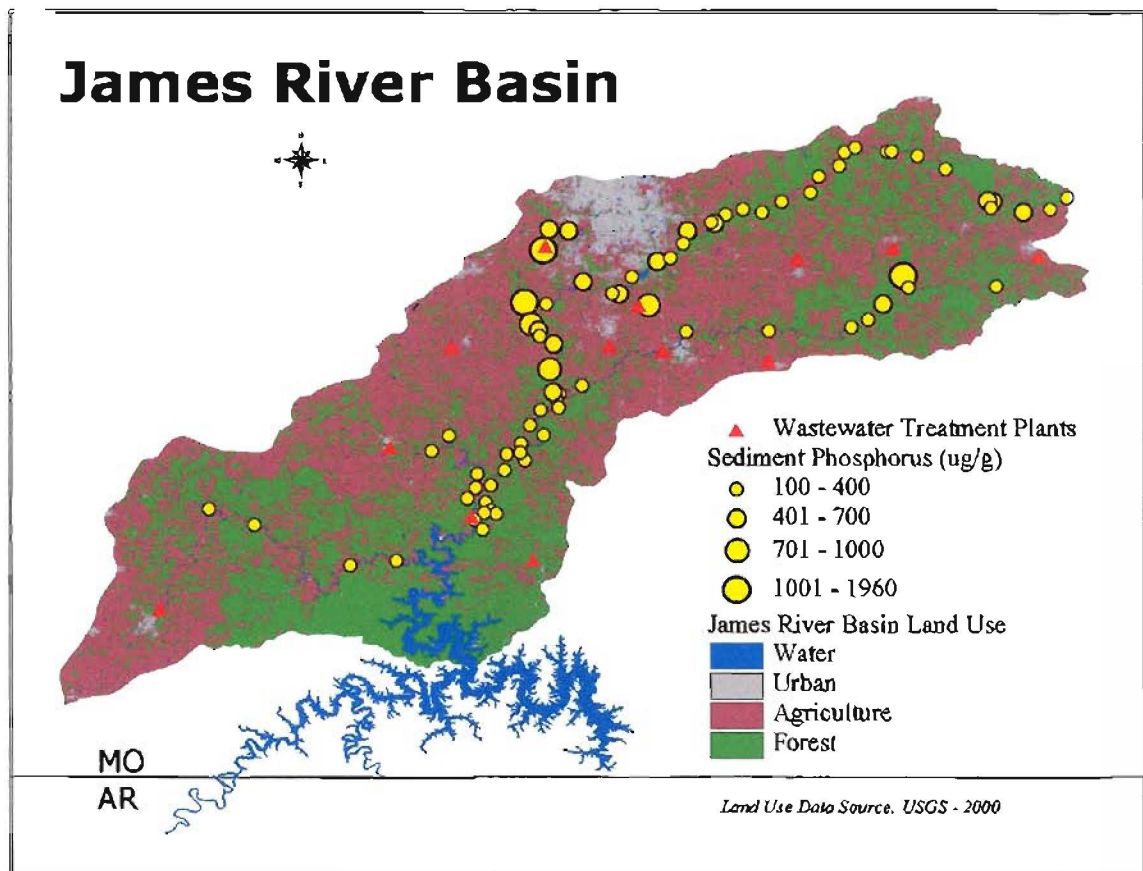


Figure 5.2 Spatial distribution of phosphorus concentrations.

The concentration of sediment phosphorus varied longitudinally from the headwaters to Galena in a pattern reflecting the inputs of phosphorus from major tributaries (Figure 5.3). The increased concentration at the sixty-kilometer river distance marks the confluence of Wilson Creek, a two hundred and forty seven square kilometer watershed that drains south Springfield and receives effluent from the Springfield Wastewater Treatment Plant. The Wilson creek watershed also has one of the highest percentages of urban land use, approximately 28%, compared to other sub watersheds in the basin.

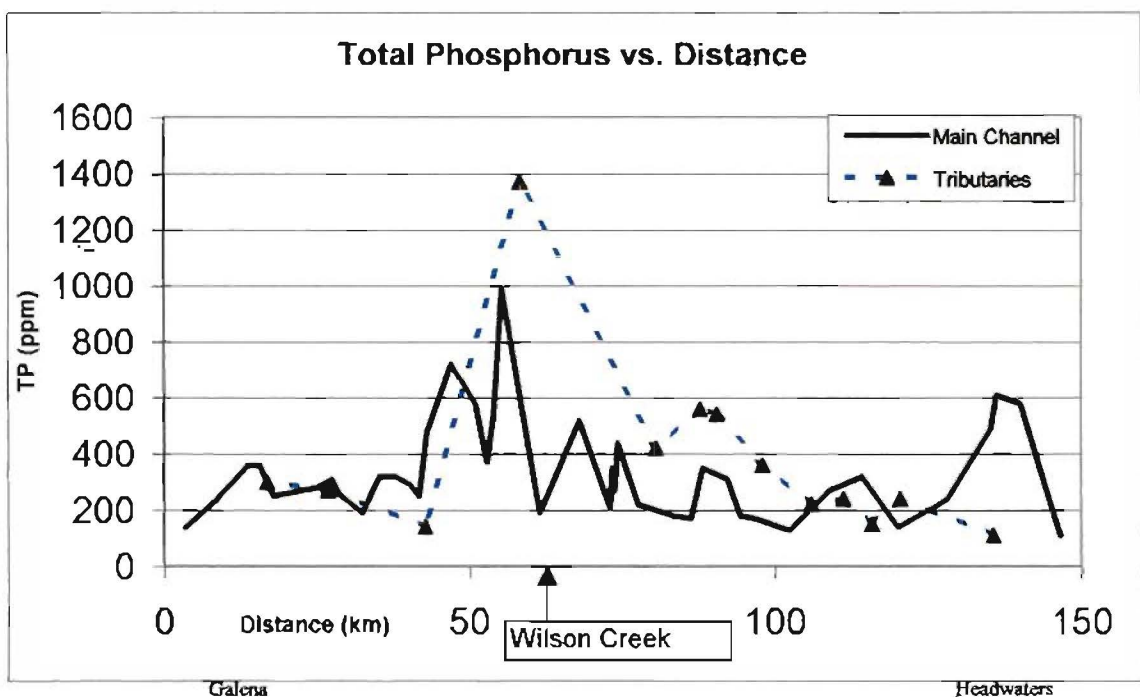
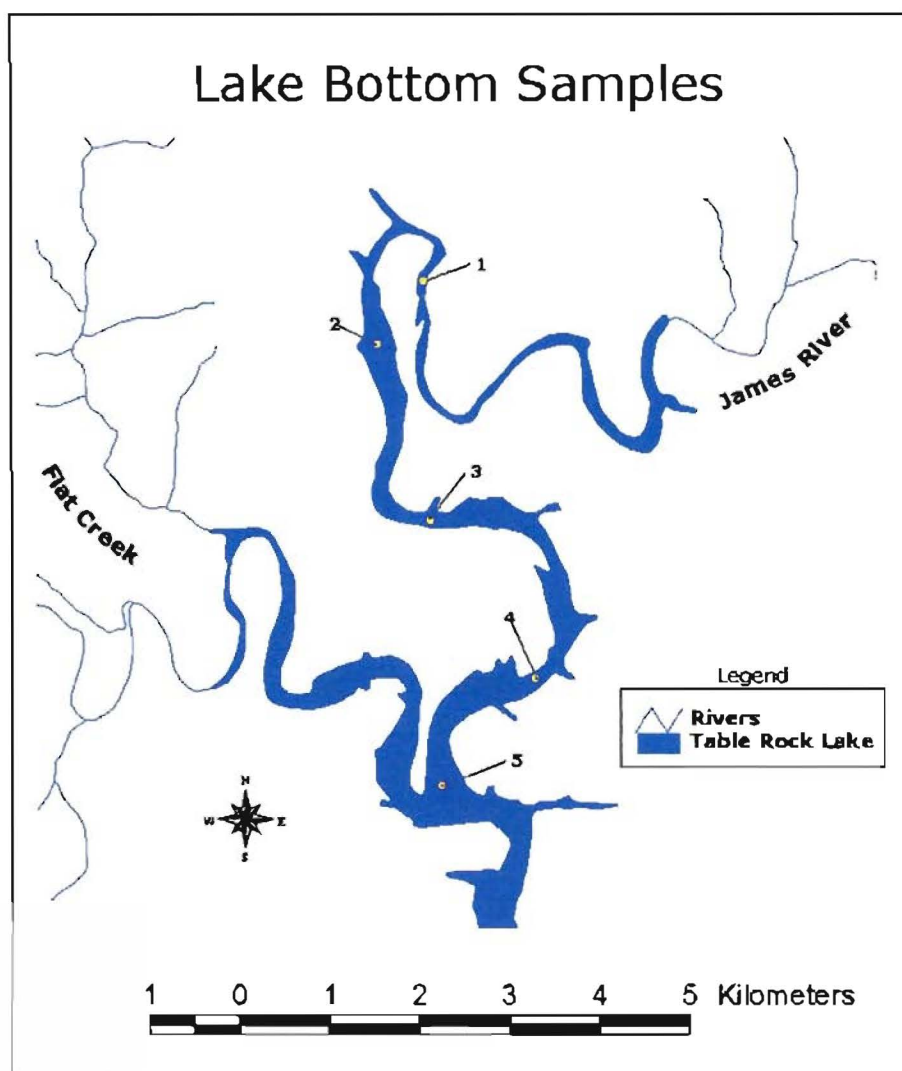


Figure 5.3 Downstream variations of main channel and tributary phosphorus concentrations. The solid line represents the concentration of phosphorus in samples taken from the main channel and the dotted line represents the phosphorus concentration in samples taken from tributaries near the confluence of the James River. This demonstrates how the concentration of phosphorus in the tributaries influences the concentration of phosphorus in the main channel.

Lake Bottom Sampling

Sediment samples were collected from the bottom of the James River arm of Table Rock Lake to assess the concentrations of sediment phosphorus accumulated in the lake. The samples were taken in November of 1999 from a small boat and using a GPS to mark the position (Figure 5.4). A lake bottom sampler tied to a 100 ft rope was lowered off the edge of the boat three times and a composite sample from the three samples was used for the analyses.

The percent sand in the samples is highest in the northern part of the James River arm of Table Rock Lake near the mouth of the James River and it decreases with the depth of the lake. The percent sand increases again at Site 5 near the confluence of Flat Creek where currents could move more sand size material into this part of the lake from the tributary watershed. The higher concentrations of phosphorus can be explained by the corresponding increases in organic matter and decreases in sand. This trend is evident in the relationship between these components of sediment composition and phosphorus found in the streambed samples analyzed throughout the basin. Again, variations in sediment-phosphorus are influenced by sediment composition, mainly due to a change in organic matter content in this case. Sites 2, 3, and 4 indicate at least a moderate level of contamination as compared to stream sediment-phosphorus levels in the James River.



James River Arm Bottom Samples	SED-P	%OM	%SAND
1	240	1.41	73
2	800	6.31	4
3	1070	5.93	2
4	910	4.91	3
5	290	1.51	40

Figure 5.4 Locations of Lake Bottom Samples and Sediment-Phosphorus concentrations.

Sampling Error

Within-site variability

There was a need to understand how sediment-phosphorus concentrations and sediment properties varied at each sampling site. The coefficient of variation (C_v) is used to explain the within site variability of phosphorus, percent sand, and percent organic matter. This reflects the local-scale spatial variability of sediment composition within deposits of the same age and sampling error among deposits of different ages. In addition, this analysis examines analytical error due to mistakes and instrument limitations. This information is useful for understanding the variability of sediment characteristics using this sampling methodology and the degree to which changes in sediment-phosphorus may be related to sampling error. The C_v measures the relative scatter in data with respect to the mean. When the C_v is small, the data scatter compared to the mean is small. When the C_v is large compared to the mean, the amount of variation is large.

The standard deviation of the phosphorus concentrations ranged from 10 to 190 ppm and the coefficient of variation ranged from 5 to 39% (Table 5.4). Site 31 that is located approximately one kilometer downstream of the Springfield wastewater treatment plant had the highest standard deviation, but a relatively low coefficient of variation of 10. The variability could also be due to the corresponding variations in the percent sand and the percent organic matter at that same location. These variations could be due to depositional patterns at that sampling site. Site 38 had the highest C_v and considering that the phosphorus concentrations for the “A” and “C” samples were 440 and 400 respectively, it could be that the concentration of 190 for the “B” sample is not

representative of that location. Overall, there is some variability in the phosphorus concentrations for the sites used in the within site comparison.

Table 5.4 Within Sample Site Variance of Sediment Phosphorus.

	Sed-P					
SAMPLE	ppm					
SITE	A	B	C	MEAN	σ	C_v
7 Upper James River	270	190	220	227	40	18
21 Upper James River	390	310	370	357	42	12
22 Upper James River	310	350	360	340	26	8
23 Pearson Creek	460	560	530	517	51	10
30 Upper Wilson Creek	560	540	700	600	87	15
31 Wilson Creek (below WWTP)	1760	1960	2140	1953	190	10
37 Lower James River	630	520	440	530	95	18
38 Lower James River	440	190	400	343	134	39
43 Finley Creek	609	660	670	646	33	5
46 Finley Creek	250	300	380	310	66	21
59 Lower James River	400	310	420	377	59	16
75 Lower James River (near Galena)	210	200	220	210	10	5

For the within site comparison of percent sand, the standard deviation ranged from 2 to 24 and the C_v ranged from 2 to 112 (Table 5.5). The standard deviation again was the highest at site 31, approximately one kilometer downstream of the Springfield wastewater treatment plant. The C_v for site 31 was 41 again having relatively low variability compared to the other samples in the within site comparison. The site with the highest C_v was site 43. At site 43 the “A”, “B”, and “C” samples were 18, 1, and 5 respectively. The high variability for the percent sand at this location could be due to the

depositional setting in which flow varied spatially at the time of deposition or there could have been errors in the laboratory procedures.

Table 5.5 Within Sample Site Variance of Percent Sand.

SAMPLE SITE	SAND %			MEAN	σ	C_v
	A	B	C			
7 Upper James River	84	68	70	74	9	12
21 Upper James River	22	30	36	29	7	24
22 Upper James River	34	29	17	26	8	32
23 Pearson Creek	15	6	20	13	7	54
30 Upper Wilson Creek	27	26	6	20	12	58
31 Wilson Creek (below WWTP)	31	72	76	60	24	41
37 Lower James River	13	19	36	23	12	50
38 Lower James River	54	64	40	52	12	24
43 Finley Creek	18	1	5	8	9	112
46 Finley Creek	77	62	74	71	8	11
59 Lower James River	99	95	98	97	2	2
75 Lower James River (near Galena)	96	94	98	96	2	2

The standard deviation for the within site comparison of percent organic matter, for ranged from 0.06 to 2.24 and the C_v ranged from 4 to 39 (Table 5.6). Site 30 had the highest C_v of 39 with the percent organic matter for the “A”, “B”, and “C” samples being 4.31, 4.67, and 8.36. There was very little difference between the “A” and “B” samples, meaning that the high variance could be attributed to the “C” sample. The higher organic matter in the “C” sample could have been due to a larger piece of detritus that was present in that sample or variability of the organic material at that site.

Table 5.6 Within Sample Site Variance of Percent Organic Matter.

SAMPLE SITE	OM %LOI			MEAN	σ	C _v
	A	B	C			
7 Upper James River	1.85	1.73	2.54	2.04	0.44	21
21 Upper James River	3.38	3.15	3.25	3.26	0.12	4
22 Upper James River	7.10	6.22	7.03	6.78	0.49	7
23 Pearson Creek	7.36	8.13	9.48	8.32	1.07	13
30 Upper Wilson Creek	4.31	4.67	8.36	5.78	2.24	39
31 Wilson Creek (below WWTP)	7.20	4.95	4.62	5.59	1.40	25
37 Lower James River	5.40	6.06	3.83	5.10	1.15	22
38 Lower James River	2.99	1.78	3.73	2.83	0.98	35
43 Finley Creek	11.90	10.52	10.78	11.07	0.73	7
46 Finley Creek	4.07	5.14	3.72	4.31	0.74	17
59 Lower James River	0.83	0.95	1.10	0.96	0.14	14
75 Lower James River (near Galena)	0.73	0.80	0.84	0.79	0.06	7

Between-site Variability

The triplicate samples were categorized based on land use and proximity to wastewater treatment plants. The coefficient of variation of sediment-phosphorus, percent sand, and organic matter were compared (Table 5.7). This was done to understand the within-site variability of sediment-phosphorus, percent sand, and organic matter between sample sites that are affected by different types of land use and point sources. The within-site variability of sediment-phosphorus was least at sites that were immediately below wastewater treatment plants. The highest within-site variability was found at sites where the contributing drainage area was greater than 35 % urban.

Table 5.7 Analysis of Site Triplicate samples.

Watershed Condition	Sed-P (ppm)		Cv % (100 x stdev/mean)		
	Range	Mean	Sed-P	Sand %	OM %
Rural (>40% Forested)	200-400	288	14	20	13
Mixed (<20% urban)	300-500+	435	14	42	15
Urban (>35% urban)	500-600	565	17	54	31
Below WWTP	>1000	1953	10	41	25

The within-site coefficient of variation for sediment-phosphorus is more closely related to the within-site coefficient of variation for organic matter between all of the triplicate sites (Figure 5.5). The percent sand within each of the triplicate sites varies greatly between sites compared to the variation of sediment-phosphorus within each site throughout the basin. To some degree, variations in sediment-phosphorus are caused by variations in sediment composition, mainly organic matter. In general, within site variability is about 15 % of the mean and is < 10 % when sediment composition effects are considered.

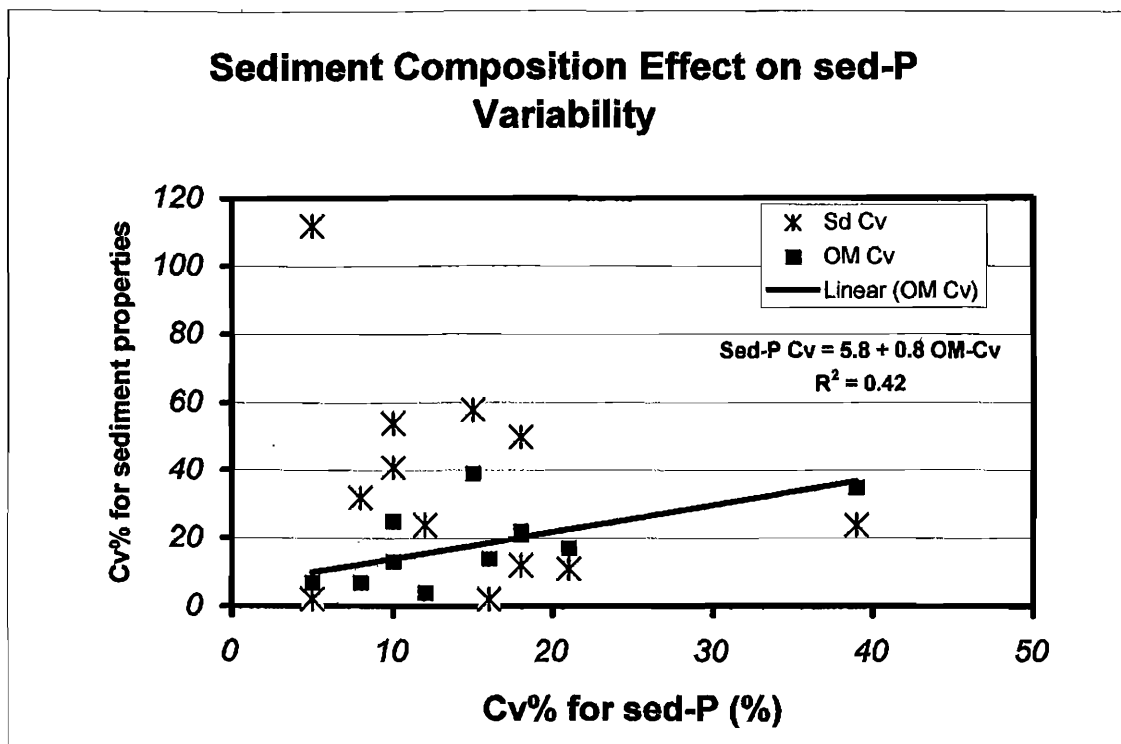
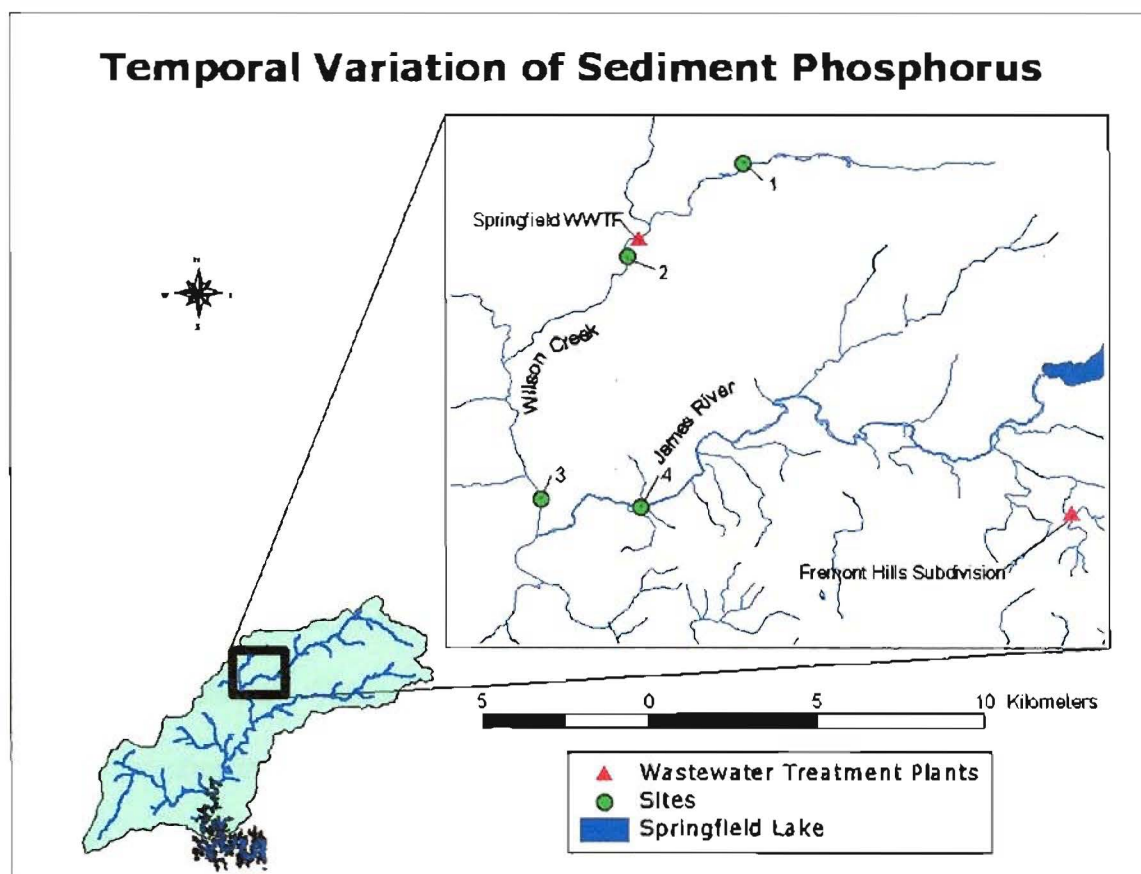


Figure 5.5 Comparison of between-site the variability of sediment-phosphorus and sediment properties.

Temporal Variability

Four of the original sample sites were revisited in March of 2001 to examine the variation of sediment-phosphorus concentrations through time. If sediment monitoring is to be useful, the variability from year to year should be minimal if watershed conditions remain constant. GPS was used to re-locate the sample sites and the same methods were applied to the samples to determine the geochemistry and sediment composition. For comparison purposes, the sites were renumbered (Figure 5.6). Between August of 1999 and March of 2001, there have been several bankfull floods and a hundred-year flood event that would have scoured and redeposited the sediment deposit that was sampled in August 1999. Additionally, the treatment plant in Springfield has implemented treatment

processes that have reduced effluent phosphorus concentrations to approximately 0.5 mg/L or less. Although the limit is not official as of July of 2001, phosphorus in the effluent has been consistently at or below 0.5 mg/L since January of 2001.

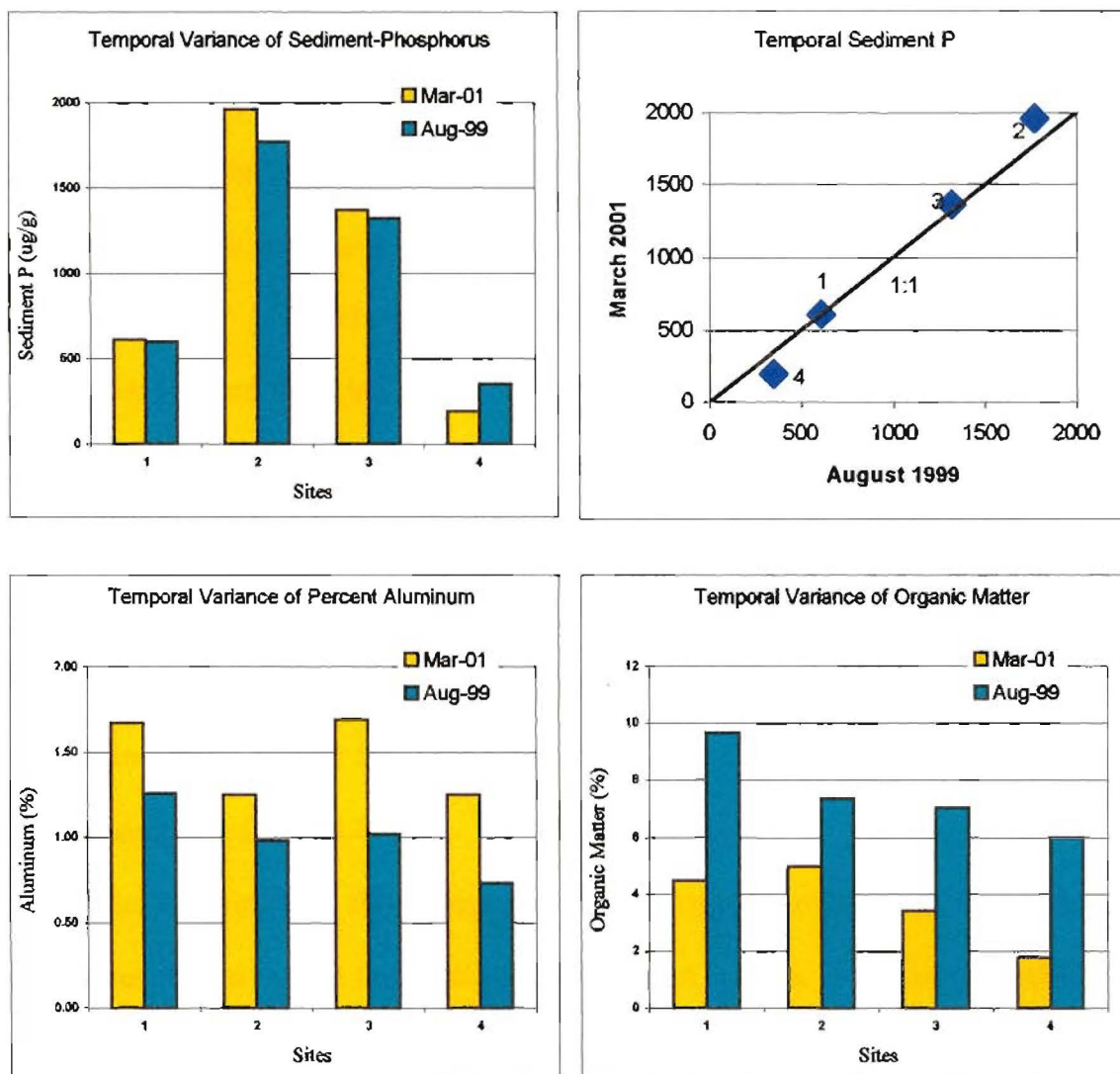


			2000 Land Use		
			Urb	Agr	For
Site 1	Original site 29	South Creek upstream of WWTP	75%	20%	5%
Site 2	Original site 31	Wilson Creek downstream WWTP	52%	38%	10%
Site 3	Original site 32	Wilson Creek near confluence with James River	28%	60%	12%
Site 4	Original site 38	James River upstream of Wilson Creek	6%	61%	33%

Figure 5.6 Sites that were sampled in August of 1999 and March of 2001.

The comparison of concentrations at these sites between these two dates shows little change (Figure 5.7). The concentration of phosphorus at Site 1 in 1999 was 600 and in March of 2001, the concentration was 610. Even though the land use in the drainage area above this Site is mostly urban, there is very little change in the concentration. At Site 2, the concentration of sediment-phosphorus is higher in 2001 than in 1999 even after reductions in phosphorus from the Springfield wastewater treatment plant. Even though there have been reductions from the plant the sediment can continue to adsorb phosphorus from other upstream sources depending on grain size and organic matter.

For all of the Sites, the percent organic matter was less in 2001 than in 1999. This decrease in organic matter should be related to a decrease in sediment-phosphorus. This is not the case. There was also an overall increase in the percent aluminum in the 2001 samples. Since the percent aluminum is sometimes related with clay-sized particles and clay-sized particles have more adsorption capacity, there should be an increase in sediment-phosphorus. This is also not the case. Other factors are involved that could explain the similar concentrations found between these two sampling dates. The upstream inputs from point and nonpoint sources, especially the wastewater treatment plant, could have remained relatively constant during the period between when these samples were taken. It could also be assumed in this situation that sediment composition has a minimal effect on sediment-phosphorus concentrations.



Site	August 1999			March 2001			%Difference		
	SEDP (µg/g)	OM%	Al%	SEDP (µg/g)	OM%	Al%	Sed-P	OM	Al
1-South Creek	600	9.67	1.26	610	4.46	1.67	2%	-54%	33%
2-Wilson Creek	1770	7.36	0.98	1960	4.95	1.25	11%	-33%	28%
3-Wilson Creek	1320	7.05	1.02	1370	3.41	1.69	4%	-52%	66%
4-James River	350	5.98	0.73	190	1.78	1.25	-46%	-70%	71%

Figure 5.7 Temporal comparison of sediment-phosphorus concentrations and sediment properties. Samples were taken at the same location in August 1999 and March 2001.

Land Use and Sediment Composition Effects

Pearson Correlation Matrix Analysis

Pearson Correlation was used to determine if there are significant statistical relationships among spatial, geomorphic, and sediment composition variables. Pearson's correlation reflects the degree of linear relationship between two variables. It ranges from +1 to -1. A correlation of +1 means that there is a perfect positive linear relationship between variables. A correlation of -1 means that there is a perfect negative linear relationship between variables. Near zero values, indicate no relationship. The variables that were used in the Pearson correlation were, Sediment Phosphorus (P), Percent Organic Matter (OM), Percent Sand (Sand), Percent Urban Land Use (Urban), Percent Agricultural Land Use (Agri), Percent Forested Land Cover (Forest), Drainage Area Above Each Sample Site (Ad), Sample Site Reach Slope (Slope), and the Point Source Loading Index (PSLI).

The variables with the strongest positive or negative relationship with sediment-phosphorus will be used in the multivariate regression analysis. Some of the variables in the Pearson correlation matrices that are in the same category have the potential to be correlated positively and negatively to each other. For example, since the land use percentages used in this study were categorized into three types, urban, agricultural, and forested and all three land uses total 100% the land use percentages could be cross related.

The Pearson correlations for all of the sites show that there is a significant positive correlation between sediment phosphorus and the PSLI, percent organic matter, and percent urban area within the drainage area of the sample site (Table 5.8).

Table 5.8 Pearson Correlations for All Sediment Sampling Locations.

N = 80	TP	OM	SAND	URBAN	AGRI	FOREST	AD	PSLI	SLOPE
TP	1	0.569	-0.360	0.473	-0.089	-0.454	-0.156	0.682	-0.072
OM		1	-0.770	0.132	0.064	-0.208	-0.424	0.045	0.199
SAND			1	-0.198	0.070	0.157	0.492	0.052	-0.365
URBAN				1	-0.560	-0.610	-0.075	0.400	-0.056
AGRI					1	-0.315	0.176	-0.203	<u>-0.261</u>
FOREST						1	-0.094	<u>-0.261</u>	0.319
AD							1	-0.086	-0.292
PSLI								1	-0.036
SLOPE									1
Bold Values are significant at the 0.01 level (2-tailed).									
Underlined Values are significant at the 0.05 level (2-tailed).									

The Pearson correlation for sites that are affected by point and nonpoint sources show that there is a significant positive correlation between sediment phosphorus and the PSLI, percent urban area, and percent organic matter (Table 5.9). This set of samples also displays a significant negative correlation between sediment phosphorus and the percent sand in the sample.

Table 5.9 Pearson Correlations for Sediment Sampling Locations affected by Point and Nonpoint sources.

N = 53	TP	OM	SAND	URBAN	AGRI	FOREST	AD	PSLI	SLOPE
TP	1	0.594	-0.407	0.795	-0.429	-0.416	-0.230	0.738	0.037
OM		1	-0.785	0.080	-0.174	0.079	-0.379	0.106	<u>0.303</u>
SAND			1	0.023	0.080	-0.097	0.408	0.010	-0.186
URBAN				1	-0.438	-0.619	0.046	0.903	-0.140
AGRI					1	-0.434	0.113	-0.474	0.261
FOREST						1	-0.160	-0.484	-0.075
AD							1	-0.184	-0.419
PSLI								1	0.023
SLOPE									1
Bold Values are significant at the 0.01 level (2-tailed).									
Underlined Values are significant at the 0.05 level (2-tailed).									

The Pearson correlation for sites affected by nonpoint sources of pollution only show a significant positive correlation between sediment phosphorus and organic matter (Table 5.10). There is also a significant negative correlation between sediment phosphorus and the percent forested area within the drainage area of the sample site and the percent sand in the sample. In all of these correlations, sediment phosphorus was positively correlated with organic matter (> 0.569). This indicates that the phosphorus in the sediment is closely associated with organic matter or the conditions that lead to organic matter accumulation in stream sediments.

Table 5.10 Pearson Correlations for Sediment Sampling Locations affected by nonpoint sources.

N = 27	TP	OM	SAND	URBAN	AGRI	FOREST	AD	SLOPE
TP	1	0.781	-0.540	<u>0.417</u>	0.287	-0.769	-0.325	-0.177
OM		1	-0.681	0.117	<u>0.394</u>	-0.516	-0.360	0.084
SAND			1	-0.280	-0.107	<u>0.436</u>	<u>0.481</u>	-0.341
URBAN				1	-0.582	-0.631	-0.194	-0.120
AGRI					1	-0.263	-0.018	-0.256
FOREST						1	0.244	<u>0.388</u>
AD							1	-0.306
SLOPE								1

Bold Values are significant at the 0.01 level (2-tailed).

Underlined Values are significant at the 0.05 level (2-tailed).

The Pearson correlation was determined between all of the variables that were accumulated for the sampling sites during the course of this study (Table 5.11). These variables included percent urban, agricultural, or forested land use in the drainage area of the sample site, the point source loading index (PSLI), the drainage area of the sample site, the reach slope of the sample site, percent sand and organic matter in the sample, and all of the other 31 elements. The correlation between nickel and phosphorus could be explained by the use of nickel in phosphate fertilizer production (Moore and Ramamoorthy, 1984). Sediment-phosphorus and aluminum is positively correlated because the percent aluminum in a sediment sample is usually positively related with the percent clay in the sample. The clay-sized particles have more adsorption capacity than larger sand-sized particles (Sonzogni, 1982). Although oxide coatings formed on the surface of sand-sized particles can increase the adsorption capacity of sand (Holtan, 1988). This is evident in the positive correlation between manganese and phosphorus.

Table 5.11 Pearson Correlations Between Sediment Phosphorus and other Spatial, Geomorphic, and Geochemical Parameters. *Bold Numbers Indicate that Correlation is significant at the 0.01 level (2-tailed).*

	ALL	POINT and NONPOINT	NONPOINT
	N=80	N=53	N=27
URBAN	0.473	0.795	0.417
AGRI	-0.089	-0.429	0.287
FOREST	-0.454	-0.416	-0.769
PSLI	0.682	0.738	NA
AD	-0.156	-0.230	-0.325
SLOPE	-0.072	0.037	-0.177
SAND	-0.360	-0.407	-0.540
OM	0.569	0.594	0.781
Al	0.516	0.671	0.534
Ba	0.677	0.819	0.771
Ca	0.488	0.649	0.387
Co	0.651	0.800	0.714
Cr	-0.071	-0.064	-0.206
Cu	0.014	0.004	0.584
Fe	0.408	0.519	0.336
K	0.455	0.593	0.399
Mg	0.238	0.446	0.292
Mn	0.646	0.830	0.693
Ni	0.797	0.860	0.616
Pb	0.680	0.819	0.542
S	0.568	0.610	0.670
Sr	0.622	0.715	0.450
V	0.400	0.506	0.320
Zn	0.304	0.573	0.339

Multivariate Regression Modeling

To determine the relationship between sediment-phosphorus and the variables that had the strongest Pearson correlation, stepwise multivariate regression was used to explain and predict the concentrations of sediment phosphorus in the James River Basin. Some spatial variables were negatively correlated such as urban and forested land use. There were also sediment composition variables that were negatively correlated such as percent sand and organic matter. All of the variables were entered into the SPSS statistics program and the stepwise regression was used to eliminate variables that did not strengthen the model. The models with the highest R^2 were used to develop three equations to predict sediment phosphorus. First, an equation was derived for all of the sample sites. Then equations were derived for sites that are affected by point and nonpoint sources and sites that are only affected by nonpoint sources.

All three of the equations used to describe the sediment phosphorus included percent organic matter. The equations for the sites that were affected by point sources were strengthened by the PSLI. In this application, the PSLI was an effective method of modeling the wastewater treatment plant loadings spatially. The PSLI is a key variable because it incorporates the drainage area of the point source and places it spatially in the drainage area of the sample site.

All Sample Sites

The variables used to predict sediment phosphorus for all of the sampling sites (n=80) were the percent organic matter in the sample, the percent of forested land cover in the drainage area of the sampling site, and the PSLI. The R^2 for the equation used to develop the relationship between the observed phosphorus and the predicted phosphorus is 0.87 (Figure 5.8).

Model Summary for All Sample Sites

Dependent Variable: Sediment-Phosphorus

Predictors: (Constant), PSLI, OM, FOREST

R Square	Std. Error of the Estimate
0.79	140.56

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	319	54		5.815	.000
OM	48	5	0.502	9.306	.000
FOREST	-468	138	-0.189	-3.390	.001
PSLI	877	78	0.610	11.150	.000

Sediment-P = Constant (319) + % OM (48) + % Forested (-468) + PSLI (877)

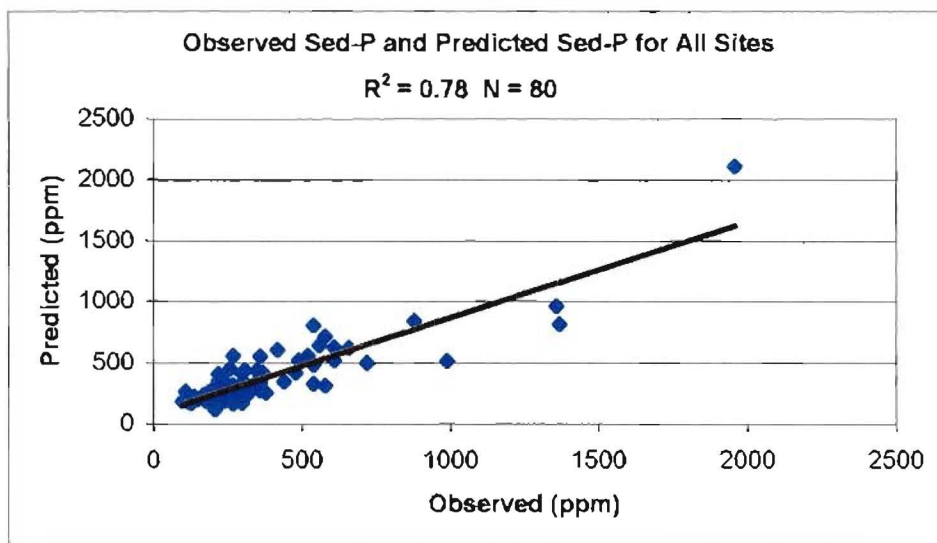


Figure 5.8 Sediment phosphorus concentrations compared to predicted phosphorus concentrations for all sample sites.

Sites Affected by both Point and Nonpoint Sources

The variables used to predict sediment phosphorus for the sampling sites affected by point and nonpoint sources (n=53) were the percent organic matter in the sample and the PSLI. The R^2 for the equation used to develop the relationship between the observed phosphorus and the predicted phosphorus is 0.92 (Figure 5.9).

Model Summary for Sites Affected by both Point and Nonpoint Sources

Dependent Variable: Sediment-Phosphorus

Predictors: (Constant), PSLI, OM

R Square	Std. Error of the Estimate
0.81	150.36

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	153	29		5.181	.000
OM	62	7	0.521	8.476	.000
PSLI	911	82	0.682	11.088	.000

$$\text{Sediment P} = \text{Constant (153)} + \% \text{OM (62)} + \text{PSLI (911)}$$

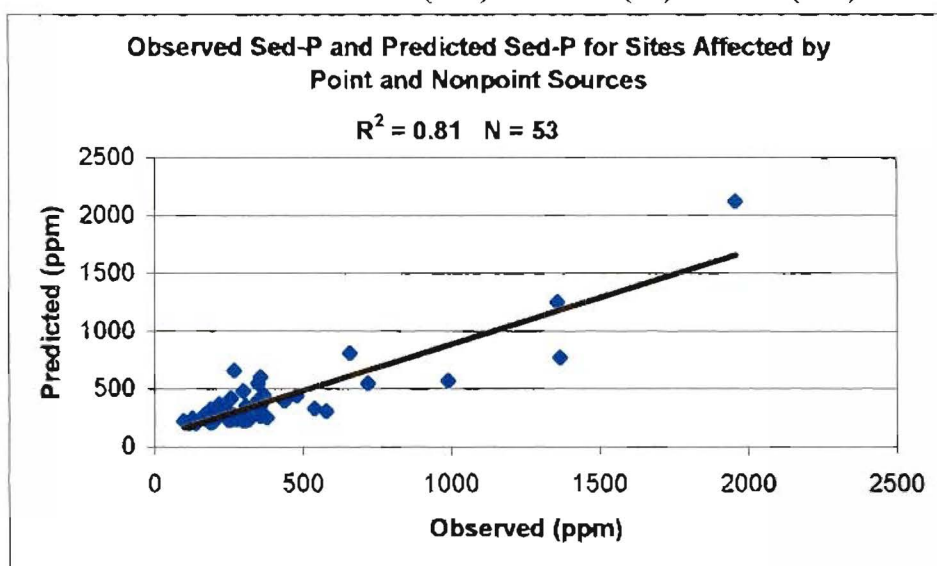


Figure 5.9 Sediment phosphorus concentrations compared to predicted phosphorus concentrations for sample sites affected by point and nonpoint sources.

Sites Affected by Nonpoint Sources

The variables used to predict sediment phosphorus for the sampling sites affected by nonpoint sources (n=27) were the percent organic matter in the sample and the percent of forested land cover in the drainage area of the sampling site. The R^2 for the equation used to develop the relationship between the observed phosphorus and the predicted phosphorus is 0.79 (Figure 5.10).

Model Summary for Sites Affected by Nonpoint Sources

Dependent Variable: Sediment-Phosphorus

Predictors: (Constant), FOREST, OM

R Square	Std. Error of the Estimate
0.79	94.35

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	375	66		5.636	.000
OM	32	6	0.524	4.829	.000
FOREST	-554	120	-0.498	-4.584	.000

$$\text{Sediment P} = \text{Constant (375.76)} + \% \text{Forested } (-554.38) + \% \text{OM (32.07)}$$

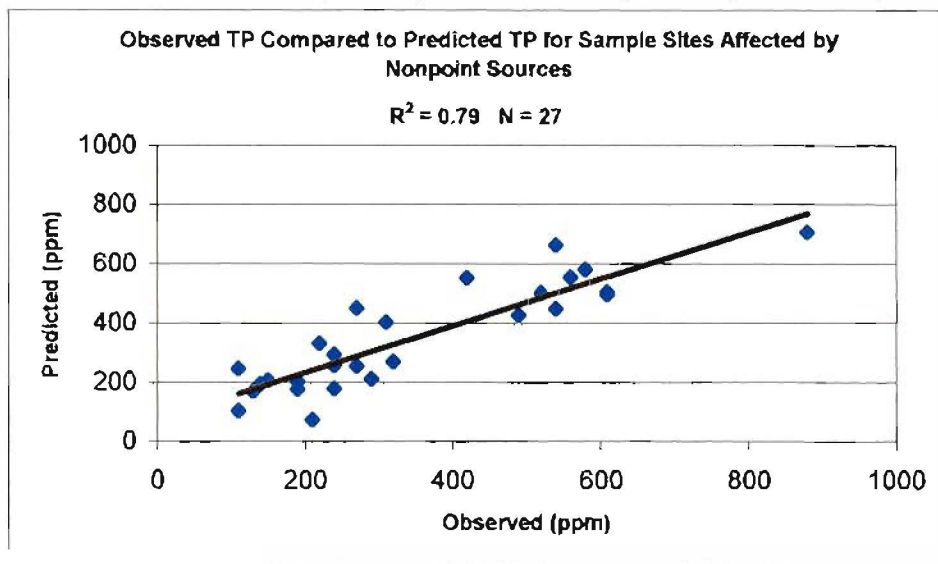


Figure 5.10 Sediment phosphorus concentrations compared to predicted phosphorus concentrations for sample sites affected by nonpoint sources.

Sediment and Water Column Relationship

Two agencies, the City of Springfield Department of Public Works Southwest treatment plant (SWTP) and the United States Geological Survey (USGS) provided the water sample data used in this study (Table 5.12). Samples were collected on the James River, Wilson Creek, and Finley Creek during periods ranging from 1970–1998. Samples were taken at Site 6 (James River–Frazer Bridge) by the USGS approximately once a month from 1970 to 1998. The water samples were analyzed for total phosphorus, suspended, and dissolved phosphorus. These samples reflect a range of seasonal and flow conditions from baseflow to near bankfull floods.

The samples from both agencies were combined to determine mean total phosphorus concentrations for the station at Site 6 (Frazer Bridge). The EPA recommends that total phosphorus should not exceed 0.1 mg/L in streams that enter a lake or reservoir (Peterson *et al.*, 1995). Median phosphorus concentration from 85 streams draining relatively undeveloped watersheds in the U.S. was 0.022 mg/L (Clark *et al.*, 2000). None of the sites in the James River Basin had a mean total phosphorus concentration less than the EPA's recommendations (MDNR, 2001).

Table 5.12 Water column samples provided by the USGS and the City of Springfield.

Station	Number of	Dates	Mean TP		
	Samples		mg/L	σ	C_v
Wilson Creek - Below Plant	57	9/92 - 3/99*	3.68	1.54	41.85
Wilson Creek - Above Plant	11	9/92 - 3/99*	0.49	0.46	93.72
Wilson Creek- Manley Ford	56	9/92 - 3/99*	2.14	1.56	72.90
James River - Nelson Mill	36	9/92 - 2/99*	0.40	0.49	122.50
James River - Delaware Town	56	9/92 - 3/99*	0.99	0.82	82.83
James River - Frazer Bridge	238	6/93-7/94*; 1/70-8/98**	1.04	1.03	99.04
Finley River - Above James River	34	5/94 - 2/99*	0.56	0.97	173.21
James River - Hootentown Access	47	9/92 - 3/99*	0.64	0.46	71.88
James River - Galena	43	6/93 - 8/98*	0.51	0.42	82.35
* Samples Taken by the SWTP					
** Samples Taken by the USGS					

Nine of the sediment sampling locations and the water column sampling locations were located within the same reach on the main stem of the James River and its tributaries (Figure 5.11). Comparisons are made between these different phosphorus-monitoring techniques due to the close proximity of these sampling locations.

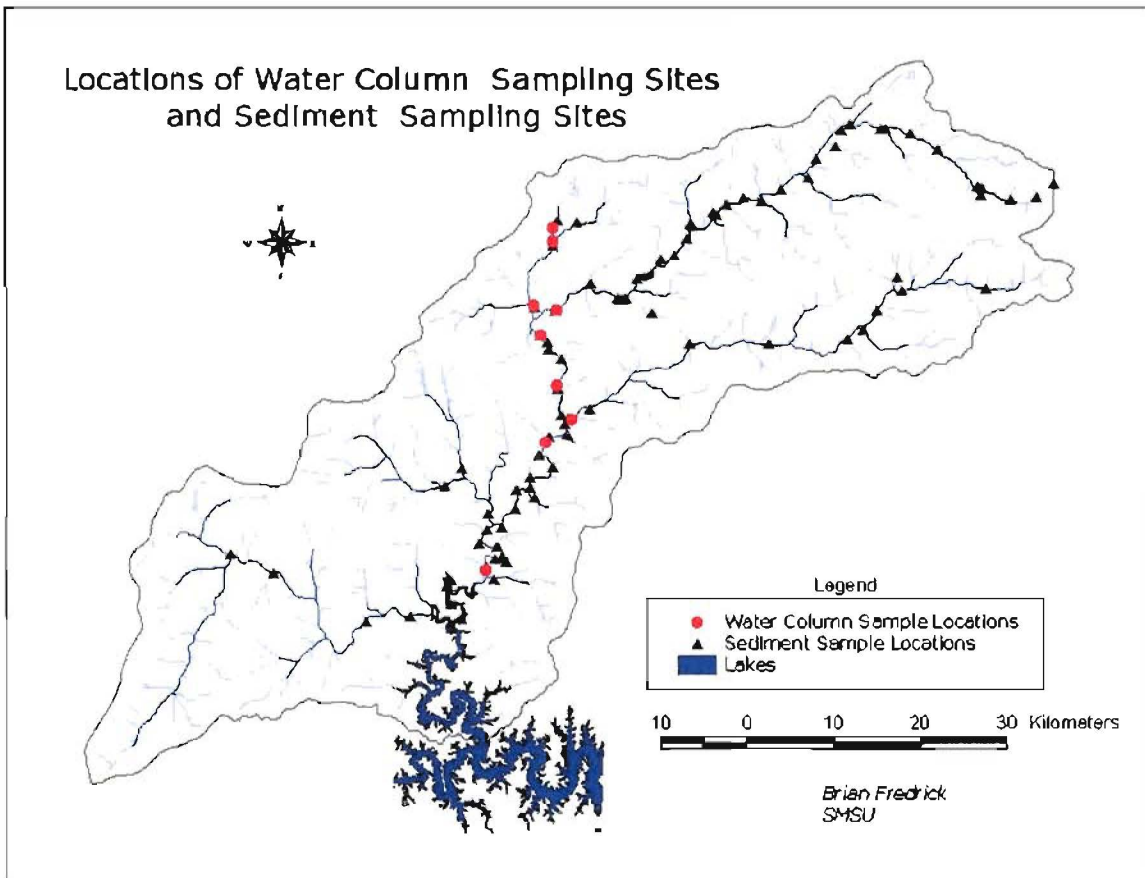


Figure 5.11 Nine locations where water column total phosphorus and sediment total phosphorus were compared

Regression Trend

A point spatial join was performed with the two geographic data sets (Table 5.13). This process lists the water column and sediment sampling sites that are in close proximity of each other. The maximum distance between the sites did not exceed one kilometer upstream or downstream.

Table 5.13 Spatially joined table of water column phosphorus and sediment phosphorus

Site Name	Water Column Mean TP mg/l	Sediment P µg/g
Finley River - Above James River	0.60	140
James River - Delaware Town Access	0.99	990
James River - Frazer Bridge	1.04	720
James River – Galena	0.50	140
James River - Hootentown Access	0.64	320
James River - Nelson Mill	0.40	190
Wilson Creek - Manley Ford	2.16	1370
Wilson Creek (Below Plant)	3.68	1960
Wilson Creek (Above Plant)	0.49	540

The relationship between water column total phosphorus and sediment phosphorus was compared at the nine sites using regression. There is a strong relationship ($R^2 = 0.98$) between water column phosphorus and sediment phosphorus (Figure 5.12). Although water column phosphorus can vary greatly depending on discharge, this relationship could be used to assess the spatial variation of phosphorus concentrations in the water column.

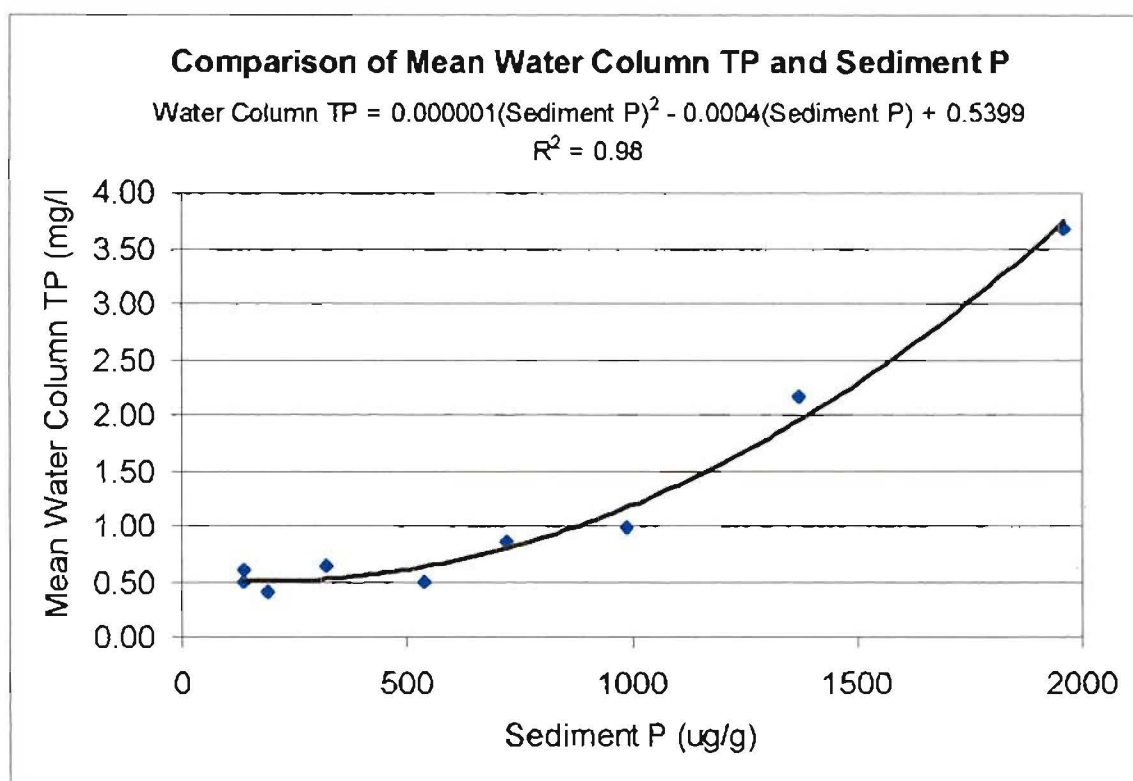


Figure 5.12 Relationship between water column total phosphorus and sediment phosphorus.

Water Quality Assessment

The equation (Water Column TP = $0.000001(\text{Sediment P})^2 - 0.0004(\text{Sediment P}) + 0.5399$) was used to estimate water-column phosphorus (Figure 5.13). The lowest predicted water-column phosphorus that the equation calculated was 0.5 mg/L. The predicted water-column phosphorus could be used in a relative sense to assess areas in the watershed that could potentially have increased phosphorus levels. Future monitoring and analysis of the relationship between sediment phosphorus and water column phosphorus could better the understanding of this interrelationship. Presently, TMDL efforts suggest a baseflow concentration of 0.07-mg/l total phosphorus limits for the James River. The results here suggest that on an annual load basis, mean total

phosphorus concentrations are presently up to 50 times that in the watershed. Again, higher concentrations are associated with wastewater treatment plants.

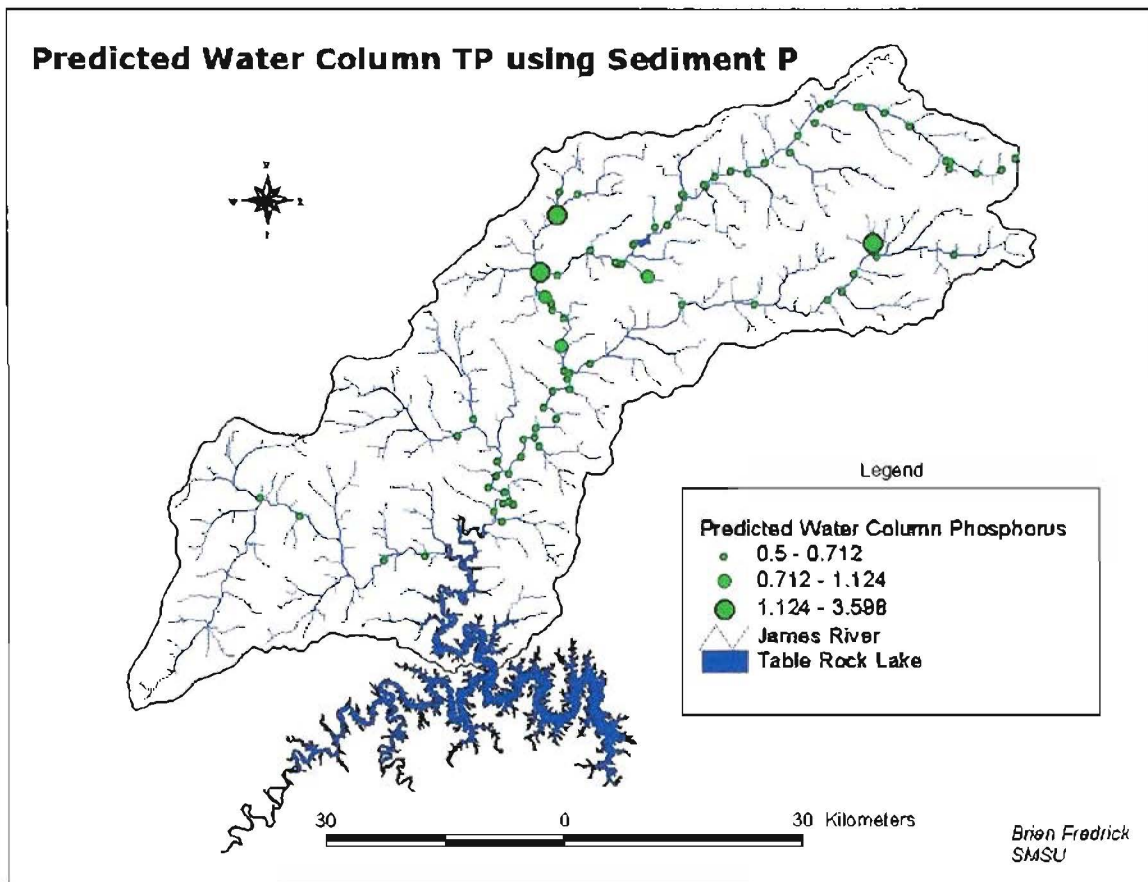


Figure 5.13 Predicted water column total phosphorus (mg/L) using sediment phosphorus ($\mu\text{g/g}$).

CHAPTER 6

SUMMARY AND CONCLUSIONS

This study underscores the role of sediment as an agent of pollution dispersal and helps to understand the spatial variation of pollutants in a multiple-use watershed. It focuses on understanding of the relationship between fluvial sediment geochemistry, land use, and relative influences of point and nonpoint source pollution on sediment-phosphorus at the watershed scale. This study was conducted to better understand the role that sediment plays in the dispersion and transport of phosphorus in rivers. Using sediment composition, land use/land cover, and the location and loadings of wastewater treatment plants, three equations were developed that could be used to predict phosphorus concentrations in fluvial sediments. An association was also developed between water column phosphorus and sediment-phosphorus which could further improve the usefulness of sediment as an environmental monitoring tool.

The findings of this study also show that there is a need for the implementation of management strategies to reduce the phosphorus concentrations in the James River Basin. Overall, the major effect of wastewater treatment plants clouds nonpoint sources of phosphorus. Regulations are being established that will reduce the concentration of phosphorus in wastewater treatment plant effluents. Many wastewater treatment plants in the basin have and are taking steps to reduce concentrations and have successfully reduced levels near the permitted amount. Reducing phosphorus concentrations in wastewater treatment plant effluents could slow the process of eutrophication in Table Rock Lake. However, there are other ways to begin the process of reducing the amount of phosphorus being transported in the James River. Some of the methods include

structural and non-structural best management practices, comprehensive watershed management, and community awareness and education. All of these components can be combined to reduce non-point source pollution problems.

As shown in this study, land use practices influence non-point sources of pollution. While relatively high sediment-phosphorus levels are found in agricultural streams, they are also found in urban streams. The Springfield metropolitan area is not the only area in the Table Rock watershed that has been experiencing land use change. Urban land use adjacent to Table Rock Lake can negatively influence water quality. The city of Branson in Missouri, over the last twenty- five years has experienced incredible growth due to a successful tourism industry. The rapid conversion of forested areas to urban areas around the lake can cause almost-immediate negative impacts on water quality in the lake. With proper management techniques in place such as onsite sediment and erosion control and riparian buffers, communities can continue to be economically successful and preserve water quality.

The dissolved and suspended phosphorus may not be solely to blame for the eutrophication problem in Table Rock Lake. The streambed sediment is acting as a temporary sink for sediment that is enriched with phosphorus. As the enriched sediment moves through the system, it continues to absorb phosphorus and is eventually deposited in the James River arm of Table Rock Lake. Once deposited in the low energy area at the river/lake boundary, the phosphorus may be desorbed from the sediment and made available for the growth of algae. The perception of decreased water quality and increased algae blooms in this part of the lake could be attributed to near bankfull flood events or the flood of 1993, when large amounts of phosphorus-enriched sediment were

transported through the system and deposited in the lake. The cycle of floods and drought could have a direct relationship on the water quality in Table Rock Lake. Presently, SMSU is studying the nature of sediment-phosphorus contamination in the James River Arm.

This research provides a better understanding of the role sediment plays in the storage and transport of contamination in watersheds as applied to questions of pollution management. This study specifically benefits resource managers in the region by assisting them in the assessment of sub-watersheds restoration or management purposes. The identification of sub-watersheds that are contributing increased amounts of nonpoint source pollution to the James River can be targeted for the implementation of Best Management Practices. The information in this study could be used to develop total maximum daily load limits since scientists could use results to identify levels of pollution inputs.

The main conclusions of this study are:

- 1) The mean sediment-phosphorus concentration in the basin was 366 ($\mu\text{g/g}$), the median was 275 ($\mu\text{g/g}$), and concentrations ranged from 100 to 1960 ($\mu\text{g/g}$). Seventy-five percent of the 80 sites had sediment-phosphorus concentrations that would be considered low compared to phosphorus levels in source material throughout the watershed. When the source area samples are grouped by concentration, < 400 ($\mu\text{g/g}$) seems to be relatively non-polluted. A pollution threshold of 700 ($\mu\text{g/g}$) was used to roughly identify phosphorus levels that were

above background and 1000 ($\mu\text{g/g}$) was used to categorize heavily contaminated sediments.

- 2) Analysis of the spatial and temporal variability of sediment-phosphorus concentration indicates that sampling errors tend to be less than 20%. The low variability of sediment-phosphorus, percent sand, and organic matter within each of the triplicate analysis demonstrates that one grab sample from each site is sufficient to describe the watershed-scale trends investigated here.
- 3) The key variables used to predict sediment-phosphorus in the regression models were organic matter, forested land cover, and the PSLI (Point Source Loading Index). Organic matter was the only non-spatial variable that would have to be measured by taking samples in the field and analyzing for OM in the lab. The other variables could be acquired through local geographic data suppliers. Attempts to spatially model the distribution of organic matter in sediments have not been successful.
- 4) The strong regression trend between water-column total phosphorus and sediment-phosphorus shows promise for meshing these two types of monitoring techniques. The equations developed to predict water column phosphorus could be combined with hydrologic data and used to estimate loadings of phosphorus in watershed-scale studies.

The next step would be to focus on smaller sub-watersheds within the basin. Sub-watersheds that have higher concentrations could be targeted and a more intense sampling network could be established that could further refine spatial variables that effect sediment-phosphorus levels. This study could help

to establish a baseline of concentrations that could be used in future assessments of sediment quality the James River Basin. All of the original sampling sites could be revisited and compared with the current land conditions within the basin. The same techniques used to analyze geochemical and sediment properties in this study could be used in future studies to add to the understanding of how these sediment properties change over time. Further experimentation is needed to refine the relationship between water-column phosphorus and sediment-phosphorus. More samples of water and sediment collected at the same time need to be compared to understand this relationship. If this relationship could be better refined and understood, sediment surveys could play an important role in monitoring pollution in watersheds. In addition, more sediment surveys could be conducted in adjacent watersheds that could aid in establishing sediment pollution guidelines for the region.

LITERATURE CITED

- Adamski, J.C., J.C. Peterson, D.A. Freiwald, and J.V. Davis. 1995. Environmental and Hydrological Setting of the Ozark Plateaus Study Unit, Arkansas, Kansas, Missouri, and Oklahoma. U.S. Geologic Survey, Water-Resources Investigations Report 94-4022.
- Allgood, F.P., and I.D. Persinger. 1979. Missouri general soil map and soil association descriptions. United States Department of Agriculture in cooperation with Missouri Agricultural Experiment Station, Columbia, Missouri.
- Arnold, C.L., and J.C. Gibbons. 1996. Impervious Surface Coverage, The Emergence of a Key Environmental Indicator. Journal of the American Planning Association. 62:2 243-258.
- Baker, D.B. 1984. Project summary: Fluvial transport and processing of sediments and nutrients in large agricultural drainage basins. EPA-600/S3-83-054.
- Beaulac, M. N. and K.H. Reckhow. 1982. An examination of land use-nutrient export relationships. Water Resource Bulletin. 18, 1013-1024.
- Beveridge, T.R. 1978. An Introduction to the Geologic History of Missouri. Missouri Department of Natural Resources, Division of Geology and Land Survey.
- Bortleson, G.C., and G.F. Lee. 1974. Phosphorus, iron, and manganese distribution in sediment cores of Wisconsin lakes. Limnology and Oceanography 19:794-801.
- Boström, B., M. Jansson, and C. Forsberg,. 1982. Phosphorus Release from Lake Sediments. Arch. Hydrobiologica. Stuttgart, November 1982.
- Buol, S.W., F.D. Hole, and R.J. McCracken. 1989. Soil Genesis and Classification. Iowa State University Press. p.81.
- Center for Watershed Protection. 1998. Rapid Watershed Planning Handbook.
- Chalmers, Ann T. 1998. Distribution of Phosphorus in Bed Sediments of the Winooski River Watershed, Vermont, 1997. United States Department of the Interior, U.S. Geological Survey. USGS Fact Sheet FS-108-98.
- Chemex Labs, Inc. 1999. ICP-AES Multi Element Analysis-Nitric-Aqua-Regia Leach Package. [HTTP://www.chemex.com](http://www.chemex.com).
- Clark, G.M., D.K. Mueller, and M.A. Mast. 2000. Nutrient concentrations and Yields in Undeveloped Stream Basins of the United States. Journal of the American Water Resources Association. 36: 4. pp. 849-860.

Clean Water Act, 33 U.S.C: 7401 et seq. (1963-1990).

Colman, J.A., and R.F. Sanzolone. 1991. Surface- Water -Quality Assessment of the Upper Illinois River Basin in Illinois, Indiana, and Wisconsin: Geochemical Data for Fine-fraction Streambed Sediment from High- and Low-order Streams, 1987. USGS Open-File Report 90-571, 108 p.

Combest, K.B. 1991. Trace metals in sediment: spatial trends and sorption processes. Water Resources Bulletin. 27(1):19-28.

Craig, J.R., D.J. Vaughan, and B.J. Skinner. 1988. Resources of the Earth. Prentice-Hall: Englewood Cliffs, NJ.

Dean, W.E. 1974. Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods. Journal of Sedimentary Petrology. 44:424-248.

Dillon P.J. and W.B. Kirchner. 1975. The effects of geology and land use on the export of phosphorus from watersheds. Water Resources. 9, 135-148.

Edzwald, J.K., D.C. Toensing, and M.C. Leung. 1976. Phosphate adsorption reactions with clay minerals. Environmental Science and Technology. 10:485-490.

Emmerth, P.P. and D.R. Bayne. 1996. Urban Influence on Phosphorus and Sediment Loading of West Point Lake, Georgia. Water Resource Bulletin.

Environmental Protection Agency. 1992. Managing Nonpoint source Pollution: Final Report to Congress on Section 319 of the Clean Water Act. United States Environmental Protection Agency #EPA-506/9-90. Washington, DC: USEPA Office of Water.

Environmental Protection Agency. 1994. The Quality of our Nations Waters: 1992. United States Environmental Protection Agency #EPA-841-S94-002. Washington, DC: USEPA Office of Water.

Feltz, H.R. 1980. Significance of Bottom Material Data in Evaluating Water Quality. Contaminants and Sediments, Vol. 1. Ann Arbor Science Publishers, Inc. pp. 271-286.

Field, R. and R.E. Pitt, 1990. Urban Storm-Induced Discharge Impacts: U.S Environmental Protection Agency Research Program Review. Water Science and Technology 22(10-11):1-7.

Gibbs, R.J. 1977. Transport Phases of Transitional Metals in the Amazon and Yukon Rivers. Geological Society of America Bulletin; 88:829-843.

- Graf, W.L. 1994. Plutonium and the Rio Grande: Environmental Change and Contamination in the Nuclear Age. New York: Oxford University Press.
- Graf, W.L. 1996. Transport and deposit of plutonium-contaminated sediments by fluvial processes, Los Alamos Canyon, New Mexico. Geological Society of America Bulletin; October 1996; v.108; no. 10; p. 1342-1335.
- Grobler, D.C. and M.J. Silberbauer. 1985. The combined effect of geology, phosphate sources and runoff on phosphate export from drainage basins. Water Resources Vol. 19, No. 8 pp. 975-981.
- Hakanson, L. and M. Jansson. 1983. Principles of Lake Sedimentology. Springer-Verlag, Berlin Heidelberg.
- Harris, S.L. 1997. Inorganic and Organic Constituents and Grain-size Distribution in Streambed Sediment and Ancillary Data for the Connecticut, Housatonic, and Thames River Basins, 1992-94: U.S. Geological Survey Open-File Report 96-397, 48 p.
- Hearn, P.P. 1985. Controls on Phosphorus Mobility in the Potomac River Near the Blue Plains Wastewater Treatment Plant. U.S. Geological Survey Water-Supply Paper 2231.
- Hem, J.D. 1985. Study of the Chemical Characteristics of Natural Water. Department of the Interior, U.S. Geological Survey; Alexandria, VA. 236 p.
- Holdren, G. and D. Armstrong. 1980. Factors affecting the phosphorus release from intact lake sediment cores. Environmental Science and Technology. 14:79-87.
- Hollis, G.E. 1975. The Effects of Urbanization on Floods of Different Recurrence Interval: Water Resources Research, v. 11, p. 431-435.
- Holtan, H.L. Kamp-Nielsen, and A.O. Stuanes. 1988. Phosphorus in sediment, water, and soil: an overview. Hydrobiologia 170:19-34.
- Horowitz, A.J. 1991. A Primer on Sediment-Trace Element Chemistry. Lewis Publishers, New York, New York, 136 pp.
- Imboden, D. 1974. Phosphorus model of lake eutrophication. Limnology and Oceanography. 19:297-304.
- Jacobson, R.B. and Karen Bobbitt Gran. 1999. Gravel Sediment Routing from Widespread, Low-Intensity Landscape Disturbance, Current River Basin, Missouri. Earth Surface Processes and Landforms. 24, 897-917.

- Jacobson, R.B. 1995. Spatial Controls on Patterns of Land-use Induced Stream Disturbance at the Drainage-basin Scale—An Example from Gravel-bed Streams of the Ozark Plateaus, Missouri. U.S. Geologic Survey, Rolla Missouri.
- Jones, J.R. 1993. Limnology of Missouri reservoirs: an analysis of regional patterns. Lake and Reservoir Management. 8; 1 (17-30).
- Juracek, K.E. 1998. "Analysis of Lake-Bottom Sediment to Estimate Historical Nonpoint-Source Phosphorus Loads." Journal of the American Water Resources Association. 34:6 1449-1463.
- Kerr, Robert S., James River-Wilson Creek Study, U.S. Dept. of the Interior, Federal Water Pollution Control Administration, June 1969.
- Kiner, L.K., and C. Vitello. 1997. James River Basin Inventory and Management Plan. Missouri Department of Conservation.
- Knighton, D. 1998. Fluvial forms and processes: A new perspective. Oxford University press. pp. 107-113.
- Knowlton, M.F. and J.R. Jones. 1990. Summer distribution of nutrients, phytoplankton, and dissolved oxygen in Table Rock Lake, a large midwestern reservoir. Arch. Hydrobiological Supplement. 83; 197-225.
- Kuo, S., and E.G. Lotse. 1974. Kinetics of phosphate adsorption and desorption by lake sediments. Soil Science. 38:50-54.
- Leeder, M.R. 1982. Sedimentology: Process and Product. George Allen & Unwin. London. pp. 5-9.
- Leopold, L.B., Wolman, M.G., and Miller, J.P. 1964. Fluvial Processes in Geomorphology. Dover Publications, INC. New York. pp. 151.
- Leopold, L.B. 1968. Hydrology for Urban Land Planning: A Guidebook on the Effects of Urban Land Use: U.S. Geological Survey Circular 554, 18p.
- Leopold, L.B. 1995. A View of a River. Harvard University Press. Cambridge, Massachusetts. London, England, pp. 208.
- Leyland, D. 1999. Table Rock Lake: Region - Ozark Highlands: 1998 trophic state - mesotrophic to hypereutrophic. Government Report. Missouri Department of Natural Resources. Jefferson City, Missouri. Pp. 15-28.
- Li, W.C., D E. Armstrong, J.D.H. Williams, R.F. Harris, and J.K. Syers. 1972. Rate and extent of inorganic phosphate exchange in lake sediments. Soil Science. 36:279-285.

- Line, D.E., D.L. Osmond, R.W. Gannon, J.A. Gale, *et al.* 1995. Nonpoint Sources. Water Environment Research; 67(4):685-700.
- Litke, D.W. 1999. Review of Phosphorus Control Measures in the United States and Their Effects on Water Quality. USGS.
- MacCoy, D.E. and Black, R.W. 1998. Organic Compounds and Trace Elements in Freshwater Streambed Sediment and Fish from the Puget Sound Basin: U.S. Geological Survey Fact Sheet 105-98.
- McCallister, D.L., and T.J. Logan. 1978. Phosphate adsorption-desorption characteristics of soils and bottom sediments in the Maumee River basin of Ohio. Journal of Environmental Quality. 7:87-92.
- Minns C.K. and M.G. Johnson. 1979. Temporal variation in the nutrient export of rivers draining into the Bay of Quinte, Ontario, Canada. Water Resource Bulletin. 15, 1061-1072.
- Missouri Department of Natural Resources (MDNR). 2001. Public Notice of Draft Total Maximum Daily Load Analysis. James River near Springfield in Webster, Greene, Christian and Stone Counties, Missouri. January 19, 2001.
- Missouri Department of Natural Resources. 1999. Fax, Permitted Dischargers in the James River Basin.
- Missouri Department of Natural Resources (MDNR). 1998. Lakes of Missouri Volunteer Program Data Report. Oberecht, D.V., Pope, F.E., Jones, J.R. Department of Fisheries and Wildlife. University of Missouri. Columbia, MO.
- Missouri Unified Watershed Assessment Steering Committee. 1998. State of Missouri Unified Watershed Assessment Final Report. USDA-Natural Resources Conservation Service, Parkade Center, Suite. 250. Columbia, MO.
- Moore, J.W. and S. Ramamoorthy. 1984. Heavy Metals in Natural Waters: Applied Monitoring and Impact Assessment. Springer-Verlag, New York. pp. 167.
- Morris, G.L. and J. Fan. 1997. Reservoir Sedimentation Handbook. McGraw-Hill.
- Mortimer, C. 1941. The exchange of dissolved substances between mud and water in lakes. Ecology. 29:280-329.
- Novotny, V. and G. Chesters. 1981. Handbook of nonpoint pollution sources and management. New York: Van Nostrand Reinhold.

- Peterson, J.C., J.C. Adamski, R.W. Bell, J.V. Davis, S.R. Femmer, D.A. Freiwald, and R.L. Joseph. 1995. Water Quality in the Ozark Plateaus, Arkansas, Kansas, Missouri, and Oklahoma. U.S. Geological Survey Circular 1158.
- Pionke, H.B., W.J. Gburcek, A.N. Sharpley, and R.R. Schnabel. 1996. Flow and nutrient export patterns for an agricultural hill-land watershed. Water Resource Res. 32:1795-1804.
- Pocernich, M. and D.W. Litke. 1997. Nutrient Concentrations in Wastewater Treatment Plant Effluents, South Platte River Basin. Journal of the American Water Resources Association. 33:1 205-214.
- Pye, K. 1994. Sediment Transport and Depositional Processes. Blackwell Scientific Publications.
- Ritter, D.F., C.R. Kochel, and J.R. Miller. 1995. Process Geomorphology. Third Edition. Wm. C. Brown Publishers. pp. 197.
- Rosich, R.S. and P. Cullen. 1981. Nutrient Runoff. In Proceedings of the water quality management symposium. Institute of Technology. Caulfield, Australia.
- Sharpley, A.N. 1993. Assessing phosphorus bioavailability in agriculture soils and runoff. Fertilizer Research. 36:259-272.
- Sharpley, A.N. and S.J. Smith. 1991. Prediction of bioavailable phosphorus loss in agricultural runoff. Journal of Environmental Quality. 21:32-37.
- Sharpley, A.N., S.J. Smith, and R.G. Menzel. 1989. Phosphorus Dynamics in Agricultural Runoff and Reservoirs in Oklahoma. Lake and Reservoir Management. 5(2): 75-81.
- Smith, R.L. 1990. Ecology and Field Biology. Fourth ed. Harper Collins Publishers, NY.
- Sonzogni, W.C., S.C. Chapra, D.E. Armstrong, and T.J. Logan. 1982. Bioavailability of phosphorus inputs to lakes. Journal of Environmental Quality. 11(4) :555-563.
- Spahr, N.E. and K.H. Wynn. 1997. Nitrogen and Phosphorus in Surface Waters of the Upper Colorado River Basin. Journal of the American Water Resources Association. 33:3 547-560.
- Stone, M. and A. Mudroch. 1989. The Effect of Particle Size, Chemistry and Mineralogy of River Sediments on Phosphate Adsorption. Environmental Technology Letters, Vol. 10, pp. 501-510.

- Stuanes, A.O. 1982. Phosphorus sorption by soil. A review. In A.S. Eikum & R.W. Seabloom (eds.), *Alternative wastewater treatment; Low cost small systems, research and development*. D. Reidel Publishing Company. 145-152.
- Stumm, W. and J.J. Morgan. 1981. Case studies : Phosphorus, iron and manganese. Chap. 10 in *Aquatic Chemistry : An introduction emphasizing chemical equilibria in natural waters*. Wiley Interscience, NY, NY.
- Svendsen, L.M., A. Rebsdorf, and P. Nornberg. 1993. Comparison of Methods for Analysis of Organic and Inorganic Phosphorus in River Sediment. Water Resources. Vol. 27, No. 1, pp. 77-83.
- Syers, J.K., R.F. Harris, and D.E. Armstrong. 1973. Phosphate chemistry in lake sediments. Journal of Environmental Quality. 2:1-14.
- Taylor, A.W., and H.M. Kunishi. 1971. Phosphate equilibria on stream sediment and soil in a watershed draining an agricultural region. Journal of Agriculture and Food Chemistry. 19:827-831.
- Trimble, S.W. 1997. Contribution of Stream Channel Erosion to Sediment Yield from an Urbanizing Watershed: Science, v. 278, p. 1442-1444.
- U.S. EPA. 1983. Nationwide Urban Runoff Program (NURP). Final Report. Washington, D.C.
- U.S. EPA 1995. National Water Quality Inventory, Report to Congress. Office of Water, Washington, D.C.
- Uttormark, P.D., Chapin, J.D., and K.M. Green. 1974. Estimating nutrient loadings of lakes from nonpoint sources. EPA-660/3-74-020. Washington, DC.
- Van Metre, P.C. and E. Callender. 1996. Identifying water-quality trends in the Trinity River, Texas, USA, 1969-1992, using sediment cores from Lake Livingston. Environmental Geology. 28 (4) December 1996.
- Vighi, M., S. Soprani, P. Puzzarini, and G. Menghi. 1991. Phosphorus loads from selected watersheds in the drainage area of the North Adriatic Sea. Journal of Environmental Quality. 20:439-444.
- Wagner, R.A., Tisdale, T.S., and J. Zhang. 1996. A framework for Phosphorus Transport Modeling in the Lake Okeechobee Watershed. Journal of the American Water Resources Association. 32:1 57-73.
- Walling, D.E. 1983. The Sediment Delivery Problem. Journal of Hydrology. 65, pp. 209-237.

Watershed Committee of the Ozarks, Water Resources of Greene County, 1997.

White, J.W. 2001. Non-Point Pollution Monitoring using Bed Sediment Surveys in the Kings River Basin, NW, Arkansas. Unpublished Masters Thesis. Springfield, Missouri: Southwest Missouri State University, Department of Geography, Geology, and Planning.

Wolman, H.G. 1977. Changing needs and opportunities in the sediment field. Water Resources Research.

Yaksich, S.M. and F.H. Verhoff. 1983. Sampling strategy for river pollutant transport. Journal of Environmental Engineering. 109, 219-231.

APPENDIX

SAMPLE	Al	As	Ba	Ca	Co	Cr	Cu	Fe	K	Mg	Mn	P	Pb
	%	ppm	ppm	%	ppm	ppm	ppm	%	%	%	ppm	ppm	ppm
JMS 01B	2.82	8	130	0.19	5	43	7	2.65	0.11	0.19	55	110	20
JMS 02B	1.38	8	190	1.5	17	61	12	2.44	0.11	0.85	1345	310	24
JMS 03B	1.33	8	140	0.83	15	52	13	1.98	0.11	0.26	1180	580	24
JMS 04B	1.36	<2	120	1.37	10	52	13	1.66	0.11	0.37	395	610	30
JMS 05B	1.16	2	100	1.2	11	55	11	1.73	0.09	0.41	365	490	24
JMS 06B	0.57	6	50	0.35	6	68	7	1.41	0.04	0.2	165	240	24
JMS 07B	0.45	4	40	0.22	6	121	4	1.8	0.03	0.07	445	190	18
JMS 08B	0.41	<2	30	0.15	4	77	4	0.98	0.03	0.08	80	140	14
JMS 09B	0.64	8	50	0.37	9	143	8	3.08	0.05	0.13	300	320	12
JMS 10B	0.33	4	30	0.08	4	92	3	1.21	0.03	0.04	75	130	10
JMS 11B	0.4	8	40	0.32	5	139	4	1.29	0.04	0.14	170	170	12
JMS 12B	0.44	4	40	0.21	5	63	5	0.89	0.04	0.09	55	220	10
JMS 13B	0.59	2	50	0.42	7	164	5	1.54	0.06	0.15	190	270	20
JMS 14B	0.63	20	110	0.11	18	175	6	3.95	0.03	0.05	1385	240	42
JMS 15B	0.86	<2	50	0.24	14	32	10	1.71	0.3	0.24	315	110	16
JMS 16B	1.09	4	90	0.22	7	68	9	2.16	0.11	0.12	165	240	26
JMS 17B	0.44	4	40	0.08	6	184	4	1.44	0.04	0.05	300	150	8
JMS 18B	0.86	6	100	0.84	9	65	7	1.48	0.08	0.14	785	360	16
JMS 19B	0.43	4	50	0.14	6	119	4	1.74	0.03	0.05	350	180	14
JMS 20B	1.19	6	120	1.79	10	64	13	1.32	0.11	0.23	410	540	26
JMS 21B	1.17	<2	130	0.33	12	101	8	1.52	0.11	0.14	1170	310	20
JMS 22B	0.78	<2	70	0.45	7	148	10	1.05	0.08	0.13	195	350	12
JMS 23B	1.42	<2	100	4.46	10	41	15	1.5	0.11	0.9	590	560	118
JMS 24B	0.39	<2	30	0.42	4	209	3	0.95	0.04	0.1	175	170	6
JMS 25B	1.36	<2	130	11.35	11	45	22	1.57	0.11	0.17	800	420	42
JMS 26B	0.73	<2	60	0.22	6	70	6	1.25	0.07	0.08	335	180	14
JMS 27B	0.63	4	70	0.26	7	162	7	1.17	0.08	0.05	640	220	16
JMS 28B	1.87	16	440	2.1	42	111	16	3.64	0.19	0.11	5260	880	56
JMS 29B	1.67	4	160	1.46	19	80	12	2.81	0.1	0.16	1000	610	16
JMS 30B	1.85	10	260	2.06	21	89	18	2.62	0.14	0.13	2490	540	66
JMS 31B	1.25	2	260	6.57	34	177	22	3.7	0.08	0.11	2720	1960	118
JMS 32B	1.69	<2	140	2.39	13	156	29	2.25	0.14	0.15	985	1370	78
JMS 33B	1.06	<2	110	0.6	11	86	15	1.51	0.11	0.12	760	340	22
JMS 34B	0.75	<2	60	1.26	5	160	22	1.23	0.08	0.08	400	350	10
JMS 35B	1.14	10	120	1.25	10	178	49	1.8	0.11	0.12	1075	440	20
JMS 36B	0.62	2	60	0.88	5	186	17	1.1	0.06	0.07	405	210	10
JMS 37B	1.68	<2	160	2.55	11	105	43	1.74	0.18	0.19	1820	520	34
JMS 38B	1.25	<2	60	0.24	5	59	7	1.59	0.09	0.08	300	190	14
JMS 39B	1.69	<2	280	3.39	11	85	71	1.66	0.19	0.23	1375	990	42
JMS 40B	1.31	<2	140	1.41	11	83	24	1.66	0.14	0.16	1155	720	42

SAMPLE	Al	As	Ba	Ca	Co	Cr	Cu	Fe	K	Mg	Mn	P	Pb
	%	ppm	ppm	%	ppm	ppm	ppm	%	%	%	ppm	ppm	ppm
JMS 41B	0.4	8	40	0.09	12	147	4	3.29	0.01	0.03	470	270	20
JMS 42B	0.47	2	50	0.93	9	146	5	1.93	0.03	0.12	555	190	18
JMS 43B	1.42	8	120	1.17	10	47	11	1.53	0.15	0.24	350	660	14
JMS 44B	1.5	<2	160	1.79	14	73	14	1.58	0.17	0.35	2840	1360	14
JMS 45B	0.87	2	70	0.35	7	139	6	1.07	0.08	0.1	400	190	12
JMS 46B	0.61	2	50	6.54	6	104	1345	1.17	0.05	0.2	650	300	40
JMS 47B	0.31	4	30	0.16	4	270	2	0.99	0.02	0.03	95	140	2
JMS 48B	0.45	4	40	0.14	6	267	5	2.07	0.03	0.07	325	170	14
JMS 49B	0.74	16	110	0.11	18	195	6	3.72	0.04	0.05	1295	300	22
JMS 50B	0.41	12	30	0.25	6	262	5	1.17	0.03	0.06	165	130	10
JMS 51B	0.28	4	40	0.7	5	114	6	1.35	0.03	0.07	200	250	34
JMS 52B	0.38	14	40	0.21	8	204	4	2.07	0.03	0.05	425	290	20
JMS 53B	0.35	6	40	0.53	8	105	3	1.58	0.02	0.04	320	320	14
JMS 54B	0.72	<2	60	0.8	8	111	6	1.1	0.06	0.13	635	270	8
JMS 55B	0.78	<2	40	0.5	8	84	5	1.24	0.06	0.18	225	210	14
JMS 56B	0.4	4	50	0.47	7	141	4	1.68	0.03	0.05	375	320	16
JMS 57B	0.35	<2	30	0.26	6	101	2	1.07	0.03	0.08	210	190	14
JMS 58B	0.35	10	30	0.46	6	105	3	1.4	0.02	0.07	225	260	14
JMS 59B	0.28	<2	40	0.65	8	98	3	1.76	0.01	0.04	455	310	12
JMS 60B	0.3	2	40	0.63	6	109	3	1.42	0.02	0.06	450	280	16
JMS 61B	0.43	6	50	1.23	8	125	4	1.58	0.04	0.1	365	380	12
JMS 62B	0.97	<2	60	0.84	5	101	7	1.13	0.09	0.2	420	250	12
JMS 63B	0.41	8	50	0.53	8	154	4	1.75	0.03	0.06	395	360	16
JMS 64B	0.67	4	60	1.05	8	147	6	1.54	0.06	0.14	515	360	16
JMS 65B	0.48	4	50	0.73	5	153	4	1.25	0.04	0.1	355	300	18
JMS 66B	1.02	6	90	1.52	9	86	7	1.15	0.09	0.11	780	260	10
JMS 67B	0.45	6	50	2.28	7	106	4	1.69	0.04	0.11	440	300	10
JMS 68B	0.43	<2	40	2.19	7	125	3	1.34	0.03	0.09	375	270	2
JMS 69B	0.89	2	60	0.28	7	93	4	1.18	0.06	0.06	525	220	12
JMS 70B	0.72	<2	50	0.5	6	116	4	1.25	0.05	0.12	425	220	20
JMS 71B	0.3	2	40	0.17	6	113	1	1.15	0.02	0.04	335	120	10
JMS 72B	0.47	2	30	0.28	4	130	3	0.75	0.04	0.1	230	100	12
JMS 73B	0.35	6	30	0.44	6	116	3	1.5	0.03	0.07	200	260	12
JMS 74B	0.47	2	40	0.99	5	168	4	0.97	0.04	0.23	175	240	12
JMS 75B	0.3	6	20	0.25	4	82	1	0.99	0.04	0.07	135	200	8
JMS 76B	0.4	<2	30	0.94	4	91	2	1.06	0.03	0.12	160	140	4
JMS 77B	0.64	8	60	0.76	8	168	9	1.56	0.05	0.06	460	540	24
JMS 78B	0.56	<2	50	0.89	4	149	9	0.94	0.05	0.08	320	370	18
JMS 79B	0.64	<2	70	0.74	9	162	9	2.11	0.05	0.07	560	580	24
JMS 80B	0.63	2	70	1.76	6	159	12	1.14	0.06	0.3	540	480	12

SAMPLE	S	Sr	V	Zn	OM	% Sand	Watershed	Point
	%	ppm	ppm	ppm	%		Reach	source
JMS 01B	0.01	13	52	28	4.95	6.42	Upper James	no
JMS 02B	0.01	14	46	48	4.67	4.69	Upper James	no
JMS 03B	0.05	11	31	54	10.53	10.47	Upper James	no
JMS 04B	0.07	11	26	64	9.46	7.44	Upper James	no
JMS 05B	0.07	13	28	78	7.30	23.77	Upper James	no
JMS 06B	0.03	6	27	74	3.49	56.57	Upper James	no
JMS 07B	0.01	8	31	48	1.73	68.99	Upper James	no
JMS 08B	0.02	5	18	28	1.63	76.92	Upper James	no
JMS 09B	0.04	5	55	52	3.82	64.46	Upper James	no
JMS 10B	<0.01	4	20	22	1.06	80.55	Upper James	no
JMS 11B	0.01	9	20	26	1.55	70.53	Upper James	yes
JMS 12B	0.03	3	16	26	6.02	74.77	Upper James	no
JMS 13B	0.03	8	26	36	3.43	66.24	Upper James	no
JMS 14B	<0.01	4	76	74	1.54	79.32	Upper James	no
JMS 15B	<0.01	7	16	24	2.42	3.42	Upper James	no
JMS 16B	0.02	7	31	42	4.60	23.41	Upper James	no
JMS 17B	<0.01	6	25	14	0.88	78.79	Upper James	no
JMS 18B	0.05	8	26	32	7.18	41.69	Upper James	yes
JMS 19B	<0.01	4	31	34	1.16	82.02	Upper James	yes
JMS 20B	0.1	13	21	150	11.54	12.51	Upper James	no
JMS 21B	0.01	8	26	44	3.15	31.04	Upper James	yes
JMS 22B	0.05	8	20	54	6.22	30.53	Upper James	yes
JMS 23B	0.11	20	22	1100	8.13	5.99	Upper James	no
JMS 24B	0.03	7	15	264	1.93	81.17	Upper James	yes
JMS 25B	0.05	43	28	144	6.41	19.70	Lower James	no
JMS 26B	<0.01	4	20	40	1.59	38.65	Upper James	yes
JMS 27B	0.03	10	18	46	3.40	51.41	Lower James	yes
JMS 28B	0.07	14	71	84	11.35	23.05	Lower James	no
JMS 29B	0.01	13	49	78	4.46	33.81	Lower James	no
JMS 30B	0.01	18	49	220	4.67	27.17	Lower James	no
JMS 31B	0.03	36	78	224	4.95	75.22	Lower James	yes
JMS 32B	0.04	21	37	236	3.41	57.98	Lower James	yes
JMS 33B	0.02	8	29	88	3.12	48.82	Lower James	yes
JMS 34B	0.04	15	24	64	3.95	73.43	Lower James	yes
JMS 35B	0.04	21	36	94	3.79	65.41	Lower James	yes
JMS 36B	0.03	14	21	46	2.31	74.97	Lower James	yes
JMS 37B	0.04	22	30	98	6.06	20.58	Lower James	no
JMS 38B	<0.01	6	29	48	1.78	65.53	Lower James	yes
JMS 39B	0.06	43	24	160	6.32	11.42	Lower James	yes
JMS 40B	0.05	15	26	134	6.01	19.36	Lower James	yes

SAMPLE	S	Sr	V	Zn	OM	% Sand	Watershed	Point
	%	ppm	ppm	ppm	%		Reach	source
JMS 41B	<0.01	7	60	48	1.18	93.77	Finley	yes
JMS 42B	0.01	13	35	32	1.79	87.06	Finley	no
JMS 43B	0.09	12	21	58	10.52	1.38	Finley	yes
JMS 44B	0.13	16	25	88	17.60	5.78	Finley	yes
JMS 45B	0.01	8	19	32	2.62	47.75	Finley	yes
JMS 46B	0.03	22	17	108	5.14	65.15	Finley	yes
JMS 47B	0.01	7	15	38	0.70	92.31	Finley	yes
JMS 48B	<0.01	12	38	30	1.31	87.88	Finley	yes
JMS 49B	<0.01	13	71	28	1.01	89.81	Finley	yes
JMS 50B	0.01	7	19	28	1.39	94.21	Finley	yes
JMS 51B	0.01	7	13	56	1.08	89.13	Lower James	yes
JMS 52B	<0.01	5	35	66	0.97	91.72	Lower James	no
JMS 53B	0.01	6	26	66	1.12	90.28	Lower James	yes
JMS 54B	0.02	7	18	34	8.04	58.10	Lower James	no
JMS 55B	0.03	7	21	32	2.40	74.45	Lower James	yes
JMS 56B	<0.01	7	27	66	1.18	89.79	Lower James	yes
JMS 57B	<0.01	5	18	38	0.66	88.89	Lower James	yes
JMS 58B	<0.01	5	22	52	1.16	90.65	Lower James	yes
JMS 59B	0.01	5	27	66	0.95	95.68	Lower James	yes
JMS 60B	0.01	6	23	52	1.11	91.31	Lower James	yes
JMS 61B	0.02	9	24	60	1.43	87.01	Lower James	yes
JMS 62B	0.01	8	18	48	2.17	50.26	Lower James	yes
JMS 63B	0.01	5	27	60	1.65	87.75	Lower James	yes
JMS 64B	0.01	9	23	70	3.09	76.81	Lower James	yes
JMS 65B	0.01	7	19	48	1.44	85.53	Lower James	yes
JMS 66B	0.02	7	19	52	4.09	45.18	Lower James	yes
JMS 67B	0.01	7	26	44	2.07	80.67	Lower James	yes
JMS 68B	0.01	8	19	74	1.75	81.46	Lower James	yes
JMS 69B	0.01	4	19	234	2.75	67.59	Flat	yes
JMS 70B	0.01	7	20	132	2.15	77.09	Flat	yes
JMS 71B	<0.01	12	19	48	0.64	95.31	Flat	yes
JMS 72B	<0.01	13	12	34	0.99	86.76	Flat	yes
JMS 73B	0.01	5	24	50	1.01	97.62	Lower James	yes
JMS 74B	0.03	9	15	46	2.48	85.52	Lower James	yes
JMS 75B	<0.01	4	16	34	0.80	94.25	Lower James	yes
JMS 76B	<0.01	5	17	32	0.70	87.88	Lower James	yes
JMS 77B	0.03	9	25	88	2.42	79.93	Lower James	yes
JMS 78B	0.03	9	14	66	4.35	81.90	Lower James	yes
JMS 79B	0.02	8	36	94	2.12	82.35	Lower James	yes
JMS 80B	0.05	14	17	90	4.28	63.62	Lower James	yes

SAMPLE	PSLI	%	%	%	Ad	SLOPE
	(Mg P/km ² /yr)	urban	ag	for	Km2	
JMS 01B	.00000	0.00%	21.64%	78.36%	0.40	0.0492
JMS 02B	.00000	0.19%	76.60%	22.75%	5.63	0.0120
JMS 03B	.00000	2.32%	72.96%	24.42%	30.41	0.0037
JMS 04B	.00000	1.45%	65.97%	32.24%	48.34	0.0036
JMS 05B	.00000	1.32%	64.95%	33.42%	61.41	0.0054
JMS 06B	.00000	1.04%	56.32%	42.37%	119.16	0.0022
JMS 07B	.00000	0.89%	56.97%	41.83%	141.56	0.0050
JMS 08B	.00000	0.65%	56.23%	42.77%	193.21	0.0020
JMS 09B	.00000	0.72%	57.32%	41.58%	238.52	0.0008
JMS 10B	.00000	0.64%	54.95%	43.97%	426.43	0.0021
JMS 11B	.00001	0.82%	56.69%	42.05%	510.03	0.0015
JMS 12B	.00000	0.91%	55.49%	43.39%	93.15	0.0025
JMS 13B	.00000	0.62%	56.85%	42.14%	280.25	0.0010
JMS 14B	.00000	0.04%	54.57%	45.07%	19.06	0.0051
JMS 15B	.00000	1.01%	60.74%	38.04%	11.11	0.0114
JMS 16B	.00000	0.01%	57.87%	41.81%	36.54	0.0020
JMS 17B	.00000	1.30%	62.34%	36.15%	31.26	0.0036
JMS 18B	.00183	2.24%	71.82%	25.62%	57.57	0.0072
JMS 19B	.00001	0.82%	56.64%	42.09%	521.02	0.0015
JMS 20B	.00000	2.51%	81.62%	15.16%	28.34	0.0054
JMS 21B	.00002	0.90%	58.56%	40.07%	575.09	0.0015
JMS 22B	.00002	0.97%	58.65%	39.90%	588.06	0.0011
JMS 23B	.00000	15.40%	68.67%	15.37%	57.87	0.0033
JMS 24B	.00002	2.21%	59.32%	37.98%	649.79	0.0017
JMS 25B	.00000	71.64%	21.11%	5.87%	15.77	0.0037
JMS 26B	.00002	2.32%	59.84%	37.33%	673.36	0.0017
JMS 27B	.00001	4.56%	58.41%	36.31%	706.17	0.0019
JMS 28B	.00000	5.63%	87.55%	6.24%	6.91	0.0103
JMS 29B	.00000	74.47%	20.83%	4.19%	60.50	0.0054
JMS 30B	.00000	37.74%	47.45%	14.42%	36.24	0.0020
JMS 31B	1.81819	51.59%	38.44%	9.38%	121.25	0.0020
JMS 32B	.43729	27.46%	60.14%	11.88%	247.22	0.0017
JMS 33B	.00002	4.59%	59.87%	34.80%	765.24	0.0017
JMS 34B	.00002	4.63%	59.86%	34.77%	766.68	0.0017
JMS 35B	.00002	4.59%	59.86%	34.82%	764.39	0.0017
JMS 36B	.00000	4.68%	59.85%	34.73%	768.73	0.0017
JMS 37B	.00000	39.22%	47.24%	12.85%	25.36	0.0023
JMS 38B	.00000	6.24%	60.24%	32.73%	852.19	0.0011
JMS 39B	.02055	10.61%	61.00%	27.65%	1140.73	0.0009
JMS 40B	.01922	10.29%	61.24%	27.72%	1179.58	0.0008

SAMPLE	PSLI	%	%	%	Ad	SLOPE
	(Mg P/km ² /yr)	urban	ag	for	Km2	
JMS 41B	.00000	0.81%	52.25%	46.77%	293.04	0.0014
JMS 42B	.00001	0.08%	52.90%	46.90%	48.44	0.0027
JMS 43B	.00004	1.08%	54.22%	44.55%	213.16	0.0014
JMS 44B	.00226	2.61%	53.38%	43.87%	15.29	0.0043
JMS 45B	.00001	1.01%	59.55%	39.08%	504.63	0.0021
JMS 46B	.00006	1.91%	64.30%	33.36%	648.71	0.0008
JMS 47B	.00018	1.86%	64.04%	33.66%	666.94	0.0040
JMS 48B	.00064	1.77%	61.94%	36.17%	48.66	0.0045
JMS 49B	.00019	1.15%	54.96%	43.73%	161.30	0.0018
JMS 50B	.00001	0.64%	54.04%	45.06%	391.90	0.0020
JMS 51B	.00638	7.13%	62.24%	29.99%	1878.88	0.0011
JMS 52B	.00000	0.03%	64.21%	35.74%	27.97	0.0059
JMS 53B	.00712	7.00%	62.25%	30.10%	1914.11	0.0010
JMS 54B	.00002	0.31%	66.27%	33.33%	56.76	0.0113
JMS 55B	.00002	1.33%	29.45%	69.10%	58.34	0.0029
JMS 56B	.00732	6.90%	62.36%	30.09%	1940.87	0.0011
JMS 57B	.00702	6.85%	62.24%	30.25%	1954.08	0.0011
JMS 58B	.00008	6.79%	62.09%	30.47%	1973.10	0.0009
JMS 59B	.00688	6.78%	62.09%	30.46%	1973.96	0.0009
JMS 60B	.00646	6.59%	62.18%	30.58%	2037.69	0.0009
JMS 61B	.00643	6.57%	62.15%	30.61%	2042.20	0.0009
JMS 62B	.00760	6.55%	62.09%	30.69%	2051.01	0.0009
JMS 63B	.00442	5.60%	64.66%	29.10%	2453.51	0.0008
JMS 64B	.00448	5.56%	64.63%	29.17%	2469.96	0.0008
JMS 65B	.00112	5.55%	64.62%	29.18%	2472.54	0.0008
JMS 66B	.00497	0.11%	83.45%	16.25%	112.36	0.0035
JMS 67B	.00442	0.63%	78.67%	20.30%	395.97	0.0018
JMS 68B	.00399	0.94%	78.95%	19.89%	208.76	0.0024
JMS 69B	.00219	2.06%	74.06%	23.48%	410.64	0.0031
JMS 70B	.00282	1.83%	70.07%	27.67%	466.09	0.0021
JMS 71B	.00095	1.32%	59.16%	39.03%	706.53	0.0007
JMS 72B	.00081	1.25%	57.89%	40.34%	765.14	0.0007
JMS 73B	.00689	5.52%	64.41%	29.41%	2487.76	0.0017
JMS 74B	.00496	5.51%	64.35%	29.48%	2491.05	0.0018
JMS 75B	.00495	5.51%	64.33%	29.49%	2492.52	0.0012
JMS 76B	.00494	5.50%	64.31%	29.51%	2494.63	0.0040
JMS 77B	.02043	10.58%	60.98%	27.70%	1143.94	0.0007
JMS 78B	.02018	10.47%	61.02%	27.76%	1151.16	0.0007
JMS 79B	.02002	10.47%	61.02%	27.76%	1155.63	0.0007
JMS 80B	.01983	10.05%	61.22%	27.97%	1208.74	0.0010

SAMPLE	DMS_X	DMS_Y	RIVER	
			CREEK	COUNTY
JMS 01B	-92 43 26	37 12 27	JAMES RIVER	WEBSTER
JMS 02B	-92 44 40	37 11 38	JAMES RIVER	WEBSTER
JMS 03B	-92 46 44	37 11 28	JAMES RIVER	WEBSTER
JMS 04B	-92 48 58	37 12 13	JAMES RIVER	WEBSTER
JMS 05B	-92 49 22	37 12 19	JAMES RIVER	WEBSTER
JMS 06B	-92 52 28	37 14 37	JAMES RIVER	WEBSTER
JMS 07B	-92 54 34	37 15 35	JAMES RIVER	WEBSTER
JMS 08B	-92 56 52	37 15 56	JAMES RIVER	WEBSTER
JMS 09B	-92 59 58	37 15 46	JAMES RIVER	WEBSTER
JMS 10B	-93 4 44	37 12 13	JAMES RIVER	GREENE
JMS 11B	-93 7 35	37 11 38	JAMES RIVER	GREENE
JMS 12B	-93 2 31	37 12 57	PANTHER CREEK	WEBSTER
JMS 13B	-93 1 56	37 14 2	JAMES RIVER	WEBSTER
JMS 14B	-93 00 27	37 14 51	NORTH CAROLINA CREEK	WEBSTER
JMS 15B	-92 49 5	37 11 44	WILDCAT CREEK	WEBSTER
JMS 16B	-92 56 29	37 15 55	DRY CREEK	WEBSTER
JMS 17B	-92 59 14	37 16 12	TURBO CREEK	WEBSTER
JMS 18B	-93 6 10	37 11 31	SAWYER CREEK	GREENE
JMS 19B	-93 8 56	37 11 13	JAMES RIVER	GREENE
JMS 20B	-93 9 46	37 10 35	TURNERS CREEK	GREENE
JMS 21B	-93 9 59	37 10 40	JAMES RIVER	GREENE
JMS 22B	-93 11 36	37 9 52	JAMES RIVER	GREENE
JMS 23B	-93 11 46	37 10 1	PEARSON CREEK	GREENE
JMS 24B	-93 12 4	37 9 5	JAMES RIVER	GREENE
JMS 25B	-93 14 3	37 7 47	GALLOWAY CREEK	GREENE
JMS 26B	-93 13 2	37 8 00	JAMES RIVER	GREENE
JMS 27B	-93 15 55	37 6 36	JAMES RIVER	GREENE
JMS 28B	-93 14 46	37 4 25	FARMER BRANCH	CHRISTIAN
JMS 29B	-93 20 41	37 10 2	SOUTH CREEK	GREENE
JMS 30B	-93 22 11	37 10 8	WILSON CREEK	GREENE
JMS 31B	-93 22 33	37 8 33	WILSON CREEK	GREENE
JMS 32B	-93 23 57	37 4 40	WILSON CREEK	CHRISTIAN
JMS 33B	-93 17 4	37 5 18	JAMES RIVER	CHRISTIAN
JMS 34B	-93 17 14	37 5 18	JAMES RIVER	CHRISTIAN
JMS 35B	-93 16 52	37 5 20	JAMES RIVER	CHRISTIAN
JMS 36B	-93 17 25	37 5 21	JAMES RIVER	CHRISTIAN
JMS 37B	-93 19 36	37 6 15	JAMES RIVER	GREENE
JMS 38B	-93 22 21	37 4 32	JAMES RIVER	CHRISTIAN
JMS 39B	-93 23 31	37 3 1	JAMES RIVER	CHRISTIAN
JMS 40B	-93 22 10	36 59 39	JAMES RIVER	CHRISTIAN

SAMPLE	DMS X	DMS Y	RIVER	
			CREEK	COUNTY
JMS 41B	-92 59 32	37 2 51	FINLEY CREEK	CHRISTIAN
JMS 42B	-92 58 16	37 3 24	STEWART CREEK(FINELY CREEK)	CHRISTIAN
JMS 43B	-92 57 13	37 4 37	FINLEY CREEK	CHRISTIAN
JMS 44B	-92 55 40	37 6 40	TERELL BRANCH	WEBSTER
JMS 45B	-93 11 51	37 2 32	FINLEY CREEK	CHRISTIAN
JMS 46B	-93 19 41	36 58 29	FINLEY CREEK	CHRISTIAN
JMS 47B	-93 21 21	36 57 51	FINLEY CREEK	STONE
JMS 48B	-92 48 42	37 5 55	FINLEY CREEK	WEBSTER
JMS 49B	-92 55 17	37 5 47	FINLEY CREEK	WEBSTER
JMS 50B	-93 5 41	37 2 34	FINLEY CREEK	CHRISTIAN
JMS 51B	-93 21 35	36 57 30	JAMES RIVER	STONE
JMS 52B	-93 21 25	36 56 49	JAMES RIVER	STONE
JMS 53B	-93 22 48	36 56 40	JAMES RIVER	STONE
JMS 54B	-93 23 59	36 52 54	GOFF CREEK	STONE
JMS 55B	-93 27 8	36 47 48	RAILEY CREEK	STONE
JMS 56B	-93 23 36	36 55 33	JAMES RIVER	STONE
JMS 57B	-93 22 33	36 54 48	JAMES RIVER	STONE
JMS 58B	-93 24 17	36 54 10	JAMES RIVER	STONE
JMS 59B	-93 24 18	36 53 31	JAMES RIVER	STONE
JMS 60B	-93 25 21	36 53 23	JAMES RIVER	STONE
JMS 61B	-93 25 30	36 52 12	JAMES RIVER	STONE
JMS 62B	-93 26 32	36 51 5	JAMES RIVER	STONE
JMS 63B	-93 27 38	36 50 53	JAMES RIVER	STONE
JMS 64B	-93 28 18	36 50 5	JAMES RIVER	STONE
JMS 65B	-93 26 54	36 49 51	JAMES RIVER	STONE
JMS 66B	-93 29 36	36 54 44	SPRING CREEK(CRANE CREEK)	STONE
JMS 67B	-93 27 33	36 51 54	CRANE CREEK	STONE
JMS 68B	-93 30 55	36 53 37	CRANE CREEK	STONE
JMS 69B	-93 47 37	36 49 17	LITTLE FLAT CREEK	BARRY
JMS 70B	-93 44 15	36 48 6	FLAT CREEK	BARRY
JMS 71B	-93 37 3	36 45 8	FLAT CREEK	BARRY
JMS 72B	-93 33 36	36 45 29	FLAT CREEK	STONE
JMS 73B	-93 26 30	36 49 11	JAMES RIVER	STONE
JMS 74B	-93 26 7	36 48 57	JAMES RIVER	STONE
JMS 75B	-93 27 00	36 49 3	JAMES RIVER	STONE
JMS 76B	-93 27 46	36 48 32	JAMES RIVER	STONE
JMS 77B	-93 22 56	37 2 36	JAMES RIVER	CHRISTIAN
JMS 78B	-93 22 50	37 2 9	JAMES RIVER	CHRISTIAN
JMS 79B	-93 21 51	37 1 34	JAMES RIVER	CHRISTIAN
JMS 80B	-93 21 54	36 58 2	JAMES RIVER	STONE

SAMPLE	SITE DESCRIPTION
JMS 01B	APPROXIMATELY 0.19 KM UPSTREAM OF COUNTY ROAD 208
JMS 02B	APPROXIMATELY 0.1 KM DOWNSTREAM OF COUNTY ROAD 215
JMS 03B	APPROXIMATELY 0.17 KM UPSTREAM OF COUNTY ROAD 229
JMS 04B	APPROXIMATELY 0.32 KM UPSTREAM OF COUNTY ROAD 230
JMS 05B	APPROXIMATELY 0.45 KM DOWNSTREAM OF STATE HWY O
JMS 06B	APPROXIMATELY 0.08 KM UPSTREAM OF COUNTY ROAD 409
JMS 07B	APPROXIMATELY 0.21 KM UPSTREAM OF STATE HWY KK
JMS 08B	APPROXIMATELY 0.39 KM UPSTREAM OF STATE HWY B
JMS 09B	APPROXIMATELY 0.56 KM UPSTREAM OF STATE HWY A
JMS 10B	APPROXIMATELY 0.05 KM UPSTREAM OF STATE HWY YY
JMS 11B	APPROXIMATELY 0.24 KM UPSTREAM OF STATE HWY 125
JMS 12B	APPROXIMATELY 5.09 KM DOWNSTREAM OF STATE HWY B
JMS 13B	APPROXIMATELY 0.18 KM UPSTREAM OF STATE HWY B
JMS 14B	APPROXIMATELY 0.10 KM UPSTREAM OF STATE HWY B
JMS 15B	APPROXIMATELY 0.04 KM UPSTREAM OF COUNTY ROAD 226
JMS 16B	APPROXIMATELY 0.18 KM DOWNSTREAM OF COUNTY ROAD 404
JMS 17B	APPROXIMATELY 0.24 KM DOWNSTREAM OF COUNTY ROAD 478
JMS 18B	APPROXIMATELY 0.13 KM UPSTREAM OF STATE HWY AD
JMS 19B	APPROXIMATELY 2.22 KM DOWNSTREAM OF STATE HWY 125
JMS 20B	APPROXIMATELY 0.10 KM DOWNSTREAM OF STATE HWY NN
JMS 21B	APPROXIMATELY 0.25 KM DOWNSTREAM OF OLD STATE HWY D
JMS 22B	APPROXIMATELY 3.82 KM DOWNSTREAM OF OLD STATE HWY D
JMS 23B	APPROXIMATELY 0.67 KM DOWNSTREAM OF FARM ROAD 193
JMS 24B	APPROXIMATELY 0.30 KM UPSTREAM OF COUNTY ROAD 194
JMS 25B	APPROXIMATELY 0.05 KM UPSTREAM OF STATE HWY 60
JMS 26B	APPROXIMATELY 1.55 KM UPSTREAM OF STATE HWY 60
JMS 27B	APPROXIMATELY 0.28 KM DOWNSTREAM OF DAM AT LAKE SPRINGFIELD
JMS 28B	APPROXIMATELY 1.83 KM DOWNSTREAM OF US HWY 65
JMS 29B	APPROXIMATELY 0.37 KM DOWNSTREAM OF GOLDEN AVE
JMS 30B	APPROXIMATELY 0.07 KM UPSTREAM OF BROOKLINE RD.
JMS 31B	APPROXIMATELY 0.36 KM UPSTREAM OF STATE HWY M
JMS 32B	APPROXIMATELY 0.24 KM DOWNSTREAM OF MANLEY FORD
JMS 33B	APPROXIMATELY 1.40 KM UPSTREAM OF US HWY 160
JMS 34B	APPROXIMATELY 1.70 KM UPSTREAM OF US HWY 160
JMS 35B	APPROXIMATELY 1.09 KM UPSTREAM OF US HWY 160
JMS 36B	APPROXIMATELY 0.76 KM UPSTREAM OF US HWY 160
JMS 37B	APPROXIMATELY 0.18 KM DOWNSTREAM OF RIVER DOWNS RD.
JMS 38B	APPROXIMATELY 3.22 KM UPSTREAM OF CONFLUENCE OF WILSON CREEK
JMS 39B	APPROXIMATELY 0.61 KM UPSTREAM OF STATE HWY 14 (DELAWARE TOWN ACCESS)
JMS 40B	APPROXIMATELY 1.68 KM DOWNSTREAM OF SHELVIN ROCK RD. (BOAZ)

SAMPLE	SITE DESCRIPTION
JMS 41B	APPROXIMATELY 0.30 KM UPSTREAM OF STATE HWY ZZ?
JMS 42B	APPROXIMATELY 0.07 KM DOWNSTREAM OF MARSHFIELD RD
JMS 43B	APPROXIMATELY 2.49 KM UPSTREAM OF STATE HWY KK
JMS 44B	APPROXIMATELY 0.09 KM UPSTREAM OF ROAD 354
JMS 45B	APPROXIMATELY 0.28 KM DOWNSTREAM OF RIVERSIDE RD
JMS 46B	APPROXIMATELY 0.02 KM DOWNSTREAM OF RIVERDALE RD
JMS 47B	APPROXIMATELY 0.57 KM UPSTREAM OF CONFLUENCE WITH JAMES RIVER
JMS 48B	APPROXIMATELY 0.16 KM UPSTREAM OF STATE HWY BB
JMS 49B	APPROXIMATELY 0.08 KM DOWNSTREAM OF STATE HWY Z
JMS 50B	APPROXIMATELY 0.14 KM UPSTREAM OF ROAD 125-17C
JMS 51B	APPROXIMATELY 1.02 KM DOWNSTREAM OF STATE HWY M
JMS 52B	APPROXIMATELY 2.44 KM DOWNSTREAM OF STATE HWY M
JMS 53B	APPROXIMATELY 4.59 KM DOWNSTREAM OF STATE HWY M
JMS 54B	APPROXIMATELY 0.23 KM DOWNSTREAM OF STATE HWY V
JMS 55B	APPROXIMATELY 1.11 KM UPSTREAM OF STATE HWY 13
JMS 56B	APPROXIMATELY 1.92 KM DOWNSTREAM OF ROAD V20
JMS 57B	APPROXIMATELY 3.11 KM UPSTREAM OF ROAD V70
JMS 58B	APPROXIMATELY 0.62 KM DOWNSTREAM OF ROAD V70
JMS 59B	APPROXIMATELY 1.89 KM DOWNSTREAM OF ROAD V70
JMS 60B	APPROXIMATELY 4.42 KM DOWNSTREAM OF ROAD V70
JMS 61B	APPROXIMATELY 7.83 KM DOWNSTREAM OF ROAD V70
JMS 62B	APPROXIMATELY 1.12 KM UPSTREAM OF CONFLUENCE OF CRANE CREEK
JMS 63B	APPROXIMATELY 1.23 KM DOWNSTREAM OF CONFLUENCE OF CRANE CREEK
JMS 64B	APPROXIMATELY 3.19 KM DOWNSTREAM OF CONFLUENCE OF CRANE CREEK
JMS 65B	APPROXIMATELY 5.60 KM DOWNSTREAM OF CONFLUENCE OF CRANE CREEK
JMS 66B	APPROXIMATELY 0.08 KM UPSTREAM OF STATE HWY CC
JMS 67B	APPROXIMATELY 1.56 KM UPSTREAM OF STATE HWY AA
JMS 68B	APPROXIMATELY 0.44 KM SOUTH OF STATE HWY BB
JMS 69B	APPROXIMATELY 0.11 KM DOWNSTREAM OF STATE HWY C
JMS 70B	APPROXIMATELY 0.10 KM DOWNSTREAM OF STATE HWY WW
JMS 71B	APPROXIMATELY 0.20 KM DOWNSTREAM OF STATE HWY EE
JMS 72B	APPROXIMATELY 0.09 KM DOWNSTREAM OF ROAD 76-100
JMS 73B	APPROXIMATELY 6.30 KM UPSTREAM OF STATE HWY 176
JMS 74B	APPROXIMATELY 5.59 KM UPSTREAM OF STATE HWY 176
JMS 75B	APPROXIMATELY 3.65 KM UPSTREAM OF STATE HWY 176
JMS 76B	APPROXIMATELY 0.46 KM UPSTREAM OF STATE HWY 176
JMS 77B	APPROXIMATELY 0.37 KM DOWNSTREAM OF STATE HWY 14
JMS 78B	APPROXIMATELY 1.33 KM DOWNSTREAM OF STATE HWY 14
JMS 79B	APPROXIMATELY 3.18 KM DOWNSTREAM OF STATE HWY 14
JMS 80B	APPROXIMATELY 0.16 KM UPSTREAM OF STATE HWY M