

To the Graduate Council:

I am submitting herewith a thesis written by Angela Nicole Danovi entitled "Phosphorus Distribution in Channel-Bed Sediments in Beaver Creek, Knox County, Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

Carol Harden, Major Professor

We have read this thesis
and recommend its acceptance:

Liem Tran

Michael Essington

Accepted for the Council

Carolyn R. Hodges
Vice Provost and Dean of the Graduate School

**Phosphorus Distribution in Channel-Bed Sediments in Beaver Creek,
Knox County, Tennessee**

A Thesis Presented for
the Master of Science
Degree
The University of Tennessee, Knoxville

Angela Nicole Danovi
May 2011

Copyright © 2011 by Angela Nicole Danovi
All rights reserved.

DEDICATION

This thesis is dedicated to my mother and my sister who have shown me love and support throughout my life, especially while completing this project.

I am proud to also dedicate this thesis to the late Ms. Susan Rome, former middle school science teacher at St. Ann's School in Bartlett, TN. Her love of science combined with her ability to transfer scientific knowledge while encouraging scientific inquiry inspired me to pursue advanced study in science.

ACKNOWLEDGEMENTS

I am extremely appreciative for the assistance and support from the following individuals who helped me to complete this thesis.

Thank you to Dr. Carol Harden, for serving as my advisor, supporting this project, and assisting me in all aspects of this research including assisting with planning the project, assisting with fieldwork, and editing this thesis. Her help and guidance were invaluable to me while completing this work.

Thank you to Dr. Liem Tran for his advice and guidance throughout this project. His ingenuity helped me in the field and his expertise in statistics and geography helped me to improve my work presented here.

Thank you to Dr. Michael Essington for providing lab space and expertise in soil chemistry. He was always willing to assist me with any aspect of this thesis and his guidance and expertise helped me to improve my understanding of soil and sediment processes and improve the information contained within this document.

Thank you to the following Geography graduate students, James Baginski, Nancy Li, and Tim Green, and Geography professors, Dr. Carol Harden and Dr. Liem Tran, for providing their assistance in the field, especially in difficult field conditions. They were extremely helpful to me in completing the necessary fieldwork for this project.

Thank you to Roy Arthur, Knox County Watershed Coordinator, for assisting me with locating sampling sites within the Beaver Creek Watershed that met the scope and plan for this project.

Thank you to a late unnamed landowner who graciously assisted me with this research project. He held a lifelong love and appreciation for the Beaver Creek Watershed and was eager to see this study completed.

I am pleased to acknowledge a grant that supported the work described here. For one year, I was supported as a Fellow by the University of Tennessee's GK-12 Earth Project, funded by the National Science Foundation through Grant No. 0538420 to Dr. Sally Horn, Dr. Ken Orvis, and Dr. Lynn Champion. The GK-12 Earth Project covered some of the field and laboratory costs of this project.

I am also very appreciative of the personal support provided to me from Ms. Clara M. Johnson. Her support was vital to me while I completed this project. Additionally, Michael Sawyer and Angela Rogers also provided their personal support while I completed this work.

Lastly, I am extremely grateful for the support from my mother, Demarious K. Danovi. She always encouraged me during my graduate studies and also provided direct support and moral support to me throughout this process. After receiving her Masters in English, she inspired me to pursue my graduate studies. I am happy to be able to share this completed thesis with her.

ABSTRACT

Beaver Creek, located in North Knox County, Tennessee, is on the Tennessee 303(d) list as an impaired stream that fails to meet its designated uses. Phosphorus (P) is one of the major pollutants of the stream. High P levels within surface water can lead to water quality problems including low dissolved oxygen, overgrowth of algae, and eutrophication. Two sources, pasture grazing areas and major municipal point sources, have been identified as important contributors of P to Beaver Creek. The objective of this study was to analyze the total P and Mehlich III extractable P concentrations of sediments in Beaver Creek and determine if a P signal could be identified in sediments collected along two stream reaches, less than 1500 m long, adjacent to a cattle farm and a wastewater treatment plant (WWTP). Eight sites were sampled within Beaver Creek, divided between two locations. At each sample location, four sample sites were selected. One site, the “control” was upstream of the P input. One, the “source,” was immediately downstream of the P input. Two additional sites, one within 200 m and the second within 400 m downstream of the source, were selected at each location. Nine sediment samples were collected at each sample site. Sediments were analyzed for total P (SW-3050B) and Mehlich III extractable P. ANOVA was run between the sites at each location and t-tests were completed to look for significant differences and a downstream signal. At the cattle farm, P concentrations of sediments at the downstream 2 site were significantly higher than sediment P concentrations at the three other sites. However, unexpectedly high results from the control sample site, combined with unexpectedly low results from the source sample site made it difficult to assess whether the cattle farm was affecting

sediment P in Beaver Creek. At the WWTP, the sediment P near the outfall was significantly higher than sediment P at the control. Sediments at the downstream 1 site had significantly higher P concentrations than sediments at the other three sites, indicating that the WWTP may be affecting sediment P in Beaver Creek. This study supports the hypothesis that increased P concentrations could be attributable to P inputs from a WWTP. However, further study is needed about the effects that pastures have on sediment P concentrations within Beaver Creek.

TABLE OF CONTENTS

Chapter 1: Introduction	1
Phosphorus in the Environment	3
Phosphorus Movement and Interaction in Water.....	5
Mass Balance of Phosphorus in Water	7
Nutrient Research in East Tennessee	9
Research Objective	9
Research Questions and Hypotheses	10
Organization of Thesis	11
Chapter 2: Study Area.....	12
Physiographic Setting	14
Beaver Creek Landuse	16
Environmental Concerns of Beaver Creek	17
Residential and Agricultural Activity in Beaver Creek Watershed	21
Study Locations	22
Location 1: Cattle Farm	24
Location 2: Wastewater Treatment Plant.....	26
Chapter 3: Study Design and Methods	28
Study Design.....	28
Sample Site Overview.....	30
Field Methods	40

Lab Methods	42
Lab Analyses.....	43
Mehlich III P –Extraction Procedure	44
Inductively Coupled Plasma – Analysis	44
Data Entry and Statistical Analysis.....	45
Comparison of Total P and Mehlich III extractable P Within Sampling Locations.	45
Chapter 4: Results.....	48
Descriptive Statistics.....	50
Cattle Farm.....	50
Wastewater Treatment Plant	57
Comparison of Total P and Mehlich III extractable P Within Sampling Locations.....	64
ANOVA – Within Sampling Locations	64
Levene’s Test for Equal Variance.....	66
Comparison of Sampling Sites at the Cattle Farm.....	68
Comparison of Sampling Sites at the Wastewater Treatment Plant	71
Upstream Comparisons.....	73
Cattle Farm.....	73
Wastewater Treatment Plant	75
Chapter 5: Discussion	78
Overview.....	78
Discussion on the cattle farm.....	79
Discussion on the WWTP	82

Research Conclusions	83
Future Research and Future Implications	84
VITA.....	93

LIST OF TABLES

Table 2-1. Excerpt of Tennessee 303(d) list featuring Beaver Creek.....	20
Table 3-1. Sample site descriptions, GPS coordinates, stream widths, sample dates, and segment distances at the cattle farm.....	33
Table 3-2. Sample site descriptions, GPS coordinates, stream widths, sample dates, and segment distances at the WWTP.....	38
Table 4-1. Total P results by sample site at the cattle farm.....	48
Table 4-2. Mehlich III P results by sample site from the cattle farm.....	49
Table 4-3. Total P results by sample site at the WWTP.....	49
Table 4-4. Mehlich III P results by sample site from the WWTP.....	50
Table 4-5. Descriptive statistics for total P at the cattle farm.....	51
Table 4-6. Descriptive statistics for Mehlich III P at the Cattle Farm.....	51
Table 4-7. Descriptive Statistics for total P at the WWTP (mg P/kg sediment).....	58
Table 4-8. Descriptive Statistics for Mehlich III P at the WWTP (mg P/kg sediment)...	58
Table 4-9. ANOVA results between sites for total P at the cattle farm.....	65
Table 4-10. ANOVA results between sites for Mehlich III P at the cattle farm.....	65
Table 4-11. ANOVA results between sites for total P at the WWTP.....	65
Table 4-12. ANOVA Results for Mehlich III P at the WWTP.....	65
Table 4-13. Levene's test for equal variances for total P results between sample sites at the cattle farm.....	66
Table 4-14. Levene's test for equal variances for Mehlich III P results between sample sites at the cattle farm.....	67
Table 4-15. Levene's test for equal variances for total P results between sample sites at the WWTP.....	67

Table 4-16. Levene's test for equal variances for Mehlich III P results between sample sites at the WWTP.....	67
Table 4-17. Two tailed t-test results for Total P between sample sites at the cattle farm	69
Table 4-18. Two tailed t-test results for Mehlich III P between sample sites at the cattle farm.....	69
Table 4-19. Mann-Whitney results for total P between sampling sites at the cattle farm	70
Table 4-20. Mann-Whitney results for Mehlich III P between sample sites at the cattle farm.....	71
Table 4-21. Two tailed t-test results for total P between sample sites at the WWTP.....	72
Table 4-22. Two tailed t-test results for Mehlich III P between sample sites at the WWTP.....	72
Table 4-23. Mann-Whitney results for total P between sample sites at the WWTP.....	72
Table 4-24. Mann-Whitney results for Mehlich III P between sample sites at the WWTP.....	73
Table 4-25. One tailed t-test results for total P between sample sites at the cattle farm...	75
Table 4-26. One tailed t-test results for Mehlich III P between sample sites at the cattle farm.....	75
Table 4-27. One tailed t-test results for total P between sites at the WWTP.....	76
Table 4-28. One tailed t-test results for Mehlich III P between sites at the WWTP.....	76

LIST OF FIGURES

Figure 2.1. Map of watersheds in Knox County, TN.	13
Figure 2.2. Map of physiographic regions of Tennessee.	15
Figure 2.3. Pie chart of 2004 landuse composition of Beaver Creek Watershed.	17
Figure 2.4. Map of north Knox County, TN designating the cattle farm and the WWTP sampling locations..	23
Figure 2.5. Map of the cattle farm sampling location in Knox County, Tennessee.	25
Figure 2.6. Map of the WWTP sampling location in Knox County, Tennessee	27
Figure 3.1. Sampling design plan..	29
Figure 3.2. Map of cattle farm sampling sites: control, source, downstream 1, and downstream 2.	34
Figure 3.3. Photo of cattle farm pasture near the farm sampling site in Beaver Creek Watershed	35
Figure 3.4. Photo of Beaver Creek upstream of the cattle farm.	35
Figure 3.5. Photo of first cattle access area from the farm to Beaver Creek.	36
Figure 3.6. Photo of second cattle access area from the farm to Beaver Creek.....	36
Figure 3.7. Photo of third cattle access area from the farm to Beaver Creek.	37
Figure 3.8. Photo of Beaver Creek downstream from cattle farm.	37
Figure 3.9. Map of WWTP sampling sites: control, source, downstream 1, and downstream 2.	39
Figure 3.10. Photo of in stream sampling near the streambank at the cattle farm sampling site in Beaver Creek.	41
Figure 3.11. Photo of midstream sampling at the cattle farm sampling site in Beaver Creek.	41
Figure 4.1. Histogram of total P data from all sample sites at the cattle farm.....	52

Figure 4.2. Histogram of Mehlich III P data from all sample sites at the cattle farm.	53
Figure 4.3. Box plots for total P results from cattle farm sampling sites, control, source, downstream 1, and downstream 2.....	55
Figure 4.4. Box Plots for Mehlich III P results from the cattle farm sampling sites: control, source, downstream 1, and downstream 2.....	56
Figure 4.5. Histogram of total P data from all sites at the WWTP.....	59
Figure 4.6. Histogram of Mehlich III P data from all sites at the WWTP.....	60
Figure 4.7. Box Plots for total P results from the WWTP sampling sites: control, source, downstream 1, and downstream 2.....	62
Figure 4.8. Box Plots for Mehlich III P results from the WWTP sampling sites: control, source, downstream 1, and downstream 2.	63

Chapter 1

Introduction

Water is essential for all life on Earth. However, usable water for humans, plants, and animals is generally only available as fresh surface or ground water. Most of Earth's water is unavailable for human and animal use because it is in oceans or locked in glaciers and ice caps. The imbalance of available fresh drinking water, with such a small fraction of water in lakes, rivers, streams, estuaries, and groundwater, leaves these fresh surface water resources vulnerable to overuse and pollution.

The quality of fresh water is important because it is used for human consumption, recreation, fishing, agriculture, and commercial industry. Since the 1940s, global annual water usage has rapidly increased (Biswas, 1997). This global increase is a result of large increases in water usage per capita, combined with population increases. As a result of these combined increases, the amount of water available per capita within individual nations is projected to dramatically decrease over the next 40 years (Biswas, 1997). Additionally, population movement to arid climates found in Arizona and Nevada has placed increased pressure for water availability and high quality water on already diminished water resources.

Water availability and water quality are linked because increased contamination of water reduces its availability, while also increasing the costs for water treatment. In many cases, certain water contaminants cannot be easily removed or water decontamination would become too costly for communities. Therefore, maintaining high quality water or improving water quality within local watersheds has become recognized as one of the most effective measures for maintaining or increasing water supplies.

Chemical properties of water also make fresh water supplies vulnerable to degradation. The H₂O molecule is polar, having a slight positive charge on the hydrogen side and a slight negative charge on the oxygen side. This property allows water to dissolve and mobilize pollutants, transfer those pollutants to a nearby waterway, and transport them downstream to larger water bodies, where water quality problems can become exacerbated. When precipitation falls on the land surface within a watershed, it can transport pollutants and degrade the receiving waters. Sediment, chemicals, and pathogens can be transported by water and can impact water quality directly or indirectly, causing degradation, loss of fish and animal habitat, and increased costs and effort to make water potable for human consumption. Water quality problems associated with chemical interactions include nutrient enrichment, oxygen-consuming wastes, inorganic chemicals, organic chemicals, sediments, infectious agents, radioactive substances, and thermal energy (Pierzynski et al., 2000).

One of the most prevalent water quality problems is nutrient enrichment. Nutrient enrichment of waterways causes long-term water quality and water usage problems (Carpenter et al., 1998; Bricker et al., 2008). These problems include the formation of toxic algal blooms, decrease of dissolved oxygen in water, fish kills, and loss of aquatic biodiversity, including decreases in aquatic plant and animal species. In 1990, eutrophication, a result of nutrient enrichment, was considered to be the most common surface water impairment in the nation (US EPA 1990). In 1996, eutrophication was cited as the reason for water quality impairment in approximately 50% of lakes and over 60% of impaired river reaches (US EPA, 1996).

Eutrophication is generally defined as an increase in the nutrient levels of water that increases growth of algae and macrophytes and decreases water quality (Young et al., 1999; Pierzynski et al., 2000). As watersheds are transformed by humans from a natural state into

agricultural or urban uses, nutrients can become mobilized and readily enter the waterways, causing nutrient enrichment at the source and downstream (Becher et al., 2000). Increased nutrient levels in water often stimulate algal growth, resulting in large plumes that can choke waterways, degrade water quality, and produce foul odors and unpalatable water. In extreme cases, eutrophic waters can cause fish kills as a result of decreased dissolved oxygen levels.

While nutrient enrichment involves both nitrogen and phosphorus (P), lake-based studies of the effects of manipulating the nitrogen/phosphorus ratio have shown P controls to have the greater impact on algal production (Schindler, 1977; Schindler et al., 2008). Models by Prairie et al. (1989) also have found a positive relationship between total P and chlorophyll a in lakes and have supported Schindler's findings. Therefore, today, most of the work controlling nutrient enrichment of waterways focuses on limiting P.

Phosphorus in the Environment

Two main forms of P exist in the environment: organic P and inorganic P. Each of these forms of P can exist in two phases, soluble and particulate. Organic P is bound in organic matter such as grasses, algae, or higher plants and animals and is comprised from both living and dead plant and animal matter. In waterbodies, organic particulate P can include algae, fish, and benthic macroinvertebrates. Soluble organic P can include dissolved organic P that originates in animal excrement. Human and animal wastes "represent a transformation of biologically accumulated P from food crops to potentially recyclable organic matter" (Pierzynski et al., 2005). As microbes break down organic P, soluble organic P is released and over time can be converted into stable forms of inorganic P.

Soluble inorganic P exists in two orthophosphate forms, H_2PO_4^- and HPO_4^{2-} , known as soluble reactive phosphorus, and can become available through desorption, dissolution, and extraction processes. These processes dissociate the chemical bonds that hold the phosphate anions to the soil matrix and make the phosphate anion available for plant uptake. If the phosphate anion is transported to a waterway, it will be available for algal uptake. Consequently, any land area that contributes large amounts of orthophosphates can be facilitating nutrient enrichment and excessive algal growth in the waterway.

Particulate P represents organic P and orthophosphates that are tightly bound to sediment or organic particles. It includes all of the solid phosphate forms, phosphates adsorbed to clay minerals, and organic phosphates. Particulate P may be suspended in the water column or may be settled to the bottom of a lake or waterway. Particulate P enters a waterbody through overland erosion or through the erosion of streambanks and has been estimated to make up as much as 75-90% of all P that is moving from the land (Sharpley and Halvorson, 1994). Since less energy is required to move smaller particles from land, clays and organic matter are more readily moved from the land to waterways. The greater surface area of smaller particles provides increased sites for phosphate adsorption. A portion of particulate P is bioavailable and particulate P can actually represent a more long-term P source in aquatic systems because P cycling can continue to occur depending on environmental conditions in an aquatic system. Consequently, particulate phosphates can transform into soluble phosphates and be released from benthic sediments into the water column (Haggard et al., 2005).

Bioavailable P is generally considered to be the fraction of total P that is available for algal uptake (Zhou, 2001; Banom and Sarkar, 2004). Identifying bioavailable P is important because excessive algal growth has been connected to eutrophication and hypoxia in creeks,

streams and rivers, which is directly related to bioavailable P. Recent research focusing on bioavailable sediment P is limited, and researchers have not identified a singular extraction process as the best process to identify and quantify bioavailable P (Zhou, 2001; Branom and Sarkar, 2004; Hoffman et al., 2009).

Phosphorus Movement and Interaction in Water

Phosphorus is introduced into water bodies from natural and anthropogenic sources. Naturally, P is found in watersheds containing igneous or sedimentary phosphate rocks (Stewart et al., 2005). As those rocks weather, the phosphates can enter the soil matrix or attach to water molecules and enter the waterway. Generally, the natural mechanisms of phosphorus cycling do not yield a substantial imbalance or net increase of phosphorus levels within waterways. Therefore, aquatic nutrient imbalances do not become a concern until anthropogenic landuse changes occur.

When humans enter a watershed, their activities facilitate a net increase of phosphates entering the waterways (Caraco, 1993). For example, sediment cores from the Great Lakes show evidence of phosphorus increases due to anthropogenic activities as early as the 1800s (Schelske et al., 1983). Today, the major anthropogenic activities that have been identified for contributing P to waterways include animal agriculture (Simon et al, 2005; James et al., 2007), crop agriculture (Sharpley et al.,1992; Sharpley et al., 1994), suburban/urban landuse (Nungesser and Franz, 1997), and municipal wastewater treatment plants (WWTPs) (Haggard et al., 2001; Marti et al., 2004).

Phosphorus can be introduced into a waterway through two avenues, point source inputs and non-point source inputs. Point sources are generally defined as those that directly discharge

to a stream. Wastewater treatment plants are generally considered to be the main potential point sources because they process water that contains human waste and household chemicals, such as soaps and detergents, which often contain phosphates, and the treated effluent is released to a waterbody. Non-point sources of P are located across the spectrum of landuse and may not directly release pollutants to streams. Two types of landuses, animal agriculture and crop agriculture, have traditionally been considered the major contributors of non-point source P.

Past research of P inputs to aquatic systems has focused separately on P inputs from WWTPs and P inputs from agricultural sources. Haggard et al. (2001) studied the effect of WWTP effluent on downstream water and sediments in the receiving stream. The researchers found that a large portion of the effluent moved through the receiving stream and reached the confluence and downstream lake. They hypothesized that P was not retained by in-stream sediments due to the long net nutrient uptake length required to retain the nutrients released by the WWTP.

Bowes et al. (2005) analyzed the impact of the E.U. regulations in reducing overall P loads and investigated whether tighter controls on all European wastewater treatment plants could reduce P loads. Through modeling and sampling, it was determined that controlling only the major wastewater treatment plants would decrease overall dissolved P load by 52%. The model was re-run to test a scenario in which all wastewater treatment plants had P reductions of 80%. In this scenario, P concentrations were found to be highly reduced throughout the channel, not just below the points of the major wastewater treatment plants.

Simon et al. (2005) completed a comparative study between two coastal Virginia watersheds that were geologically and geographically similar. The main difference between the watersheds was that the Pocomoke River watershed contained large areas of intensive agriculture

(broiler chickens) while the Popes Creek watershed did not have any intensive agricultural practices. As a result of the intensive production of broiler chickens, land managers in the Pocomoke River watershed used large amounts of chicken litter as fertilizer on the land. In contrast, the Popes Creek watershed did not have such fertilizer inputs. The researchers found concentrations of total P from sediments in Pocomoke River to be approximately twice those from Popes Creek.

These research projects demonstrate that individual P inputs can profoundly impact water quality. However, many streams that are considered impaired due to nutrient enrichment have both agricultural activities and WWTPs contributing P to the receiving water. With various nutrient contributing activities within a watershed, it could be helpful to differentiate the P inputs because, as nutrient regulations are reformed and Total Maximum Daily Loads (TMDLs) are developed, remediation activities should match the inputs. Additionally, local changes in landuse may shift nutrient inputs. Therefore, identifying and quantifying P levels at different input points could be helpful to future analysis and remediation efforts.

Mass Balance of Phosphorus in Water

In both aquatic and terrestrial systems, P naturally shifts in a dynamic equilibrium.

“The total quantity of P in a lake or other surface water body will be controlled by the balance between the inputs from external sources (agriculture, runoff, and point-sources) and the outputs as water drains from the lake via rivers, streams, or other water courses” (Pierzynski et al., 2005). Golterman (2004) presented the aquatic ecosystem mass balance of P with the following equation,

$$P_{in} = \Delta \text{ sed} + P_{out} + \Delta (o-P)_w,$$

where “ P_{in} = P entering the lake ($\text{g m}^{-2} \text{ y}^{-1}$); P_{out} = P leaving the lake ($\text{g m}^{-2} \text{ y}^{-1}$); $\Delta \text{ sed}$ = P entering the sediment ($\text{g m}^{-2} \text{ y}^{-1}$); $\Delta (\text{o-P})_w$ = increase in P concentration in water depth ($\text{g m}^{-2} \text{ y}^{-1}$)” (Golterman, 2004).

Researchers studying P concentrations of sediments and overlying water in lakes and marshes have found sediment P to strongly correlate with aqueous P, indicating the amount of P sorbed to fine sediments increases as a function of increased P concentration in water (Qiu and McComb, 2000; Haggard et al., 2005). Shifts in aquatic ecosystem P are caused by chemical or physical changes within the system. For example, P adsorbed to sediments may become available when soluble P is depleted, when Fe in sediments is reduced under anoxic conditions, or when external or internal environmental conditions cause turbulence and resuspension of sediments (Pierzynski et al., 2005). Also, increased pH can result in decreased P sorption to sediments and an increased soluble P concentration because “functional groups on the surface of clays and metal oxides become deprotonated, thus the colloidal surface becomes more negatively charge” (Pierzynski, et al., 2005).

Two equations, the Freundlich Equation and the Langmuir Equation, quantify P sorption and desorption processes from soils and sediments to solution. A third way to describe P equilibrium is the EPC_0 (Equilibrium Phosphate Concentration at zero sorption). This is defined as the inorganic orthophosphate concentration that causes no adsorption or release when sediment is suspended in inorganic orthophosphate solutions (Golterman, 2004). The values derived from the EPC_0 describe the potential of a soil or sediment to release P from the sediment or adsorb P to the sediment when in contact with water flowing waters. “Soils or sediments with high EPC_0 values that interact with low P waters will desorb P; conversely, if values are low soils or sediments will sorb P, reducing the P concentration of runoff or streamflow and

decreasing the potential for eutrophication” (Pierzynski, et al., 2005). EPC_0 supports the idea that P will reach an equilibrium between the sediments and overlying water.

Nutrient Research in East Tennessee

Limited research has been conducted in East Tennessee to analyze the impact of phosphorus on streams and rivers (Mulholland et al., 1985; Johnson and Treece, 1998; Hampson et al., 2000). While Hampson et al. (2000) focused on watersheds with multiple nutrient inputs, such as agriculture and WWTPs, their work encompassed a very large geographic area from upper East Tennessee to Chattanooga and from the Cumberland Plateau to Asheville, NC. Although their research is helpful for understanding and describing regional processes, it does not allow for analysis of local agricultural or WWTP inputs. Therefore, this thesis research, on a smaller geographic area within a sub-basin of their larger study area will further contribute to the broader knowledge of nutrient inputs in East Tennessee.

Research Objective

The purpose of this research is to analyze channel sediments and determine if P concentrations of the sediments change after exposure to higher levels of P from inputs from a cattle farm or from a wastewater treatment plant (WWTP). This research was developed to study the impact of two P inputs by collecting benthic sediment samples from the channel of Beaver Creek, located in Knox County, Tennessee. The channel sediments were obtained from immediately upstream of, at, and immediately downstream from the cattle farm and the wastewater treatment plant in order to evaluate changes in P concentrations of the sediments before and after exposure to the P sources.

While aquatic dissolved P concentration is generally considered an important standard when evaluating water quality and is the standard by which Beaver Creek is judged to be nutrient enriched (TDEC, 2006a), dissolved P data ignore other potentially plant-available forms of phosphorus that are found within benthic sediments of streams, lakes, and other water bodies. Due to the need to control aquatic dissolved P levels and nutrient enrichment, past work on Beaver Creek has focused on the dissolved P (TDEC, 2006a), with no known research found on the P levels of sediments within the Beaver Creek channel. Additionally, past research has not specifically examined the impact of an individual source of P on the creek. Therefore, this research will obtain new information about P levels in stream sediments that has been previously unavailable for Beaver Creek while contributing to a growing body of work regarding P and aquatic sediments.

Research Questions and Hypotheses

Two questions were proposed for this research:

1. Can a total P signal from a cattle farm and a WWTP be identified in the streambed sediments at and below an input point? I hypothesized that a signal would be found at and downstream from the input point. The signal would be identified by significantly increased P levels when compared with the sediments found upstream of the cattle farm and the WWTP.
2. Would the sediments at and below the P sources, the cattle farm and the wastewater treatment plant, have elevated Mehlich III extractable P concentrations? I hypothesized that the sediments at and downstream of the input point would have Mehlich III extractable P.

Organization of Thesis

This thesis is organized into five chapters. Chapter 1, “Introduction” has provided a general review of literature pertaining to P and water quality issues and presented the research objective. Chapter 2, “Study Area,” provides an overview of Beaver Creek Watershed, its geography, environmental concerns, and specific issues related to the presence of P within the watershed. The chapter also introduces the reader to the specific study locations, the cattle farm and the WWTP, and provides the reader with geographic information, surrounding landuse and historical information specific to each study location. Chapter 3, “Study Design and Methods” is divided into three parts. Part one describes the study design with definitions useful for understanding the sampling protocol that was developed and implemented to collect sediment samples from the field. Part two, the lab methods section, discusses the preliminary processing of the samples and the chemical analyses completed to obtain the P data. Part three, statistical analysis, describes the statistical processes that were taken to answer the research questions. Chapter 4, “Results,” provides the results of the statistical analyses and answers the research questions. Chapter 5, “Discussion and Conclusions” evaluates the hypotheses, data, and results, and discusses the conclusions of the thesis.

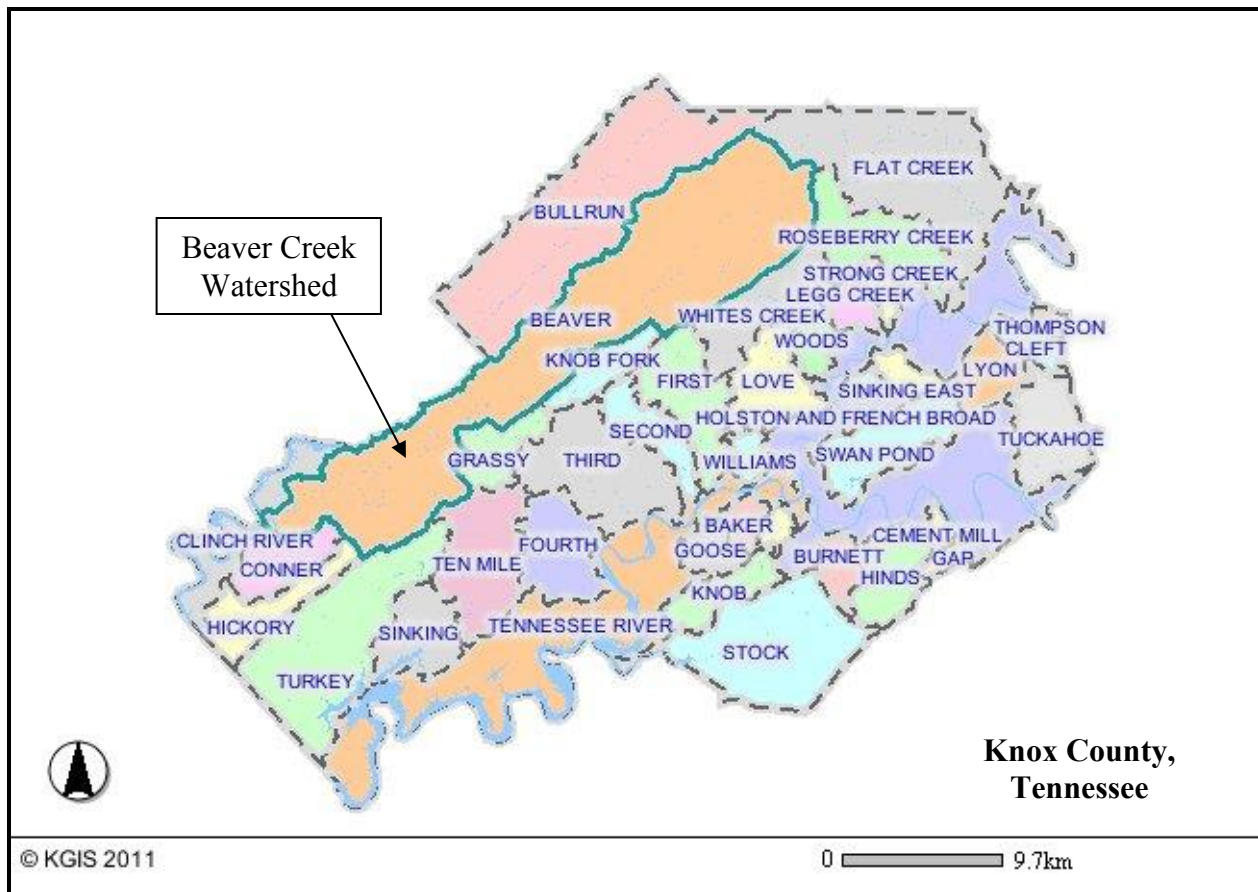
Chapter 2

Study Area

Beaver Creek Watershed (Figure 2.1) (HUC TN-06010207-011) is located in north Knox County near Knoxville, Tennessee. It is nested in the 1,631 km² Lower Clinch River Watershed. The watershed is approximately 40 km long, 5.6 km wide, and approximately 224 km² in drainage area. Copper Ridge to the northwest and Black Oak Ridge to the southeast mark the watershed boundaries. Beaver Ridge, a third ridge found within the watershed, parallels the south bank of Beaver Creek and is intersected by several tributaries (Knox County, 2006).

Most of the headwaters of Beaver Creek form in the northeast portion of the watershed. The main channel of Beaver Creek begins in northeast Knox County and runs approximately 71 km to the confluence with the Clinch River in southwest Knox County (Parish, 2002; Knox County, 2009). Over the length of its run, Beaver Creek descends approximately 85 m, resulting in a gradient of only 0.013% (Knox County, 2003). The low gradient of Beaver Creek, combined with high flows, causes the slow movement of peak flows through the system and subsequent flooding on a regular basis (Parish, 2002).

Cox Creek, Willow Fork Creek, Hines Branch, Knob Fork Creek, Grassy Creek, Meadow Creek, and Plumb Creek are the seven major tributaries of Beaver Creek. Many of these sub-watersheds contain a mixture of agricultural land and single-family residential land (Knox County, 2003). Most of the development in these sub-watersheds has occurred lower in the watershed, putting increased pollution and development pressures closer to the main channel of Beaver Creek. With the exception of Hines Branch, much of the outlying sub-watershed areas are composed of rural residential or agricultural landuses. Therefore, the potential source areas for water quality impairment are dispersed (Knox County, 2003).



Legend

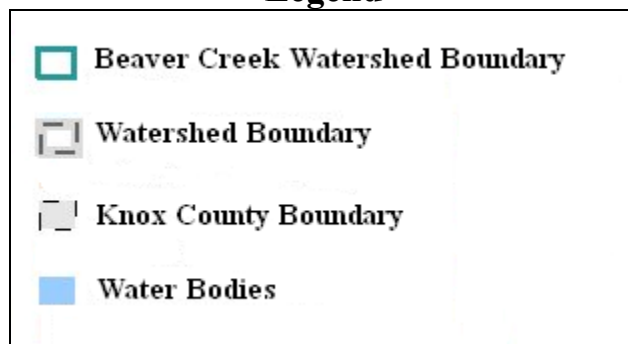


Figure 2.1. Map of watersheds in Knox County, TN. Beaver Creek Watershed is outlined in blue and identified with an arrow (KGIS, 2011).

Physiographic Setting

Beaver Creek watershed falls within the Ridge and Valley Physiographic Province (Region 67f) of East Tennessee. The Ridge and Valley Province is characterized as a low-lying area situated between the Appalachian Mountains to the east and the Cumberland Plateau to the west (Griffith et al., 1998). A broad floodplain and characteristic rolling hills of the region are found within the watershed (Knox County, 2006). Typically, this area has white oak, bottomland oak, and sycamore-ash-elm riparian forests with grasslands and cedar pine glades interspersed on the landscape (Griffith et al., 1998). The geologic material of the watershed mainly consists of limestone, dolomite, sandstone and shale, with siltstone, chert, mudstone, and marble also being found within the ecoregion (Griffith et al., 1998). Figure 2.2 is a map of the physiographic regions of Tennessee and region 67f, the Ridge and Valley Physiographic Province, is identified on it.

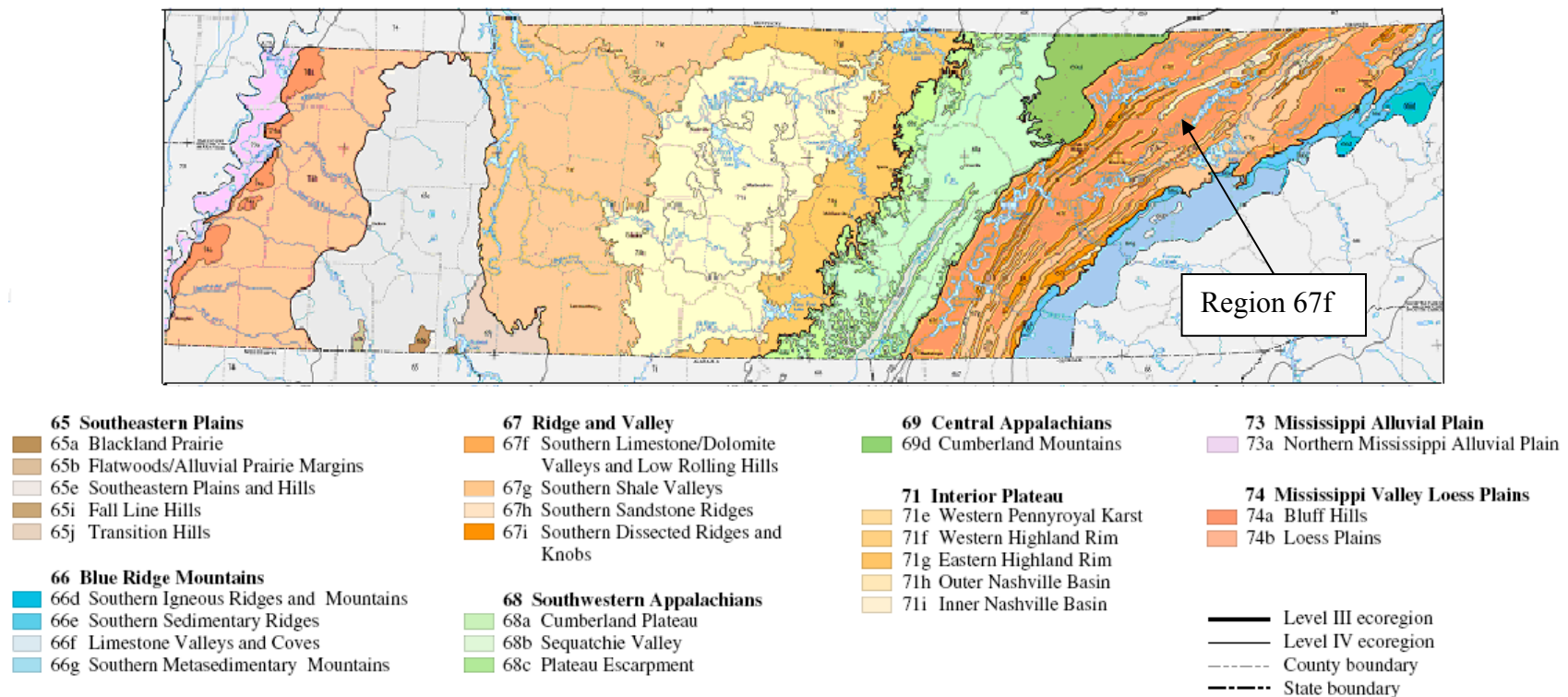


Figure 2.2. Map of physiographic regions of Tennessee. Region 67f, is identified with an arrow, and designates the region locating the Beaver Creek Watershed (Griffith et al., 1998).

Beaver Creek Landuse

Beaver Creek Watershed is considered a rapidly urbanizing watershed. In 2006, approximately 75,000 residents were estimated to live within the watershed. By 2030, the watershed population is projected to be 45% greater with approximately 108,000 residents (Knox County, 2006). In 2004, landuse composition of Beaver Creek Watershed consisted of an even percentage of residential and forested land with a slightly smaller area dedicated to agriculture (Figure 2.3). The landuse composition of the Beaver Creek Watershed is expected to dramatically change over the next 20 years due to development and an increase in the residential population. Knox County (2009) has estimated residential landuse to increase to 56% of the total watershed area. Meanwhile, agricultural landuse is expected to decrease to approximately 13% of the watershed area. Forested land is also projected to decrease to approximately 21% of total landuse area by 2030.

Dramatic population increases, combined with the conversion of agricultural and forested lands to residential landuse, will facilitate an increase of impervious surfaces throughout Beaver Creek watershed in the future. As a result, more water will come in contact with roads, roofs, and sidewalks, which often have contaminants on the surfaces. Additionally, increased impervious area will change the natural flow of stormwater causing water to reach streams faster. In 2006, the total impervious area of the watershed was calculated at approximately 8.7%. By 2030, impervious surfaces are projected to increase to approximately 11.8%, representing a 36% increase of impervious area (Knox County 2006; Knox County, 2009).

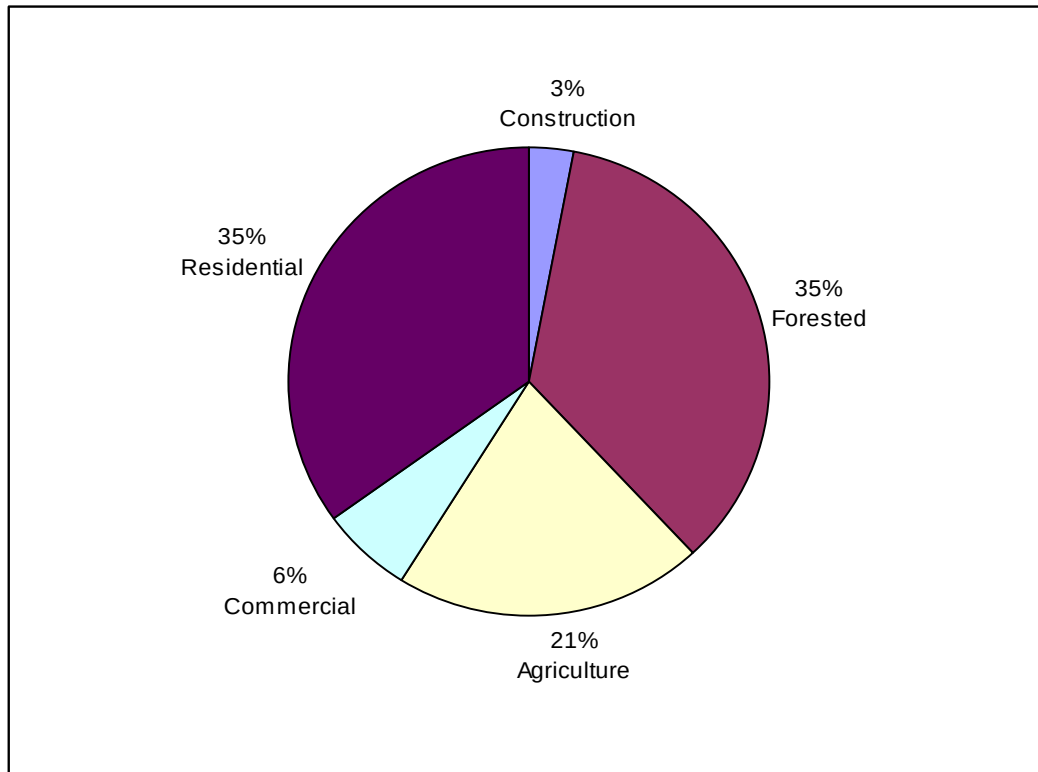


Figure 2.3. Pie chart of 2004 landuse composition of Beaver Creek Watershed (Knox County, 2006).

Environmental Concerns of Beaver Creek

Many environmental concerns have been documented as impacting Beaver Creek (Knox County, 2003; Knox County, 2006; TDEC 2006b; Knox County, 2009). Over the last decade, the water quality in Beaver Creek has been considered poor. As a result of the degraded quality of the creek, private citizens and water quality specialists have worked together to assess the status of the creek and to proactively address some of the water quality issues. The most pressing concern is Beaver Creek's presence on the Tennessee Department of Environment and Conservation's (TDEC) 303(d) list as a category 5 stream (TDEC, 2006a).

Beaver Creek's water quality is assessed every five years as part of TDEC's monitoring program required under the clean water act. Section 303(d) of the clean water act requires states to list surface waterbodies "for which technology-based limits alone do not ensure attainment of water quality standards" (USEPA, 1999). The Tennessee 303(d) list released by TDEC is a compiled list of all Tennessee surface water bodies that are "water quality limited" (TDEC, 2008). Waterbodies that are designated as "water quality limited" fail to meet one or more water quality standards. These waterbodies are considered pollution impaired and do not meet at least one of their designated uses, generally being that they are fishable and swimmable.

Part of the process for monitoring water quality and identifying impaired streams in Tennessee, includes categorizing each waterbody into one of five categories. A category 1 designation means that waterbody meets all designated uses. Category 2 means the waterbody meets some designated uses but not enough data is available to determine if all uses are being met. Category 3 means not enough data exist to determine if any designated uses are being met. Category 4 addresses the context to which specialized studies called total maximum daily loads (TMDL)s have been completed. Category 5 means that one or more designated uses for the waterbody are not being met and TMDL is required to be completed for each of the listed pollutants impacting the stream water quality (TDEC, 2008).

Beaver Creek's presence on the 303(d) list and its classification as a "category 5 stream" mean that water quality is not satisfactory for one or more designated uses of the creek and a TMDL must be established for each of the listed pollutants of the creek (Knox County, 2003). A TMDL is defined as "the sum of the individual wasteload allocations for point sources and load allocations for non point sources and natural background" (USEPA, 1999). The USEPA (1999) has established a generic TMDL equation,

$$\text{TMDL} = \text{LC} = \sum \text{WLA} + \sum \text{LA} + \text{MOS},$$

where LC is the loading capacity or the greatest loading a waterbody can receive without violating water quality standards; WLA is the wasteload allocation (the portion of the TMDL allocated to existing and future point sources); LA is the load allocation, or the portion of the TMDL allocated to existing or future nonpoint sources and the natural background; and MOS, the margin of safety, accounts for uncertainty about the relationship between pollutant loads and receiving water quality (USEPA, 1999).

The TMDL process focuses on the entire watershed rather than individual point sources alone, such as WWTPs. Each TMDL targets one specific pollutant for a specific watershed. Currently, two TMDLs exist for Beaver Creek Watershed. One TMDL addresses pathogens and the second TMDL addresses siltation and habitat alteration (TDEC, 2005; TDEC, 2006). Currently, a nutrient loading TMDL does not exist for Beaver Creek Watershed. Table 2-1 is an excerpt from the 2006 303(d) list which identifies Beaver Creek as a “water quality limited” waterbody. The table identifies the creek, length of impairment, the cause of impairment, pollutant sources, and the priority for establishing TMDLs (TDEC, 2006a). Since phosphorus and nitrogen have been identified as pollutants of Beaver Creek, a nutrient TMDL is required to be established.

Table 2-1. Excerpt of Tennessee 303(d) list featuring Beaver Creek (TDEC, 2006a).

Water-body ID	Impacted Waterbody	County	Kilometers Impaired	CAUSE /TMDL Priority	Pollutant Source	Comments
TN06010 207011 – 1000	BEAVER CREEK	Knox	36.21	Phosphorus Nitrates Escherichia coli Low dissolved oxygen Loss of biological integrity due to siltation Physical substrate habitat alterations	Major Municipal Point Source Pasture Grazing Discharges from MS4 Area	Stream is Category 5. Impaired, but EPA has approved a pathogen TMDL that addresses some of the known pollutants.
TN06010 207011 – 2000	BEAVER CREEK	Knox	22.05	Escherichia coli Loss of biological integrity due to siltation Physical substrate habitat alterations	Pasture Grazing Discharges from MS4 Area	EPA has approved a pathogen TMDL that addresses some of the known pollutants.
TN06010 20701 1 – 3000	BEAVER CREEK	Knox	12.07	Escherichia coli Loss of biological integrity due to siltation Physical substrate habitat alterations	Pasture Grazing Discharges from MS4 Area	EPA has approved a pathogen TMDL that addresses some of the known pollutants.

Residential and Agricultural Activity in Beaver Creek Watershed

Residential and agricultural landuse are inextricably connected to the current and future landuse composition of the watershed, in addition to the current and future condition of Beaver Creek. In 2006, residential and agricultural landuse together comprised 56% of the landuse in the watershed. While residential landuse has surpassed agricultural landuse within the watershed, both serve as large potential contributors of sediment, nutrients, and other pollutants currently being targeted for stricter controls to improve water quality within Beaver Creek.

One major challenge facing an area of increasing residential population is to address the water and wastewater needs. In 2006, it was estimated that the Beaver Creek Watershed had approximately 74,400 people living within the watershed boundaries (Knox County, 2006). Approximately 33,328 people in the Beaver Creek Watershed had septic systems in 2005, leaving approximately 41,000 residents of Beaver Creek Watershed connected to sewer lines to process their wastewater (TDEC, 2006b).

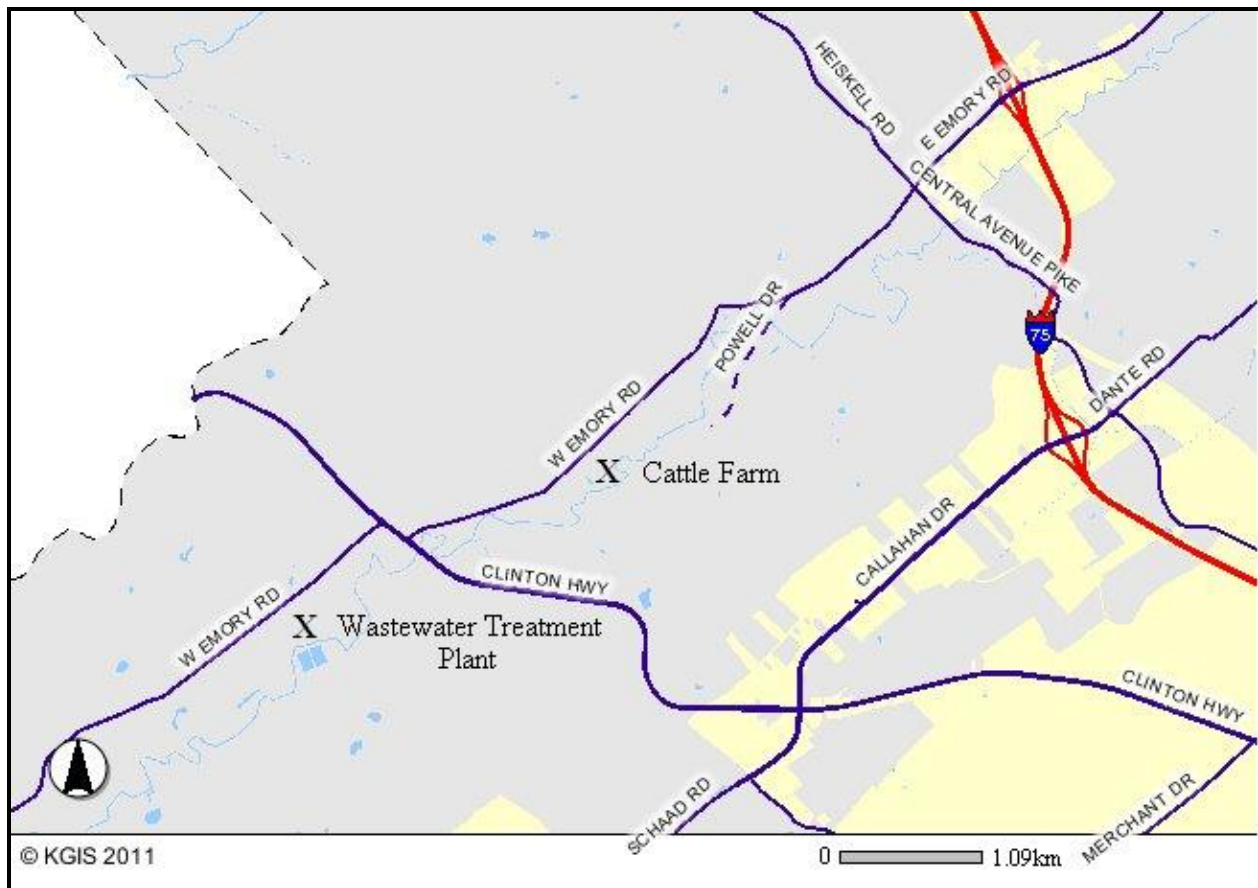
Two wastewater treatment plants are permitted to discharge processed wastewater to Beaver Creek. The plant located at stream mile 10.0 is permitted to process up to 4.0 million gallons (15,168 m³) per day (TDEC, 2003a). The plant located at stream mile 23.5 is permitted to process up to 9.0 million gallons (34,104 m³) per day (TDEC, 2003b). Recent studies of the watershed have cited these plants as major contributors of nutrients, including P, to the creek (TDEC, 2006b; Knox County, 2009). While these WWTPs are required to treat for pathogens and are included in the pathogen TMDL, Tennessee state law does not require WWTPs to provide treatment for reducing P loads. In their 2003 permits, which were active during the data collection for this study, the plants were only required to report orthophosphate and total P from a composite sample of effluent once per quarter.

As residential landuse has increased throughout the watershed, agricultural landuse has decreased. However, animal agriculture continues to be a predominant activity, with approximately 3,120 livestock animals estimated to live within the Beaver Creek Watershed (TDEC, 2006b). The livestock distribution of the watershed is estimated to comprise 2100 beef cattle, 150 milk cows, 145 hogs, 110 sheep, and 615 horses (TDEC, 2006b). All of the livestock animals were dispersed throughout the watershed and no permits have been issued for Confined Animal Feeding Operations within Beaver Creek Watershed (TDEC, 2006b).

Animal agriculture presents specific water quality problems, including the release of untreated animal waste to the creek. Untreated animal waste is released to the creek through two processes: 1) allowing animals to have direct access to the creek and 2) erosion processes that move waste from the land to the water. Although education programs and cost-sharing programs have begun to assist some farmers in transitioning to a system that keeps their animals from having direct access to Beaver Creek, some landowners have not transitioned to a new process of watering for their farm and, therefore, their animals continue to directly access the creek, potentially contributing to higher P levels in Beaver Creek.

Study Locations

The landuse composition of Beaver Creek Watershed presents an interesting opportunity to study how a cattle farm and a WWTP affect sediment P concentrations in Beaver Creek. For this research, two sampling locations, a cattle farm and a WWTP, were utilized to study the immediate and short-distance effects of a P source on streambed sediments (Figure 2.4).



Legend

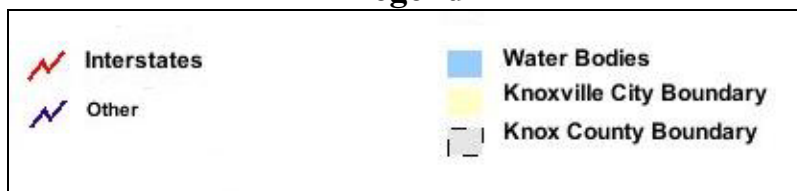


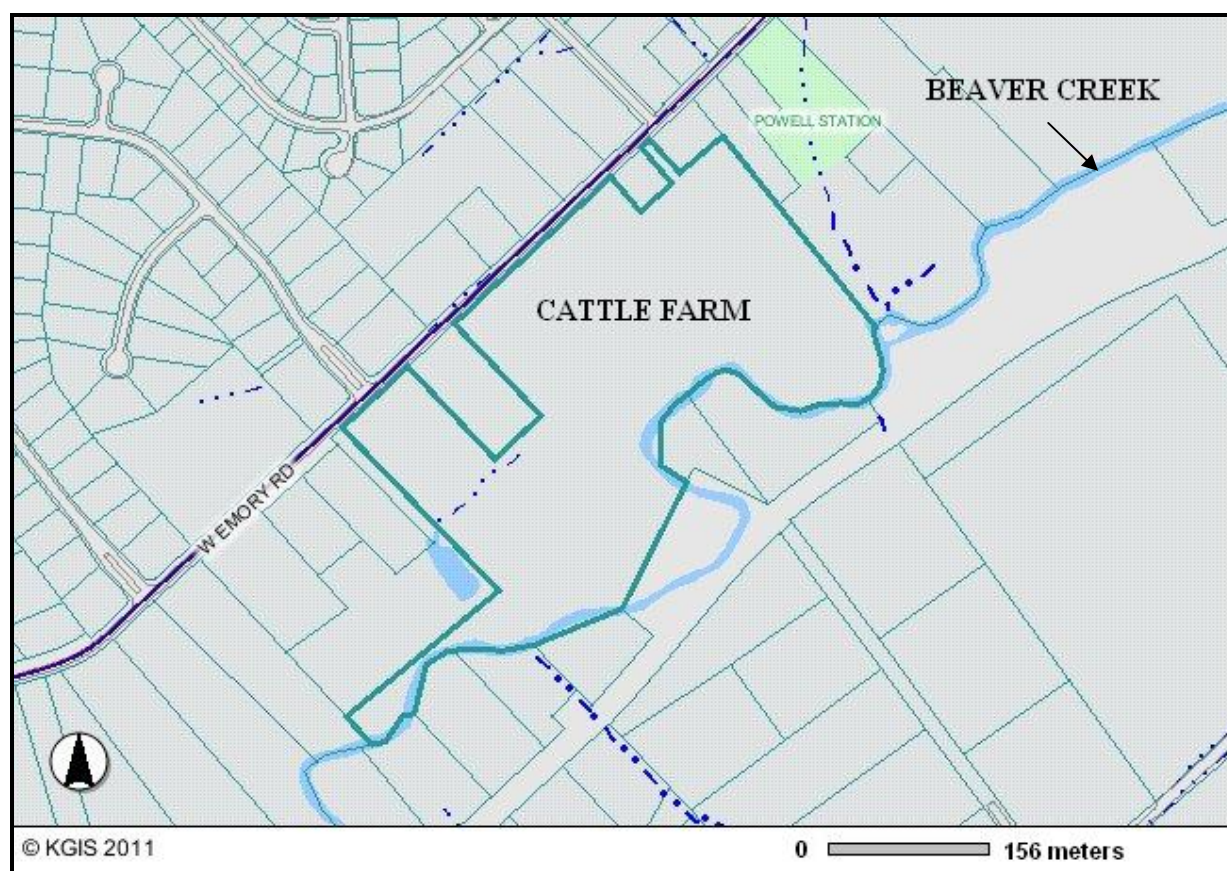
Figure 2.4. Map of north Knox County, TN designating the cattle farm and the WWTP sampling locations. Sampling locations are marked with an X (KGIS, 2011).

Location 1: Cattle Farm

A family-run cattle farm, located directly adjacent to Beaver Creek near stream km 33, was utilized for this study. At the time of sampling, approximately 40 head of cattle grazed on 125,775 m² of land (KGIS, 2010). During pre-sampling surveys, cattle were observed accessing the creek from the southwest border of the property. Conversations with the watershed coordinator indicated that the property owner had allowed his cattle to access the creek for watering and cooling for decades and planned to continue this method of watering his cattle. As a result, the activity on the farm had been maintained in a similar manner for decades and the cattle were allowed to have regular and unimpeded access to the creek.

Different landuses with minimal P inputs exist around the cattle farm. Upstream from the farm is public property where a high school, a public park, and a rarely utilized field of public land exist. Downstream from the farm is rural residential property and quasi public property belonging to a church. On the opposite side of the creek is a right-of-way with electrical transmission lines, office space, and industrial property. Rural residential property interspersed with single-family residential property is across the creek from the church. Figure 2.5 maps the cattle farm.

The long-term stability of this farm and the surrounding property provided a good opportunity to study the P impacts from the cattle while minimizing the potential effects of different landuses occurring around the farm. The cattle accessed the creek in several places along the property boundary and grazed on land directly adjacent to the creek. There was not any crop agriculture on the property so the majority of P input would be expected to have come from the cattle living there.



Legend

Roads	Cattle Farm Property Boundary
Edge of Traveled Way	Parcels
Swales	Water Bodies
Streams	County Park

Figure 2.5. Map of the cattle farm sampling location in North Knox County, Tennessee (KGIS, 2011).

Location 2: Wastewater Treatment Plant

The WWTP (Figure 2.6) utilized for this study is located near stream km 37 and is situated approximately 2.4 km southeast of the cattle farm. In distance on Beaver Creek, the WWTP is located 4.0 stream km downstream from the cattle farm. The plant sits on approximately 169,000 m² of land. During the sampling period, the plant was permitted to treat up to 9 million gallons (34,104 m³) per day of wastewater and had no requirements for treating P discharge.

Single family residential areas and rural residential areas are found immediately upstream from the WWTP. Below the WWTP are large tracts of rural residential property interspersed with open land identified by KGIS (2011) as agricultural, forested, or vacant. Directly across Beaver Creek from the WWTP is a large tract of open land. It is identified as agricultural land. While sampling at the WWTP, a cow was observed grazing on the land across from the WWTP. However, the banks appeared too steep for cattle access and no signs of cattle access such as hoof prints or impacted banks from cattle were observed during sampling at the WWTP.

This WWTP has been treating wastewater for the local residential and commercial community for decades, and the surrounding landuse has remained stable. The stability of the area surrounding the WWTP and the long-term stability of the WWTP made it a potentially good site for this study.

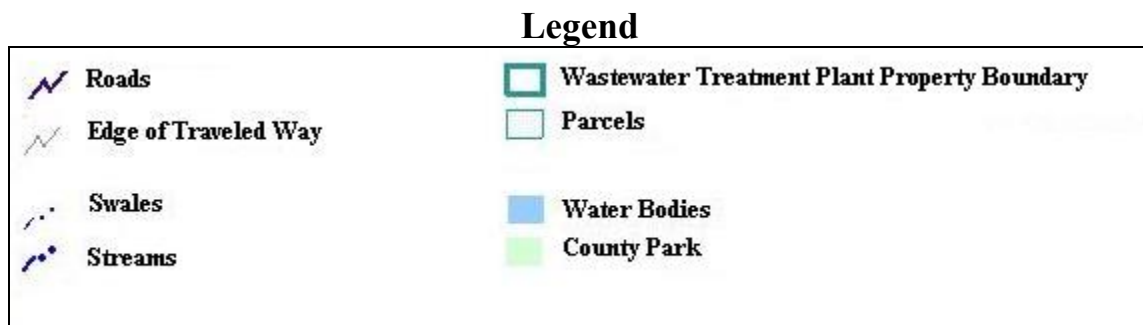
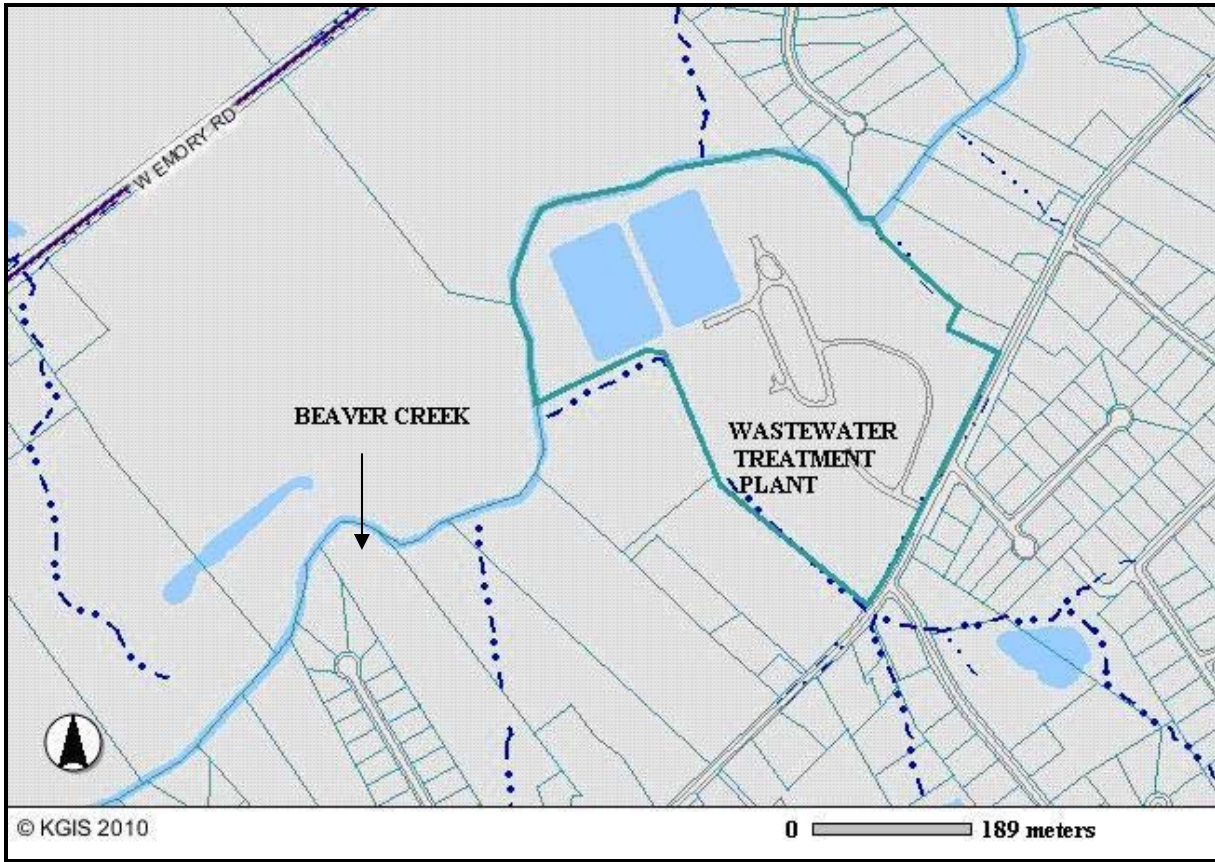


Figure 2.6. Map of the WWTP sampling location in Knox County, Tennessee (KGIS, 2010).

Chapter 3

Study Design and Methods

Study Design

The study design for this research was developed to analyze total P and Mehlich III extractable P concentrations in the sediments above and below a P input to Beaver Creek from a cattle farm and a WWTP. Samples were collected upstream of the cattle farm and upstream of the WWTP, at the cattle farm and WWTP, and downstream from the cattle farm and WWTP to analyze the immediate and short-distance sediment P impact of the cattle farm and the WWTP. The following definitions were developed to describe the sample design:

1. **Sample Location:** Two locations, the cattle farm or the WWTP, used for this study.
2. **Sample Site:** Any one of the four places at a sample location:
 - Control
 - Source
 - Downstream 1
 - Downstream 2
3. **Sample Transect:** A line across the creek perpendicular to the stream flow. It is established at a sample site.
4. **Sample Point:** A point along the sample transect where the sediment is collected from the stream.

At each sample location, four sample sites were identified: control, source, downstream 1 and downstream 2. At each sample site, three sample transects, 3 m apart, were established across the creek and were identified as A, the most upstream transect, B, the middle transect, and C, the most downstream transect. Sample points were identified along each transect at 25%, 50%, and 75 % of the distance between the banks, and sediment samples were collected from each sample point. Nine samples were thus collected from each of the sample sites, totaling 36 samples from each sampling location. Figure 3.1 illustrates the sampling plan for this project.

Sample Transects	Sample Points			Sample Sites
Transect A	1	2	3	Control
Transect B	1	2	3	
Transect C	1	2	3	
Transect A	1	2	3	Source
Transect B	1	2	3	
Transect C	1	2	3	
Transect A	1	2	3	Downstream 1
Transect B	1	2	3	
Transect C	1	2	3	
Transect A	1	2	3	Downstream 2
Transect B	1	2	3	
Transect C	1	2	3	

Figure 3.1. Sampling design plan. Sample transects A, B, and C are separated by 3 meters. Sample points 1, 2, and 3 represent 25%, 50% and 75% distances, respectively, between the creek banks. The control sample site is above the P input, the source sample site is immediately downstream from the P input, the downstream 1 and downstream 2 sample sites are the most downstream sites sampled.

The field design and sampling protocol developed for this research was modified and combined from two standard sampling designs, the standard grid method and the modified grid method for sampling near a point source (Mudroch and MacKnight, 1994; Mudroch and Azcue, 1995). The sampling design required identifying P input points at the cattle farm and at the WWTP. The sample sites, control, source, downstream 1, and downstream 2, were designated after identifying the P input at each sample location.

At the cattle farm, the P input point was identified from field observations. There were several places along the stream bank where cattle had accessed the stream, and numerous hoof prints remained visible. To account for the approximately 700 m distance adjacent to Beaver Creek where cattle were accessing the stream, the P input point was designated at the most downstream cattle access point. The WWTP had one outfall, located at the northeast corner of the property, and the P input for the WWTP was identified as the outfall.

Sample Site Overview

Four sample sites at each location were selected to collect data about the immediate impact and short-distance impact of the P input. The “control” sample site was located upstream of the P input at the cattle farm and at the WWTP and was expected to best represent the background sediment P concentrations. At the cattle farm, the control sample site was situated above the most upstream cattle access point in the pasture and upstream of the farm property. The control for the WWTP was located upstream of the wastewater outfall.

The “source” sample site was located immediately below the identified P sources at the cattle farm and the WWTP. I expected the sediment P concentrations at the source sample site to be the highest when compared to the other three sample sites. At the cattle farm, three cattle

access points were visible along the streambank. The source sample site at the cattle farm was situated approximately 700 m downstream from the control sample site. The most downstream cattle access point was designated to represent the “source” because it could include the potential upstream impacts from cattle accessing Beaver Creek. At the WWTP, the source was designated at the outfall and the sample site was located immediately downstream of the plant outfall and approximately 35 m downstream from the control sample site. Near the WWTP outfall, Beaver Creek was heavily incised and the water was moving through the channel at a high velocity.

The “downstream 1” sample site was located between the source and downstream 2. While distance was one factor in choosing the downstream 1 sample site, field conditions and stream conditions were also taken into account. The downstream 1 sample site was generally identified as the most downstream point where field and stream conditions remained comparable to the conditions at the source sample site. I expected that sediment P concentrations at the downstream 1 sample sites would be lower than those from source site, but elevated when compared to the control site and the downstream 2 site.

At the cattle farm, the downstream 1 sample site was situated approximately 150 m below the source sample site. This site was selected because it was directly upstream from an ephemeral stream and immediately upstream of identifiable changes in the landscape and in Beaver Creek. From the source sample site to the downstream 1 site, the banks were elevated, there was a steep slope from the top of the streambank down to the water in Beaver Creek, and a layer of fine sediments approximately 15 cm thick covered the streambed. Also, Beaver Creek was narrower between the source and downstream 1 sample sites than below the downstream 1 sample site. The “downstream 1” sample site at the WWTP was located immediately upstream of a sharp bend in Beaver Creek and approximately 200 m downstream of the source sample site.

The “downstream 2” sample site was located below the downstream 1 sample site. It was selected based on visible changes in field conditions and changes in conditions of Beaver Creek when compared to the downstream 1 and source sample sites. Due to distance from the source and changes in field and creek conditions, I expected the sediment P concentration of the downstream 2 sample site to be similar to the sediment P concentration of the control sample site.

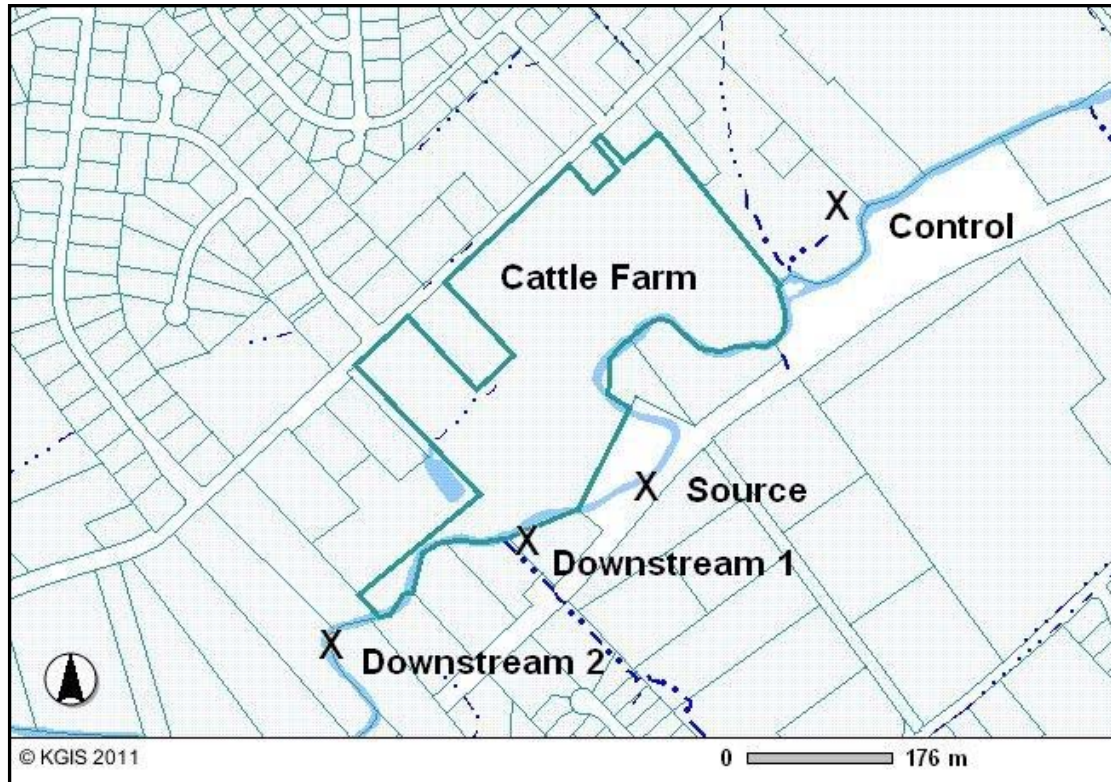
The “downstream 2” sample site at the farm was located approximately 260 m from the downstream 1 sample site and was situated downstream from the cattle farm property. Below the downstream 1 sample site, at the cattle farm, the pasture land became flatter with lower stream banks that gently sloped to Beaver Creek. The creek became broader and had a deeper layer of fine sediment, approximately 35 cm thick, covering the streambed.

The “downstream 2” sample site at the WWTP was selected based on field and stream conditions and because it was the sample site where WWTP personnel were required to collect grab samples for required water quality analysis. The downstream 2 sample site was located approximately 170 m downstream of the downstream 1 sample site and was situated downstream of the sharp bend in the stream and immediately upstream of an entering tributary.

Each sample site is described, GPS coordinates are identified, and the segment length between each sample site is given for the cattle farm (Table 3-1) and WWTP (Table 3-2). The sample sites, control, source, downstream 1, and downstream 2 are mapped for the cattle farm (Figure 3.2) and WWTP (Figure 3.9). Figures 3.3 – 3.8 depict the cattle farm and cattle access points to Beaver Creek.

Table 3-1. Sample site descriptions, GPS coordinates, stream widths, sample dates, and segment distances at the cattle farm.

Sample	Description	GPS Coordinate	Stream Width (meters)	Sample Date	Approximate Segment Distance (meters)
Control	Located upstream of fence separating the cattle pasture from the adjacent property and upstream of visually identifiable cattle access points to the stream.	N 36° 01.544' W 84° 01.854'	13.2 m	08/24/07	0 m
Source	Located at the most downstream visually identifiable point of stream access for the cattle.	N 36°01.337' W 84°02.039'	6.0 m	10/26/07	700 m
Downstream 1	Located downstream of lowest visually identifiable cattle input point in the lower pasture and upstream of a small ephemeral stream that enters Beaver Creek.	N 36°01.326' W 84°02.147'	6.7 m	10/26/07	150 m
Downstream 2	Located past the downstream property boundary of the farm.	N 36°01.267' W 84°02.312'	9.7 m	10/26/07	250 m
Total					1100 m



Legend

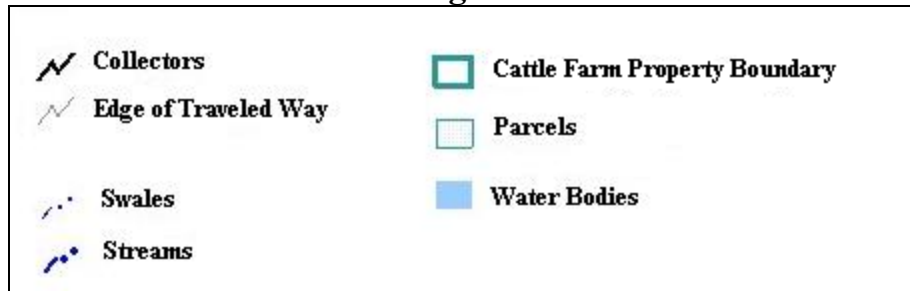


Figure 3.2. Map of the cattle farm sampling sites: control, source, downstream 1, and downstream 2, designated with an X, located within Beaver Creek Watershed in north Knox County, Tennessee (KGIS, 2011).



Figure 3.3. Photo of the cattle farm pasture near the farm sampling site in Beaver Creek Watershed, Knox County, Tennessee.



Figure 3.4. Photo of Beaver Creek upstream of the cattle farm, Knox County, Tennessee.



Figure 3.5. Photo of first cattle access area from the farm to Beaver Creek.



Figure 3.6. Photo of second cattle access area from the farm to Beaver Creek.



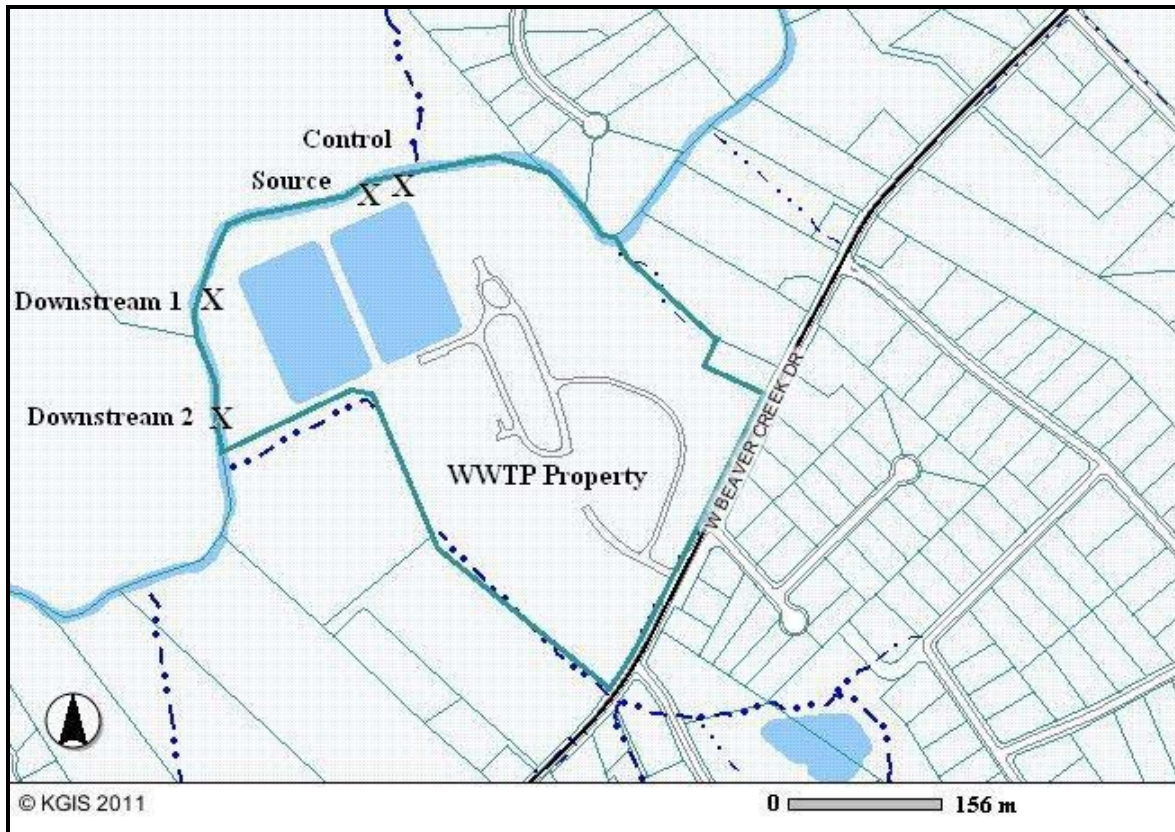
Figure 3.7. Photo of third cattle access area from the farm to Beaver Creek.



Figure 3.8. Photo of Beaver Creek downstream from cattle farm.

Table 3-2. Sample site descriptions, GPS coordinates, stream widths, sample dates, and segment distances at the WWTP.

Sample Location	Sample Site Description	GPS Coordinates	Stream Width (meters)	Sample Date	Approximate Segment Distance (meters)
Control	Located upstream of WWTP Outfall	N 36° 00.723 W 84° 03.5940	7.3 m	9/7/07	0 m
Source	Located immediately downstream of outfall where fine sediments were available to sample. Outfall is sited at stream mile 23.5.	N 36° 00.723 W 84° 03.614	9.5 m	9/13/07	35 m
Downstream 1	Located downstream of the source and just before a major bend in the stream.	N 36° 00.669 W 84° 03.7428	11 m	9/7/07	200 m
Downstream 2	Located downstream of the source and after a major bend in the stream.	N 36° 00.594 W 84° 03.76	9.2 m	9/13/07	175 m
Total					410 m



Legend

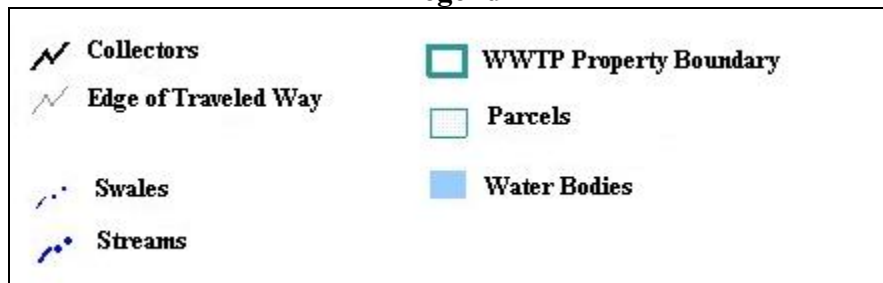


Figure 3.9. Map of sampling sites; control, source, downstream 1, and downstream 2, designated with an X, at the WWTP located within Beaver Creek Watershed in north Knox County, Tennessee (KGIS, 2011).

Field Methods

At the cattle farm, the control site was sampled on August 24, 2007 and the source, downstream 1, and downstream 2 sample sites were sampled on October 26, 2007. At the WWTP, the control and downstream 1 sites were sampled on September 7, 2007, and the source and downstream 2 sites were sampled on September 13, 2007.

The following protocol was followed at each sample site to ensure a standard process for sample collection. When the sample site was identified in the field, a measuring tape was stretched across the stream, and the width of the stream channel was measured and recorded. This provided the middle transect from which, two additional transects were identified 3 m above and 3 m below the base transect. The most upstream transect was identified as transect A, the middle as transect B, and the most downstream as transect C. Three sampling points were identified along each transect at 25%, 50%, and 75 % of the distance between the stream banks.

A field assistant and I waded into the water to the first sample point on transect C. I collected samples using the LaMotte dredge. For each collection attempt, the dredge was lowered to the surface of the streambed and the top 5 cm of sediment was collected. The dredge was closed and brought up to the water surface. At the water surface, the sediment was placed into a 1 qt Ziploc® bag. The bag was marked with a code identifying the location, sample site, transect, and point from where the sample collected. The bag was sealed and placed on ice to be returned to the lab. Transects were sampled in an upstream movement in order to minimize the chance that sediments from one transect would become mixed with sediments on other transects. After sampling along transect C, I moved 3 m upstream to transect B and collected three samples along the transect at 25%, 50% and 75% distances between the banks. Then, I moved upstream and sampled the site along transect A. Figures 3.10 and 3.11 depict the sampling process.



Figure 3.10. Photo of in stream sampling near the streambank at the cattle farm sampling site in Beaver Creek.



Figure 3.11. Photo of midstream sampling at the cattle farm sampling site in Beaver Creek.

Secondary Sampling Device

During the downstream 2 and the source sampling at the WWTP, I encountered problems with operating the LaMotte dredge. The sediments at these sample sites contained rocks and sticks that caused the dredge to fail to completely close, resulting in the loss of most of the sediment sample collected. To solve the sediment collection problems, a second sediment dredge was developed in the field.

The improvised sampling dredge consisted of a 1-gallon plastic container taped to a pole. The top half of the container was cut off and discarded. The bottom half of the container served as the sediment collection device. Small holes were cut in the bottom of the plastic container to allow water to drain from it while the sediment remained in the bottom.

The improvised dredge worked well for collecting sediment, especially in places where debris and rocks made it difficult to utilize the LaMotte dredge. When using the improvised dredge, I was careful to only take sediment from the top of the stream bed in order to maintain sampling continuity of the top 5 cm. Ultimately, I believe I was more effective in collecting sediment from the top 5 cm of the streambed using the improvised dredge because I usually only had to make one grab attempt per sample. Regardless of which sampler was used, I maintained the sampling protocol and design throughout the sampling process.

Lab Methods

The samples were returned to the Environmental Dynamics lab in the Burchfiel Geography Building. Fine sediments remained suspended within stream water in the bags when they were returned to the lab. To allow the sediments to settle, the bags were set up for 24-48

hours. Once the stream water became clear and there were no visible sediments suspended in the water column, the overlying water was drained from the bags.

Two different methods were attempted to drain water from the bags. The first method was to open the bag at the top and slowly tip it sideways to let out the water. However, tipping the bag over caused fine sediments to become agitated and re-suspended in the water column resulting in a substantial loss of sediment when the water was drained from the top. The second method was to drain the water from the sample bag keeping the bag upright, cutting a small hole in the bottom corner of the bag, and allowing the water to drain slowly out of the bottom of the bag. Since the finest sediments were located near the top and since this required less agitation of the sediment within the bag, the second method proved to be more efficient in retaining sediments.

After releasing the stream water, the sample bags were completely cut open and laid out on the lab table for the sediments to air dry for approximately one week. After the sediments were air dried, they were put into a new Ziploc® bag. The bags were labeled with the field identification code, sealed, and held in a box for preparation for chemical analysis.

Lab Analyses

To prepare samples for analysis, each dried sample was crushed with a mortar and pestle and the crushed sample was sieved through a 2 μ m sieve. All particles 2 μ m or smaller were saved in the Ziploc® bag.

On March 11, 2008, 72 samples were delivered to A & L Analytical Laboratories in Memphis, TN. The samples were chemically analyzed on March, 14, 2008 for total P. On March 25, 2008 the samples were chemically analyzed for Mehlich III extractable P.

Total P was extracted by the EPA method SW 3050B (USEPA, 1996a). USEPA (1996a) describes this method as “an acid digestion that will dissolve almost all elements that could become ‘environmentally available.’” The method requires digesting, 1 g (dry weight) of sample with repeated additions of nitric acid and hydrogen peroxide. The resulting digestate solution is reduced in volume while heating and then brought to a final volume of 100 mL.

To prepare the digestate solution for ICP analysis, hydrochloric acid is added and it is refluxed. The digestate is then covered with a watch glass or vapor recovery device. The sample is placed on a heating source and refluxed at 95°C for 15 minutes. After the reflux, the sample is filtered through Whatman No. 41 filter paper, collected in a 100-mL volumetric flask, and the flask is filled to volume and ready for analysis by ICP-AES.

Mehlich III P –Extraction Procedure

Samples were analyzed for Mehlich III extractable P. Mehlich III extracting solution is 0.2 M acetic acid (CH_3COOH) + 0.25 M ammonium nitrate (NH_4NO_3) + 0.015 M ammonium fluoride (NH_4F) + 0.13 M nitric acid (HNO_3) + 0.001 M EDTA (Soil and Plant Analysis Council, Inc., 2000). To complete the extraction process, 3 g of soil are mixed with 30 mL of Mehlich III extracting solution. The sample is shaken on a shaker for 5 minutes at 120 oscillations per minute. The sample is then filtered through No. 42 Whatman filter paper and collected (Carter, 1993).

Inductively Coupled Plasma – Analysis

Both the total P and Mehlich III extractable P extracts were analyzed by ICP-AES according to the procedures outlined in EPA method 6010B (USEPA, 1996b). The results for each sample in mg/Kg were available on March 26, 2008.

Data Entry and Statistical Analysis

The data were compiled and entered into SPSS for statistical analysis. Descriptive statistics were run for both total P and Mehlich III extractable P for both sampling locations to provide the maximum, minimum, range, mean, and standard deviation for the data sets. The data were graphed as box plots and histograms to review their distribution. The data were statistically analyzed by analysis of variance, one and two-tailed t-tests, and the Mann-Whitney non-parametric test.

Comparison of Total P and Mehlich III extractable P Within Sampling Locations

The first research question was “could a total P signal from a wastewater treatment plant and a cattle farm be identified in the streambed sediments at and below a visually identifiable input point?” The second question was “would the sediments at and below the P sources at the cattle farm and the WWTP contain elevated Mehlich III extractable P?” To answer these questions, an Analysis of Variance (ANOVA), two-tailed t-test, Mann-Whitney test, and one-tailed t-tests were completed. The ANOVA was run between the sampling sites for total P and for Mehlich III extractable P at both the cattle farm and the WWTP. The purpose of the ANOVA was to test whether there were significant differences occurred within the data between sampling sites at each sampling location. For this test, the following hypotheses were developed:

H_0 : All sampling site means are equal

H_1 : The means of at least two groups are different.

Based on the ANOVA results, a series of t-tests with $\alpha = 0.05$ were completed to determine which groups of sample sites were significantly different. In each t-test, the following hypotheses were used, and the null hypothesis was rejected only if $p \leq 0.05$

H_0 : The means of the sample sites are equal

H_1 : The means of the sample sites are unequal.

Total P and Mehlich III extractable P sediment values from the following pairs of sites at the cattle farm and the WWTP were compared using the t-test:

- Control : Source
- Control : Downstream 1
- Control : Downstream 2
- Source : Downstream 1
- Source : Downstream 2
- Downstream 1 : Downstream 2.

Before reviewing the t-test results in SPSS, the two samples were analyzed to determine if the variances could be considered equal by reviewing the results of the Levene's test. The Levene's test provided a p -value for each set of sample sites being tested. If the Levene's test p -value was $p \leq 0.05$, the t-test was completed assuming unequal variances. If the Levene's test p -value was $p > 0.05$, equal variances were assumed for the t-test

The Mann-Whitney test was performed on all sets of data that were tested with the two-tailed t-test. This non-parametric test was utilized because of the small data sets, the occurrence of some outlying variables, and the presence of non-normal data within the sub datasets. The Mann-Whitney test was run as a check to the t-test results to determine if there were major differences in results between the Mann-Whitney results and the t-tests results. The following

hypotheses were tested with the Mann-Whitney test statistic, and the null hypothesis was rejected only if the $p \leq 0.05$.

H_0 : The data from the two sample sites have the same distributions

H_1 : The data from the two sample sites do not have the same distributions.

One-tailed t-tests were performed to determine if sites downstream contained a significantly greater sediment P concentration than those upstream. P concentrations from one site will be considered to be significantly greater to another site with $p \leq 0.05$.

- Source : Control
- Downstream 1: Control
- Downstream 2: Control
- Downstream 1 : Source
- Downstream 2 : Source
- Downstream 1 : Downstream 2

(The first site = sample site A, the second site = sample site B)

For the one-tailed t-tests, the following hypotheses were proposed and the null hypothesis was rejected only if the $p \leq 0.05$.

H_0 : the mean of sample site A $\leq$ the mean of sample site B

H_1 : the mean of sample site A $>$ the mean of sample site B

Chapter 4 Results

The objective of this research was to analyze the spatial distribution of phosphorus in the stream bed sediments in Beaver Creek to determine if there was a significant impact from a P-contributing source to the P loads of the bed sediments. In addition, the research was also designed to test whether significant differences existed in P in fine bed sediments between locations containing a cattle farm and a WWTP. Data tables below provide total P and Mehlich III extractable P concentrations of sediments collected from Beaver Creek at the cattle farm and the WWTP (Table 4-1, Table 4-2) (Table 4-3, Table 4-4).

Table 4-1. Total P results by sample site at the cattle farm (mg P /kg sediment)

Control	25%	50%	75%
Transect A	628	576	554
Transect B	765	497	533
Transect C	644	510	554
Source	25%	50%	75%
Transect A	467	478	533
Transect B	500	518	553
Transect C	457	431	636
Downstream-1	25%	50%	75%
Transect A	696	639	500
Transect B	541	535	610
Transect C	544	587	490
Downstream-2	25%	50%	75%
Transect A	581	639	668
Transect B	552	644	686
Transect C	693	687	626

Table 4-2. Mehlich III extractable P results by sample site from the cattle farm (mg P/kg sediment).

Control	25%	50%	75%
Transect A	18	19	18
Transect B	14	19	18
Transect C	15	17	20
Source	25%	50%	75%
Transect A	19	12	15
Transect B	17	17	15
Transect C	17	16	13
Downstream-1	25%	50%	75%
Transect A	18	13	16
Transect B	15	17	16
Transect C	17	15	15
Downstream-2	25%	50%	75%
Transect A	17	29	34
Transect B	17	26	25
Transect C	17	17	22

Table 4-3. Total P results by sample site at the WWTP (mg P/kg sediment).

Control	25%	50%	75%
Transect A	455	530	424
Transect B	557	445	441
Transect C	462	528	485
Source	25%	50%	75%
Transect A	652	687	575
Transect B	718	696	604
Transect C	623	620	627
Downstream-1	25%	50%	75%
Transect A	758	879	971
Transect B	808	756	778
Transect C	736	733	793
Downstream-2	25%	50%	75%
Transect A	854	535	578
Transect B	1000	796	474
Transect C	513	605	635

Table 4-4. Mehlich III extractable P results by sample site from the WWTP (mg P/kg sediment).

Control	25%	50%	75%
Transect A	21	22	30
Transect B	34	22	21
Transect C	18	18	20
Source	25%	50%	75%
Transect A	85	95	101
Transect B	76	79	109
Transect C	81	93	111
Downstream-1	25%	50%	75%
Transect A	116	105	103
Transect B	112	117	117
Transect C	115	120	127
Downstream-2	25%	50%	75%
Transect A	102	84	93
Transect B	78	69	99
Transect C	119	84	88

Descriptive Statistics

Cattle Farm

Descriptive statistics at the cattle farm for total P (Table 4-5) and Mehlich III extractable P (Table 4-6) provide the minimum and maximum values, range, mean, and median for each sample site. Total P at the farm ranged from 431 mg P/kg sediment to 765 mg P/kg. The mean value for total P at the farm was 576 mg P/kg. Total P mean values were lowest at the source sample site and highest at the downstream 2 sample site. Mehlich III extractable P at the farm ranged from 12 mg P/kg to 34 mg P/kg. The overall Mehlich III extractable P mean value was 18 mg P/kg. Mehlich III extractable P mean values were lowest at the source site and the downstream 1 site and the highest values were found at the downstream 2 sample site.

Table 4-5. Descriptive Statistics for total P at the cattle farm (mg P/kg sediment)

	N	Min	Max	Range	Mean	Median	Std. Deviation
All Sites	36	431	765	334	576	554	80
Control	9	497	765	268	584	554	81
Source	9	431	636	205	508	500	62
Downstream1	9	490	696	206	571	544	68
Downstream 2	9	552	693	141	641	644	49
Source + D1 + D2	27	431	696	265	573	553	80
Control + D1 + D2	27	490	765	275	599	587	73

Table 4-6. Descriptive statistics for Mehlich III extractable P at the cattle farm (mg P/kg sediment)

	N	Min	Max	Range	Mean	Median	Std. Deviation
All Sites	36	12	34	22	18	17	4
Control	9	14	20	6	18	18	2
Source	9	12	19	7	16	16	2
Downstream 1	9	13	18	5	16	16	1
Downstream 2	9	17	34	17	23	22	6
Source + D1 + D2	27	12	34	22	18	17	5
Control + D1 + D2	27	13	34	21	19	17	5

The total P histogram of the cattle farm shows a broad distribution with a continuous data range from 400 mg P/Kg to approximately 700 mg P/kg (Figure 4.1). Most total P values fall between 500 mg P/kg and 700 mg P/kg and one higher value is found at 750 mg P/kg. The Mehlich III extractable P histogram shows a continuous distribution of data between 10 mg P/kg and 25 mg P/kg sediment followed by three discontinuous frequency classes at 25 mg P/kg, 30 mg P/kg, and 35 mg P/kg (Figure 4.2).

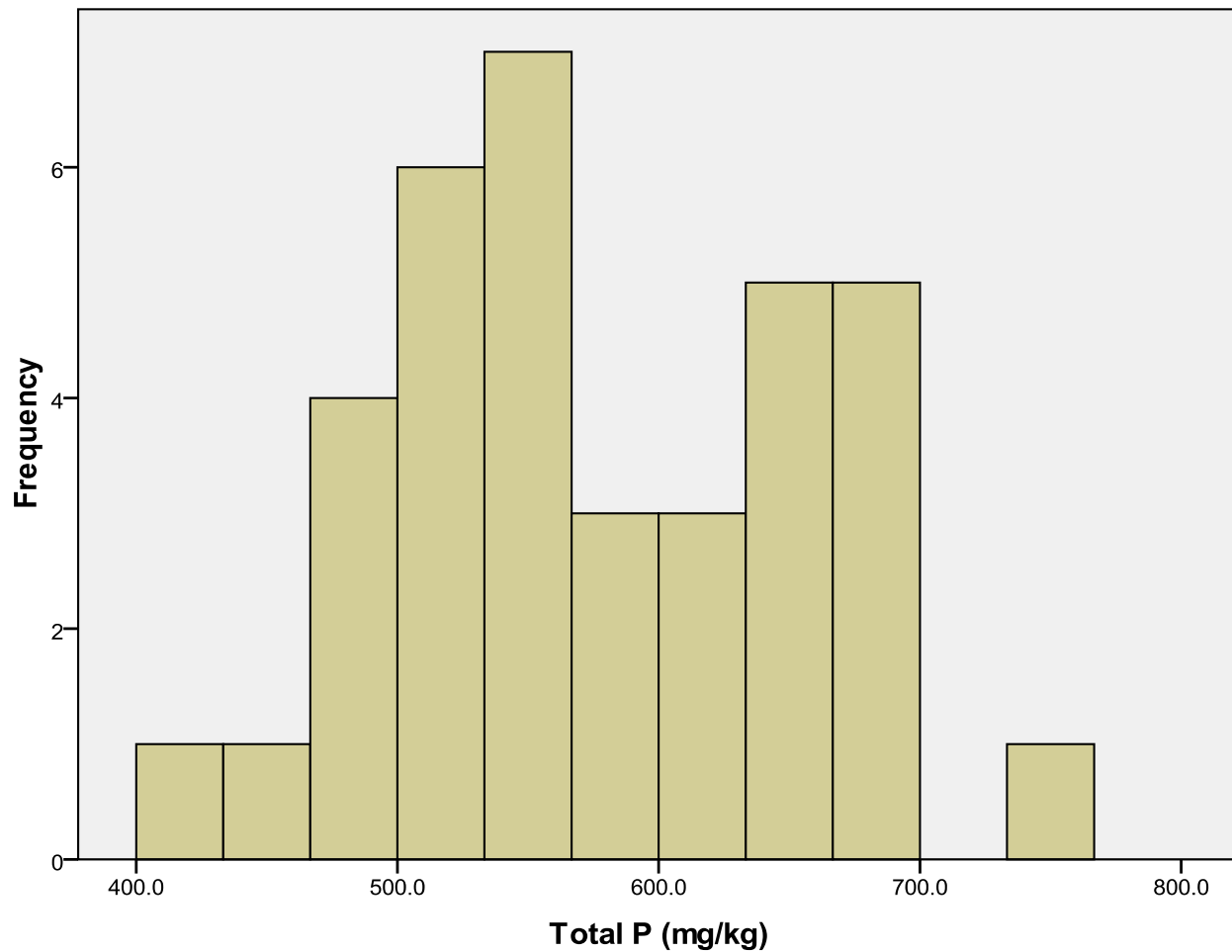


Figure 4.1. Histogram of total P data from all sample sites at the cattle farm (mg P/kg) (n=36).

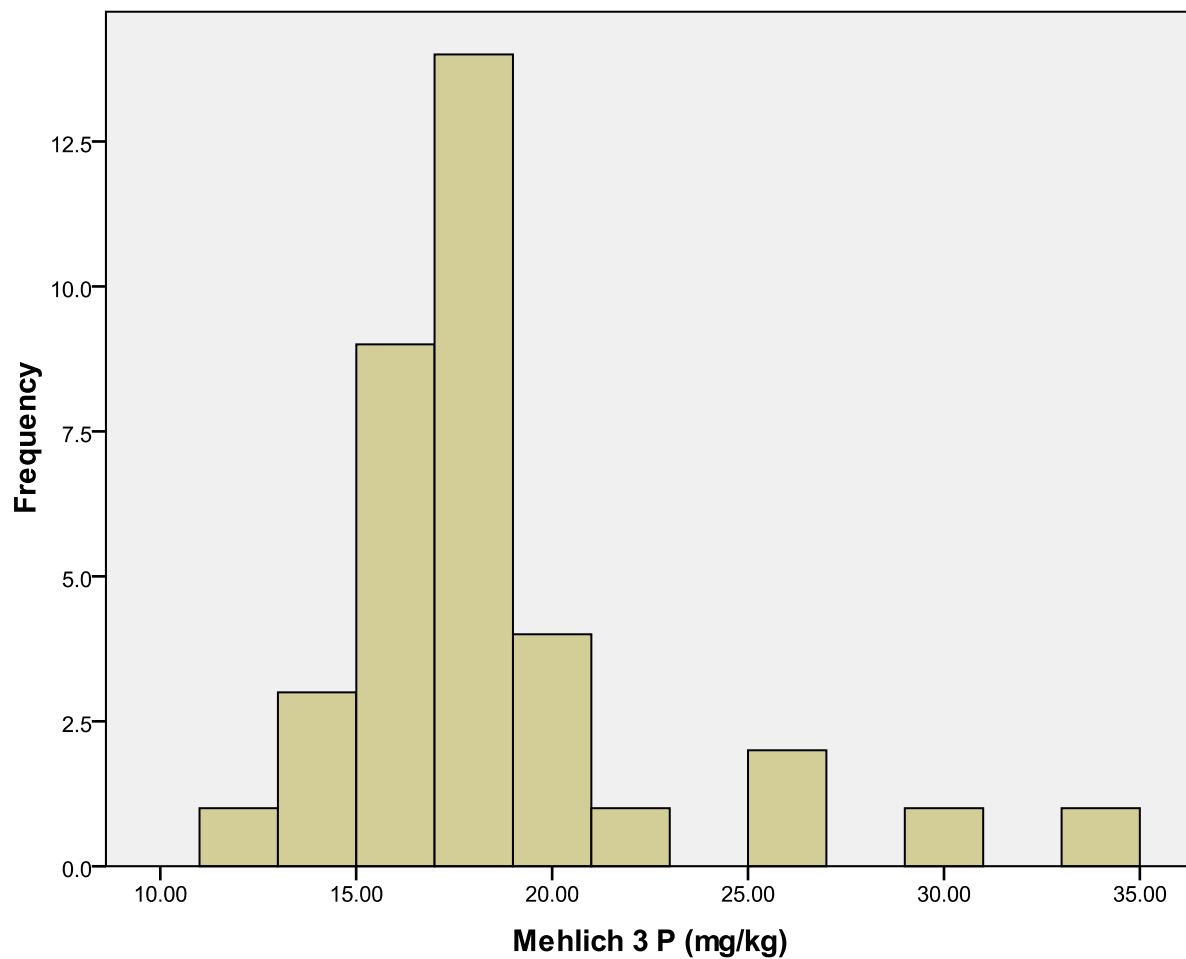


Figure 4.2. Histogram of Mehlich III extractable P data from all sample sites at the cattle farm (mg P/kg) (n = 36).

Box plots for total P and Mehlich III extractable P were developed to display the distribution of the data values within each sampling site (Figure 4.3, Figure 4.4). For the farm, the total P box plot shows the control site with the greatest range of total P concentration values in relation to the other three sites. With one outlier excluded, the source site at the cattle farm had the lowest median and overall smallest range in total P values in comparison to the other three sites. The control, downstream 1, and downstream 2 sites had a large overlap of total P values.

The Mehlich III extractable P box plots show overlapping values with similar ranges at the control, source, and downstream 1 sites. The downstream 2 site shows a broader range, with values that extend far beyond the maximum values of the other three sample sites. The box plots for total P at the cattle farm and Mehlich III extractable P at the cattle farm follow similar trends, with the median of the control being slightly greater than the source and downstream 1 sample site medians.

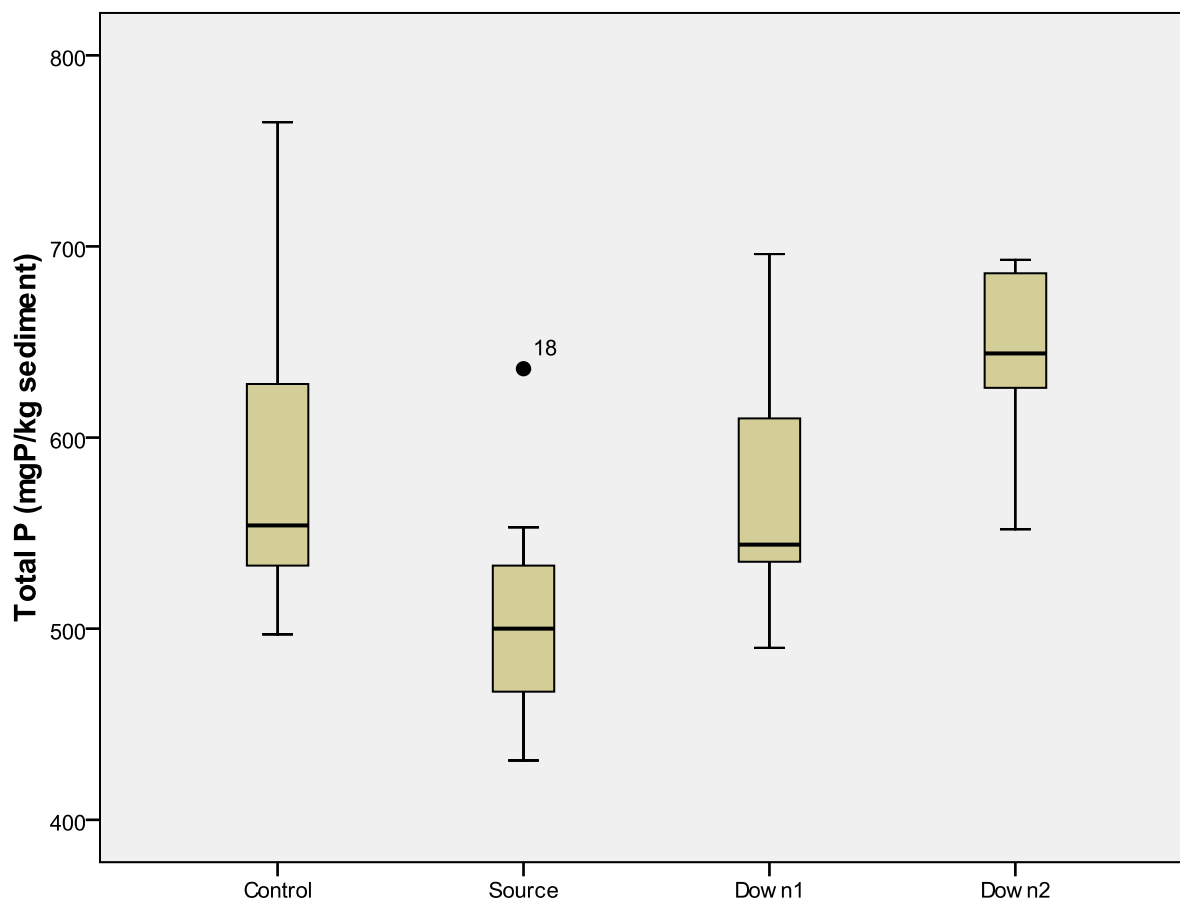


Figure 4.3. Box plots from the cattle farm of total P in bed sediments. Top line of the box is the 75th percentile, the bottom of the box is the 25th percentile, and the middle line is the median. The whiskers represent the highest and lowest values that are not outliers. (mg P/kg) (n=36)

- Denotes an outlier, a value that is between 1.5 and 3 times the interquartile range, for the 18th value at the cattle farm (636 mg P/kg).

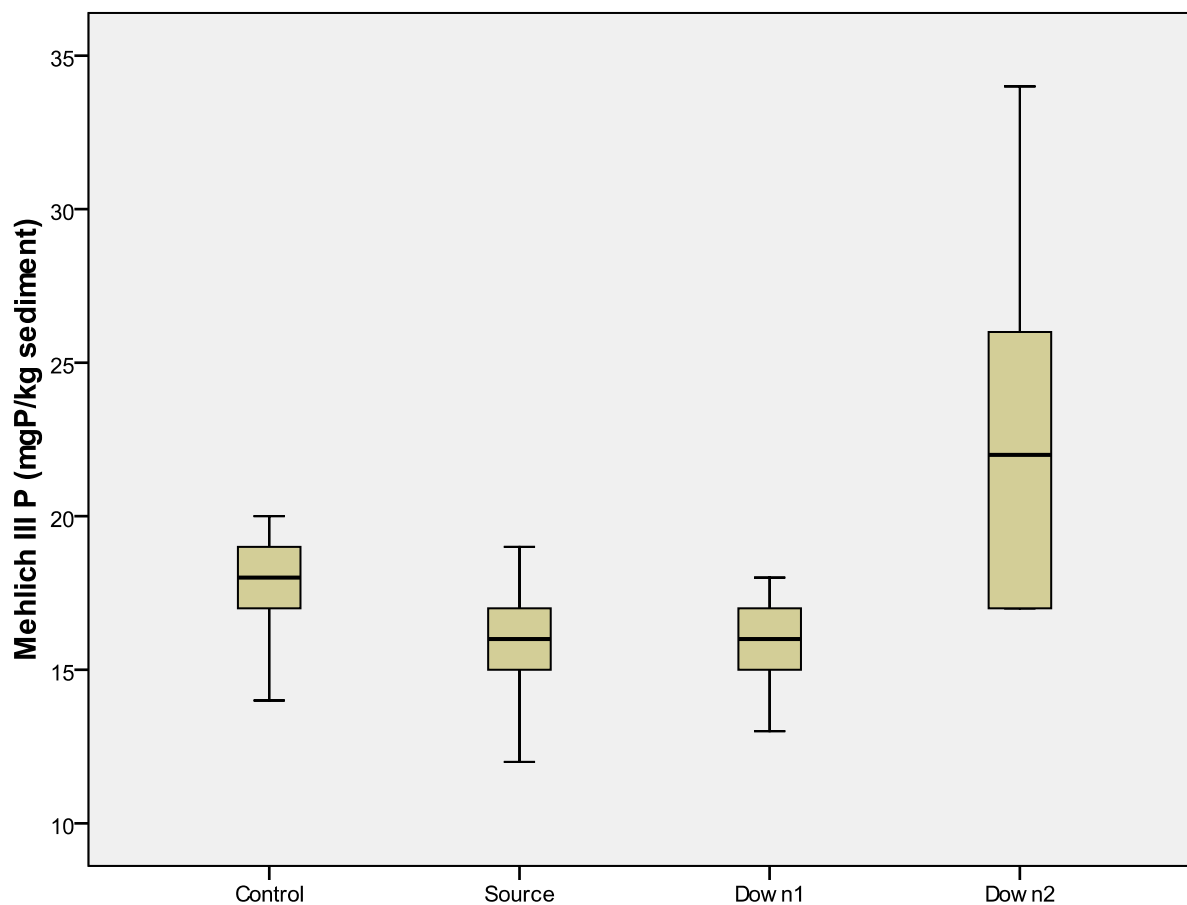


Figure 4.4. Box plots from the cattle farm of Mehlich III extractable P in bed sediments. Top line of the box is the 75th percentile, the bottom of the box is the 25th percentile, and the middle line is the median. The whiskers represent the highest and lowest values that are not outliers (mg P/kg) (n=36).

Wastewater Treatment Plant

Total P values at the WWTP ranged from a minimum of 424 mg P/kg sediment to a maximum of 1000 mg P/kg sediment (Table 4-7). Overall mean total P at the WWTP was 648 mg P/kg. The control sample site had the lowest mean total P value, while the downstream 1 sample site had the highest mean total P value. Mehlich III extractable P values at the WWTP ranged from a minimum of 18 mg P/kg to a maximum of 127 mg P/kg (Table 4-8). The overall mean Mehlich III extractable P value was 80 mg P/kg. The control had the lowest Mehlich III extractable P mean, while the downstream 1 had the highest Mehlich III extractable P mean value.

The total P histogram from the WWTP shows a nearly even distribution between 400 mg P/kg and 800 mg P/kg, with a drop off in frequency as the values increased to 1000 mg P/kg (Figure 4.5). The Mehlich III extractable P histogram shows two distinct groups of values at the WWTP (Figure 4.6). Values in the lower group are evenly distributed about 25 mg P/kg. Values of Mehlich III extractable P in the higher group are distributed about the 100 mg P/kg mark. No values are seen at the 50 mg P/kg mark.

Table 4-7. Descriptive Statistics for total P at the WWTP (mg P/kg sediment).

	N	Min	Max	Range	Mean	Median	Std. Deviation
All sites	36	424	1000	576	648	625	152
Control	9	424	557	133	480	462	47
Source	9	575	718	143	644	627	47
Downstream 1	9	733	971	238	801	778	78
Downstream 2	9	474	1000	526	665	605	178
Source + D1 + D2	27	474	1000	526	703	696	132

Table 4-8. Descriptive Statistics for Mehlich III extractable P at the WWTP (mg P/kg sediment).

	N	Min	Max	Range	Mean	Median	Std. Deviation
All sites	36	18	127	109	80	90.5	36
Control	9	18	34	16	22	21	5
Source	9	76	111	35	92	93	13
Down 1	9	103	127	24	114	116	7
Down 2	9	69	119	50	90	88	15
Source + D1 + D2	27	69	127	58	99	101	16

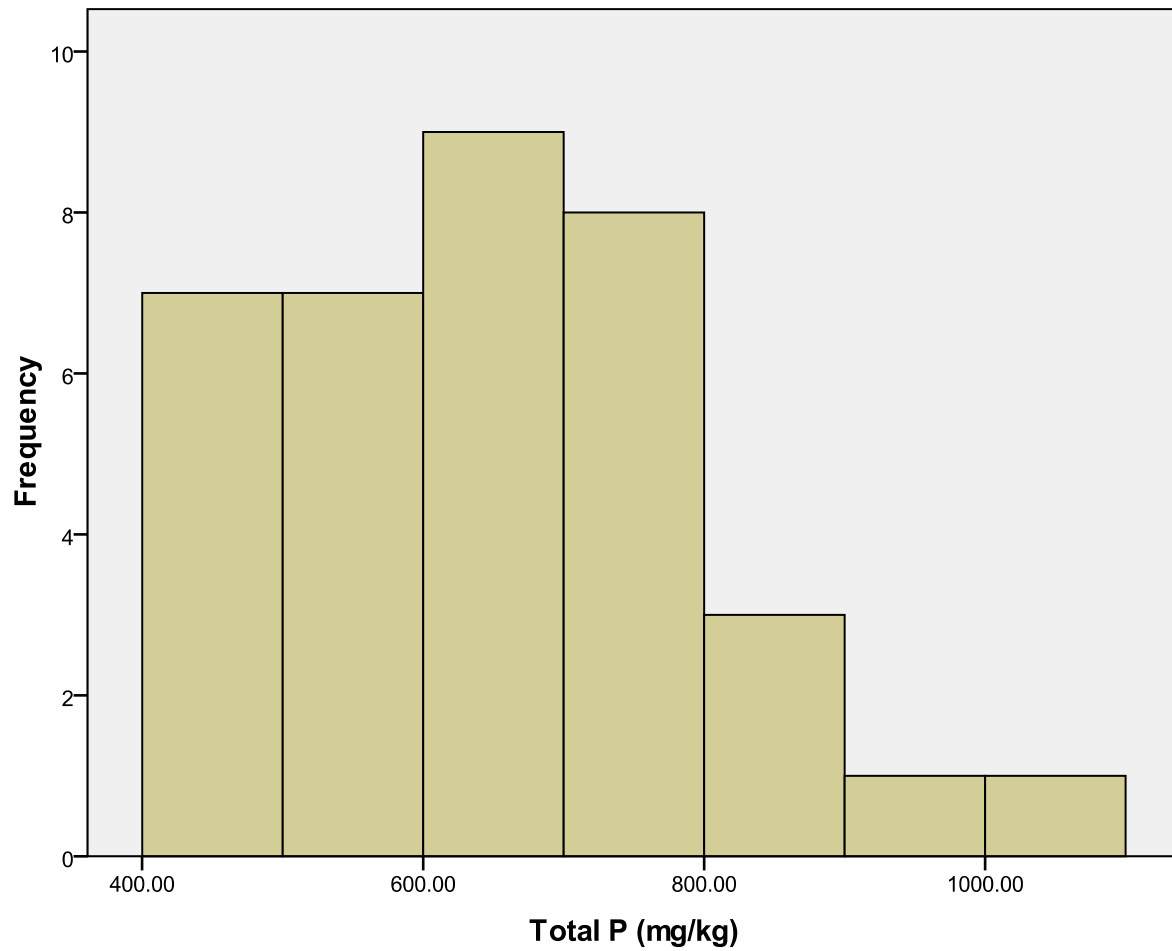


Figure 4.5. Histogram of total P data from the WWTP (mg P/kg) (n=36).

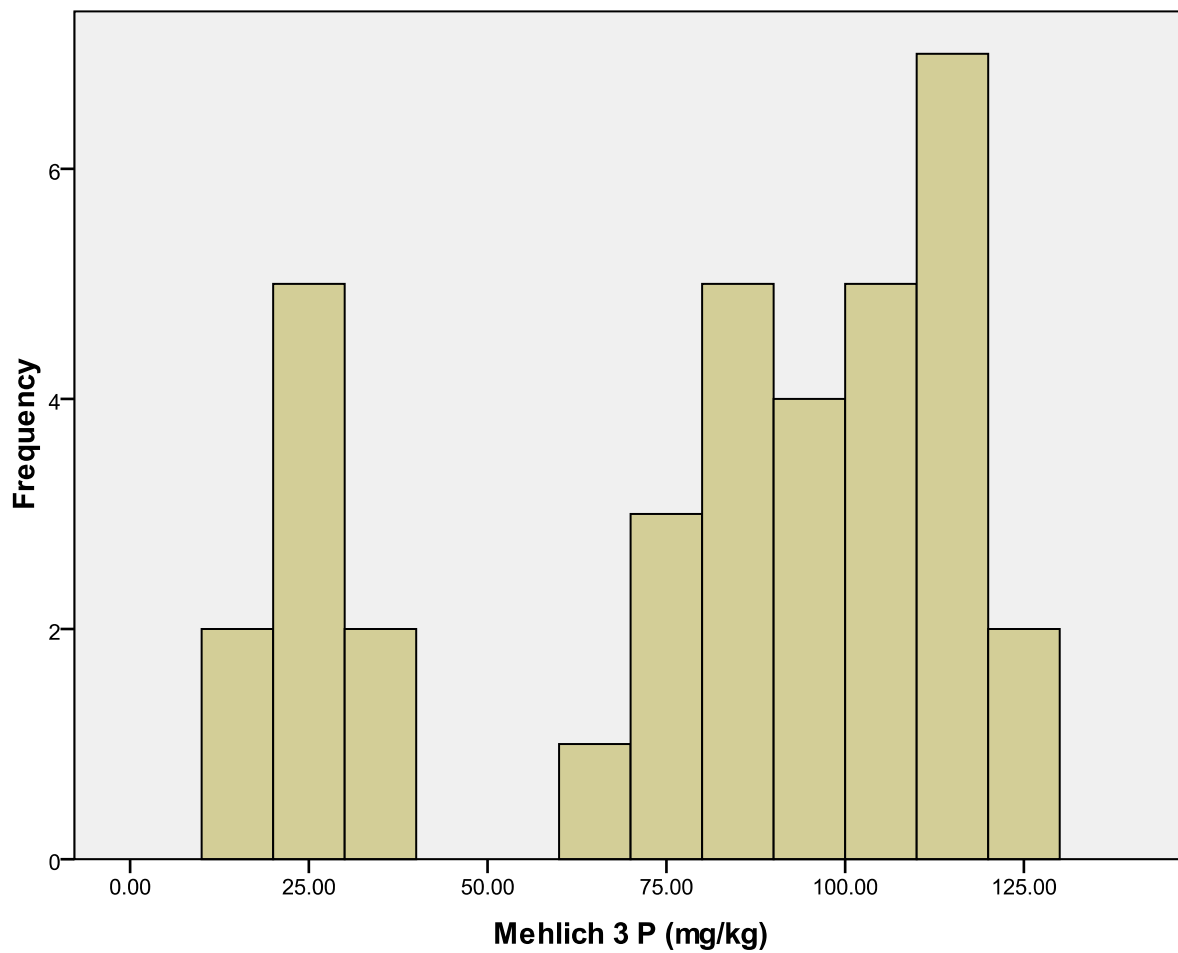


Figure 4.6. Histogram of Mehlich III extractable P data from the WWTP (mg P/kg) (n=36).

Box plots for total P and Mehlich III extractable P were developed to display the distribution of the data values within each sampling site at the WWTP. Total P box plots (Figure 4.7) for the WWTP show the control, source, and downstream 1 to have a similar range in values while the downstream 2 sample site has a much large value range. There is a slight overlap in values between the control and source sample sites and the source and downstream 1 sample sites. Downstream 2 values heavily overlap with those of the other three sample sites. One outlier is identified on the box plots at the downstream 1 sample site.

Mehlich III extractable P box plots (Figure 4.8) follow a similar trend to the total P box plots. The smallest range in values is seen at the control sample site and the largest value range is seen at the downstream 2 sample site. Three outliers are identified at the control and two outliers are identified at the downstream 1 sample site. Two major differences between the total P and Mehlich III extractable P box plots are the control values for the Mehlich III P have no overlap with any of the other three sites and the downstream 2 sample site values more follow the source sample site values more closely than either the downstream 1 or control sample sites.

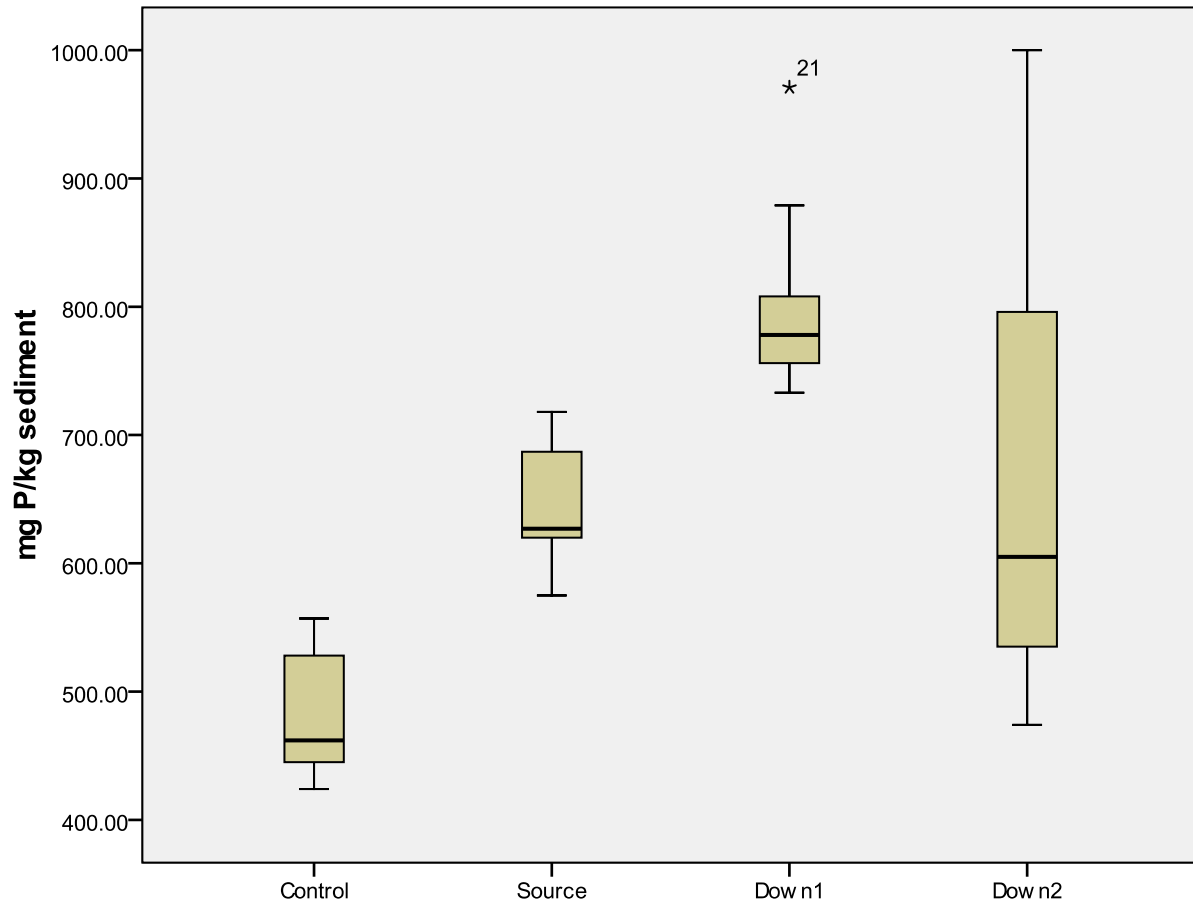


Figure 4.7. Box Plots from the WWTP of total P in bed sediments. Top line of the box is the 75th percentile, the bottom of the box is the 25th percentile, and the middle line is the median. The whiskers represent the highest and lowest values that are not outliers, values that are between 1.5 and 3 times the interquartile range (mg P/kg) (n=36).

* Denotes an extreme outlier, a value that is more than 3 times the interquartile range, for the 21st data point (971mg P/kg).

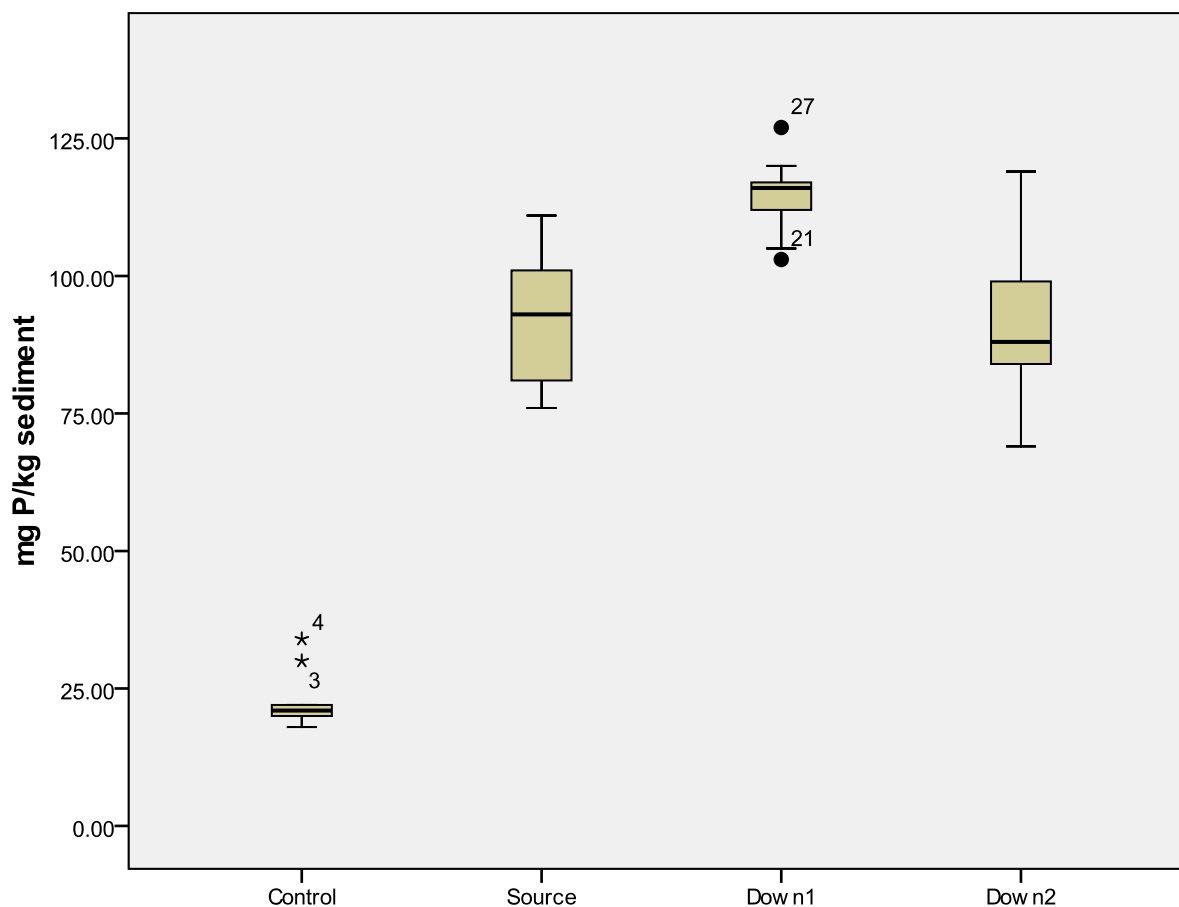


Figure 4.8. Box Plots from the WWTP of Mehlich III extractable P in bed sediments. Top line of the box is the 75th percentile, the bottom of the box is the 25th percentile, and the middle line is the median. The whiskers represent the highest and lowest values that are not outliers, values that are between 1.5 and 3 times the interquartile range (mg P/kg) (n=36).

- Denotes an outlier, a value that is between 1.5 and 3 times the interquartile range, for the 21st and 27th values at the WWTP (103 mg P/kg, 127 mg P/kg).
- * Denotes an extreme outlier, a value that is more than 3 times the interquartile range, for the 3rd and 4th data points (30 mg P/kg, 34 mg P/kg).

Comparison of Total P and Mehlich III extractable P Within Sampling Locations

Three major questions were posed for hypothesis testing in this research. The first question was: Can a total P signal from a cattle farm and a WWTP be identified in the streambed sediments at and below an input point? To statistically analyze if a P signal was found in the sediments at and downstream of the input point, the following three analyses were performed:

1. Analysis of Variance (ANOVA) at each sample location
2. Two tailed t-tests between each sample site at each sample location
3. One-tailed t-test comparing an upstream and downstream site

ANOVA – Within Sampling Locations

Results of the four ANOVA tests showed significant differences in both total P and Mehlich III extractable P between sampling sites at both the cattle farm and the WWTP. At the cattle farm, differences between sample sites for total P were significant, $p = 0.02$, (Table 4-9) and differences between sample sites for Mehlich III extractable P were significant, $p = 0.00$ (Table 4-10). At the WWTP, differences between sample sites for total P were significant, $p = 0.00$ (Table 4-11) and differences between sample sites for Mehlich III extractable P were significant, $p = 0.00$ (Table 4-12).

The ANOVA results support the hypothesis that P values at at least two sample sites at each sample location differ significantly and indicate that the P inputs from the cattle farm and the WWTP may be affecting sediment P in the streambed of Beaver Creek. These results also support completing two-tailed t-tests between each of the sample sites to determine which sample sites have significant differences in sediment P concentrations.

Table 4-9. ANOVA for total P between sample sites at the cattle farm.

Cattle Farm Total P	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	81268	3	27089.407	6.105	.002*
Within Groups	141992	32	4437.271		
Total	223260	35			

* denotes significance at $p \leq 0.05$.

Table 4-10. ANOVA for Mehlich III extractable P between sample sites at the cattle farm.

Cattle Farm Mehlich III extractable P	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	290	3	96.991	7.764	.000*
Within Groups	399	32	12.493		
Total	690	35			

* denotes significance at $p \leq 0.05$.

Table 4-11. ANOVA for total P between sample sites at the WWTP.

WWTP Total P	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	466142	3	155380.991	14.739	.000*
Within Groups	337345	32	10542.056		
Total	803488	35			

* denotes significance at $p \leq 0.05$.

Table 4-12. ANOVA for Mehlich III extractable P between sample sites at the WWTP.

WWTP Mehlich III extractable P	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	42539	3	14179.704	121.439	.000*
Within Groups	3736	32	116.764		
Total	46275	35			

* denotes significance at $p \leq 0.05$.

Levene's Test for Equal Variance

Prior to performing and analyzing results for the two sample t-test, the sample variances of the sites were analyzed by the Levene's test to determine if they were equal. In SPSS, the Levene's test results are provided as part of the t-test. If the Levene's test p -value was $p > 0.05$, the sample sites were assumed to have equal variances. If the Levene's test p -value was $p \leq 0.05$ the sample sites were not assumed to have equal variances for the t-test analysis.

The results of the Levene's test for sample sites at the farm showed no differences in variances between any of the sites for total P (Table 4-13), but, Mehlich III extractable P (Table 4-14) at the downstream 2 sample site had a significantly different variance from the control, source, and downstream 1 sample sites. The Levene's test results for total P at the WWTP (Table 4-15) showed the variance of the downstream 2 sample site differed from those of the control, source, and downstream 1 sample sites. For Mehlich III extractable P at the WWTP (Table 4-16), the control site variance differed from those of the source and downstream 2 sample sites.

Table 4-13. Levene's test for equal variances total P results between sample sites at the cattle farm.

Sample Sites	F-Value	Significance
Control - Source	0.653	0.431
Control - Downstream 1	0.161	0.693
Control - Downstream 2	1.735	0.206
Source - Downstream 1	0.263	0.615
Source - Downstream 2	0.296	0.594
Downstream 1 - Downstream 2	1.326	0.266

Table 4-14. Levene's test for equal variances for Mehlich III extractable P between sample sites at the cattle farm.

Sample Sites	F-Value	Significance
Control - Source	0.159	0.695
Control - Downstream 1	0.524	0.480
Control - Downstream 2	11.972	0.003*
Source - Downstream 1	1.303	0.270
Source - Downstream 2	10.401	0.005*
Downstream 1 – Downstream 2	15.142	0.001*

* denotes unequal variances ($p \leq 0.05$)

Table 4-15. Levene's test for equal variances for total P results between sample sites at the WWTP

Sample Sites	F-Value	Significance
Control - Source	0.003	0.958
Control - Downstream 1	0.905	0.355
Control - Downstream 2	11.935	0.003*
Source - Downstream 1	0.943	0.346
Source - Downstream 2	11.962	0.003*
Downstream 1 - Downstream 2	6.780	0.019*

* denotes unequal variances ($p \leq 0.05$)

Table 4-16. Levene's test for equal variances for Mehlich III extractable P results between sample sites at the WWTP.

Sample Sites	F-Value	Significance
Control - Source	7.677	0.014*
Control - Downstream 1	0.447	0.513
Control - Downstream 2	5.257	0.036*
Source - Downstream 1	4.139	0.059*
Source - Downstream 2	0.023	0.881
Downstream 1 – Downstream 2	3.161	0.094

* denotes unequal variances ($p \leq 0.05$)

Comparison of Sampling Sites at the Cattle Farm

The results of the two-tailed t-tests for Total P at the farm showed values at the downstream 2 sample site to significantly differ from both the source sample site values ($p = 0.00$), and the downstream 1 sample site values ($p = 0.02$) (Table 4-17). The source sample site total P values also significantly differed from control sample site total P values ($p = 0.04$). The remaining pairs of total P t-tests-control and downstream 1, control and downstream 2, and source and downstream 1-had no significant differences.

Two-tailed t-test results for Mehlich III extractable P at the cattle farm showed the downstream 2 sample site values to significantly differ from the values at the control ($p = 0.04$), the source ($p = 0.01$), and the downstream 1 sample sites ($p = 0.01$) (Table 4-18). The Mehlich III extractable P values at the control sample site also differed significantly from the downstream 1 sample site ($p = 0.04$). The two remaining pairs of Mehlich III extractable P t-tests from the cattle farm-the control and source, and the downstream 1 and source-did not significantly differ.

The two-tailed t-test results at the cattle farm support the hypothesis that a P signal can be found in the sediments downstream of the cattle farm. While the P values from control sample site did not prove to be the lowest, the source sample site values were the least and values became progressively higher at the downstream 1 and downstream 2 sample sites. The difference of means between the source and downstream 2 sample site was significant for both the total P and Mehlich III extractable P analyses, indicating that sediment P values downstream from the cattle farm are being affected by P input at the farm. However, the spike in P values seen at the downstream 2 sample site may not only be attributable to the cattle farm because an ephemeral stream converges with Beaver Creek between the downstream 1 and downstream 2 sample sites and may be affecting sediment P at the downstream 2 site.

Table 4-17. Two-tailed t-test results for Total P between sample sites at the cattle farm

Sample Sites (site 1 – site 2)	Site 1 mean	Site 2 mean	t	df	Sig. (2-tailed)
Control - Source	584	508	2.10	16	0.04*
Control - Downstream 1	584	571	0.37	16	0.72
Control - Downstream 2	584	641	-1.77	16	0.10
Source - Downstream 1	508	571	-2.08	16	0.06
Source - Downstream 2	508	641	5.09	16	0.00*
Downstream 1 - Downstream 2	571	641	-2.53	16	0.02*

* denotes significance at $p \leq 0.05$.

Table 4-18. Two-tailed t-test results for Mehlich III extractable P between sample sites at the cattle farm.

Sample Sites (site 1 – site 2)	Site 1 mean	Site 2 mean	t	df	Sig. (2-tailed)
Control - Source	17.56	15.67	1.94	16	0.07
Control - Downstream 1	17.56	15.78	2.18	16	0.04*
Control - Downstream 2	17.56	22.67	-2.34	9.53	0.04*
Source - Downstream 1	15.67	15.78	-0.13	16	0.90
Source - Downstream 2	15.67	22.67	3.17	9.91	0.01*
Downstream 1 – Downstream 2	15.78	22.67	-3.21	8.89	0.01*

* denotes significance at $p \leq 0.05$.

Mann-Whitney Results

The results of the Mann-Whitney non-parametric test generally supported the results of the two-tailed t-tests (Table 4-19, Table 4-20). Two deviations between the results of the t-test and the results of the Mann Whitney test occurred at the cattle farm. The total P t-test results between the source sample site and the downstream 1 sample site at the cattle farm did not show a significant difference. However, the Mann-Whitney test showed the values of the source sample site of the cattle farm to significantly differ from the values of the downstream 1 sample site ($p = 0.04$). The second deviation from t-test results, found in the Mehlich III extractable P values between the control and the downstream 2 sample sites at the cattle farm, showed the control site to significantly differ from the downstream 2 sampling site ($p = 0.04$). Mann-Whitney results showed the control and downstream 2 sample sites did not significantly differ ($p = 0.22$).

Table 4-19. Mann-Whitney results for total P between sampling sites at the cattle farm

Cattle Farm Sample Sites	Mann-Whitney <i>U</i>	<i>Z</i>	Mann-Whitney Exact <i>p</i>-value	Sig. (2-tailed) t-test
Control – Source	15.50	-2.21	0.02*	0.04*
Control - Downstream 1	37.00	-0.309	0.80	0.72
Control - Downstream 2	19.50	-1.856	0.06	0.10
Source - Downstream 1	17.50	-2.032	0.04*	0.06
Source - Downstream 2	4.00	-3.223	0.00*	0.00*
Downstream 1 - Downstream 2	16.50	-2.12	0.03*	0.02*

* denotes significance at $p \leq 0.05$

Table 4-20. Mann-Whitney results for Mehlich III extractable P between sample sites at the cattle farm.

Cattle Farm Sample Sites	Mann - Whitney U	Z	Mann- Whitney Exact p-value	Sig. (2-tailed) t- test
Control – Source	19.50	-1.876	0.06	0.07
Control - Downstream 1	18.00	-2.014	0.05*	0.04*
Control - Downstream 2	26.00	-1.297	0.22	0.04*
Source - Downstream 1	40.50	0.000	1.00	0.90
Source - Downstream 2	10.00	-2.776	0.01*	0.01*
Downstream 1 - Downstream 2	8.00	-2.931	0.00*	0.01*

* denotes significance at $p \leq 0.05$

Comparison of Sampling Sites at the Wastewater Treatment Plant

Total P results of the two-tailed t-test at the WWTP show the control to significantly differ from the source ($p = 0.00$), downstream 1 ($p = 0.00$), and downstream 2 sampling sites ($p = 0.02$) (Table 4-21). Additionally, the downstream 1 sample site was found to significantly differ from the source sample site ($p = 0.00$). No significant difference in total P of channel bed sediments was shown between either the source and downstream 2 sample sites or the downstream 1 and downstream 2 sample sites.

Mehlich III extractable P results of the two-tailed t-test at the WWTP show the control sampling site to significantly differ from the source ($p = 0.00$), downstream 1 ($p = 0.00$), and downstream 2, ($p = 0.00$) sampling sites (Table 4-22). The downstream 1 sampling site differed significantly from the source sample site ($p = 0.00$), and the downstream 2 sampling site ($p = 0.00$). No significant difference in Mehlich III extractable P was shown between the source and downstream 2 sampling sites.

Table 4-21. Two-tailed t-test results for total P between sample sites at the WWTP.

Sample Sites (Site 1 – Site 2)	Site 1 mean	Site 2 mean	t	df	Sig. (2-tailed)
Control – Source	481	645	7.40	16	0.00*
Control - Downstream 1	481	801	10.59	16	0.00*
Control - Downstream 2	481	666	3.01	9.104	0.02*
Source - Downstream 1	645	801	5.17	16	0.00*
Source - Downstream 2	645	666	0.34	9.115	0.74
Downstream 1 - Downstream 2	801	666	2.10	10.94	0.06

* denotes significance at $p \leq 0.05$

Table 4-22. Two tailed t-test results for Mehlich III extractable P between sample sites at the WWTP.

Sample Sites (Site 1 – Site 2)	Site 1 mean	Site 2 mean	t	df	Sig. (2-tailed)
Control – Source	22.89	92.22	14.82	10.77	0.00*
Control - Downstream 1	22.89	114.67	30.11	16.00	0.00*
Control - Downstream 2	22.89	90.67	12.96	10.16	0.00*
Source - Downstream 1	92.22	114.67	4.53	12.67	0.00*
Source - Downstream 2	92.22	90.67	0.24	16	0.82
Downstream 1 - Downstream 2	114.67	90.67	4.38	16	0.00*

* denotes significance at $p \leq 0.05$

The results at the WWTP for both total P and Mehlich III extractable P support the hypothesis that a P signal exists in the sediments downstream from the control of the WWTP. The values of both forms of P are lowest at the control and highest at the downstream 1 sampling sites corresponding with the largest difference of means between the two sites. The difference between the control and the three downstream sites supports the hypothesis that a sediment P signal exists. The Mann-Whitney non-parametric test supports the results of the two tailed t-test for both total P and Mehlich III extractable P at the WWTP and no significant deviations were found between the t-test results and the Mann-Whitney results (Table 4-23, Table 4-24).

Table 4-23. Mann-Whitney results for total P between sample sites at the WWTP.

WWTP Sample Sites	Mann-Whitney <i>U</i>	<i>Z</i>	Mann-Whitney Exact <i>p</i> -value	Sig. (2-tailed) t- test
Control – Source	0.00	-3.576	0.00*	0.00*
Control - Downstream 1	0.00	-3.576	0.00*	0.00*
Control - Downstream 2	8.00	-2.87	0.03*	0.02*
Source - Downstream 1	0.00	-3.576	0.00*	0.00*
Source - Downstream 2	35.00	-0.486	0.67	0.74
Downstream 1 - Downstream 2	22.00	-1.634	0.11	0.06

* denotes significance at $p \leq 0.05$

Table 4-24. Mann-Whitney results for Mehlich III extractable P between sample sites at the WWTP.

WWTP Sample Sites	Mann-Whitney <i>U</i>	<i>Z</i>	Mann-Whitney Exact <i>p</i> -value	Sig. (2-tailed) t- test
Control – Source	0.00	-3.582	0.00*	0.00*
Control – Downstream 1	0.00	-3.584	0.00*	0.00*
Control – Downstream 2	0.00	-3.584	0.00*	0.00*
Source – Downstream 1	4.00	-3.225	0.00*	0.00*
Source – Downstream 2	37.50	-0.265	0.80	0.82
Downstream 1 – Downstream 2	7.00	-2.961	0.00*	0.00*

* denotes significance at $p \leq 0.05$

Upstream Comparisons

Cattle Farm

One-tailed t-tests at the cattle farm tested downstream changes in total P concentration of the sediments (Table 4-25). The results showed sediments at the control sample site to have significantly greater values of P than those at the source sample site ($p = 0.02$). Control sample site sediments did not differ significantly from those at the downstream 1 or downstream 2 sample sites. Sediments at the downstream 2 sample site were found to have significantly greater values of total P than sediments at the source ($p = 0.00$) and downstream 1 ($p = 0.01$) sample sites.

At the cattle farm, one-tailed t-test results for Mehlich III extractable P showed the concentration in sediments at the control sample site did not differ significantly from those at the source sample site ($p = 0.04$) (Table 4-26). Mehlich III extractable P values at the control were significantly higher than those at the downstream 1 sample site, ($p = 0.02$). Sediment Mehlich III extractable P values at the control were significantly lower than those at the downstream 2 sample site, ($p = 0.02$). The downstream 2 sample site was found to have significantly higher Mehlich III extractable P values than the control ($p = 0.02$), source ($p = 0.01$), and downstream 1 sample sites ($p = 0.01$).

Both the total P and Mehlich III extractable P results reflect an increase in the sediment P concentrations downstream from the cattle farm, at the downstream 2 sampling site. While the sediment P values at the source sampling site were lowest in comparison to the other three sites, the downstream 2 sampling site, which is immediately downstream from the farm, shows significantly higher values of P in sediments, indicating a P input is affecting sediment P at the downstream 2 sampling site. Sediments at the downstream 2 sample at the cattle farm may not only be affected by the farm because an ephemeral stream enters Beaver Creek between the downstream 1 and downstream 2 sample sites, potentially contributing to significantly increased sediment P values at the downstream 2 site.

Table 4-25. One-tailed t-test results for total P between sample sites at the cattle farm.

Sample Sites (Site 1 – Site 2)	Site 1 Value	Site 2 Value	t-stat	one-tailed critical t-value	Df	p-value (one-tailed)
Downstream 2 – Control	642	584	1.77	1.74	16	0.04*
Downstream 2 – Source	641	508	5.091	1.75	16	0.00*
Downstream 2 – Downstream 1	641	571	2.529	1.75	16	0.01*
Downstream 1 – Control	571	584	.369	1.74	16	0.35
Downstream 1 – Source	571	508	2.075	1.75	16	0.03*
Control – Source	584	508	2.210	1.75	16	0.02*

* denotes mean of sample A > the mean of sample B (significance at $p \leq 0.05$)

Table 4-26. One-tailed t-test results for Mehlich III extractable P between sample sites at the cattle farm

Sample Sites (Site 1 – Site 2)	Site 1 Value	Site 2 Value	t-stat	one-tailed critical t-value	Df	p-value (one-tailed)
Downstream 2 – Control	22.67	17.56	2.33	1.81	10	0.02*
Downstream 2 – Source	22.67	15.67	22.67	1.81	16	0.01*
Downstream 2 – Downstream 1	22.67	15.78	3.21	1.83	9	0.01*
Downstream 1 – Control	15.78	17.56	2.18	1.74	16	0.02
Downstream 1 – Source	15.78	15.67	0.13	1.75	16	0.45
Control – Source	17.56	15.67	1.94	1.75	16	0.04*

* denotes mean of sample A > the mean of sample B (significance at $p \leq 0.05$)

Wastewater Treatment Plant

One tailed t-tests at the WWTP tested downstream changes of total P and Mehlich III extractable P concentrations in the sediments. (Table 4-27, Table 4-28). Results showed sediments at the source, downstream 1, and downstream 2 sampling sites to have significantly greater values of total P than the control sampling site, $p = 0.00$, $p = 0.00$, and $p = 0.01$, respectively. Sediments at the downstream 1 sampling site were found to have significantly greater total P concentrations than those at the source sampling site ($p = 0.00$). Total P in sediments at the source and downstream 2 sampling sites did not significantly differ.

Table 4-27. One tailed t-test results for total P between sites at the WWTP.

Sample Sites (Sample 1 – Sample 2)	Site 1 Value	Site 2 Value	t-stat	one-tailed critical t- value	Df	p-value (one- tailed)
Downstream 2 - Control	666	481	3.010	1.83	9	0.01*
Downstream 2 - Source	666	645	0.340	1.83	9	0.37
Downstream 1 - Control	801	481	10.59	1.75	16	0.00*
Downstream 1 - Source	801	645	5.17	1.75	16	0.00*
Downstream 1 - Downstream 2	801	666	2.10	1.75	16	0.03*
Source - Control	645	481	7.40	1.75	16	0.00*
(Source, Downstream 1, and Downstream 2) - Control		481	7.497	1.69	34	0.00*

** denotes mean of sample A > the mean of sample B (significance at $p \leq 0.05$)*

Table 4-28. One-tailed t-test results for Mehlich III extractable P between sites at the WWTP.

Sample Sites (Site 1 – Site 2)	Site 1 Value	Site 2 Value	t-stat	one-tailed critical t- value	df	p-value (one-tailed)
Downstream 2 - Control	90.67	22.89	12.955	1.81	10	0.00*
Downstream 2 - Source	90.67	92.22	0.238	1.75	16	0.41
Downstream 1 - Control	114.67	22.89	30.111	1.75	16	0.00*
Downstream 1 - Source	114.67	92.22	4.532	1.77	13	0.00*
Downstream 1 - Downstream 2	114.67	90.67	4.380	1.75	16	0.00*
Source – Control	92.22	22.89	14.827	1.80	11	0.00*
(Source, Downstream 1, and Downstream 2) – Control			21.222	1.69	34	0.00

**denotes mean of sample A > the mean of sample B (significance at $p \leq 0.05$)*

One-tailed t-test results for Mehlich III extractable P at the wastewater treatment plant followed a similar trend to total P results. Sediments at the source, downstream 1, and downstream 2 sampling sites were significantly greater than the sediments at the control sampling site, $p = 0.00$, $p = 0.00$, and $p = 0.00$, respectively. Downstream 1 sampling site sediments had significantly greater values of Mehlich III extractable P than sediments at the source sampling site ($p = 0.00$). Mehlich III extractable P values at the downstream 2 sample site and the source sample site did not differ significantly.

The combined data from the source, downstream 1 and downstream 2 sample sites were tested against the control values to evaluate changes in sediment P downstream from the outfall. Sediment P concentrations from the combined sites were found to be significantly greater than the control for total P ($p = 0.00$) and Mehlich III extractable P, ($p = 0.00$).

The results at the WWTP show a significant trend in sediment P at the source and downstream 1 sample sites when compared to the control, supporting the hypothesis that there is a sediment P signal in the sediments at and downstream from the WWTP.

Chapter 5

Discussion

Overview

Beaver Creek in north Knox County, Tennessee, has been identified on the Tennessee 303(d) list as a “category 5” stream, meaning that the creek is “water quality limited” and fails to meet one or more of its uses (TDEC, 2006a). One of the pollutants listed for Beaver Creek on the 303(d) list is phosphorus. This means a future detailed study of P loading and P inputs will have to be completed and a TMDL will have to be written to address and improve the P concentrations within Beaver Creek.

Two pollutant sources listed by TDEC for contributing phosphorus to Beaver Creek are pasture grazing areas and major municipal point sources. Since phosphorus levels in Beaver Creek have been shown to impair the water quality of the creek and, since two major activities within Beaver Creek Watershed, agriculture and wastewater processing, have been attributed to contributing to higher P levels within the creek, Beaver Creek appeared to be a good study location to research P near these landuses.

Phosphate concentrations in water can fluctuate over a short period of time, requiring multiple sampling events to yield reliable data for analysis. Conversely, Garnier et al. (1999) found sediments to retain P in reservoirs over a short period of time. Additionally sediment P is recognized by the USEPA to be important in TMDL considerations (USEPA, 1999). Therefore, in order to minimize the number of sampling events that would be required for studying aquatic P while also accessing samples potentially affected by these activities, sediment P concentrations were utilized.

This research proposed to answer two questions. The first question was whether a signal could be identified by P concentration of fine channel-bed sediments from Beaver Creek at and downstream of a cattle farm and a WWTP. The second question was whether elevated Mehlich III P concentrations would be found in the collected sediments. Total P and Mehlich III P were extracted from fine sediments collected from the channel bed at the P source and at downstream sample sites at the cattle farm and the WWTP, and the P values were compared to P values from the upstream control.

Discussion on the cattle farm

When designing the sample plan, the “control” sediments were expected to represent the background P concentration, and to be used to compare to potentially affected sediments at the source and downstream sample sites. At the cattle farm, values of P in channel-bed sediments differed from the expected pattern. Sediments at the “control” sampling site had the second highest mean P concentration, compared to the sediments from the other three sampling sites. Statistically, total P concentrations of sediments at the control site were significantly greater than concentrations at the source sample site and the control did not differ significantly from the downstream 1 and downstream 2 sample sites.

Two factors may have influenced the P concentrations at the control. First, the “control” sampling site, while being upstream of the farm and outside of the fenced-in pasture land for the cattle, may not have been far enough upstream to be removed from the effects of cattle activity. Although the streambanks at the control sample site were steep and did not appear to allow easy stream access for the cattle, it seems probable, with low flows and easily wadable conditions, the

cattle could have accessed Beaver Creek from the farm and waded upstream into the area sampled for the “control.”

At the cattle farm, the total P data from the control site show that the highest value of each transect is located adjacent to the farm, on the right side of the stream. This pattern may reflect a tendency for the cattle to access the creek from the farm property and then move upstream, staying closer to the farm side of the creek.

The second factor which may have contributed to elevated P concentrations at the control sample site, is the natural variability in the P concentrations of Beaver Creek sediments. Given the historical landuse of Beaver Creek Watershed, other past inputs including other livestock operations and leaking septic systems may have a current impact on sediment P at the control sample site. Additionally, since the natural variability of Beaver Creek sediments is unknown, the sediment P concentration at the control site at the cattle farm may not be abnormal, despite nearby data from the source sample site showing the control to be elevated.

Although no clear explanation exists for the unexpected results in the P concentration of the sediments at the control sample site at the cattle farm, no other P input is known to cause an elevated concentration of total P in the sediments at the control sample site of the farm. A survey of the area as well as review of NPDES documents did not indicate that another contemporary P source should be expected to contribute more P to stream sediments than the cattle farm.

The second unexpected result was found at the “source” sampling site at the farm. The expected pattern was that the “source” sediments would reflect an increase in total P concentration when compared with sediments at the control. However, at the farm, results showed the source sample site, approximately 700 m downstream from the control, to have the lowest total P values of the four sample sites.

The source sample site was directly adjacent to the pasture and immediately downstream of three identifiable cattle input points to the stream. Since the project design treated multiple cattle access points as a single source, then the immediate sediment P changes affected by the cattle may have not been captured in the sampling process. An upstream cattle access may have been more readily utilized by the cattle or the cattle may have accessed the stream but waded beyond the sampled area, affecting sediment P at other places along the stream reach. Alternately, background sediment P concentrations at this location may have been lower than the surrounding locations.

Although the control and source sampling sites differed from the expected pattern, the results show significantly greater total P values at the downstream 1 sample site, 150 m downstream of the source. Sediment P values significantly increased again at the downstream 2 sample site, approximately 400 m downstream of the source, when compared to sediments at the source and downstream 1, indicating P inputs from the farm may be affecting sediment P in Beaver Creek.

The spike in total P values at the downstream 2 sampling site may not be only attributable to the cattle farm because an ephemeral stream flows into Beaver Creek between the downstream 1 and downstream 2 sample sites. The stream appears to flow during and immediately after rainstorms, and it crosses at least four different land-use types: single family residential, commercial, wholesale, and agricultural lands. Although the stream was not flowing on the days when the downstream samples were obtained at the farm, the stream cannot be ruled out as a contributor to the significantly greater P values at the downstream 2 sample site.

At the cattle farm, Mehlich III extractable P data followed a somewhat similar trend to total P. Mehlich III extractable P concentration in sediments at the control sample site did not

differ from that of the source sample site and was significantly greater than that at the downstream 1 sample site. Mehlich III extractable P concentration in sediments at the source was the lowest of all of the sample sites at the farm and, statistically, did not differ from concentrations found in sediments at the control and downstream 1 sample sites. The concentration of Mehlich III extractable P at the downstream 2 sample site was significantly greater than the concentrations at the other three sample sites.

At the cattle farm, both the total P and Mehlich III extractable P results indicate that sediments at the downstream 2 sample site are being affected by a P input to the stream. However, sediment P concentration at the downstream 1 sample site is not significantly different from P concentrations at the source or control sample sites. The source and downstream 1 results do not conclusively indicate that the cattle farm, alone, is affecting sediment P values. The downstream 2 results, while significantly greater than those at the downstream 1 and source, do not provide a conclusive signal that the cattle farm, alone, is affecting sediment P in Beaver Creek.

Discussion on the WWTP

The WWTP data generally followed the expected trend. The control sample site had the lowest total P and Mehlich III extractable P sediment concentrations. Sediment P concentration significantly increased at the source sample site, 35 m downstream from the control, and continued to increase at the downstream 1 sample site, approximately 200 m downstream from the source. Sediment P values were the greatest at the downstream 1 sample site sediment P values, and, were significantly greater than all other sample sites along the reach. Sediment P values declined at the downstream 2 sample site, approximately 375 m downstream from the

source, although, they were still significantly greater than control values and did not differ significantly from the source.

The outfall was the single major P contributor identified in the field. Although a large pasture exists across Beaver Creek from the WWTP, there did not appear to be any evidence that cattle or other livestock were accessing the creek. But, given contemporary and historical landuse within the Beaver Creek Watershed, combined with natural variation in P values, the elevated P concentrations in the sediments may not be entirely attributable to the WWTP.

The results from the WWTP support the hypothesis that a P signal could be found in the sediments at and downstream from the WWTP. Sediment concentrations increased significantly at the source site, just 35 m downstream from the control, and concentrations remained elevated throughout the study reach. Only the downstream 2 sample site, 375 m downstream from the control, showed a decline in sediment P.

Research Conclusions

Pasture grazing has been identified as one of the major P contributors to Beaver Creek (TDEC, 2006; TDEC, 2008). Sediment P concentrations approximately 400 m downstream from the most downstream cattle access were significantly greater than the P concentrations at the access point, but, the sediment P values may have been affected by a nearby tributary. Overall, P concentrations of sediments from Beaver Creek near the cattle farm studied in this research do not clearly indicate that farm is having a significant affect on sediment P, at or up to 400 meters downstream in Beaver Creek.

Municipal point sources have also been identified as one of the major P contributors to Beaver Creek (TDEC, 2006; TDEC, 2008). At the WWTP, sediment P concentrations increased

significantly from the control to the source and again, from the source to the downstream 1 sample site. P concentrations began to decrease at the downstream 2 sample site, but, still remained significantly elevated over the control sample site. The results of this study indicate that the WWTP may be having a significant effect on P concentrations in Beaver Creek sediments near the outfall and up to 375 m downstream from the outfall.

This study supports the hypothesis that increased P concentrations could be attributable to P inputs from a WWTP. However, further study is needed about the effects that pastures have on sediment P concentrations within Beaver Creek.

Future Research and Future Implications

This research revealed issues inherent with sampling a non-point source input, such as the cattle farm. The data from the cattle farm proved to not follow the expected trend. However, moving too far away from the cattle farm to define a single “control” sampling site might have resulted in ambiguous and unreliable “control” sample data. Rather than using a single “control” site against which source and downstream changes are tested, future researchers might study the broader variability of P in sediments across both the watershed and within the creek. The data from such a study could be used as a basis to test specific locations or expected P inputs.

Future research on stream affects from cattle farms or WWTPs may focus on a more direct connection between the source and the impact on water quality. For example, cattle that have unimpeded access to a stream will most likely contribute high levels of fecal coliforms or *E. coli* to the water. A future project may look at the source and downstream effects from a cattle farm in relation to changes in fecal coliform or *E. coli* levels. It is also important to continue to research how agricultural areas affect P concentrations in streams and stream

sediments. While agricultural land use is decreasing within the Beaver Creek Watershed, it will still remain an important part of the watershed composition. Although a single farm may not show significant P input to Beaver Creek, collectively, agricultural land use may have an important effect on P levels within the creek. Therefore, additional study on agricultural P inputs to Beaver Creek would be informative towards the broader research connecting phosphorus and agriculture while also being helpful for future planning to address reducing overall P loading within the creek.

WWTPs continue to be an important issue within watersheds, and many water quality issues have been attributed to WWTPs. WWTPs present an interesting opportunity to research how human ingested matter moves through the wastewater system and is discharged to surface waterbodies. For example, one group of researchers is studying anti-biotic resistance of bacteria found within a wastewater treatment plant (Li et al., 2009). Such research is important to public health and may also prove to reveal important environmental impacts. Additionally, a similar study to this one on phosphorus could be developed to research the source and immediate downstream changes in concentrations of medications, caffeine, or estrogen levels, all which may be better fingerprinted to a WWTP.

Future work researching phosphorus is probable. Future P studies, especially in Beaver Creek, may include increased sampling sites, in stream, on the streambank, and within the watershed, to gain a better understanding of the natural variability of P within the sediments and soils of the study area. Also, research quantifying other fractions of P, including algal available P, could be helpful in effectively reducing phosphate concentrations in water. While much work has been done on lakes and reservoirs on P cycling, little work has been completed on P cycling

within moving water, such as Beaver Creek. A P cycling study would be interesting to see if and how P sediment concentrations change throughout a year in Beaver Creek.

Future research in Beaver Creek Watershed will likely need to address the effects of increasing residential development on water quality. As Beaver Creek Watershed further develops, stream quality and nutrient levels will continue to be a major issue within the watershed. One major P contributing source that was not analyzed in this research is the impact of residential areas on P concentration in the stream and in stream sediments. Not only do large residential areas require increasing volumes of water and wastewater to be treated, but they may also contribute high volumes of P to nearby waterways due to activities such as lawn maintenance and the development of recreational areas, such as golf courses.

Since the sample collection of this research, a WWTP within the Beaver Creek Watershed has expanded and upgraded its treatment process to accommodate the increased demand for water and wastewater within the watershed. It will be interesting to see how, while working to reduce overall P concentrations in Beaver Creek, the long-term changes towards a more commercial and residential watershed, with increased wastewater processing, will impact the future stream quality of Beaver Creek.

LIST OF REFERENCES

- Becher, K. D., D. J. Schnoebelen, and K. K. B. Akers, 2000. Nutrients Discharged to the Mississippi River from Eastern Iowa Watersheds, 1996-1997. *Journal of the American Water Resources Association* 36(1):161-173.
- Biswas, A. K., 1997. Water Development and Environment. In: Water Resources: Environmental Planning, Mangement, and Development, Asit K. Biswas (Editor). McGraw-Hill, New York, New York. pp. 1-35.
- Bowes, M. J., J. Hilton, G. P. Irons, D. D. Hornby, 2005. The relative contribution of sewage and diffuse phosphorus sources in the River Avon Catchment, southern England: Implications for nutrient management. *Science of the Total Environment* 344: 67-81.
- Branom, J. R., and D. Sarkar, 2004. Phosphorus Bioavailability in Sediments of a Sludge-Disposal Lake. *Environmental Geosciences* 11(1):42-52.
- Bricker, S. B., B. Longstaff, W. Dennison, A. Jones, K. Boicourt, C. Wicks, and J. Woerner., 2008. Effects of Nutrient Enrichment in the Nation's Esturaries: A Decade of Change. *Harmful Algae* 8:21-32.
- Caraco, N. F., 1993. Disturbance of the Phosphorus Cycle: A Case of Indirect Effects of Human Activity. *Trends in Ecology and Evolution* 8(2):51-54.
- Carpenter, S. R., N. F. Caraco, D. L. Correll, R. W. Howarth, A. N. Sharpley, and V. H. Smith, 1998. Nonpoint Pollution of Surface Waters with Phosphorus and Nitrogen. *Ecological Applications* 8(3):559-568.
- Carter, Martin R. (ed.), 1993. Soil Sampling and Methods of Analysis. Boca Raton, FL: CRC Press.
- Garnier, J., B. Laporcq, N. Sanchez, and X. Philippon, 1999. Biogeochemical mass-balances (C, N, P, Si) in three large reservoirs of the Seine Basin (France). *Biogeochemistry* 47: 119–146
- Golterman, H. L., 2004. *The Chemistry of Phosphate and Nitrogen Compounds in Sediments*. Kluwer Academic Publishers, Norwell, MA, ISBN-10: 1402019513
- Griffith, G.E., J.M. Omernik, and S.H. Azevedo. 1998. Ecoregions of Tennessee. (2 sided color poster with map, descriptive text, summary tables, and photographs). U.S. Geological Survey, Reston, VA. Scale 1:940,000.
- Haggard, B. E., D. E. Storm, and E. H. Stanley, 2001. Effect of a Point Source Input on Stream Nutrient Retention. *Journal of the American Water Resources Association* 37(5):1291-1299.

- Haggard, B. E., E. H. Stanley, and D. E. Storm, 2005. Nutrient Retention in a point-source-enriched stream. *Journal of the North American Benthological Society* 24(1):29-47.
- Hampson, P. S., M. W. Treece, Jr., G. C. Johnson, S. A. Alstedt, and J. F. Connell, 2000. Water Quality in the Upper Tennessee River Basin, Tennessee, North Carolina, Virginia, and Georgia 1994-98. U.S. Geological Survey Circular; 1205, 31p. <http://pubs.usgs.gov/circ/circ1205/pdf/circular1205.pdf>
- Hoffman, A. R., D. E. Armstrong, R. C. Lathrop, and M. R. Penn, 2009. Characteristics and Influence of Phosphorus Accumulated in the Bed Sediments of a Stream Located in an Agricultural Watershed. *Aquatic Geochemistry* 15(3):371-389.
- James, E., P. Kleinman, T. Veith, R. Stedman, and A. Sharpley, 2007. Phosphorus Contributions from Pastured Dairy Cattle to Streams of the Cannonsville Watershed, New York. *Journal of Soil and Water Conservation* 62(1):40-47.
- Johnson, G. C, and M. W. Treece, 1998. Phosphorus in Streams of the Upper Tennessee River Basin, 1970-93. U.S. Geological Survey National Water Quality Assessment Program – Upper Tennessee River Basin Study Unit. Open File Report 98-532, 6p. <http://pubs.usgs.gov/of/1998/ofr98-532/pdfs/PhosphorusPDF.pdf>
- Knox County Engineering and Public Works, 2003. *Beaver Creek Watershed Assessment-Draft*. Knox County Engineering and Public Works, Stormwater Division http://www.knoxcounty.org/stormwater/pdfs/beavercreek_draft.pdf
- Knox County Engineering and Public Works, 2006. *Beaver Creek Watershed Restoration Plan*. Knox County Engineering and Public Works, Stormwater Division. Knoxville, TN http://www.knoxcounty.org/stormwater/pdfs/BCWPlan_2006.pdf
- Knox County Engineering and Public Works. 2009. *Ecological Credit Trading Pilot Study for the Beaver Creek Watershed*. Prepared for the Beaver Creek Task Force. Knox County Engineering and Public Works, Stormwater Division. Knoxville, TN http://www.knoxcounty.org/stormwater/pdfs/BeaverCreek_ECT_FinalReport_072009.pdf
- Knoxville, Knox County, KUB Geographic Information System (KGIS), 2011. <http://kgis.org/Portal/Default.aspx>. Accessed March, 2011.
- Marti, E., J. Aumatell, L. Gode, M. Poch, and F. Sabater, 2004. Nutrient Retention Efficiency in Streams Receiving Inputs from Wastewater Treatment Plants. *Journal of Environmental Quality* 33:285-293.
- Mudroch, A. and S. D. MacKnight, 1994. Project and Data Review. In: *Handbook of Techniques for Aquatic Sediment Sampling: Second Edition*, Alena Mudroch and Scott D. MacKnight (Editor). Lewis Publishers, CRC Press, Boca Raton, Florida, pp 5-16.

- Mudroch, A. and J. M. Azcue, 1995. *Manual of Aquatic Sediment Sampling*. Lewis Publishers, CRC Press, Boca Raton, Florida.
- Mulholland, P. J., D. Newbold, J. W. Elwood, L. A. Ferren, and J. R. Webster, 1985. Phosphorus Spiraling in a Woodland Stream: Seasonal Variations. *Ecology* 66(3):1012-1023
- Nungesser, P. and D. Franz, 1997. Urban Influence on Phosphorus and Sediment Loading of West Point Lake, Georgia. *Journal of the American Water Resources Association* 30(1):215-217.
- Parish, E., 2002. *Linking Channel Instability to Urbanization in the Upper Beaver Creek Watershed, Knox County, Tennessee*. M.S. Thesis, University of Tennessee, Knoxville, Tennessee.
- Pierzynski, G. M., J. T. Sims, and G. F. Vance, 2000. *Soils and Environmental Quality: Second Edition*. CRC Press, Boca Raton, Florida, ISBN-10: 0849300223
- Pierzynski, G. M., J. T. Sims, and G. F. Vance, 2005. *Soils and Environmental Quality: Third Edition*. CRC Press, Boca Raton, Florida, ISBN-10: 0849316162
- Prairie, T. Y., C. M. Duarte, and J. Kalff, 1989. Unifying Nutrient – Chlorophyll Relationships in Lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 46(7): 1176–1182.
- Qiu, S. and A. J. McComb (2000). Properties of sediment phosphorus in seven wetlands of the Swan Coastal Plain, S-W. Australia. *Wetlands* 20(2): 267-279.
- Schelske, C. L., E. F. Stoermer, D. J. Conley, J. A. Robbins, and R. M. Glover, 1983. Early Eutrophication in the Lower Great Lakes. *Science* 222:320-322.
- Schindler, D. W., 1977. Evolution of Phosphorus Limitation in Lakes. *Science* 195:260-262.
- Schindler, D. W., R. E. Hecky, D. L. Findlay, M. P. Stainton, B. R. Parker, M. J. Paterson, K. G. Beaty, M. Lyng, and S. E. M. Kasian, 2008. Eutrophication of Lakes Cannot Be Controlled By Reducing Nitrogen Input: Results of a 37-Year Whole-Ecosystem Experiment. *Proceedings of the National Academy of Sciences of the United States of America* 105(32):11254-11258.
- Sharpley, A. N., S. J. Smith, O. R. Jones, W. A. Berg, and G. A. Coleman, 1992. The Transport of Bioavailable Phosphorus in Agricultural Runoff. *Journal of Environmental Quality* 21:30-35.

- Sharpley, A. N., S. C. Chapra, R. Wedepohl, J. T. Sims, T. C. Daniel, and K. R. Reddy, 1994. Managing Agricultural Phosphorus for Protection of Surface Waters: Issues and Options. *Journal of Environmental Quality* 23:437-451.
- Sharpley, A. N., and A. D. Halvorson, 1994. The Management of Soil Phosphorus Availability and its Impact on Surface Water Quality. In: *Soil Processes and Water Quality*. R. Lal and B. A. Stewart (Editors). CRC Press, Inc. Boca Raton, Florida, pp. 7-90.
- Simon, N. S., O. P. Bricker, W. Newell, J. McCoy, and R. Morawe, 2005. The Distribution of Phosphorus in Popes Creek, VA, and in the Pocomoke River, MD: Two Watersheds with Different Land Management Practices in the Chesapeake Bay Basin. *Journal of Water, Air, and Soil Pollution* 164: 189-204.
- Soil and Plant Analysis Council, Inc., 2000. *Soil Analysis: Handbook of Reference Methods*. New York, New York: CRC Press
- Stewart, W. M., L. L. Hammond, and S. J. Van Kauwenbergh, 2005. Phosphorus as a Natural Resource. In: *Phosphorus: Agriculture and the Environment*, J. Thomas Sims and Andrew N. Sharpley (Editors). American Society of Agronomy, Inc., Crop Society of America, Inc., Soil Science Society of America, Inc. Madison, Wisconsin, pp. 3-22.
- Tennessee Department of Environment and Conservation (TDEC), 2003a. NPDES Permit No. TN0060020, Authorization to Discharge Under the National Pollutant Discharge Elimination System (NPDES) Discharger: West Knox Utility District.
- Tennessee Department of Environment and Conservation (TDEC), 2003b. NPDES Permit No. TN0024287, Authorization to Discharge Under the National Pollutant Discharge Elimination System (NPDES) Discharger: Hallsdale Powell-Utility District
- Tennessee Department of Environment and Conservation (TDEC), 2006a. Final Version Year 2006 303(d) List. Division of Water Pollution Control. Nashville, Tennessee, USA
<http://www.tn.gov/environment/wpc/publications/pdf/303d2006.pdf>
- Tennessee Department of Environment and Conservation (TDEC) 2006b. *Final TMDL for Pathogens in the Lower Clinch Watershed (HUC 06010207) Anderson, Campbell, Grainger, Knox, Loudon, Morgan, Roane, and Union Counties, Tennessee*. State of Tennessee, Department of Environment and Conservation, Division of Water Pollution Control, Submitted November 16, 2005; approved by EPA Region 4 – November 29, 2005.
- Tennessee Department of Environment and Conservation (TDEC) 2008. Final: Year 2008, 303(d) list. Division of Water Pollution Control. Nashville, Tennessee, USA
http://state.tn.us/environment/wpc/publications/2008_303d.pdf

- United States Environmental Protection Agency (U.S. EPA), 1990. National Water Quality Inventory: 1988 Report to Congress. Office of Water. U.S. Government Printing Office, Washington, D.C., USA
<http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockkey=00001JVE.txt>
- United States Environmental Protection Agency (U.S. EPA) 1996a. SW-846 Method 3050b, revision 2. Acid digestion of sediments, sludges, and soils. Revision 2. U.S. Government Printing Office, Washington, D.C., USA
<http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/3050b.pdf>
- United States Environmental Protection Agency (U.S. EPA) 1996b. SW-846 Method 6010b, revision 2. Inductively coupled plasma-atomic emission spectrometry. U.S. Government Printing Office, Washington, D.C., USA
<http://www.caslab.com/EPA-Methods/PDF/EPA-Method-6010B.pdf>
- United States Environmental Protection Agency (U.S. EPA), 1999. Protocol for developing nutrient TMDLs: First Edition. EPA 841-B-99-007. Office of Water. U.S. Government Printing Office, Washington, D.C., USA
http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/upload/2000_01_10_tmdl_nutrient_nutrient.pdf
- Young, K., G. K. Morse, M. D. Scrimshaw, J. H. Kinniburgh, C. L. MacLeod, and J. N. Lester, 1999. The relation between phosphorus and eutrophication in the Thames catchment, UK. *The Science of the Total Environment* 228: 157-183.
- Zhou, Q., C. E. Gibson, Y. Zhu (2001). Evaluation of Phosphorus Bioavailability in Sediments of three contrasting lakes in China and the UK. *Chemosphere* 42:221-225.

VITA

Angela Danovi was born in 1978 in Memphis, Tennessee to Demarious K. Danovi and Louis J. Danovi. She attended Memphis Catholic High School in Memphis and Bolton High School in Arlington, Tennessee. She graduated from Bolton in 1996. Angela attended the University of Tennessee at Knoxville for her undergraduate studies where she pursued a Bachelor of Science in Plant and Soil Sciences with a concentration in Environmental Science and Natural Resources in the College of Agricultural Sciences and Natural Resources. She graduated with her Bachelor of Science Degree in 2003. After completing her undergraduate studies, Angela served for a year as an AmeriCorps member on the Knox County CAC AmeriCorps Water Quality Team. During her term of service, she assisted state and local agencies with water quality projects while also serving as an assistant in high school ecology and environmental science classes.

Angela entered graduate school with a keen interest in water quality issues and water quality science. During her graduate tenure, she expanded her interests into environmental policy and planning. Her interest and academic knowledge in environmental issues combined with her passion in public policy has afforded her the special opportunity to serve on the volunteer staff and intern staff for presidential and gubernatorial candidates. Angela plans to combine her environmental science knowledge with her interest in public policy and serve as a policy analyst. Angela received her Master of Science Degree in Geography in May, 2011 from the University of Tennessee at Knoxville.