

THESIS

UTILIZING RIVER BANK STABILIZATION AND REACTIVE STREAM
STABILIZATION AS BEST MANAGEMENT PRACTICES FOR ACHIEVING
TOTAL MAXIMUM DAILY LOAD REGULATIONS

Submitted by

JiHee Son

Department of Civil and Environmental Engineering

In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

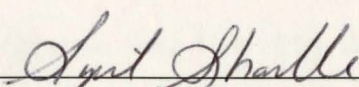
Fall 2010

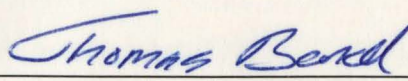
COLORADO STATE UNIVERSITY

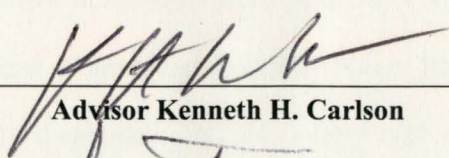
April 28, 2010

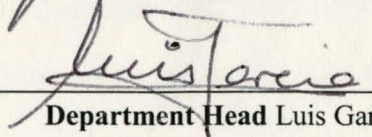
WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR
SUPERVISION BY JIHEE SON ENTITLED "UTILIZING RIVER BANK
STABILIZATION AND REACTIVE STREAM STABILIZATION AS BEST
MANAGEMENT PRACTICES FOR ACHIEVING TOTAL MAXIMUM DAILY
LOAD REGULATIONS" BE ACCEPTED AS FULFILLING IN PART
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

Committee on Graduate work


Sybil Sharvelle


Thomas Borch


Advisor Kenneth H. Carlson


Department Head Luis Garcia

ABSTRACT OF THESIS

UTILIZING RIVER BANK STABILIZATION AND REACTIVE STREAM STABILIZATION AS BEST MANAGEMENT PRACTICES FOR ACHIEVING TOTAL MAXIMUM DAILY LOAD REGULATIONS

Phosphorus is recognized as a limiting factor for growth of aquatic organisms in surface water bodies. When excess amounts of this nutrient are discharged into a stream, biomass of phytoplankton starts to increase and eutrophication can result. A Reactive Stream Stabilization (RS2) structure has been developed to stabilize the stream bank and minimize release of some agricultural nonpoint source pollutants through erosion from farms, waste sites, and animal feed lots to the stream. The RS2 system was studied for its nutrient (nitrogen and phosphorus) removal efficiency from 2003 to 2006 at the Colorado State University. Based on this study at CSU, a RS2 structure was designed and installed along the bank of the Little Bogue Creek near Grenada, Mississippi in November 2008. The scope of the research for this Master's thesis research was to assist in design and installation of a field scale RS2 structure and to conduct assessment of the initial nutrient removal performance of the system. The reactive barrier of the installed RS2 has shown high concentrations of Al and organic matter, design criteria intended to promote adsorption of phosphorus (P) and facilitate nitrogen (N) removal through denitrification. The performance of the RS2 structure was examined from the soils, monitoring wells and the stream waters that

were sampled in May and July, 2009. The mean concentration of aluminum from the reactive barrier was 2.1 mg/g soil and organic matter from the monitoring wells in the bank was 4.68 mg/L which were significantly greater than the surrounding area ($p < 0.05$). Soil Mehlich-3 P and total P (TP) were decreased by 55 % and 30 %, and 40 % of TN and 51 % of nitrate in the ground water were removed through the RS2. The RS2 is expected retain P efficiently although accumulation of P has not yet been observed. From this research, the design objectives of the RS2 structure have been satisfied and the initial sampling data shows promise. Future research will be conducted to verify the effectiveness of RS2 structures for achieving TMDL regulations.

JiHee Son
Department of Civil and
Environmental Engineering
Colorado State University
Fort Collins, CO 80523
Fall 2010

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION AND BACKGROUND	1
1.1 NUTRIENT SOURCE AND IMPACT.....	1
1.2 TMDL REGULATION: MISSISSIPPI EXAMPLES.....	7
1.2.1 TMDL Standards for a Segment of the Coldwater River, MDEQ 2008.....	9
1.2.2 TMDL Standards for the Bear Creek Watershed and the Tilda Bogue Watershed in Big Black River Basin, EPA 2007.....	12
1.3 BMP FOR NONPOINT SOURCE (NPS) TMDL	16
1.4 RIVER BANK STABILIZATION (RBS) AND REACTIVE STREAM STABILIZATION (RS2).....	21
1.4.1 River Bank Stabilization (RBS).....	21
1.4.2 Reactive Stream Stabilization (RS2).....	24
1.5 RESEARCH OBJECTIVES	27
 CHAPTER 2 MATERIALS AND METHOD	 29
2.1 FIELD SAMPLING	29
2.2 SOIL ANALYSES	32
2.2.1 Microwave Digestion.....	32
2.2.2 Aluminum (Al).....	33
2.2.3 Total Phosphorus (TP)	34
2.2.4 Mehlich-3 Phosphorus	34
2.2.5 Total Nitrogen (TN)	35
2.3 AQUEOUS ANALYSES	36
2.3.1 Total Phosphorus (TP)	36
2.3.2 Dissolved Reactive Phosphorus (DRP).....	36
2.3.3 Nitrate (NO ₃ ⁻).....	37
2.3.4 Total Organic Carbon (TOC) and Total Nitrogen (TN)	37
2.4 STATISTICAL METHOD.....	38
 CHAPTER 3 RESULTS AND DISCUSSION.....	 39
3.1 DESIGN AND CONSTRUCTION OF RS2	39
3.2 INITIAL MONITORING RESULTS	48

3.2.1 Soil Classification	48
3.2.2 Aluminum	50
3.2.3 Phosphorus	52
3.2.4 Nitrogen	57
3.2.5 Water Concentrations	58
CHAPTER 4 COST OF NUTRIENT REMOVAL.....	62
4.1 Cost of Nutrient Removal.....	62
4.1.1 Everglades Nutrient Removal Project.....	62
4.1.2 Spring Lake P-removal Project.....	64
4.1.3 Onondaga Lake Improvement Project	66
4.1.4 Ozark Stream.....	67
4.2 Estimation of Costs of Phosphorus Removal in Waste Water Treatment Facilities	69
4.3 Estimation of Costs of Phosphorus Removal by Best Management Practice Selection of Implementation Strategies/Alternatives	72
CHAPTER 5 SUMMARY OF NUTRIENT REMOVAL IN MISSISSIPPI WATERSHEDS AND FUTURE WORK.....	75
CHAPTER 6 REFERNCES.....	76
APPENDIX.....	82

LIST OF TABLES AND FIGURES

Table 1.1: Leading sources of water quality impairment (EPA, 2002).....	4
Table 1.2: Nonpoint source loads by landuse in the Coldwater River watershed: TMDL calculation (MDEQ, 2008)	11
Table 1.3: TMDL for the Coldwater river watershed (MDEQ, 2008).....	12
Table 1.4: Average annual nonpoint source loads by landuse in Bear creek-Tilda bougue watersheds and EMCs for storm events (EPA, 2007).....	14
Table 1.5: Existing point source load (EPA, 2007).....	15
Table 1.6: TMDL for the Bear creek and Tilda bogue watersheds (EPA, 2007)....	16
Table 1.7: Agricultural BMPs emphasized by the Mississippi Soil & Water Conservation Commission.....	17
Table 1.8: Mississippi's erosion control BMPs and efficiency.....	20
Table 1.9: P and sediment removal efficiency of RBS.....	23
Table 3.1: Soil characters in the RS2 study and control areas.....	49
Table 3.2: Soil Total Phosphorus (TP) and Mehlich-3 Phosphorus reduction in reactive stream stabilization (RS2) structure and control area (mean $\pm$ 95% C.I.).....	56
Table 3.3: Percentages of nutrients reduction; Total Phosphorus (TP), Dissolved Reactive Phosphorus (DRP), Total Nitrogen (TN) and Nitrate (NO ₃ -) along the stream.....	61
Table 4.1: Cost of projects.....	68
Table 4.2: Unit cost of phosphorus removal.....	71

Table 4.3: Cost of BMPs (Source: Spring Lake Watershed Plan, Spring Lake Watershed Committee, July 2008).....	73
Figure 1.1: Phosphorus cycle.....	3
Figure 1.2: Conceptual model of P-transport and utilization (modified from Haygarth and Jarvis, 1999; Watson, C.C. <i>et al.</i> , 2002).....	5
Figure 1.3: TMDL process (modified from Committee to Assess the Scientific Basis of TMDL, 2001).....	8
Figure 1.4: The Coldwater river watershed (ArcGIS).....	10
Figure 1.5: The Bear creek watersheds (ArcGIS).....	12
Figure 1.6: The Tilda bogue watersheds (ArcGIS).....	13
Figure 1.7: Conservation tillage (World Overview of Conservation Approaches and Technologies).....	18
Figure 1.8: Sediment basin (City of Milwaukee).....	19
Figure 1.9: Eroding banks of the Pembina River in northeastern North Dakota (USGS, 1995).....	22
Figure 1.10: River Bank Stabilization using Riprap Toe (Royston Hanamoto Alley & Abbey <i>et al.</i> , 2000).....	23
Figure 1.11: Cross section of RS2 structure design (modified from Watson, C. C., 2006).....	24
Figure 1.12: LPSTP and RS2 in Little bogue, Elliott, Mississippi.....	26
Figure 1.13: Plan view of LPSTP and RS2 structure in Little bogue, MS.....	26
Figure 2.1: Map of Little Bogue, Grenada, MS.....	30
Figure 2.2: Plan view of Little Bogue RS2 site.....	31
Figure 2.3: Filtration of samples using Whatman No.42 filter paper.....	33
Figure 3.1: A plan view and a cross section of the RS2 used in the field test at the ERC of CSU (Watson, C.C., 2006).....	40
Figure 3.2: Design concept of RS2 in Little Bogue, MS.....	41

Figure 3.3: The RS2 test site before constructing RS2 in Little Bogue watershed (Derrick, D., April 2, 2008).....	41
Figure 3.4: Mixing alum and mulch with soils by shovels in the RS2 barrier (Derrick, D., November 19, 2008).....	42
Figure 3.5: Mini excavator and Bobcat skid steer used for digging and conveying soils (Derrick, D., November 19, 2008).....	43
Figure 3.6: Completed areal view of the RS2 construction (Derrick, D., November 19, 2008).....	44
Figure 3.7: Monitoring wells in the field side of the RS2 barrier (Watson, C. C., January 12, 2009).....	44
Figure 3.8: The RS2 installed area in the Little Bogue watershed in January, 2009 (Watson, C.C., January 12, 2009)	45
Figure 3.9: The RS2 test area along the bank of the Little Bogue in May, 2009.....	46
Figure 3.10: Pole planted sycamore and willow in the reactive barrier in May, 2009.....	46
Figure 3.11: Monitoring wells in the upper bank and the lower bank of the reactive barrier in May, 2009.....	47
Figure 3.12: The stream and the longitudinal peak stone toe protection (LPSTP) in Little Bogue in May, 2009.....	47
Figure 3.13: Plan view of sampling site in the RS2 test area in the Little Bogue watershed..	48
Figure 3.14: Soil textural triangle.....	49
Figure 3.15: Concentration (mg/g) of total aluminum in RS2 study area and control area (error bars indicate 95% confidence intervals)	51
Figure 3.16: Concentration (mg/g) of total aluminum in the three kinds of vegetated sections; river birch (A), sycamore (B) and willow (C), and un-vegetated section (D) of RS2 study area and control area.....	51
Figure 3.17: Concentration (mg/g) of soil total phosphorus (TP) in RS2 study area and control area (error bars indicate 95% confidence intervals).....	52
Figure 3.18: Soil TP concentrations in the field side and the lower bank in the control area (error bars indicate 95% confidence intervals).....	53
Figure 3.19: Concentration (mg/g) of soil total phosphorus (TP) in the two depths; 16 inches and 36 inches of the reactive barrier (error bars indicate 95% confidence intervals).....	53
Figure 3.20: Concentration (mg/g) of Mehlich-3 Phosphorus in RS2 study area and control area (Error bars indicate 95% Confidence Intervals).....	54

Figure 3.21: Concentration (mg/g) of Mehlich-3 phosphorus in the two depths; 16 inches and 36 inches of the reactive barrier (error bars indicate 95% confidence intervals).....	55
Figure 3.22: Soil Mehlich-3 P concentrations in the field side and the lower bank in the control area (error bars indicate 95% confidence intervals).....	55
Figure 3.23: Concentration (mg/g) of soil total nitrogen (TN) in RS2 study area and control area (error bars indicate 95% confidence intervals).....	57
Figure 3.24: Soil TN concentrations in the field side and the lower bank in the control area (error bars indicate 95% confidence intervals).....	57
Figure 3.25: Concentration (mg/L) of total phosphorus (TP), dissolved reactive phosphorus (DRP), total organic carbon (TOC), total nitrogen (TN) and nitrate (NO_3^-) in waters from monitoring wells (error bars indicate 95% confidence intervals).....	58
Figure 3.26: Concentration of total phosphorus (TP) and dissolved reactive phosphorus (DRP) in stream.....	59
Figure 3.27: Concentration of total nitrogen (TN) and nitrate (NO_3^-) in stream.....	60
Figure 3.28: Concentration of total organic carbon (TOC) in stream.....	60
Figure 4.1: P removal cost comparison between BMPs, and 1 MGD WWTPs (0.5mg P/L effluent concentration) (\$/lbs P-removed).....	74

[APPENDIX]

Table 7.1: Soil fractions and characteristics in RS2 study area and control area.....	84
Table 7.2: Concentrations, standard errors (SE) and 95% confidence intervals (CI) of soil aluminum (mg/g) in RS2 study area and control area.....	85
Table 7.3: Concentrations, standard errors (SE) and 95% confidence intervals (CI) of soil total phosphorus (TP) (mg/g) in RS2 study area and control area.....	86
Table 7.4: Concentrations, standard errors (SE) and 95% confidence intervals (CI) of soil Mehlich-3 phosphorus (mg/g) in RS2 study area and control area.....	87
Table 7.5: Concentrations, standard errors (SE) and 95% confidence intervals (CI) of soil total nitrogen (TN) (mg/g) in RS2 study area and control area.....	88
Table 7.6: Concentrations, standard errors (SE) and 95% confidence intervals (CI) of total phosphorus (TP) and dissolved reactive phosphorus (DRP) (mg/L) in waters from monitoring wells and stream.....	89

Table 7.7: Concentrations, standard errors (SE) and 95% confidence intervals (CI) of total nitrogen (TN) and nitrate (mg/L) in waters from monitoring wells and stream.....90

Table 7.8: Concentrations, standard errors (SE) and 95% confidence intervals (CI) of total organic carbon (TOC) and in waters from monitoring wells and stream.....91

CHAPTER 1

INTRODUCTION AND BACKGROUND

Phosphorus is recognized as a limiting factor for growth of aquatic organisms in surface water bodies especially in lakes and artificial reservoirs. But when excess amounts of nutrients (nitrogen and phosphorus) are discharged into surface water, the biomass of phytoplankton starts to increase and shifts to bloom-forming species that may be toxic. As biomass of algae increases, water transparency decreases with taste, odor and water treatment problems a possibility. Microorganisms decompose algae when they die resulting in dissolved oxygen depletion and thus death of living organisms, fish kills, and deterioration of aesthetic value of water bodies. This event is called “eutrophication” which is the main cause of water quality “impairment” in the United States (EPA, 1996).

1.1 Nutrient Sources and Impact

Although both phosphorus and nitrogen affect water quality impairment through eutrophication, P is the most important contributor in freshwater eutrophication. Because algae can gain nitrogen from the atmosphere and they utilize nitrogen and phosphorus at a molecular ratio of 16:1. Therefore small amounts of phosphorus can distress water quality easily. A 37-year experiment on nutrient management in a Canadian lake found that P inputs directly control algae blooms (Schindler, D. W. *et al.*, 2008), and also the research of Carpenter, S. R. *et al.* shows that reducing N loads cannot control eutrophication without reducing P loads, otherwise it exacerbates algae

blooms (Carpenter, S. R., 2008). Therefore phosphorus management is crucially important for economic and environmental reasons. Preventing phosphorus input to receiving surface water bodies is considered a much more effective approach than remediation or water purification (Wilson, M.A. and Carpenter, S. R., 1999) because reducing P input prevents causes of problems that will occur by P loads into the surface water. In natural systems, phosphorus exists in both the particulate and dissolved forms including organic and inorganic phosphorus. Organic phosphorus includes relatively labile phosphorus, nucleic acids, inositols and fulvic acids (Sharpley, A. N. and Rekolainen, S., 1997). Phytic acid, phospholipids, and nucleotide phosphate are the most important and measurable organic P compounds in soils (Turner, B. L. *et al.*, 2002; Harrison, A. F., 1987; Haygarth, P. M. and Jarvis, S. C., 2002). Soil organic phosphorus is still not fully understood in terms of availability for plant growth and movement to watersheds (Frossard, E. *et al.*, 2000). Only about 1 percent of the total soil organic P is mineralized¹ per year in cotton and soybean production systems from a Mississippi study (Oldham, L., 2008). However, inorganic phosphorus, dominantly phosphate, is the bioavailable form in a natural system. Phosphate, including orthophosphate and polyphosphate, is negatively charged and therefore tends to adsorb to positively charged ions such as iron, aluminum, and calcium in soils. In Mississippi, most of the phosphorus is fixed by aluminum and iron due to abundant acidic soils in the region² (Oldham, L., 2008).

Phosphorus comes into the environment as a result of point source and nonpoint source pollution. Point sources include discharges from wastewater treatment plants (WWTPs), and nonpoint sources come from diffuse, difficult-to-identify, intermittent

¹ Mineralization is the transformation of organic phosphates to inorganic phosphates.

² When pH >7, phosphate usually reacts with Ca, and when pH<5.5, phosphate reacts with Al and Fe, and between pH 6 and 7, available phosphorus rate is high (Busman, L. *et al.*, 2002).

sources of pollutants (Novotny, V., 2002), such as natural weathering of rock, mining, and urban and agricultural runoff (Figure 1.1).

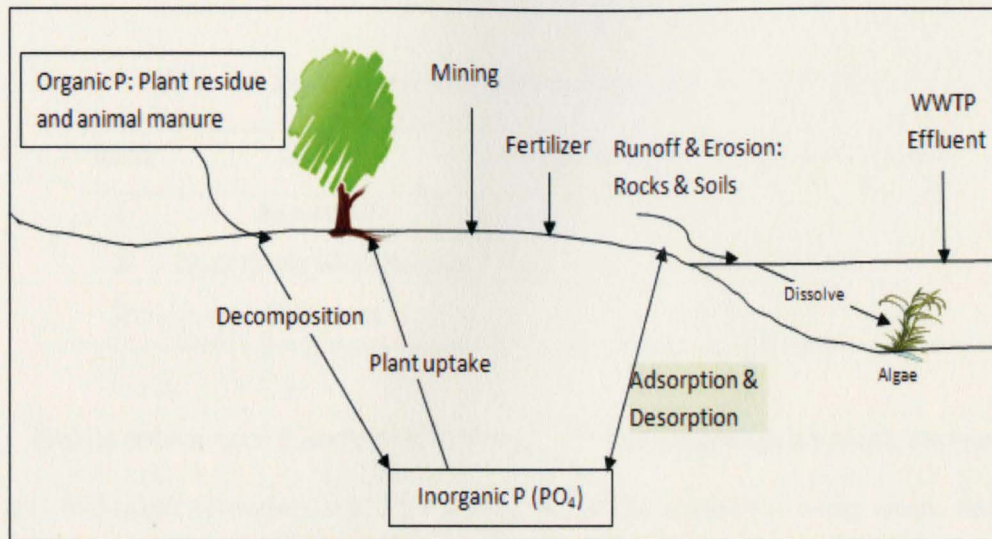


Figure 1.1: Phosphorus cycle

A substantial cause of freshwater eutrophication is nonpoint phosphorus loads from the atmosphere, lake sediments, runoff from urban lands, and mainly from increased intensive fertilization of agricultural soils in developed nations (Carpenter, S. R. *et al.*, 1998; Carpenter, S. R., 2005). It has been shown that the global P flux to the biosphere enlarged from $\approx 10\text{--}15 \text{ Tg P year}^{-1}$ in preindustrial times to $33\text{--}39 \text{ Tg P year}^{-1}$ in 2000 (Bennett, E. M. *et al.*, 2001).

EPA published a ranking of leading causes and sources of water quality impairment throughout the nation's water in 2009. The leading causes are pathogens, habitat alteration, oxygen depletion and nutrients and agriculture was cited as the main source of impairment (Table 1.1). Agriculture contributes to 38% of the distressed rivers and streams (EPA, 2009). Agricultural soils obtain P from livestock, mineral fertilizers, and municipal sludges and wastewaters. P gained by the sources decreases the soil capacity to retain P as the P is accumulated in soils for a long time and it ultimately

causes acceleration of the loss of P into the water course when there is heavy rainfall and runoff has occurred (Haygarth, P. M. and Jarvis, S. C., 2002).

Table 1.1: Leading sources of water quality impairment (EPA, 2009)

Rank	Source	Percent of impaired rivers and stream
1	Agriculture	38 %
2	Hydrologic Modification	25 %
3	Unknown	20 %

Unlike point source P loads which are typically treated through physical, chemical, and biological processes including adsorption and precipitation using alum, ferric chloride, and lime at wastewater treatment plants, nonpoint source P loads are largely controlled through “Best Management Practices (BMPs)”, economical and technically feasible ways to minimize P movement.

To be impacted by nonpoint source P in a water body, three factors must exist; source, mobilization (solubilization or detachment), and transportation (Macleod, C. and Haygarth, P. M., 2003) (Figure 1.2). Phosphorus is released to a water body from various sources, but phosphorus would not be moved to the water body if there is no source in a transportable form of P (i.e. in solution or adsorbed to soil particles that can move) (Watson, C. C. *et al*, 2002). When there is an intensive rainfall event, soil particles transfer to the water bodies through overland flow, storm flow, and subsurface flow (Macleod, C. and Haygarth, P. M., 2003). The hydrological factors are carrier and energy to transport the P, and combination of topographical factors increase the energy for P movement (Watson, C. C. *et al*, 2002; Haygarth, P. M. and Jarvis, S. C., 2002; Macleod, C. and Haygarth, P. M., 2003).

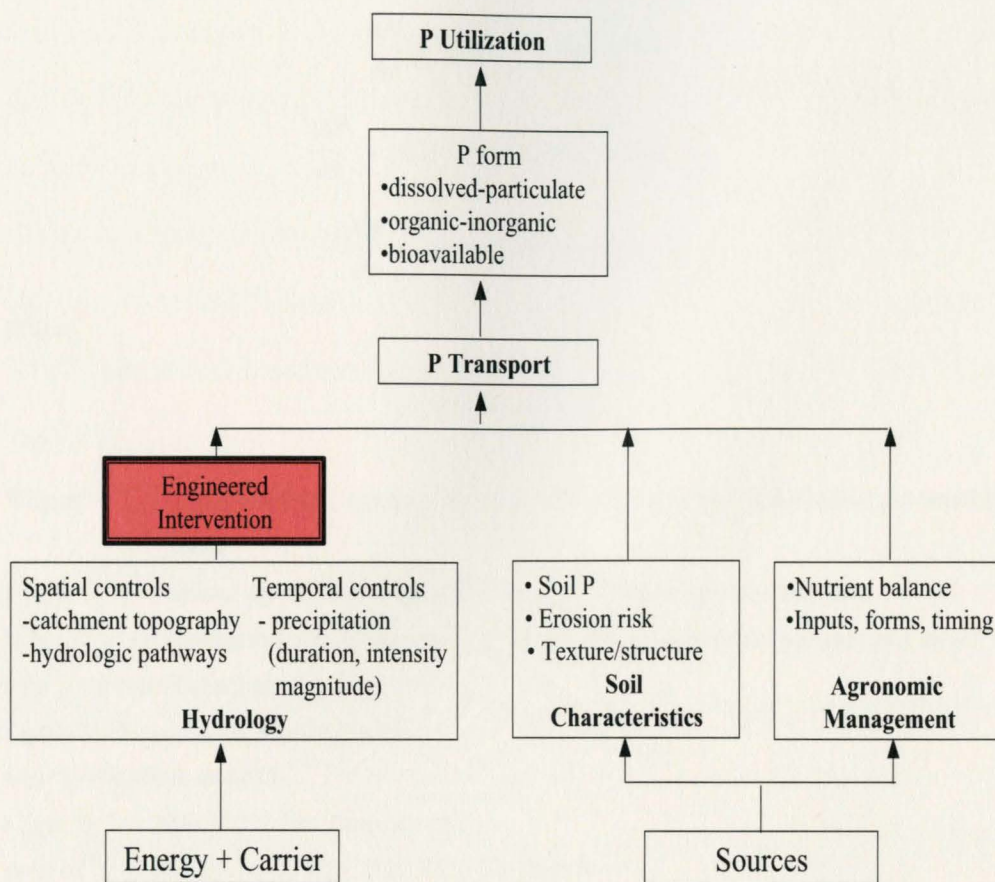


Figure 1.2: Conceptual model of P-transport and utilization (modified from Haygarth and Jarvis, 1999; Watson, C.C. *et al.*, 2002)

Once phosphorus moves into the aquatic system, P needs to be released from soil particles via mobilization to impact the environment. Mobilization of P is a mechanism of liberating P from soil, which includes two processes called solubilization when dissolved P particles are smaller than $0.45\ \mu\text{m}$, and detachment when partitioned P particles are bigger than $0.45\ \mu\text{m}$ (Beckett, R. and Hart, B. T., 1993; Haygarth, P. M. *et al.*, 1997; Nash, D. *et al.*, 2000; Macleod, C. and Haygarth, P. M., 2003). Carpenter, S. R. established different equations for phosphorus density ($\text{g}\cdot\text{m}^{-2}$) in soil (U), lake water (P), and surface sediment (M) of a system.

$$\frac{dU}{dt} = W + F - H - cU$$

$$\frac{dP}{dt} = cU - (s + h)P + rMf(P)$$

$$\frac{dM}{dt} = sP - bM - rMf(P)$$

Where,

$$f(P) = \frac{P^a}{m^a + P^a}$$

$W(\text{g}\cdot\text{m}^{-2}\cdot\text{y}^{-1})$ = Nonagricultural inputs of P to the watershed prior to disturbance, per unit lake area

$F(\text{g}\cdot\text{m}^{-2}\cdot\text{y}^{-1})$ = Annual agricultural import of P to the watershed per unit lake area

$H(\text{g}\cdot\text{m}^{-2}\cdot\text{y}^{-1})$ = Annual export of P from the watershed in farm products, per unit lake area

$c(\text{y}^{-1})$ = P runoff coefficient

$s(\text{g}\cdot\text{m}^{-2}\cdot\text{y}^{-1})$ = sedimentation rate of P

$h(\text{y}^{-1})$ = Outflow rate of P

$r(\text{g}\cdot\text{m}^{-2}\cdot\text{y}^{-1})$ = Maximum recycling rate of P

$m(\text{g}\cdot\text{m}^{-2})$ = P density in the lake when recycling is 0.5r

q = Parameter for steepness of $f(P)$ near m

From the equations, methods of eutrophication mitigation can be examined, for example, watershed management practices (modify W , F , H , or c), flushing (increase h), chemical immobilization of sediment phosphorus (decrease r), or food web manipulation (increase s). In particular, rapid P reduction in over-enriched soils through erosion control could greatly enhance water quality (Carpenter, S. R., 2005), which could diminish transport of phosphorus in surface waters and cause a decrease in phosphorus recycling within lakes (Cooke, G. D. et al., 1993).

Because of the tendency for phosphorus to sorb to soils, P usually moves as a nonpoint source if there is a runoff event. Research has shown that within a landscape, 50 to 95 percent of P transports through moving sediments which is recognized as the largest pollutant in our waters by volume and mass. Sediments are released into water

bodies via bed and bank erosion, and overland erosion. Therefore erosion control is a key method for decreasing nonpoint source P inputs to water bodies (Oldham, L., 2008; Frothingham, K. M., 2008).

For the impaired or threatened water body by point sources, nonpoint sources, or a combination of both point and nonpoint sources, a Total Maximum Daily Load (TMDL) is required by Clean Water Act (CWA) to implement State water quality standards.

1.2 TMDL Regulation: Mississippi Examples

A TMDL is established by Section 303(d) of the CWA which has objective of restoration and maintaining of the chemical, physical, and biological integrity of the nation's water, and by EPA's Water Quality Planning and Management Regulations (40 CFR 130). Appropriate control actions should be developed for all pollution sources and monitoring should be followed up to ensure that water quality standards are met. The TMDL process is based on the relationship between pollution sources and in-stream water quality conditions, and it provides a mechanism to manage point and nonpoint pollution sources (EPA, 1991; Federal Register, Aug. 23, 1999).

The TMDL consists of four components; Loading Capacity (LC), Load Allocation (LA), Wasteload Allocation (WLA), and Margin of Safety (MOS). LC is the maximum amount of loading that a water can receive without altering its water quality standards (40 CFR 130.2(f)). The estimate of LC of a receiving water body is a key step for TMDL study and for the decision on watershed management (Novotny, V., 2002). LA is the nonpoint source loads and natural background source loads which are part of LC (40 CFR 130.2(g)), and WLA is existing or future point source loads and is part of LC (40 CFR 130.2(h)). MOS accounts for uncertainties of these

estimates which could be implicit or explicit in LC (CWA section 303(d)(1)(C)), and the sum of WLAs, LAs, and MOS is the LC and is referred to as the TMDL.

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

The process of developing a TMDL typically has 5 steps; 1. Identification of water quality-limited waters requiring TMDLs, 2. Priority ranking and targeting, 3. TMDL development, 4. Implementation of control actions, and 5. Assessment of water quality-based control actions (EPA, 1991) (Figure 1.3).

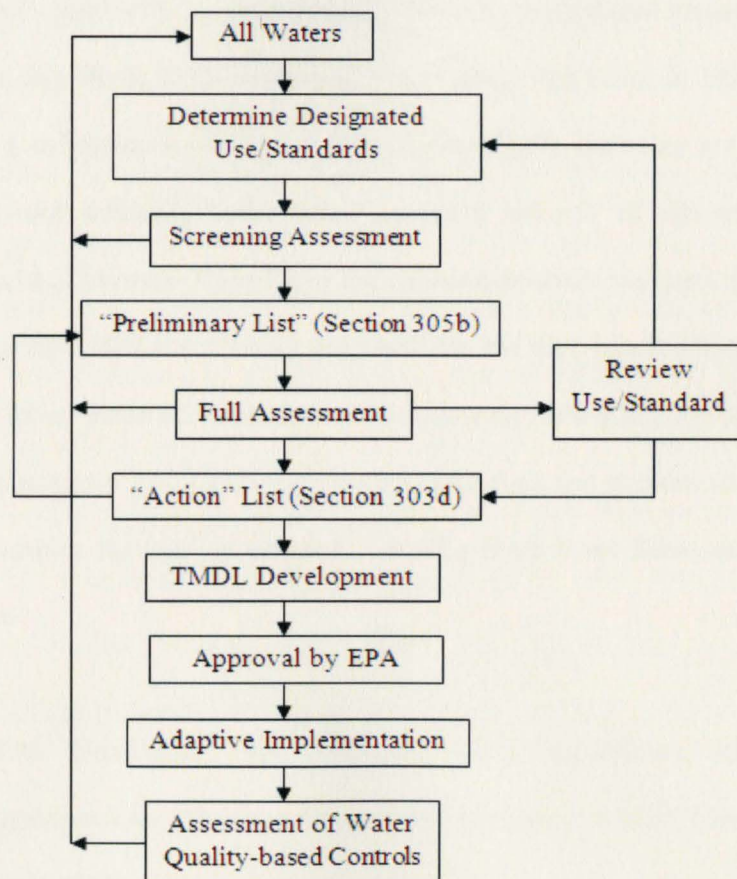


Figure 1.3: TMDL process (modified from Committee to Assess the Scientific Basis of TMDL, 2001)

EPA and the Mississippi Department of Environmental Quality have developed TMDLs for Mississippi's impaired water bodies that have been deteriorated by nutrients leading to low dissolved oxygen. Mississippi does not have numeric nutrient criteria, therefore nutrient targets were established based on modeling or statistical data analysis for the nutrient TMDLs.

Large amounts of nutrients discharge into the Mississippi River every year and the main source of these compounds are non-point sources from agricultural areas. The discharged nutrients eventually flow to the Gulf of Mexico and cause oxygen depletion with large-scale hypoxia a significant problem (National Research Council, 2008). The Big Black River Basin and Coldwater River Basin in Mississippi are considered good places to practice nutrient removal BMPs since they are impaired by nutrients which primarily come from non-point sources of agricultural lands. Particularly, the Coldwater River Basin has only non-point source impairment.

The nutrient TMDLs are being proposed for the Big Black River Basin and Coldwater River Basin of Mississippi. The following parts (Ch.1.2.1 and Ch.1.2.2) provide summaries of the TMDL development processes and methods that have been used to determine the nutrient targets for the Big Black River Basin and Coldwater River Basin.

1.2.1 TMDL Standards; Total Nitrogen, Total Phosphorus, and Organic enrichment/Low Dissolved Oxygen for a Segment of the Coldwater River, MDEQ 2008

The Coldwater River Watershed is located in Tunica and Coahoma counties in the Yazoo River Basin of Mississippi (Figure 1.4).

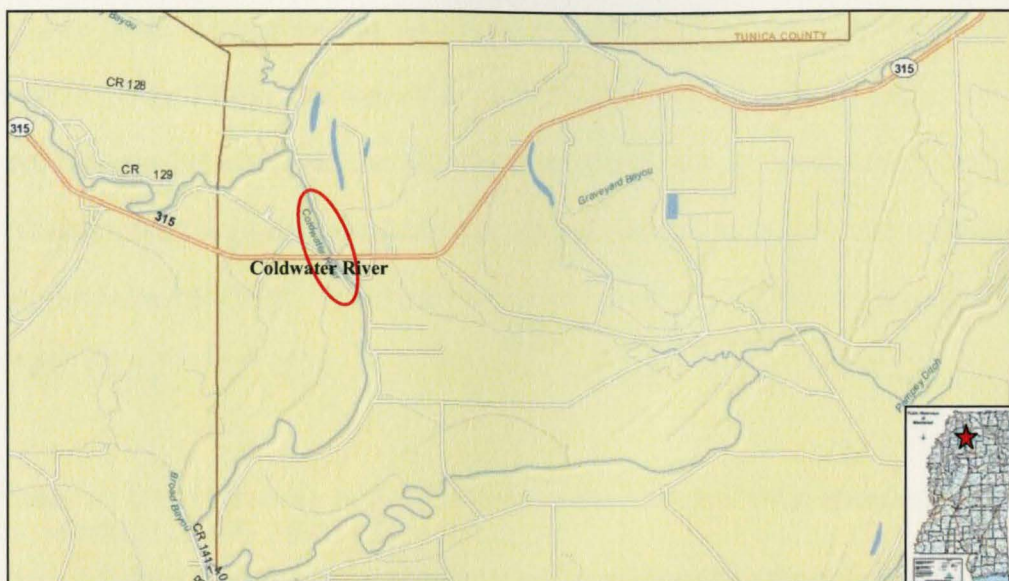


Figure 1.4: The Coldwater River watershed (ArcGIS)

The watershed contains mainly cropland, urban, and wetland landscapes and is impaired by nutrients, organic enrichment and low dissolved oxygen. Since there are no point sources in the watershed, nonpoint source is the main pollution source for the watershed. A predictive model was not used to calculate the dissolved oxygen TMDL due to the 7Q10 flow, the lowest stream flow for seven consecutive days that would be expected to occur once in ten years, being zero. The average annual flow in the watershed was calculated by utilizing the flow versus watershed area graph, and the watershed specific estimate was calculated by multiplying the land use category size by the estimated nutrient load. Then the TMDL target TN and TP loads were calculated by setting the background TBODu concentration to 2.0mg/L using the equation below.

$$\text{Nutrient load (lb/day)} = \text{Flow (cfs)} \times 5.394 \text{ (conversion factor)}^3 \times \text{Nutrient Concentration (mg/L)}$$

³ 5.394 (conversion factor) = 86,400 sec/day × 28.317 L/cf × (2.205×10⁻⁶) lb/mg

As a result, the cropland has the biggest source of TN and TP; 684.39 kg TN/day and 342.99 kg TP/day. The sum of all of TN load of 1517.3 lbs/day and TP of 754.5 lbs/day was estimated and the concentration of TN was 6.36 mg/L and TP was 3.21mg/L. The target concentration was used with the average flow for the watershed to determine the TMDL. A summary of nonpoint nutrients sources are presented in Table 1.2.

Table 1.2: Nonpoint source loads by landuse in the Coldwater River watershed: TMDL calculation (MDEQ, 2008)

Land Use	Area (acre)	Percent (%)	TN Load (lb/day)	TP Load (lb/day)
Forest	45.1	0.2	0.04	0.02
Cropland	14618.5	75.5	1505.66	754.58
Urban	641.8	3.3	1.74	0.02
Water	260.9*	1.3	0.64	0.64
Wetland	3787.6	19.6	9.22	9.22
Total	19353.9	100	1517.34	764.50
Target load			250.30	38.20
Estimate Conc.			6.36 mg/L	3.21 mg/L
Target Conc.			1.05 mg/L	0.16 mg/L
Reduction needed			83.50%	95.00%

* With flow of 44.2 cfs based on area

Based on the estimation, reductions of 83.5% for TN and 95% for TP are needed to meet the preliminary target of 1.05 mg TN/L and 0.16 mg TP/L for water bodies located in Ecoregion 73, and the TMDLs of TBOD_u, TN, and TP are calculated as 477.2lbs/day, 250.3lbs/day, and 38.2lbs/day respectively. Therefore, based on the TMDL equation mentioned earlier, the calculated TMDL is shown in Table 1.3.

Table 1.3: TMDL for the Coldwater River watershed (MDEQ, 2008)

Parameter	TMDL (lbs/day)	WLA (lbs/day)	LA (lbs/day)		MOS
			Target load	Reduction needed	
TN	250.3	0	250.3	1267.04	Implicit
TP	38.2	0	38.2	726.3	Implicit
TBODu	477.2	0	477.2	—	Implicit

1.2.2 TMDL Standards; Total Nitrogen, Total Phosphorus, and Organic enrichment/Low Dissolved Oxygen for the Bear Creek Watershed and the Tilda Bougue Watershed in Big Black River Basin, EPA 2007

The Bear Creek and Tilda Bogue watersheds are located in the Big Black River Basin of Central Mississippi in Madison County (Figure 1.5 and 1.6).

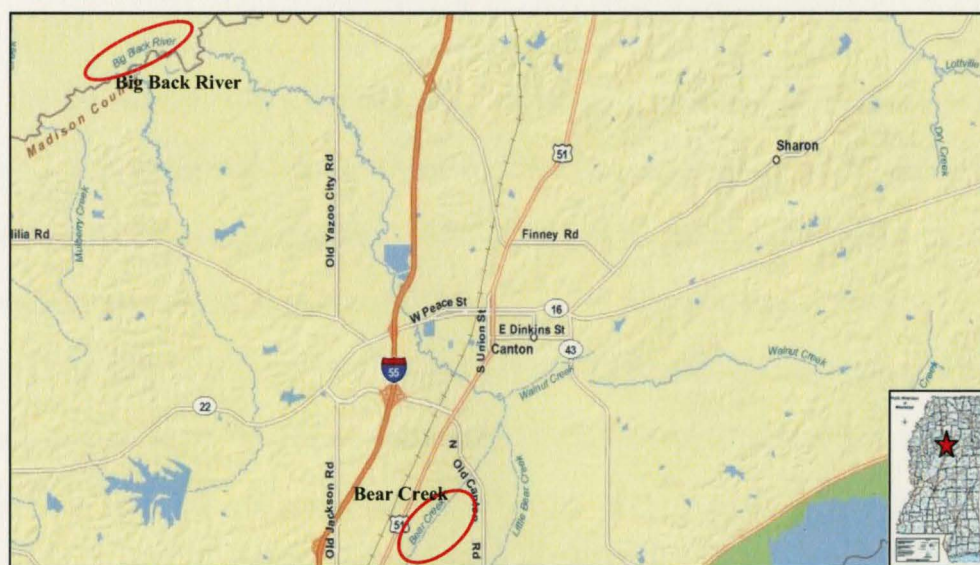


Figure 1.5: The Bear Creek watersheds (ArcGIS)

In 1996, the watersheds were placed on the Section 303(d) List of Impaired Water Bodies. The impaired segments are 11 miles long and 153 mile² in the Bear Creek

watershed, and 10.5 miles long and 24.2 mile² in the Tilda Bogue watershed. The Mississippi Department of Environmental Quality (MDEQ) found that the organic enrichment, low dissolved oxygen, nutrients, and sediment are the predominant stressors to biological impairment (MDEQ, 2006).

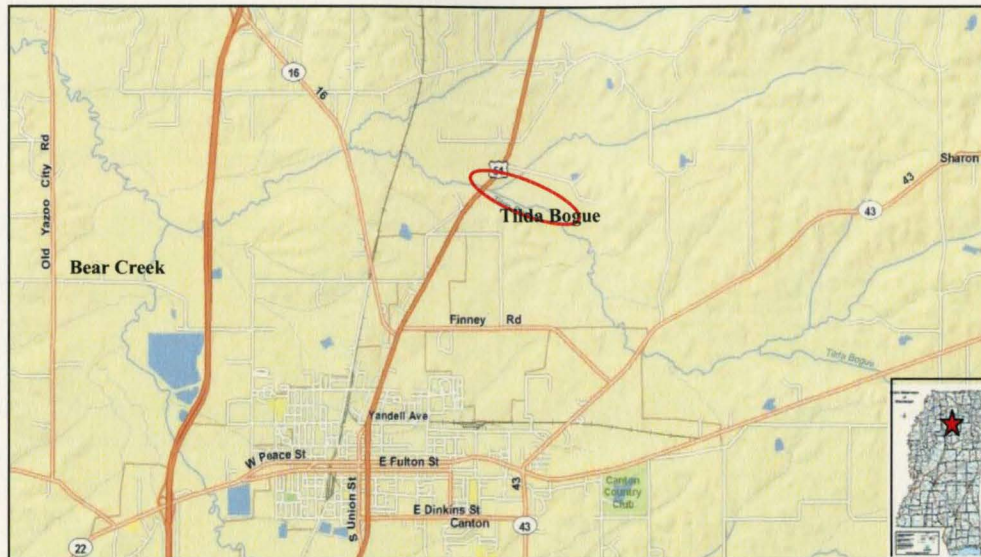


Figure 1.6: The Tilda Bogue watersheds (ArcGIS)

For the nutrient TMDL development, MDEQ uses a method of comparison to similar but unimpaired waters within the same region as suggested in the 1999 Protocol for Developing Nutrient TMDLs (EPA, 1999). An annual concentration of total nitrogen and total phosphorus in Ecoregion 65 are set as a range of 0.6 to 0.7 mg TN/L and 0.06 to 0.10 mg TP/L respectively by MDEQ's studies. According to the land use data for the watersheds established by the State of Mississippi's Automated Resource Information System (MARIS, 1997), the watersheds contain urban, forest, cropland, water, wetlands, and predominantly pastureland. The Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) Pollutant Loading (PLOAD) model (EPA, 2001) was applied for calculating average annual nonpoint source:

$$LP = \sum u (P \times PJ \times RVu \times Cu \times Au \times 2.72/12)$$

where,

LP (lbs) = Pollutant load; P (in/yr) = Precipitation; PJ = Ratio of storms producing runoff (default = 0.9); RVu (in of runoff/in of rain) = Runoff Coefficient for land use type u; $0.05 + (0.009 \times Iu)$; Iu = Percent impervious; Cu (mg/L) = Event Mean Concentration for land use type u; Au (ac) = Area of land use

Event Mean Concentration (EMC) during a runoff event with an average annual rainfall of 55 inches was used for estimating pollutant loading from the land uses (Table 1.4).

Table 1.4: Average annual nonpoint source loads by landuse in Bear Creek-Tilda Bougue watersheds and EMCs for storm events (EPA, 2007)

Land Use	Bear Creek		Tilda Bogue		EMCs		
	Area (acre)	Percent (%)	Area (acre)	Percent (%)	BOD (mg/L)	TN (mg/L)	TP (mg/L)
Forest/rural	16,342	17	3,277	19	1.00	0.30	0.06
Urban	2,614	3	0	0	5.00	1.10	0.20
Cropland (Agriculture)	24,363	25	2,884	17	4.00	2.30	0.35
Pasture/Grassland	34,376	35	6,351	37	2.00	1.00	0.10
Water	932	1	163	1	1.00	0.30	0.06
Wetlands	497	1	0	0	5.00	1.10	0.20
Scrub/Brush	18,944	19	4,435	26	-	-	-
Low-density residential	-	-	-	-	4.00	1.60	0.20
Mid-density residential	-	-	-	-	7.00	2.40	0.50
High-density residential	-	-	-	-	3.00	2.30	0.35
Communication/transportation	-	-	-	-	2.00	1.00	0.10
					Average annual NPS loads		
Total	98,067	100	17,110	100	(lbs/day)		
					1,958	704	118.8

For point source pollution, four of the active facilities out of a total of nine were identified for Bear Creek. EPA assumed effluent concentrations of 30 mg BOD₅/L, 10.0 mg TN/L, and 5.0 mg TP/L from the facilities in the Bear Creek watershed, and none for the Tilda Bogue watershed. Among four of the active facilities in the Bear Creek watershed, the Canton Hydrograph Controlled Release (HCR) Water Treatment Facility (WTF) discharges the biggest amount of effluent to Bear Creek and Tilda Bogue. The amounts of nutrients and BOD loads from Canton HCR WTF are shown in Table 1.5.

Table 1.5: Existing point source load (EPA, 2007)

Facility	Flow (mgd)	Parameter	Existing Point Source Load (lbs/day)
Canton HCR WTF	17	TN	1408
		TP	704
		BOD ₅	4246

Water Quality Analysis Simulation Program Version 7 (WASP 7.2), a technically defensible tool that can be used in the development of total maximum daily loads (TMDL), waste load allocations, and watershed protection plans (EPA), was used for the impaired stream to meet the target concentration of Ecoregion 65 by estimating nutrient loads reduction.

For the model simulation, the in-stream nutrients target concentrations of the upper level of the average annual target concentrations, 0.7 mg TN/L and 0.1 mg TP/L, were used, and the model was simulated to achieve the average DO concentration of 5 mg/L. Eventually 5 mg/L of DO was attained by reducing 50 % of nonpoint sources and decreasing point source concentration of Canton HCR facility to 2 mg TN/L and 0.5 mg TP/L. Therefore by the TMDL equation mentioned earlier, TMDL is calculated as shown in Table 1.6.

Table 1.6: TMDL for the Bear creek and Tilda Bogue watersheds (EPA, 2007)

Parameter	TMDL (lbs/day)	WLA (lbs/day)		LA (lbs/day)		MOS
		Target load	Reduction needed	Target load	Reduction needed	
TN	1166	814	594	352	352	Implicit
TP	129.8	70.4	633.6	59.4	59.4	Implicit
BOD5	5225	4246	—	979	979	Implicit

To achieve the estimated TMDL which is a sum of point source loads (WLA), non-point source loads (LA) and margin of safety (MOS), it was determined that point sources could be reduced in the Wastewater Treatment Facility (WWTF) and non-point source pollutants should be controlled through properly selected BMPs. There are various BMPs already in place, but newer and more efficient BMPs still need to be studied.

1.3 BMPs for Nonpoint Source (NPS) TMDL

Best Management Practices (BMPs) are effective and economical methods for reducing nonpoint source pollution. BMPs prevent phosphorus release from soil to water by erosion control that plays an indirect, but major role to reduce movement of phosphorus into surface water (Devlin, D. L. *et al.*, 2002). Erosion control BMPs can be classified as source control, hydrologic modification for erosion control (i.e., increasing surface storages and permeability), reduction of delivery, and removal of sediment and phosphorus from concentrated flow (Novotny, V., 2002).

Mississippi currently has an effort to encourage and promote landowners to implement agricultural BMPs for preventing and decreasing nonpoint source pollution to achieve water quality goals. The agricultural BMPs emphasized by the Mississippi Soil & Water Conservation Commission are divided into 15 categories in Table 1.7.

Table 1.7: Agricultural BMPs emphasized by the Mississippi Soil & Water Conservation Commission

Methods	BMPs
Source control	Agricultural mixing center
	Conservation treatment system
	Conservation crop rotation
	Critical area planting
	Mulching
	Prescribed grazing
	Conservation tillage
Hydrologic modification	Strip cropping
	Pollution retention structures
	Wetlands
Reduction of delivery	Vegetative filter system
	Diversion
	Grade stabilization structure
	Riparian area
Removal of sediment and pollutants from concentrated flow	Nutrient management systems

An agricultural mixing center is a place where agricultural chemicals are managed safely and collects used chemicals to avoid their negative effects to the environment. Conservation treatment system, critical area planting, conservation tillage, conservation crop rotation, and strip cropping are methods to reduce soil loss by vegetation. A conservation treatment system (i.e., conservation cover, heavy use area protection, pasture and hayland planting) and critical area planting are practices of managing bare areas by permanent vegetation cover after harvests or heavy uses.

Conservation tillage (Figure 1.7) is a planting and tillage system of leaving a minimum 30 percent of plant residues on the soil surface and it helps prevent soil erosion from runoff during the year. Conservation crop rotation is a technique that occasionally replaces growing crop on the same area in more than two years to help to preserve healthy soil states that protects soils from erosion. Strip cropping is a method

that places crop strips across the sloping lands and prevents sheet and rill erosion. Mulching increases soil stabilization by maintaining soil moisture through applying plant residues, wood chips, straw, or other mulch materials. Prescribed grazing prevents soil exposure as a consequence of overgrazing.



Figure 1.7: Conservation tillage (World Overview of Conservation Approaches and Technologies, 2002)

Pollution retention structures (i.e., pond, pollution retention reservoir, and sediment basin (Figure 1.8)) and wetlands work as storage for agricultural nonpoint source pollutants. It entraps and retains pollutants in stormwater runoff. A vegetative filter system includes constructed wetlands, field borders, filter strips, and vegetative barriers. They remove sediment and pollutants from runoff by filtration, deposition, infiltration, absorption decomposition, and stabilizing the soil surface (Mississippi Soil & Water Conservation Commission, 1999). Diversion means diverting water flow across the slope that ends up with a safe place where the water can be detained. A grade stabilization structure reduces the grade thus decelerating velocity of water flow and soil erosion or sediment transport. Riparian areas maintain the vegetative

buffer zone providing a filter system along the bank. They help stabilize the soil and trap nonpoint pollutants including nutrients before they enter water bodies.



Figure 1.8: Sediment basin (City of Milwaukee: milwaukee.gov/SedimentBasin17357.htm)

Nutrient management systems are practices planned to reduce and prevent nutrient emission to the environment. They include composting facilities, incinerators, waste treatment lagoons, waste storage facilities, and waste management systems. While most of the nutrient BMPs have proven their nutrient removal efficiency through monitoring periods as shown in Table 1.8, the cost-efficiency is still not well known due to the difficulty of evaluation. The BMPs need to be economically and technically feasible (Novotny, V., 2002), therefore cost-effectiveness is one of the primary factors for selecting a BMPs with pollutants-removal-effectiveness.

Table 1.8: Mississippi's erosion control BMPs and efficiency

BMPs			Efficiency (% removal)		Reference
			Phosphorus	Suspended solid	
Source control	Conservation treatment system	Conservation cover	30-50	30-60	Novotny, 1994
		Heavy use area protection			
		Pasture and hayland planting	< 80	< 80	Novotny, 2002
	Conservation crop rotation		30		Novotny, 2002
	Critical area planting				
	Mulching				
	Prescribed grazing				
	Conservation tillage		35-85	30-90	Novotny, 2002
Strip cropping		< 50	< 75	Novotny, 2002	
Hydrological modification	Pollution retention structure	Pond	30-65	50-80	EPA, 1999
		Pollution retention reservoir			
		Sediment basin	< 40	40-87	Novotny, 2002
	Wetlands creation/enhancement/restoration		10-70	80-90	Novotny, 2002
Reduction of delivery		Constructed wetlands	15-45	50-80	EPA, 1999
	Plant filter system	Field borders			
		Filter strip	< 50	35-90	Novotny, 2002
		Vegetative barrier			
	Diversion		20-45*	30-60	Novotny, 2002
	Grade stabilization structure			5-75	Novotny, 2002
	Riparian area		50-75	80-90	Novotny, 2002
Removal of sediment and pollutants from concentrated flow	Nutrient management system		20-90		Novotny, 2002

*Adsorbed phosphorus

1.4 River Bank Stabilization (RBS) and Reactive Stream Stabilization (RS2)

River bank stabilization (RBS) and reactive stream stabilization (RS2) are both effective BMPs for reducing and preventing phosphorus from entering the watershed (Novotny, V., 2002; Watson, C.C. *et al*, 2006). RBS can be installed alone, and also installed with RS2 to achieve additional amounts of phosphorus and nitrogen removal.

1.4.1 River Bank Stabilization (RBS)

River bank erosion contributes sediment with absorbed phosphorus to the water and streambed, and diminishes riparian vegetation leading to higher water temperatures (Novotny, V., 2002). As a consequence of a rising water temperature, diversity of biotic communities, wildlife habitats, and native plants that sustain stability and water quality are decreased (Sadlon, N.P., 1993). Also, water-retention capacity is reduced, and flood frequency is increased as a side-effect of the erosion (Waters, T. F., 1995). River bank erosion (Figure 1.9) occurs by water flow, flood events, and channel movements but human activities substantially accelerate erosion frequency. Land use changes, altering stream system (i.e., widening and straightening), and urban and agricultural development increase erosion rates hundreds of times greater than naturally occurring erosion (Pilot View RC&D, 1999).

RBS can be achieved through structural or vegetative techniques called "Soil Bioengineering". The most commonly used structural RBS method is riprap. Riprap is an enduring cover of rock pile on the river bank slope that stabilizes banks and channels protecting the outlet. The size, variation, and rough angular surfaces of the rocks create layers which deflect flow and keep the soils from eroding (ODNR, 2000).



Figure 1.9: Eroding banks of Pembina River in northeastern, ND (USGS, 1995)

Longitudinal peak stone toe protection (LPSTP) is also considered a structural RBS but it can also be used with soil bioengineering. LPSTP is a permanent stone barrier which is installed at the eroding bank toe. The well organized and slight stream orientation of the bank stones of LPSTP are usually placed two tons per linear foot and it yields nearly five feet of toe protection (US Army Corps Engineering, 2006). LPSTP could be vegetated by brush-layering⁴, willow post⁵ and pole planting⁶ to achieve an enhanced outcome (McCullah, J. *et al*, 2005).

Soil bioengineering is a technique of restoring river banks and improving slope stability by using woody vegetation. Willow and dogwood are the widespread types of woody plant, and they are known as quick and deep rooted plants which help bank stabilize more rapidly and firmly (Sadlon, N. P., 1993).

⁴ A revegetation technique by constructing layers of live woody plant cuttings and compressed soil

⁵ A revegetation technique by vertical installation of live willow cuttings

⁶ A revegetation technique by vertical installation of live pole cuttings

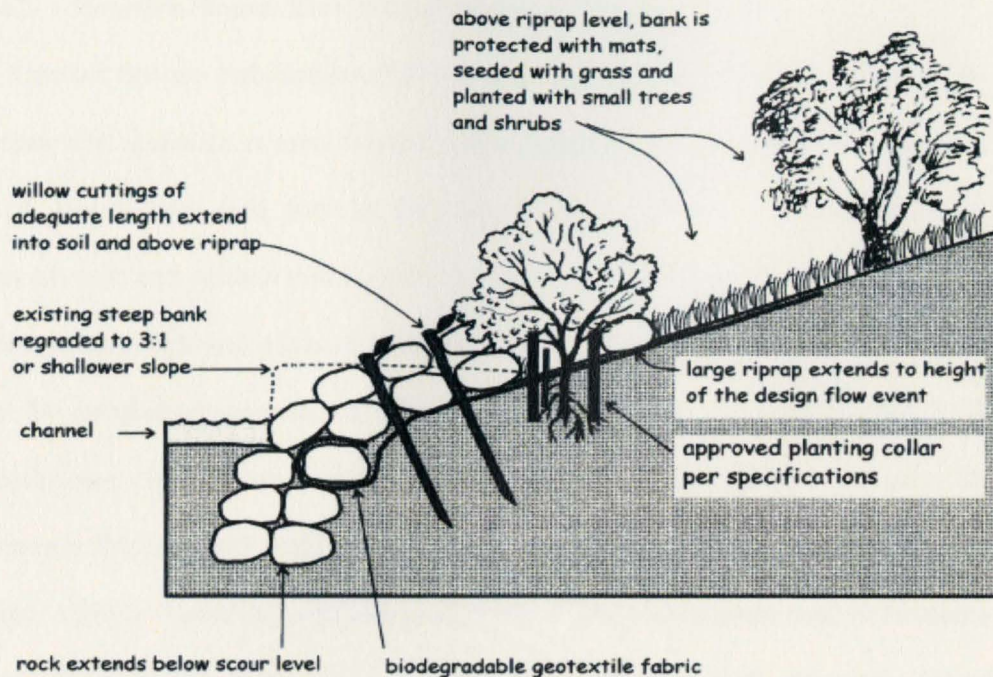


Figure 1.10: River bank stabilization using riprap toe (Royston Hanamoto Alley & Abbey et al, 2000)

River bank stabilization reduces and prevents bank vegetation and land loss, and impairment of utilities nearby the stream and it can reduce 50-70% of phosphorus and 90% of sediments as shown in Table 1.9 (Novotny, 2002). To attain continuous, successful stabilizing river banks without generating additional erosion, proper treatments and accurate techniques are required for the causes (Gerstein, J.M. *et al*, 2005).

Table 1.9: P and sediment removal efficiency of RBS

BMPs	Efficiency (% removal)		Reference
	Phosphorus	Suspended Solids	
River Bank Stabilization	50-70	90	Novotny, 2002

1.4.2 Reactive Stream Stabilization (RS2)

Reactive Stream Stabilization (RS2) is a system that is designed to stabilize the stream and minimize release of agricultural nonpoint pollutants from farms, waste sites, and animal feed lots to the stream through erosion. The RS2 diverts groundwater and surface water runoff through materials in the reactive barrier that enhance microbial and physical nutrient removal (Watson, C. C. *et al.*, 2006). RBS can be installed to improve soil erosion and pollutant runoff control through bank stabilization. The RS2 system has demonstrated its nutrient removal efficiency by Watson's 2003 to 2006 study at the Colorado State University Engineering Research Center (ERC). A cross section of a plan view of the field structure used in Watson's study is shown in Figure 1.11. The cell is constructed with 4% slope in an impermeable liner to retain the water that flows toward the reactive barrier, and the reactive barrier materials and riprap stone toe are divided by filter fabric to reduce loss of materials and provide a flow path (Watson, C. C. *et al.*, 2006).

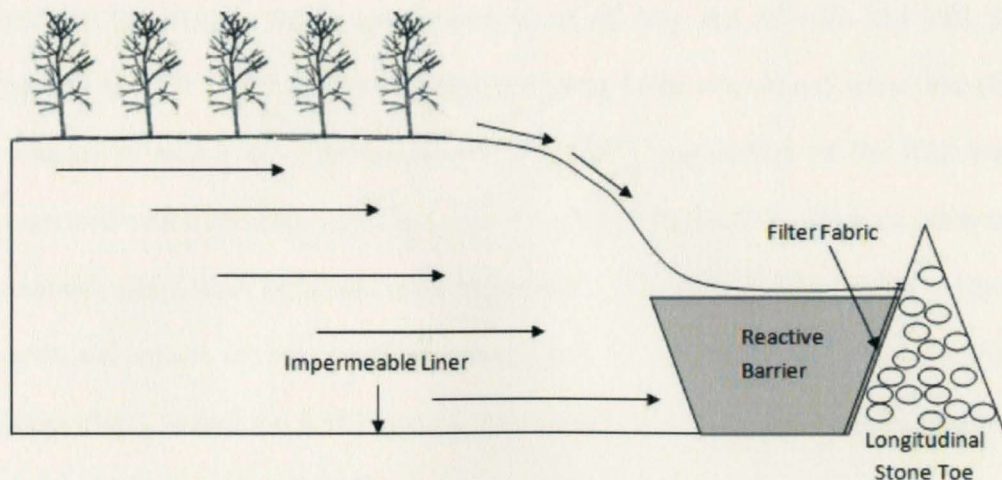


Figure 1.11: Cross section of RS2 structure design (modified from Watson, C. C., 2006)

Watson et al. found that the RS2 structure utilizing water treatment residual (WTR) as the reactive barrier material had the best phosphorus removal efficiency among the 3 evaluated materials; sawdust, WTR, and zero-valent iron (ZVI). WTR is an aluminum based media which is the residual from the coagulation and settling processes in a water treatment system and it has the capability of adsorbing large amounts of phosphorus (Gallimore et al., 1999, Haustein et al., 2000, Elliott, H. A. *et al*, 2002, and Ippolito, J. A. *et al*, 2003). When sand amended with 15% WTR was used as the reactive barrier, 98% phosphorus removal was measured versus 85% for sawdust. Since sawdust is biodegradable, the P would potentially become available in the future whereas WTR has been shown to have a very low desorption rate (Ippolito, J. A. *et al*, 2003).

Based on the results of the field study at CSU, a RS2 structure was installed at a site along a stream bank of the Little Bogue Creek in Elliott, Mississippi in November 2008. The picture of the area and the plan view of the structure are presented in Figures 1.12 and 1.13. The test area is 150 ft long and 75ft are used for the control section. The reactive barrier has dimensions of 4ft deep and 1ft wide and 20% by volume and 1.7 % by weight of aluminum (used 8.6% w/w Alum) with 19% (by volume) of mulch as a carbon source. Each 25ft long section of the RS2 was vegetated with willow, sycamore and river birch to determine their effects on nutrients removal, and a small berm was built streamward of the RS2 reactive barrier to slow down and capture surface runoff enhancing water infiltration into the reactive barrier. Water flows toward the RS2 structure from an adjacent field that was planted with corn in 2007 and cotton in 2008.

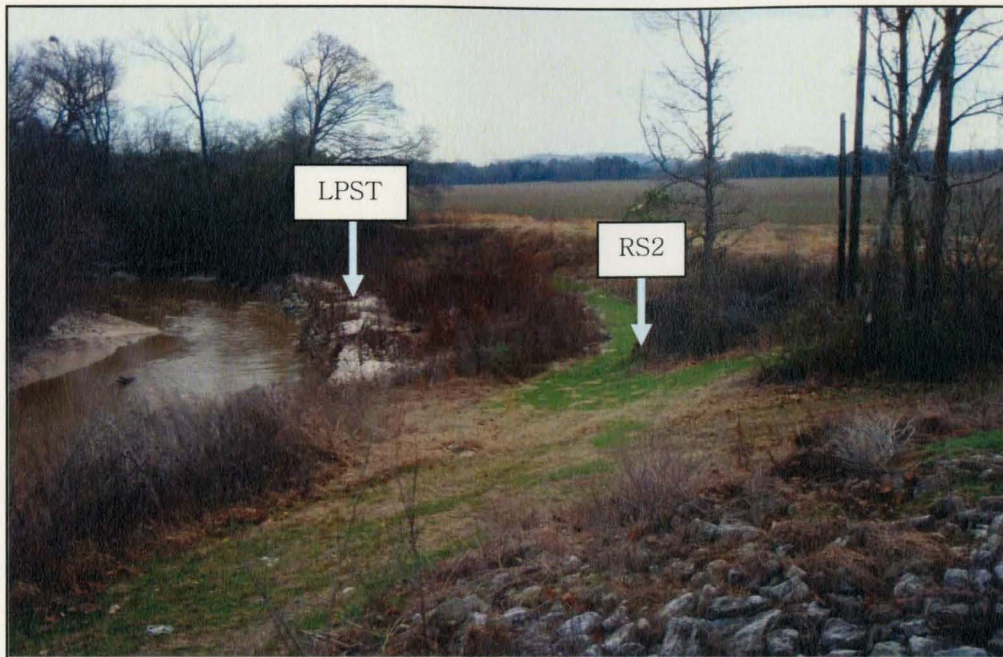


Figure 1.12: LPSTP and RS2 in Little Bogue, Elliott, Mississippi

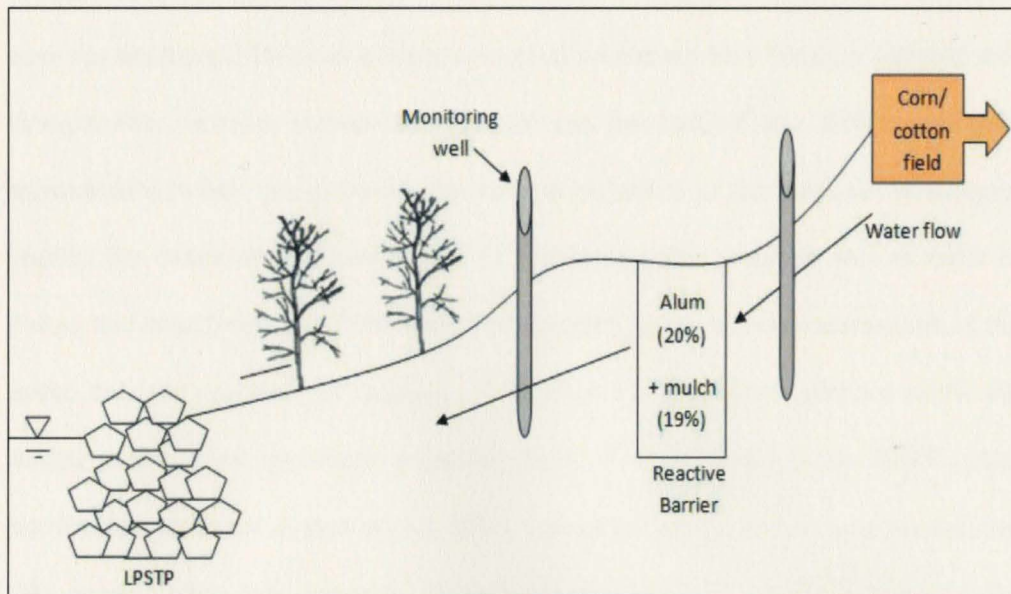


Figure 1.13: Plan view of LPSTP and RS2 structure in Little bogie, MS

Pole planting is used for the RS2 structure to enhance the strength of the structure during plant establishment and decrease the velocity of water flows near the bank

which could prevent soil loss and potential collapse of the structure (Skirrow, R., 2006). After installation of the RS2 structure and pole plantings, the surface of the RS2 was seeded with winter rye grass and mulched with hay. Monitoring wells were installed up-gradient and down-gradient of the RS2 in each section of control, planted and no planted test area.

Nutrients, especially phosphorus from an agricultural non-point source is the main factor that impairs water quality and causes eutrophication. Reactive Stream Stabilization has been developed and installed along Little Bogue watershed in Mississippi to study its effectiveness of soil erosion and nutrient removal which come from agricultural areas and discharge into the near stream.

1.5 Research Objectives

Based on the review of literature discussed above, it is hypothesized that there is a need for additional BMPs to achieve non-point source nutrient TMDLs. Further, it is thought that reactive stream stabilization can be one of the BMPs that will substantially reduce non-point source nutrient pollution in the northern Mississippi region. The scope of the research for this Master's thesis research was to assist in design and installation of a field scale RS2 structure and to conduct assessment of the initial nutrient removal performance of the system. This scope did not allow the testing of the larger hypothesis regarding BMP efficacy for achieving TMDL goals but the data collected as part of this effort will contribute to future research studying this aspect. For this research, the objectives that were established given the timeframe of the project were:

- 1) Assist in design and installation of field scale RS2 structure
- 2) Document construction of RS2 structure and evaluate adherence to construction design parameters
- 3) Provide initial data collection and evaluation of RS2 performance for limiting P and N transport to stream
- 4) Compare costs of P-removal between BMPs and WWTPs and assign value to P removal for point and non-point sources.
- 5) Evaluate cost-efficiency of RS2.

To evaluate design parameters of RS2, concentrations of alum and total organic carbon (TOC) in the RS2 test barrier and surrounding areas were analyzed to determine if enough of them are in the barrier to remove nutrients as it was designed. Concentrations of total phosphorus (TP), Mehlich-3 phosphorus and total nitrogen in soils in the field area, RS2 barrier and lower bank are required to be tested to evaluate to what extent the RS2 structure reduces soil nutrients through the barrier. Concentrations of TP, dissolved reactive phosphorus (DRP), TN and nitrate of waters in monitoring wells and along the stream are also needed to be examined to quantify the effects of RS2 on ground and stream water quality.

CHAPTER 2

MATERIALS AND METHODS

Samples were collected on two randomly selected dates to evaluate the design objectives and the initial nutrient removal performance of RS2. Twenty soil samples and nine water samples were collected in May, 2009 and fifteen soil samples were collected in July, 2009 from Little Bogue creek in Mississippi where a RS2 structure was installed in November, 2008. Aluminum, TP, Mehlich-3 phosphorus, TN and TOC were analyzed in soil samples and TP, DRP, TN, nitrate and TOC were analyzed in water samples.

2.1 Field Sampling

On May 2nd and 3rd, 2009 the first sampling of twenty soil samples and nine water samples was executed and the second sampling of fifteen soil samples was performed on July 3rd, 2009 in the Little Bogue creek in Elliot, Mississippi (Figure 2.1). Little Bogue creek is a well-suited place to study a RS2 system because it is surrounded by agricultural areas and the only expected source of pollutants in the stream is nutrients that come from the nearby agricultural lands. A soil sampling auger was used for taking soils at each soil sampling site and 100g of each soil sample was collected from the homogenized soils using a hand shovel.

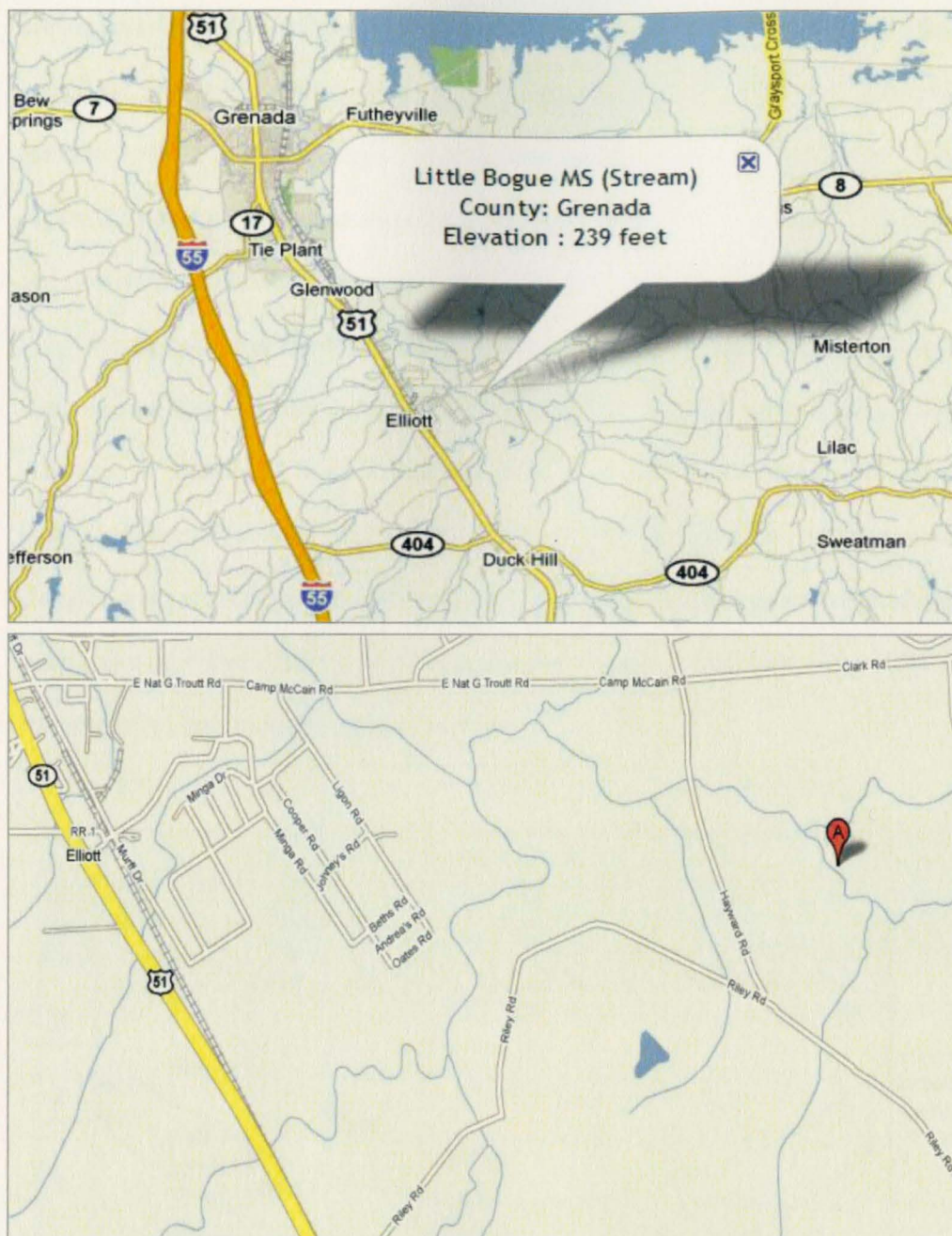


Figure 2.1: Map of Little Bogue, Grenada, MS (Google map)

For the first sampling, five soil samples were collected from both the lower bank of the barrier (section 3; see Figure 2.2), upper bank of the barrier near the agricultural field (section 1; see Figure 2.2) and ten additional soil samples were taken from the reactive barrier (section 2; see Figure 2.2) at two different depths; 16

inches and 36 inches to see differences and accumulation of P. For the second sampling, five soil samples were collected from the lower bank of the barrier (section 3; see Figure 2.2), upper bank of the barrier near the field (section 1; see Figure 2.2) and the 16 inches deep reactive barrier (section 2; see Figure 2.2). Each soil sample was collected in a labeled plastic zip bag.

A well sampler was used for collecting water samples. A well sampler is a rod-shape device that is 5 feet long and can be lengthened by 10 feet to reach ground water in the monitoring well. A volume of 0.5 L of each water sample was taken from the monitoring wells LB2, LB3, LB4, LB5 and LB6, and four surface water samples were collected from upstream, middle of the stream and downstream of the testing sites (refer to Figure 2.2). Stream samples were collected from the middle of the stream in clean one liter Nalgene bottles.

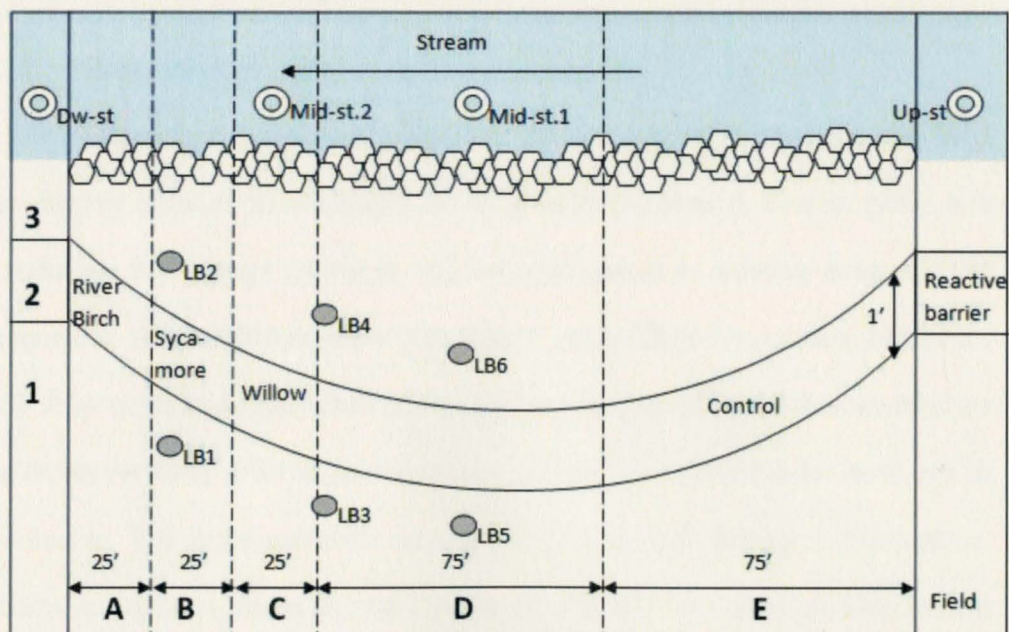


Figure 2.2: Plan view of Little Bogue RS2 site (A, B, C, D: test area; E: control area; 1: field side upper bank; 2: RS2 barrier; 3: lower bank; LBs: monitoring wells)

After sampling, all of the samples were placed in ice bags to maintain low temperature ($< 4^{\circ}\text{C}$) while they were transferring to the laboratory. Soil samples were air-dried then kept in the freezer and water sample were filtered through Whatman No.42 filter paper then preserved in a refrigerator to avoid further reactions that could affect later measurement of the samples. All samples were measured in 28 days.

2.2 Soil Analyses

For the soil phosphorus extraction, a microwave digestion method was used prior to the soil analyses. Two sediment phosphorus analyses were conducted; TP and Mehlich-3 phosphorus, phosphorus extractable by Mehlich-3 method is weakly bound phosphorus from soils represents bioavailable P, and aluminum (Al) in the soils were also measured to study its influence on P absorbability.

2.2.1 Microwave Digestion

The microwave digestion method used in the soil extraction procedure has been described by Littau, S. E. and Engelhart, W. G. in 1990 (Littau, S. E. *et al*, 1990). It is a technique that digests sediments with alkaline persulfate solution using a CEM Corporation MDS-2000 Microwave Digestion System (CEM Corporation, Matthews, NC). Prior to the experiment, half of the samples were homogenized then air-dried on flat dishes for a day at the room temperature and the rest of the samples were kept in the freezer. The dried sediments were ground and passed through a 2-mm sieve. Alkaline persulfate solution ($0.17\text{M K}_2\text{S}_2\text{O}_8 + 0.24\text{M NaOH}$) was prepared by mixing 11.25 g of potassium persulfate (Fisher scientific, Fair Lawn, NJ) and 59.5ml of 1N sodium hydroxide (Fisher scientific, Fair Lawn, NJ) in a 250ml volumetric flask with DI water. The vessel of the microwave digester was washed with 6M HCl and DI

water before and after the sample digestion. Each sample had 50 mg of sediment digested for 40 minutes in the microwave digester for oxidation with 25ml of alkaline persulfate oxidizing solution at 170°C and 135 psi. After 40 minutes, samples were cooled and vented in a fume hood, filtered through Whatman No.42 filter paper then diluted to volume in 100ml volumetric flasks (Figure 2.3).



Figure 2.3: Filtration of samples using Whatman No.42 filter paper

The pH values of the extracts were adjusted to a range of 5-7.

2.2.2 Aluminum

Soil aluminum analysis was conducted using a Hach colorimetric method (Hach method No. 8012). Each 50ml of microwave digested extractant was mixed with ascorbic acid powder to remove iron interference and Aluver3 aluminum reagent was added (Hach Company, Loveland, CO). Dark orange color was developed with increasing aluminum concentration. Then 25ml of the solution was placed in a sample cell and the rest of 25ml was mixed with bleaching3 reagent. After 15 minutes of reaction period, 25ml of bleached solution was used for a blank and a prepared 25ml

of sample in a sample cell was measured at 522nm in a Hach DR/2500 spectrophotometer (Hach Company, 2003) (Appendix Table 7.1). The minimum detection limit of the method (MDL) is 0.008 mg/L.

2.2.3 Total Phosphorus (TP)

TP was analyzed by adding Phosver3 reagent to each 10ml of digested extractant (Hach Camplany, Loveland, CO; Hach method No. 8048). Blue color was developed when ortho-P was present since orthophosphate reacts with molybdate ions and forms phosphate/molybdate complex then give blue color as ascorbic acid moderates the complex. After 2 minutes of reaction time, the concentration of ortho-P was measured at 880nm in a Hach spectrophotometer DR/2500 (Hach Company, Loveland, CO). and calculated by the equation below (Appendix Table 7.2):

$$\text{Total P} \left(\text{mg} \frac{\text{P}}{\text{g}} \text{sediment} \right) = \text{Concentration of P in extract (mg/L)} \times \frac{\text{Volume of extract (L)}}{\text{Mass of sediment (g)}}$$

A result lower than 0.03mg/L should not be reported since P MDL of the Hach colorimetric method is 0.03mg/L (Yarkin, M, 2006).

2.2.4 Mehlich-3 Phosphorus

The method was established in 1984 by Adolph Mehlich (Mehlich, A, 1984). The method is a modified version of a former Mehlich test to test acidic soils of North Carolina (Watson, M. and Mullen, R., 2007). An optimum range of Mehlich-3 P for plant growth is 45-50 mg P/kg soil (Sims, J. T., 2000). For the test, soils were air-dried, ground, then passed through a 2-mm sieve. The extracting solution (0.2N CH₃COOH + 0.25N NH₄NO₃ + 0.015N NH₄F + 0.013N HNO₃ + 0.001M EDTA) was prepared by mixing 10g of ammonium nitrate, 400 ml of deionized (DI) water, 20ml

of stock (0.375N NH₄F+ 0.025M EDTA), 5.5ml of glacial acetic acid and 420 µl of nitric acid. Then it was brought to a volume of 500ml and pH of 2.6. A mass of 2g of prepared soil sample with 20ml of the extracting solution was placed into a centrifuge tubes to be mixed on an orbital shaker at 200 rpm for 5 minutes at a room temperature (24-27°C). After mixing, the samples were filtered through Whatman No.42 filter paper and refiltered when the extracts were not clear. The extracts were analyzed by Hach colorimetric method (Hach method No. 8048) and the extracting solution was used for a blank and standards. The bioavailable P was calculated by using the equation below (Appendix Table 7.3):

$$\begin{aligned} \text{Mehlich - 3 P (mg} \frac{\text{P}}{\text{g}} \text{ sediment)} \\ = \text{Concentration of P in extract (mg/L)} \times \frac{\text{Volume of extract (L)}}{\text{Mass of sediment (g)}} \end{aligned}$$

2.2.5 Total Nitrogen (TN)

Total nitrogen (TN) was analyzed in a thermal decomposition-catalyst filled combustion tube at 720°C to form nitrogen monoxide using the Shimadzu TOC-VCS analyzer (Shimadzu Corporation, Columbia, MD). The nitrogen monoxide was volatilized in the dehumidifier and then detected in a chemiluminescence detector. The detector measured the gas-phase chemiluminescence produced by reaction of ozone with nitrogen monoxide and created a peak. The concentrations of TN were calculated using the prepared calibration curve prior to sample analysis. 10mg/L, 50mg/L and 100mg/L of TN standard solutions were used for the TN calibration curve (Shimadzu Corporation, 2008) (Appendix Table 7.4). The MDL of the analyzer is 4ug/L.

2.3 Aqueous Analyses

For aqueous measurements, total phosphorus (TP), dissolved reactive phosphorus (DRP), nitrate, total organic carbon (TOC) and total nitrogen (TN) analyses were conducted with pre-filtered samples using Whatman No.42 filter paper.

2.3.1 Total phosphorus (TP)

Water TP was measured using the Hach acid persulfate digestion method (Hach Company, 2003; Hach method No. 8190). A volume of 5ml of sample was added to acid hydrolyzable test vials with potassium persulfate, and then the solutions were heated in a COD reactor at 150°C for 30 minutes to transform organic and inorganic phosphorus to the reactive orthophosphate form. After 30 minutes of reaction, 2ml of 1.54N sodium hydroxide was added to each vial. Phosver3 reagent was added and a blue color was developed when ortho-P was present. After 2 minutes of reaction time, the concentration of ortho-P was measured at 880nm in a Hach spectrophotometer (Hach Company, Loveland, CO). The MDL of the method is 0.06 mg/L PO_4^{3-} .

2.3.2 Dissolved Reactive Phosphorus (DRP)

DRP was measured using the phosver3 reagent (Hach Company, Loveland, CO; Hach method No. 8048). Collected and filtered water samples (20ml) were prepared and 10ml was used as blanks. Phosver3 reagent was added to another 10ml of samples. After a 2 minute reaction period, DRP was measured as mg/L PO_4^{3-}P (Hach Company, 2003).

2.3.3 Nitrate

The cadmium reduction method was used for nitrate analysis. Nitraver3 reagent (Hach Company, Loveland, CO; Hach method No. 8171) which converts nitrate to nitrite was added to each sample (10ml). During the 6 minute reaction period, the converted nitrite ions and sulfanilic acid forms an intermediate diazonium salt, and develops an orange color with gentisic acid. The intensity of color was measured at 500nm as $\text{mg/L NO}_3^- \text{N}$ (Hach Company, 2003). The MDL of the method is 0.1mg/L.

2.3.4 Total Organic Carbon (TOC) and Total Nitrogen (TN)

TOC and TN were measured using the Shimadzu TOC-VCS analyzer (Shimadzu Corporation, Columbia, MD). The analyzer measured TOC by subtracting inorganic carbon (IC) concentrations from total carbon (TC) concentrations. To determine TC, samples were oxidized with phosphoric acid and persulfate in a combustion tube at 680°C to convert organic matters and carbonates to the carbon dioxide form and then a non-dispersive infrared detector (NDIR) detected the created carbon dioxide. The concentrations of TC were calculated using a pre-estimated calibration curve which was determined by relationship of peak area to TC concentration. The calibration curve was developed using prepared 10mg/L, 50mg/L and 100mg/L of TC standard solutions using potassium hydrogen thalate prior to the sample analysis. To measure IC, phosphoric acid was added to the samples to transform carbonate and bicarbonate to carbon dioxide. The NDIR sensed the carbon dioxide and the concentrations were calculated using pretested calibration curve. Prepared 10mg/L, 50mg/L and 100mg/L of IC standard solutions using sodium carbonate were used for the calibration curve (Shimadzu Corporation, 2008). TN was detected in the same way as the soil extractant.

2.4 Statistical Method

A one-tail t-test was used to assess the correlations between the field and the two depths of the RS2 barrier in Excel. The same tests were used to determine correlations between the barrier and the bank, and between the field and the bank. When p was less than a threshold value (0.05), two tested groups were considered as they are significantly different, and insignificant when p was greater than 0.05.

CHAPTER 3

RS2 DESIGN, CONSTRUCTION AND INITIAL MONITORING RESULTS

The Reactive Stream Stabilization (RS2) structure was designed and constructed along the bank of the Little Bogue watershed in November, 2008. 20% v/v alum and 19% v/v mulch were mixed with the soil in the bank and river birch, sycamore and willow were used for pole plantings to prevent soil loss and improve endurance of RS2 structure. Six monitoring wells were installed; three in the upper bank and three down gradient of the RS2 barrier. The first and second sampling events were executed in May and July, 2009.

3.1 Design and Construction of RS2

The RS2 was designed according to previous field tests at the Engineering Research Center (ERC) of CSU from 2003 to 2006 (Figure 3.1). In this test, a mixture of 15% of Wastewater Treatment Residual (WTR) with sand was filled in the reactive barrier and 98% phosphorus removal was achieved through the barrier (Chapter1, 1.4.2 Reactive Stream Stabilization (RS2)). From the result of the test, 10 to 20 % volume fraction (v/v) of WTR and 15 to 20 % of volume fraction (v/v) of mulch were targeted for the RS2 reactive barrier in the Little Bogue watershed.

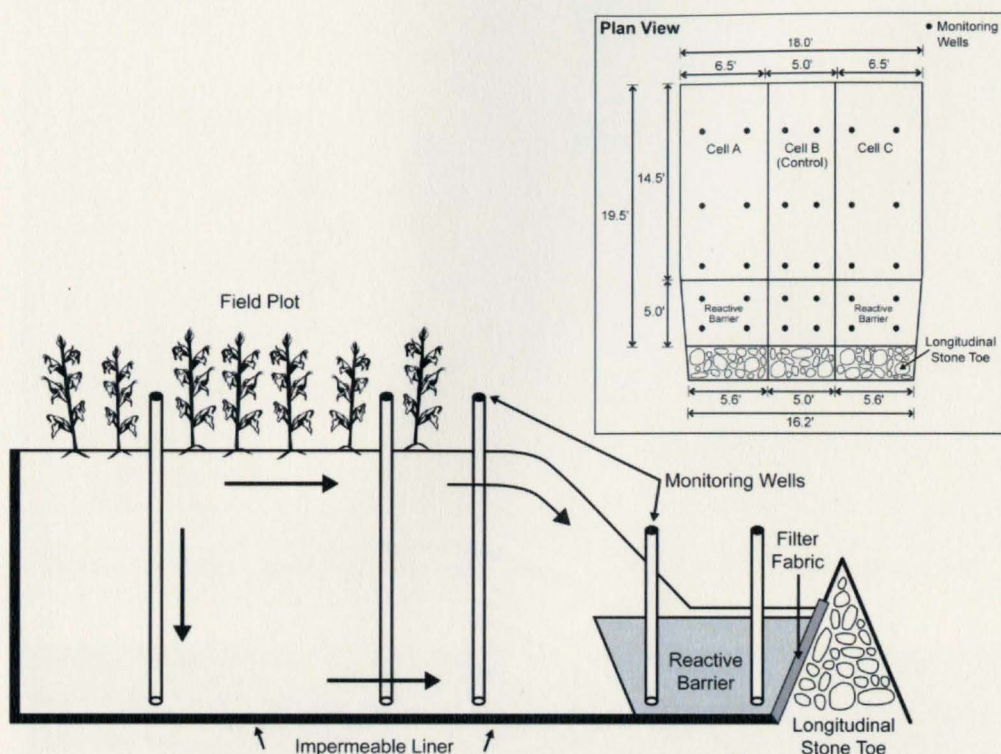


Figure 3.1: A plan view and a cross section view of the RS2 used in the field test at the ERC of CSU (Watson, C.C., 2006)

Aluminum sulfate ($\text{Al}_2\text{SO}_4 \cdot 14\text{H}_2\text{O}$) was used as a precursor of aluminum hydroxide ($\text{Al}(\text{OH})_3$) formation in-situ. Eucalyptus mulch was applied as a source of organic matter to provide electron donors for denitrification in the 150 ft long reactive barrier (Figure 3.2). A 75 ft long area adjacent to the barrier was used as a control section which has no added aluminum or organic matter (OM).

Construction of the RS2 was completed on November 19th and 20th, 2008 in the Little Bogue watershed where the bank stabilization in the form of longitudinal peak stone toe protection (LPSTP) already existed (Figure 3.3). A 150 feet long trench was dug by shovels and a mini excavator (Figure 3.5) with 1 ft wide bucket to a depth of 4 feet. Each 1.5 ft³ bag of eucalyptus mulch was mixed with two bags of aluminum sulfate and native soils in the trench (Figure 3.4).

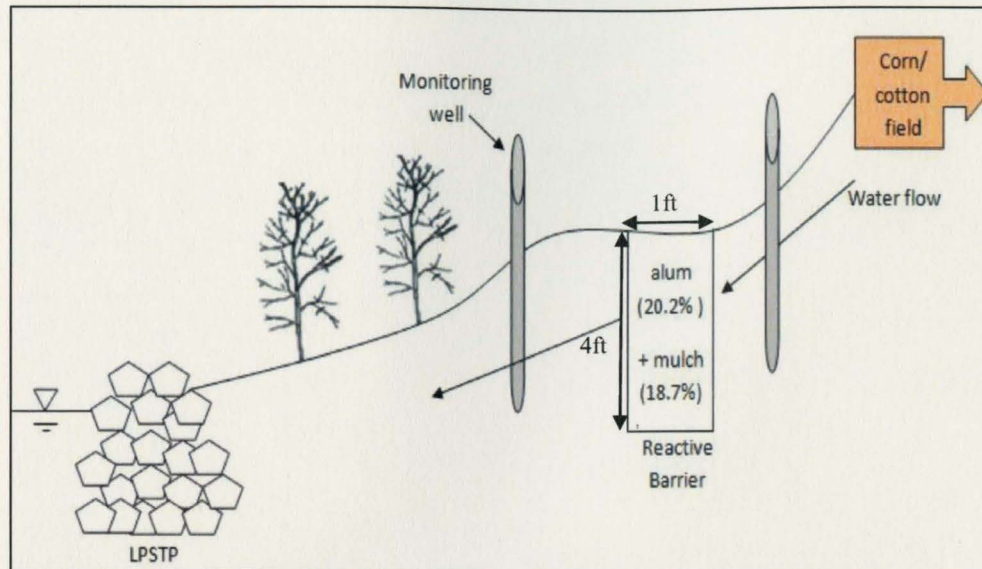


Figure 3.2: Design concept of Reactive Stream Stabilization (RS2) in Little Bogue, MS



Figure 3.3: The RS2 test site before constructing the RS2 in Little Bogue watershed (Derrick, D., April 2, 2008)

Since the weight fraction of aluminum was the main design criterion of the RS2 design for P adsorption, calculating the weight concentration of alum in the barrier was critical.



Figure 3.4: Mixing alum and mulch with soils by shovels in the RS2 barrier (Derrick, D., November 19, 2008)

When it was assumed that the 150ft long trench was excavated uniformly to 4ft deep and 1ft wide, the volume of trench was 600 cubic feet. The volume percentage of OM and alum in trench were 18.7 % and 20.2 %, respectively, and the weight percentage of aluminum was 1.7 % (see Appendix, 1 for the calculation). This weight percentage of aluminum was equivalent to 18 % v/v of WTR since the weight fraction of aluminum in WTR is 0.094. These results from the calculations are positive since the initial design criteria of the ranges of volume percentages of Al and OM were 10-20 % v/v of WTR and 15-20 % v/v of mulch, respectively.

After mixing alum and mulch with the native soils in the trench, poles of river birch, sycamore and willow were planted in increments of each 25 feet along the test trench and the rest of 75 feet of the trench remained without pole planting. To enhance infiltration of rain and surface runoff into the barrier, a small berm was built streamward of the trench and a gully on the top bank was restored. A Bobcat skid steer was used to convey soils (Figure 3.5). Excessive soils on the barrier, the berm

and the repaired gully were removed and top soils were flattened and then seeded with winter rye grass and mulched hay (Figure 3.6).

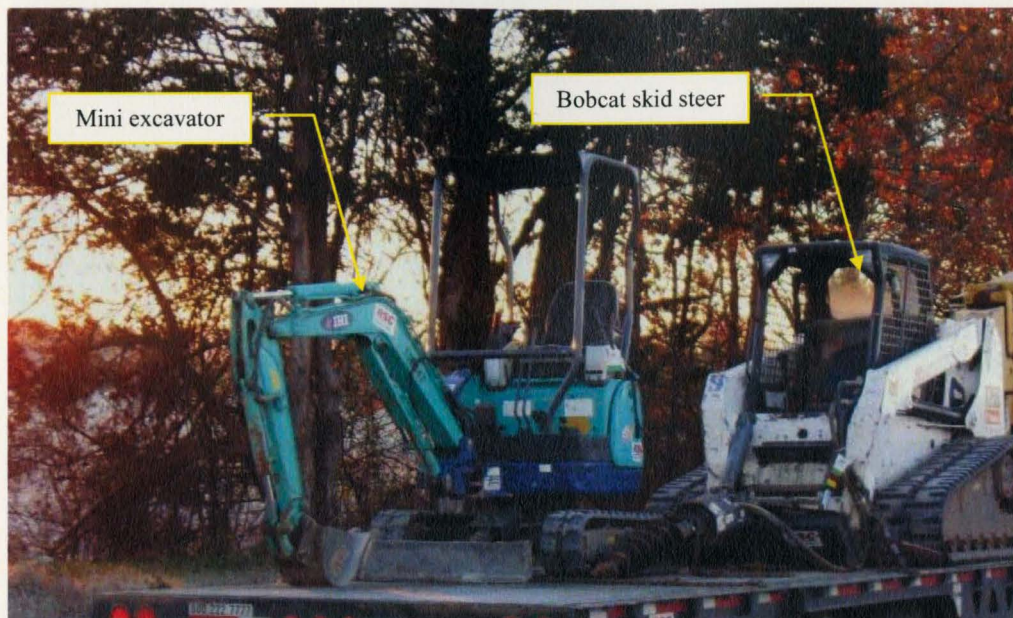


Figure 3.5: Mini excavator and Bobcat skid steer used for digging and conveying soils (Derrick, D., November 19, 2008)

Six monitoring wells were installed on January 12th, 2009. Three of them were placed on the streamward bank and three on the field side of the reactive barrier to monitor nutrients in the ground water passing through the barrier (Figure 3.7). It was observed that the seeded rye grass on the berm and the trench had substantial growth in January, 2009 (Figure 3.8).



Figure 3.6: Completed areal view of the RS2 construction (Derrick, D., November 19, 2008)



Figure 3.7: Monitoring wells in the field side of the RS2 barrier (Watson, C. C., January 12, 2009)



Figure 3.8: The RS2 installed area in the Little Bogue watershed in January, 2009 (Watson, C.C., January 12, 2009)

Five months after the RS2 construction, the first sampling was conducted on May 2nd and 3rd in the test and control areas. During the sampling days, it was humid and cloudy. The rye grass on the berm and the test trench had disappeared (Figure 3.9) and the pole-planted river birch, sycamore and willow had not grown much (Figure 3.10). Sampling methods and equipment are described in Chapter 2. Water samples were collected from the installed monitoring wells in the upper bank and the lower bank of the reactive barrier (Figure 3.11) and from the up-, mid- and down-stream section of the creek (Figure 3.12). Soil samples were taken from the trench and the field side bank and streamward bank of the trench in the test area and the control area (Figure 3.13). The second sampling was carried out on July 3rd, 2009.



Figure 3.9: The RS2 test area along the bank of the Little Bogue in May, 2009

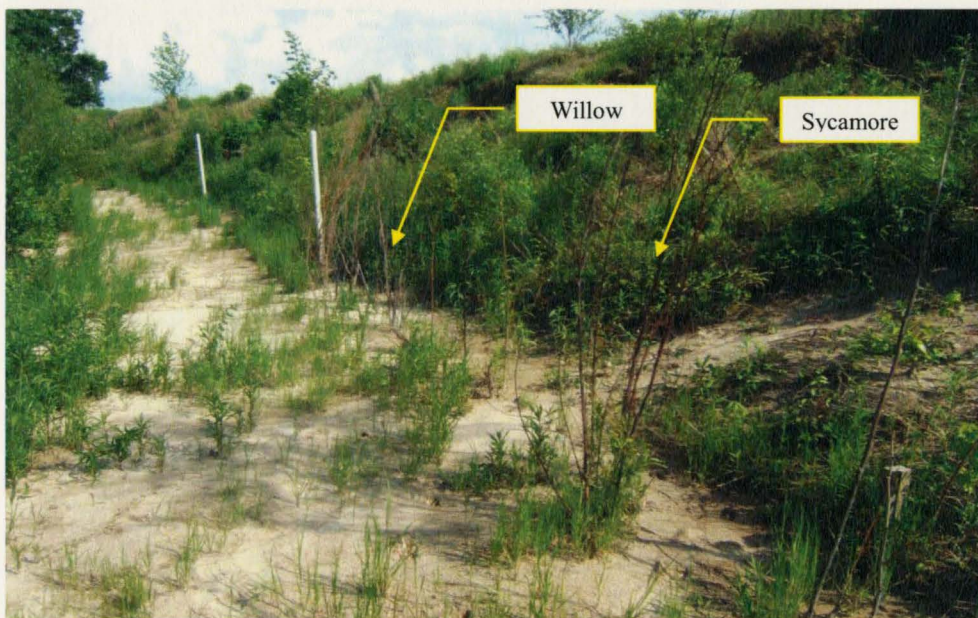


Figure 3.10: Pole planted sycamore and willow in the reactive barrier in May, 2009



Figure 3.11: Monitoring wells in the upper bank and the lower bank of the reactive barrier in May, 2009



Figure 3.12: The stream and the longitudinal peak stone toe protection (LPSTP) in Little Bogue in May, 2009

3.2 Initial Monitoring Results

Samples were collected according to the diagram shown in Figure 3.13. Sampled soils were classified and TP, Mehlich-3 P, TOC, TN and Al were measured for soil concentrations and TP, DRP, TN, nitrate and TOC were determined for water concentrations. The results are shown as average values of the first and second sample analysis.

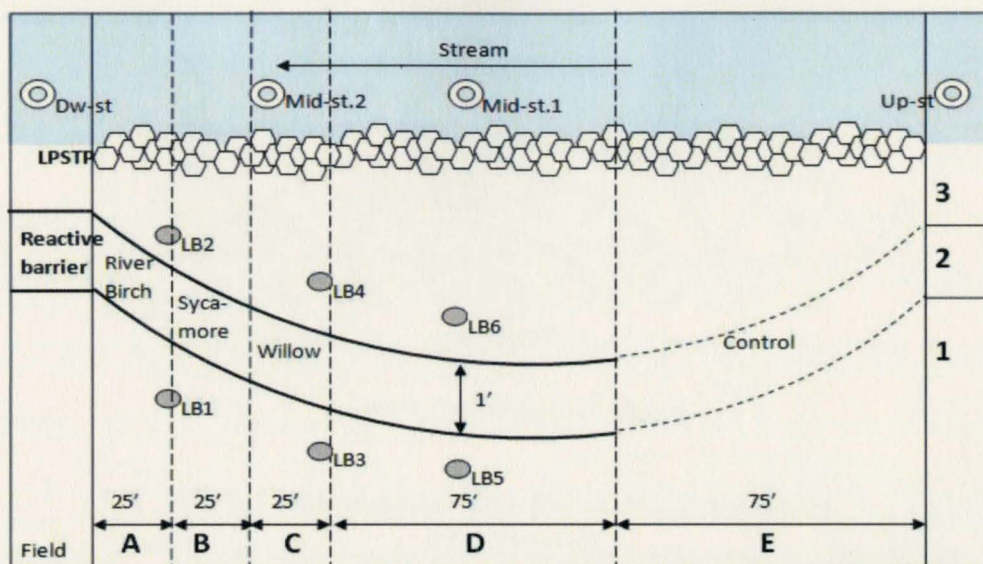


Figure 3.13: Plan view of sampling site in the RS2 test area in the Little Bogue watershed site (A, B, C, D: test area; E: control area; 1: field side upper bank; 2: RS2 barrier; 3: lower bank; LBs: monitoring wells)

3.2.1 Soil Classification

Air dried and well ground soils were sieved through 2mm and 75 μ m sieves to be characterized. The soils that did not pass through the 2mm sieve were classified as sand, the soils that passed through the 2mm sieve but not the 75 μ m sieve were categorized as silt and the soils that went through the 75 μ m sieve were classified as clay. The classified sand, silt and clay were weighted and percentages of them were calculated (Appendix Table 7.1). Based on the soil textural triangle (Figure 3.14), the classified soils were characterized in Table 3.1.

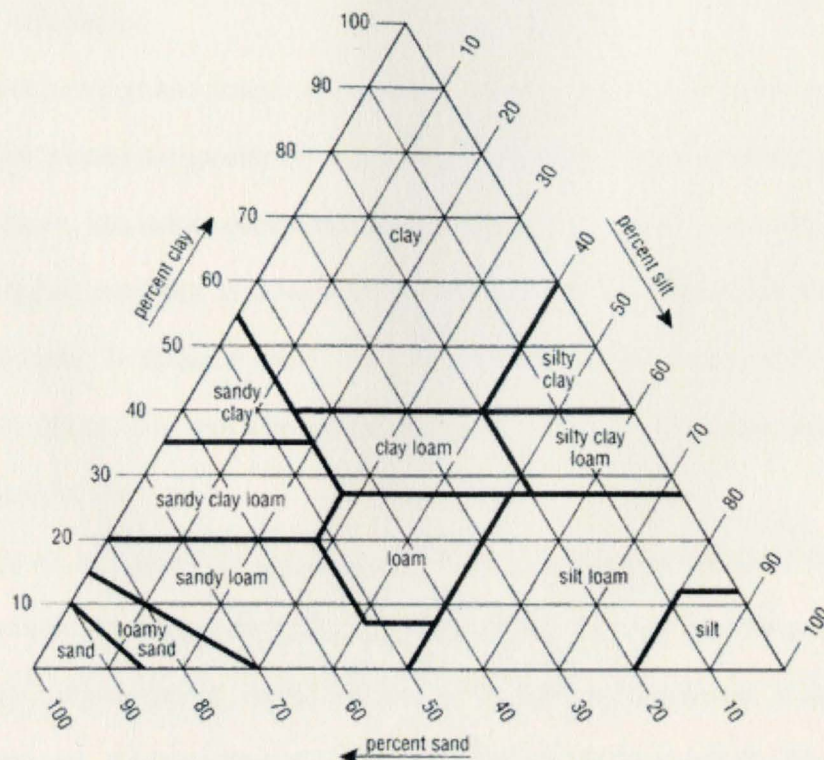


Figure 3.14: Soil textural triangle

Table 3.1: Soil characters in the RS2 study and control areas

	RS2 Study Area				Control Area
	A	B	C	D	
Field	Silty Clay	Silt Loam	Silty Clay	Silty Clay Loam	Silty Clay
Barrier (16")	Silt Loam	Silty Clay	Silty Clay	Silty Clay Loam	Silty Clay
Barrier (36")	Silty Clay	Silty Clay	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam
Bank	Silty Clay	Silty Clay	Silty Clay	Silty Clay Loam	Silty Clay Loam

55% of soil samples were silty clay, 35% were silty clay loam and the remaining 10 percent was silt loam. Silty clay soil contains 40 to 60 % of clay which has more adsorption capacity for phosphorus in soils than silt and sand.

3.2.2 Aluminum

The RS2 concept and design were developed over the past years in field research at CSU. The primary design objectives of RS2 are to stabilize the stream bank, minimize bank erosion, and reduce phosphorus and nitrogen loads through the reactive barrier that contains aluminum to adsorb phosphorus and organic matter for accelerating denitrification. To reduce P and N loads, 20.2 volume % and 1.7 weight % of alum, and 18.7 volume % of mulch as organic matter were added in the reactive barrier with the bank soils.

As shown in Figure 3.15 and 3.16, aluminum in the reactive barrier is five to ten times greater than surrounding area and is significantly greater than the control area ($p < 0.05$) verifying that one of the design objectives has been achieved. If we assume that alum was added homogeneously in the 15' long, 4' deep and 1' wide reactive barrier, it appears that the mean concentration of alum in the reactive barrier is 2.1 mg/g (Coefficient of Variance=0.49) and the mean concentration of the field in the study area is 0.67 mg/g and the mean concentration of the bank in the study area is 0.46 mg/g as similar as the concentrations in the control area, 0.53 mg/g.

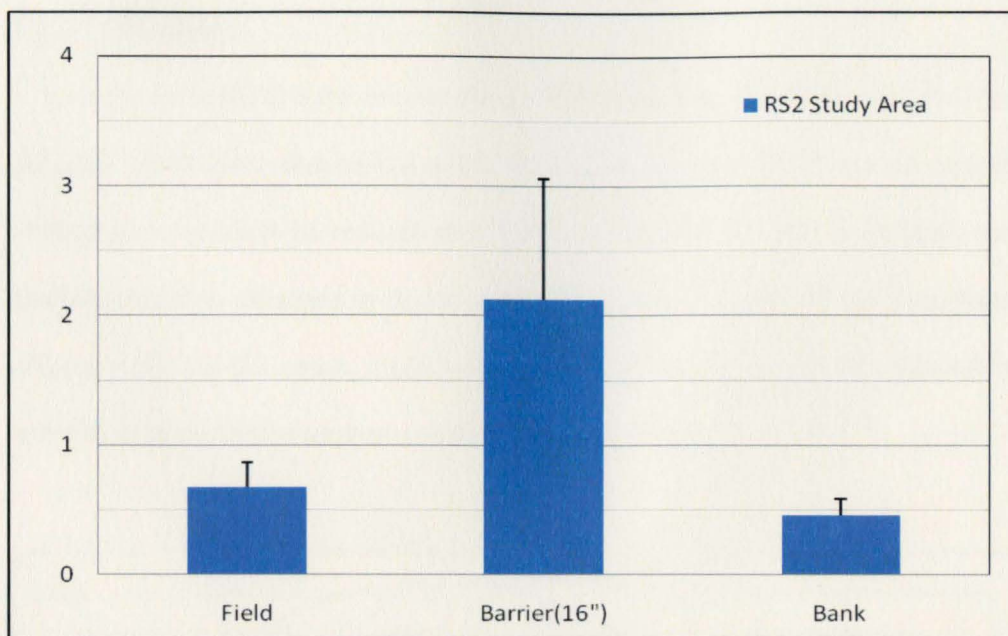


Figure 3.15: Concentration (mg/g) of total aluminum in RS2 study area (error bars indicate 95% confidence intervals)

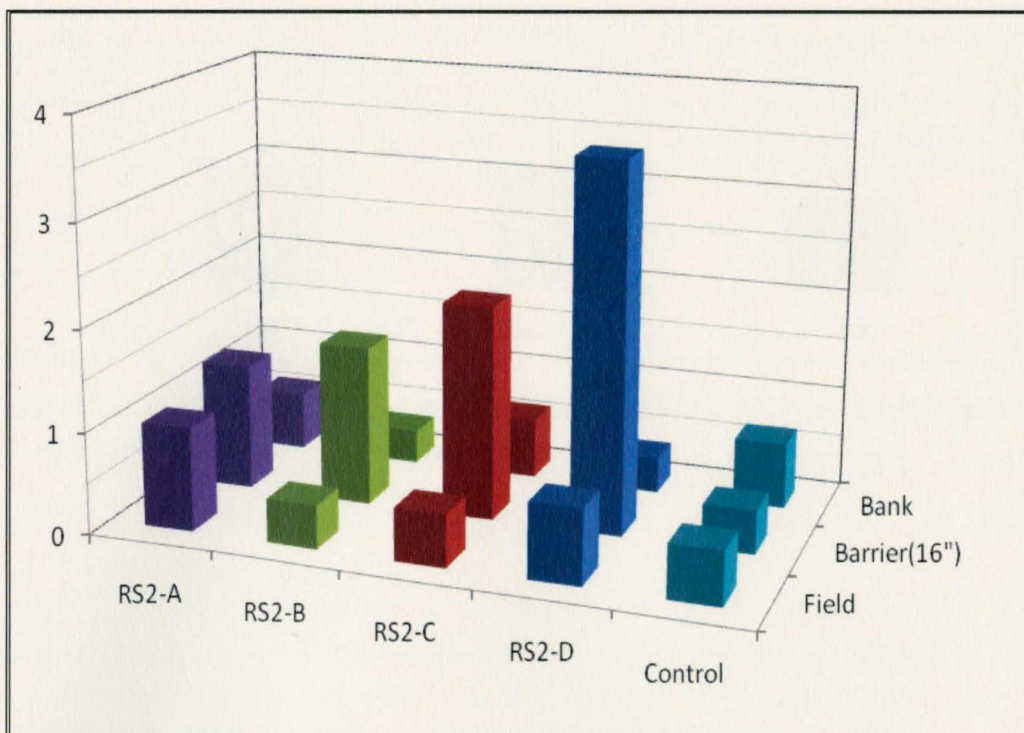


Figure 3.16: Concentration (mg/g) of total aluminum in the three kinds of vegetated sections; river birch (A), sycamore (B) and willow (C), and un-vegetated section (D) of RS2 study area and control area

3.2.3 Phosphorus

It can be expected that the concentration of phosphorus is decreasing with the bank elevation where the stream bank is stable. As shown in Figure 3.17 below, the amount of total soil P tends to be reduced significantly from field to bank in the study area ($p < 0.05$) but it is increased in the control area ($p > 0.05$, statistically not significant) (Figure 3.18). By this result, it can be assumed that the reactive barrier captured the soil TP when the field phosphorus went through the barrier.

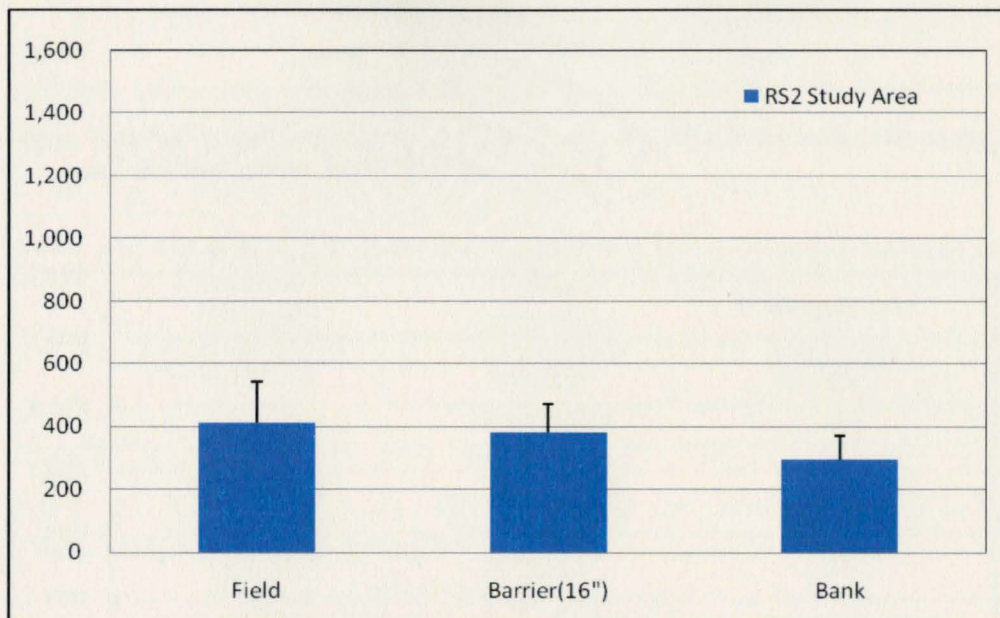


Figure 3.17: Concentration ($\mu\text{g/g}$) of soil total phosphorus (TP) in RS2 study area and control area (error bars indicate 95% confidence intervals).

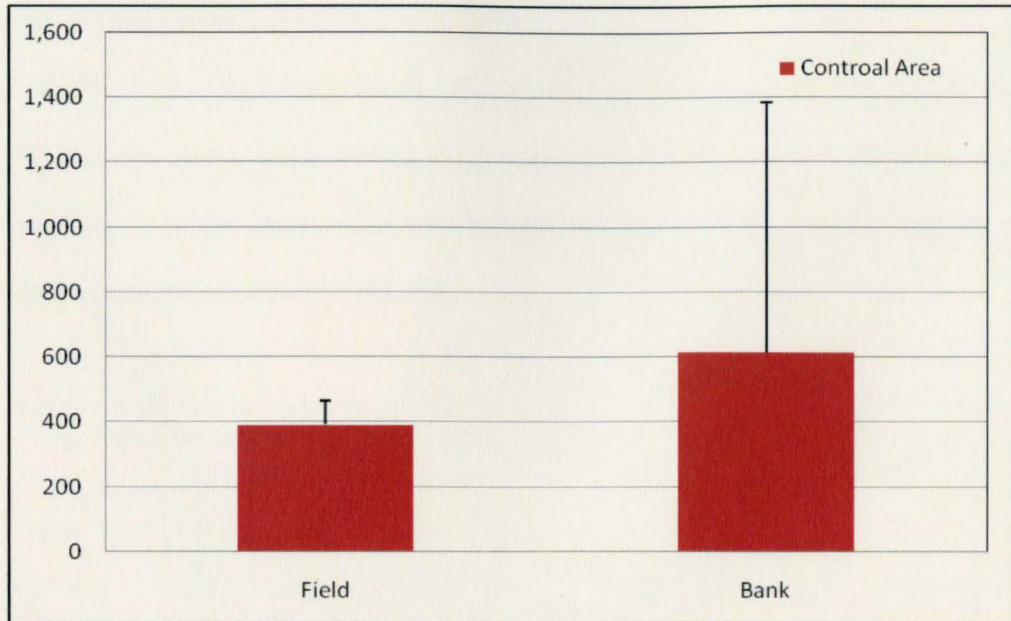


Figure 3.18: Soil TP concentrations ($\mu\text{g/g}$) in the field side and the lower bank in the control area (error bars indicate 95% confidence intervals)

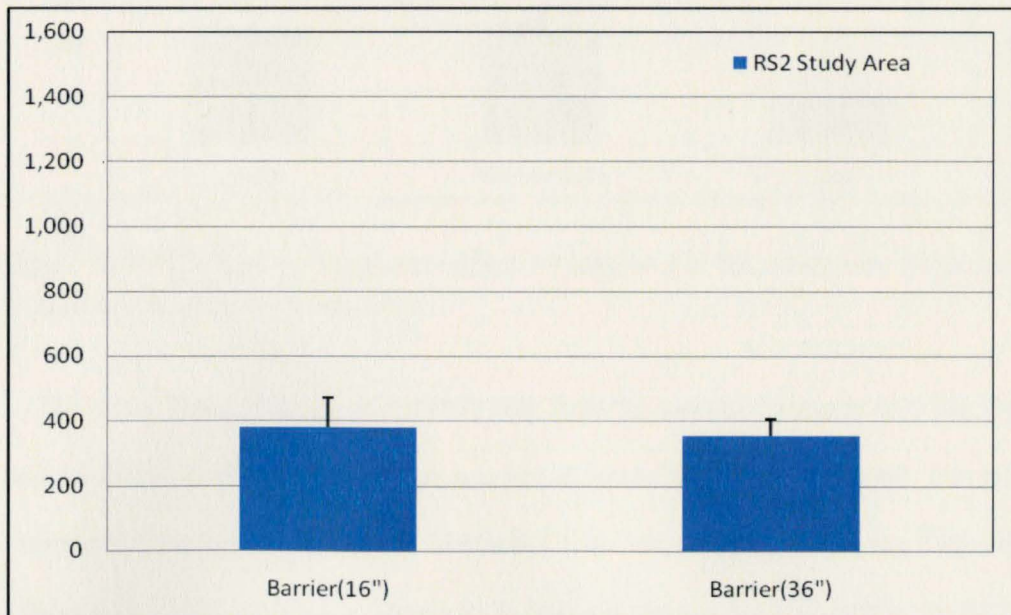


Figure 3.19: Concentration ($\mu\text{g/g}$) of soil total phosphorus (TP) in the two depths; 16 inches and 36 inches of the reactive barrier (error bars indicate 95% confidence intervals)

When we look at the concentrations of soil TP at two depths, 16 and 36 inches of the RS2 barrier, TP at the 16 inch depth is 0.03 mg/g higher than in 36 inches deep

barrier (statistically insignificant) (Figure 3.19).

Mehlich-3 P is the loosely bound, biologically available phosphorus in the soil. The result shows that Mehlich-3 P constitutes only 10 to 20 percent of TP in the soil, however, it is the major form of phosphorus needed to be reduced since it is bioavailable and causes eutrophication when it is present in excess.

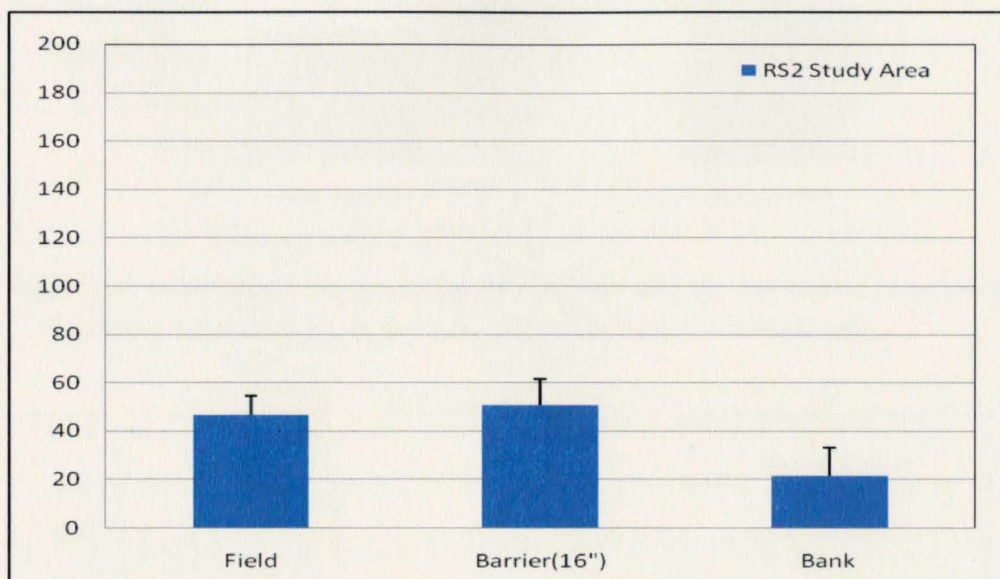


Figure 3.20: Concentration ($\mu\text{g/g}$) of Mehlich-3 Phosphorus in RS2 study area (Error bars indicate 95% Confidence Intervals)

The mean of Mehlich-3 P of the field side from the reactive barrier is 0.05 mg P/g soil as shown in Figure 3.20 and it is a lower value than it was expected, but still maintaining the optimum range of Mehlich-3 P for crop growth; 45-50 mg P/kg soil (Sims, J.T., 2000). Mehlich-3 P tends to be reduced through the RS2 barrier ($p < 0.05$) (Figure 3.20).

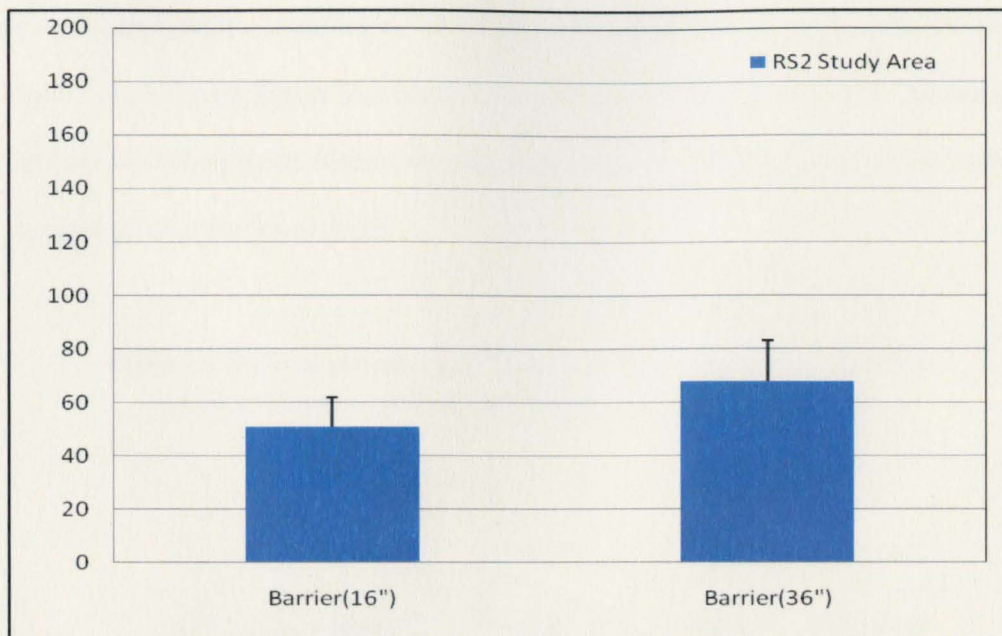


Figure 3.21: Concentration ($\mu\text{g/g}$) of Mehlich-3 phosphorus in the two depths; 16 inches and 36 inches of the reactive barrier (error bars indicate 95% confidence intervals)

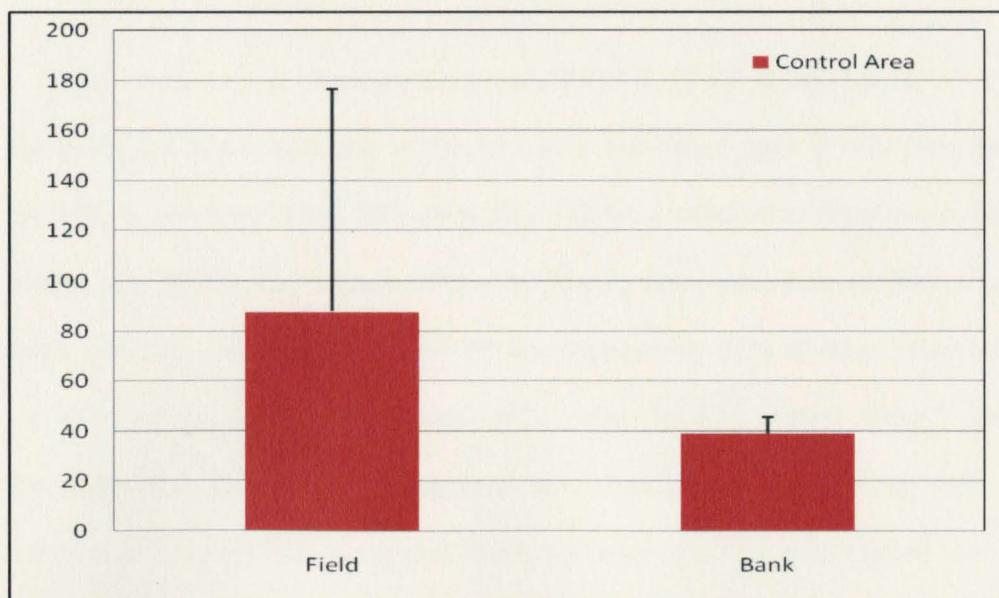


Figure 3.22: Soil Mehlich-3 P concentrations ($\mu\text{g/g}$) in the field side and the lower bank in the control area (error bars indicate 95% confidence intervals)

Mehlich-3 phosphorus was reduced from the field to the bank in the control area as well, but the range of the 95% confident interval is very wide and therefore more data

is needed to draw a conclusion. The results show that Mehlich-3 P at the 36 inch depth is 0.017 mg/g higher than at the 16 inch depth barrier (Figure 3.21). The results indicate that leaching of Mehlich-3 phosphorus may be occurring causing the higher concentration at the lower depth.

Table 3.2: Soil total phosphorus (TP) and Mehlich-3 phosphorus reductions in reactive stream stabilization (RS2) structure (mean $\pm$ 95% C.I.)

	TP (mg/g)		Mehlich-3 P (mg/g)	
	RS2	Control	RS2	Control
Field	0.41 $\pm$ 0.13	0.39 $\pm$ 0.07	0.05 $\pm$ 0.01	0.09 $\pm$ 0.09
Bank	0.30 $\pm$ 0.08	0.62 $\pm$ 0.78	0.02 $\pm$ 0.01	0.04 $\pm$ 0.01
Reduction (%)	30	+ 58	55	55

Table 3.2 shows mean concentrations with 95% C.I. of soil TP and Mehlich-3 P in the field side and the bank side of the test barrier and percentages of reductions from the field to the bank in the RS2 study area and the control area. Through the RS2 barrier, soil TP was significantly reduced by 30% of mean value from the field to the bank, however, concentration of soil TP was increased by 58% of mean value from the field to the bank in the control area where the RS2 barrier doesn't exist. Concentrations of Mehlich-3 phosphorus were significantly decreased by 55% of mean value from the field to the bank in the RS2 study area and in the control area as well. The sample size of the control area was not enough to confidently represent mean concentration of phosphorus since the range of 95% C.I. is too wide, therefore more samples in the control area are needed in the following research.

3.2.4 Nitrogen

5 months after installation, the TN was reduced through the RS2 but not at a statistically significant level (Figure 3.23).

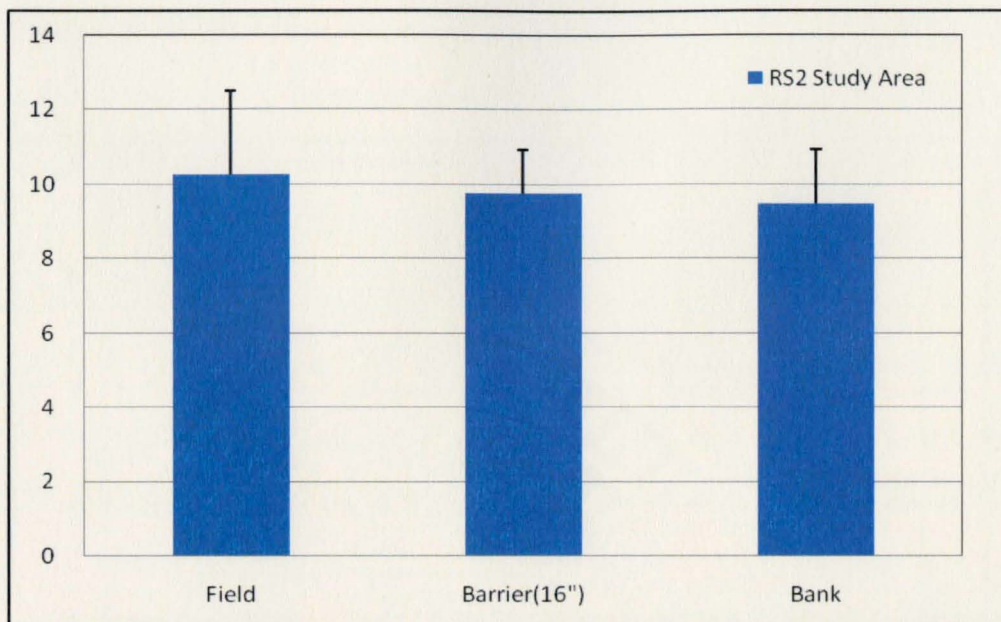


Figure 3.23: Concentration (mg/g) of soil total nitrogen (TN) in RS2 study area (error bars indicate 95% confidence intervals)

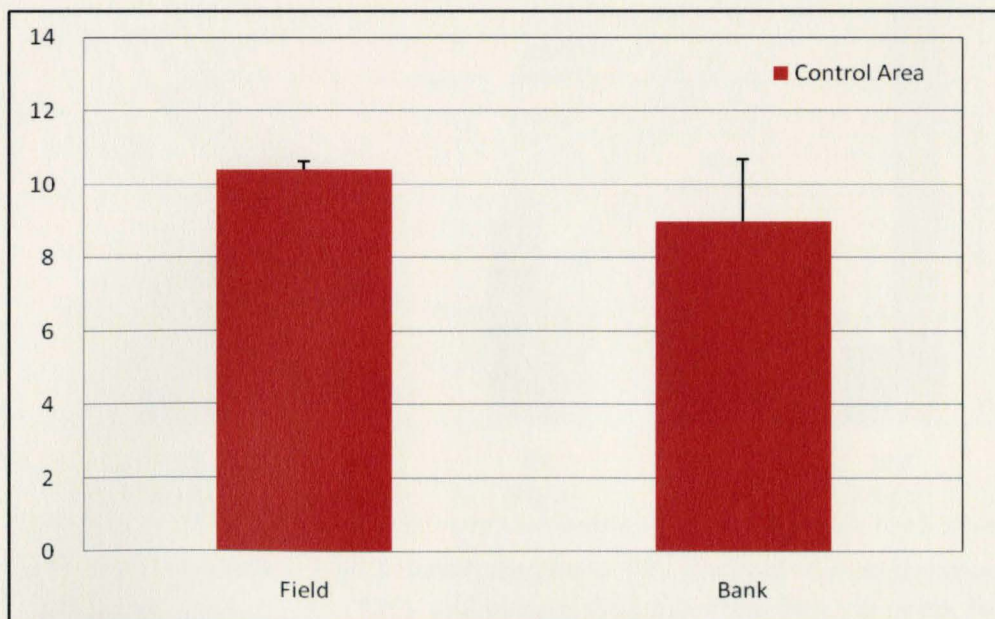


Figure 3.24: Soil TN concentrations (mg/g) in the field side and the lower bank in the control area (error bars indicate 95% confidence intervals)

3.2.5 Water Concentrations

Concentrations of TP, DRP, TN, NO₃⁻ and TOC were determined for the water samples collected from monitoring wells and the stream. The results are shown in Figure 3.25 through 3.28.

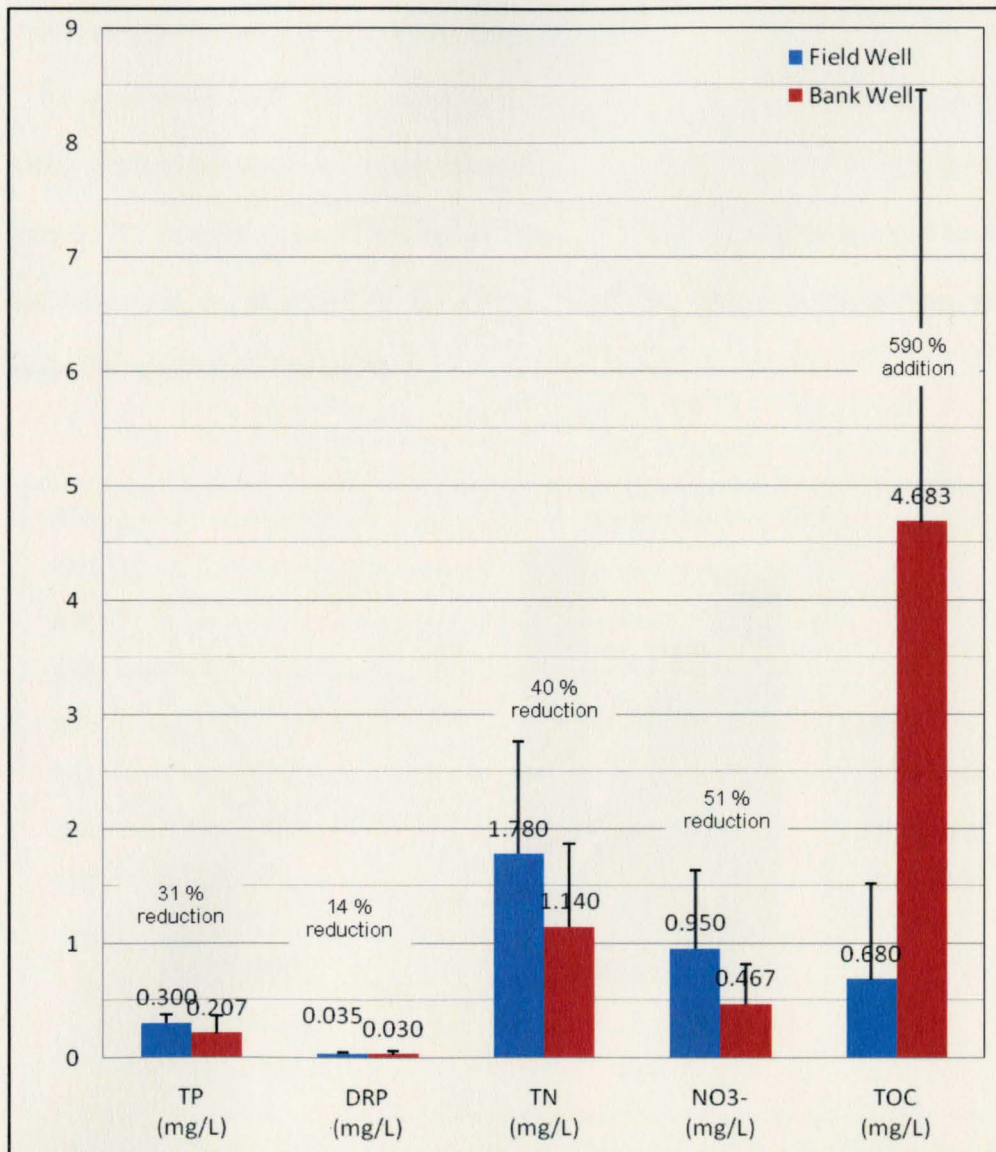


Figure 3.25: Concentration (mg/L) of total phosphorus (TP), dissolved reactive phosphorus (DRP), total organic carbon (TOC), total nitrogen (TN) and nitrate (NO₃⁻) in waters from monitoring wells (concentrations of DRP are very close to the MDL, 0.03mg/L) (error bars indicate 95% confidence intervals)

The TOC concentration across the reactive barrier is significantly higher than the field area. From Figure 3.25, the concentration of TOC in the bank well is 590% greater than the TOC in the field well. TN and nitrate (NO_3^-) concentrations showed reductions of 40 and 51% through the reactive barrier, respectively. These results support one of the key design objectives of the RS2 structure, the addition of electron donating organic matter in the reactive zone.

However water DRP reductions is low at 14% respectively as shown in Figure 3.25 while soil TP and Mehlich-3 P are reduced by respectively 30% and 55% across the barrier. The possible cause of the lower reduction in water phosphorus could be that the bank could be influenced by the stream. Phosphate deposition on the bank may occur during stream flood events.

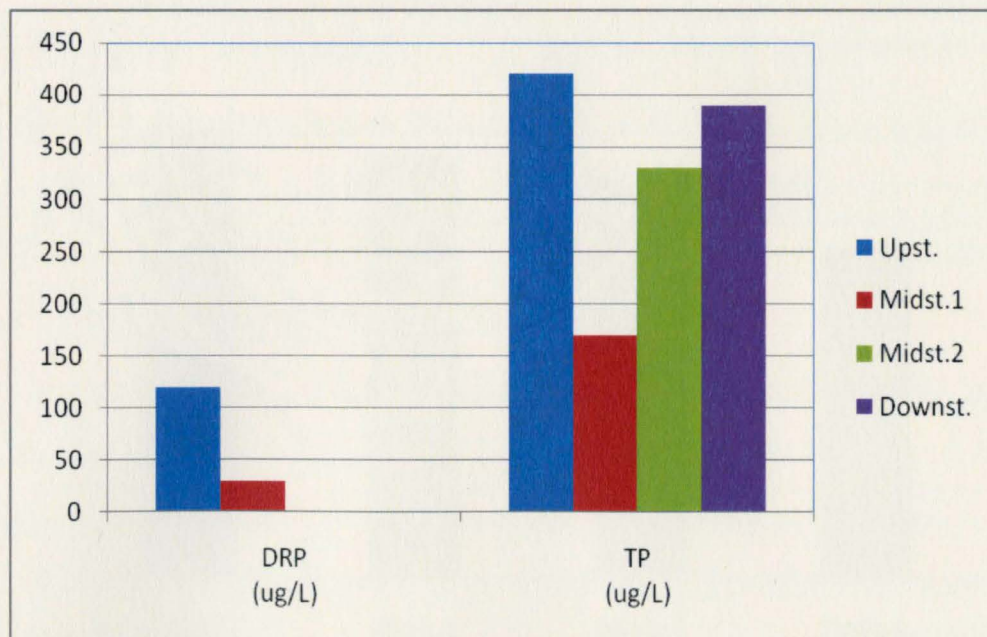


Figure 3.26: Concentration ($\mu\text{g/L}$) of total phosphorus (TP) and dissolved reactive phosphorus (DRP) in stream (DRP concentrations of mid-stream2 and downstream are below MDL, 0.03mg/L)

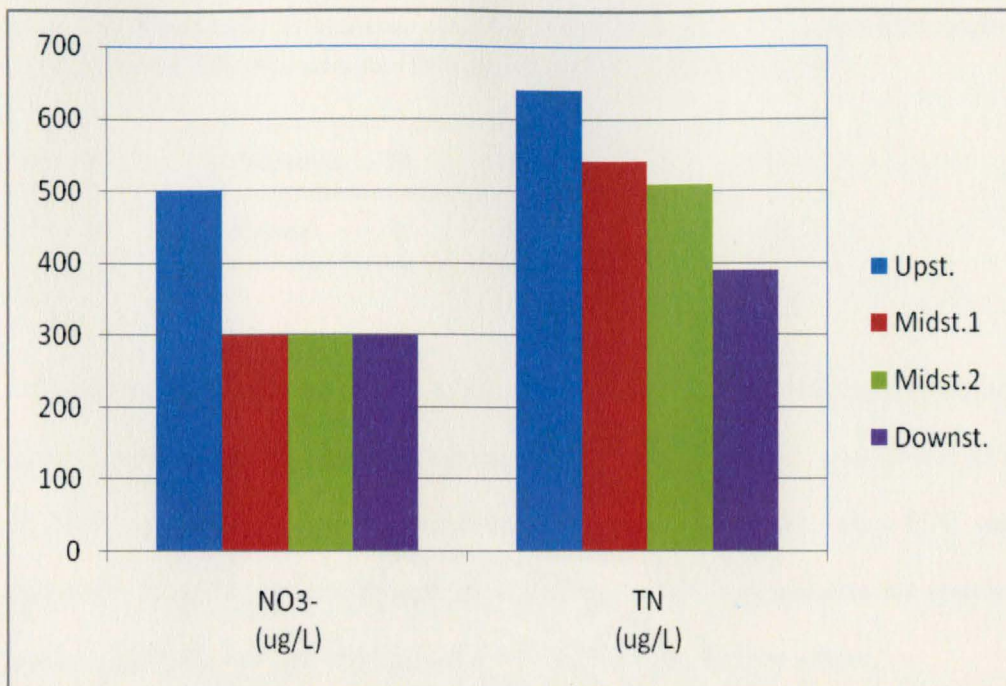


Figure 3.27: Concentration (µg/L) of total nitrogen (TN) and nitrate (NO₃⁻) in stream

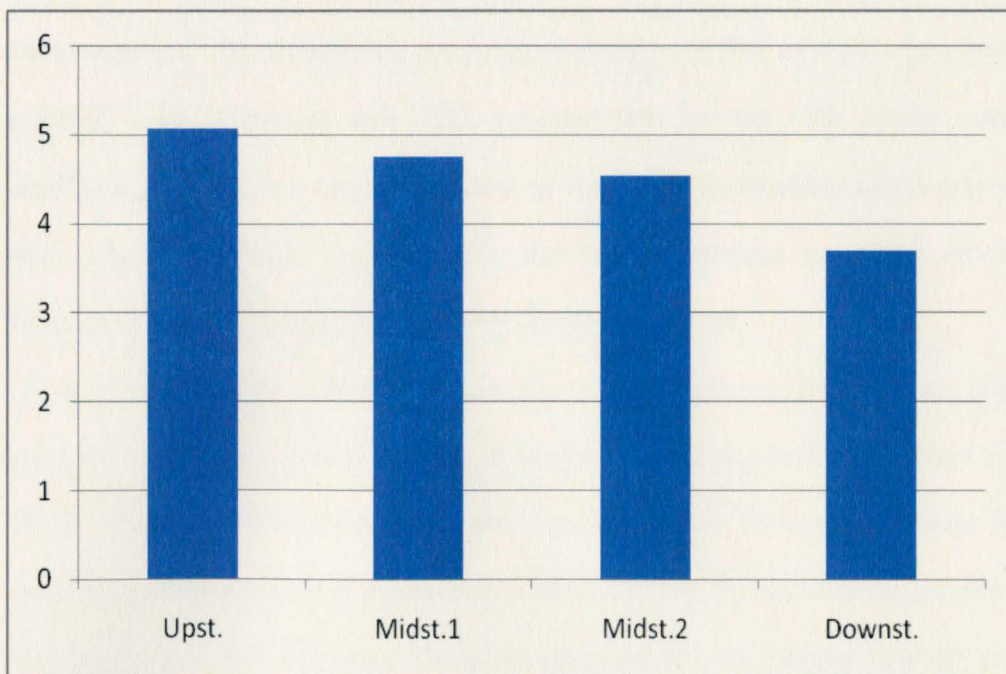


Figure 3.28: Concentration (mg/L) of total organic carbon (TOC) in stream

Table 3.3: Percentages of nutrients reduction; Total phosphorus (TP), dissolved reactive phosphorus (DRP), total nitrogen (TN) and nitrate (NO₃⁻) along the stream

% Reduction	TP	DRP	TN	NO ₃ ⁻
Stream	7	83	39	40

Nutrients tend to be decreased while they are going down through the stream ($p>0.05$, statistically not significant) (Figure 3.8, Table 3.2). And it is noted that 83% of DRP was removed from the upstream to the middle stream. Also TOC was decreased along the stream although large amount of TOC was added to the reactive barrier. Therefore it is clear that the added TOC does not affect the stream.

In this chapter, construction, design objectives and effectiveness of nutrient removal were evaluated. The construction and design objectives of RS2 appear to have been satisfied since aluminum and TOC concentrations in the RS2 barrier were significantly higher than surrounding area ($p<0.05$). The preliminary monitoring of nutrient-removal-efficiency of the RS2 barrier has provided promising results although more study is needed to draw significant conclusions.

Cost-effectiveness of nutrient removal, along with removal-efficiency are both important factors for selecting BMPs to achieve TMDL regulations. To meet the TMDL regulation, both point source and non-point source nutrient loads must be considered. Point source load reduction is attained by WWTPs and BMPs are used for non-point source load reduction. Therefore, cost comparisons between WWTPs and BMPs, are necessary to choose an effective method. Value of P-removal versus cost will be discussed in chapter 4.

CHAPTER 4

COST OF NUTRIENT REMOVAL

The control of nutrients is a major issue in water resource projects. Nutrient rich, oxygen-starved dead zones in coastal Louisiana have been of increasing interest to those concerned about Gulf of Mexico fisheries. Dodds et al. (2008) have concluded that at least \$4 billion is lost annually as a result of degradation of freshwater resources in the U.S., thus focusing the necessity to control nutrients on inland waters as well as coastal resources. Over the past years the Reactive Stream Stabilization (RS2) concept has been developed with the goal of establishing bank stabilization and RS2 as best management practices (BMPs) for nutrient control. In this chapter, the cost benefit of removing P from the river is estimated.

4.1 Cost of Nutrient Removal

The following examples of nutrient removal projects are provided from the available literature to focus on costs of nutrient removal. These values will allow reasonable comparison of the developing RS2 versus other projects.

4.1.1 Everglades Nutrient Removal Project

The Everglades is situated in a shallow limestone depression that has gradually filled in with organic material and sediments over the last 4500-5000 years.

Historically, rainfall provided the primary source of nutrients in the Everglades. In recent decades, however, increasing volumes of phosphorous enriched water have

been pumped into the Everglades upsetting the system's natural balance. This water is coming largely from the 718,000 acre Everglades agricultural area, north and west of the area. The Everglades Nutrient Removal Project (ENRP), a 1,544 ha constructed wetland, is designed to operate as a flow-through treatment system to reduce phosphorus levels in agricultural runoff/drainage that currently enters the Everglades. The ENRP site is located 25km west of the city of West Palm Beach. The land was previously farmed for sugar cane, corn and rice. A portion of the runoff/drainage that originates in the Everglades agricultural area drainage basin is being diverted from the West Palm Beach canal into the ENR. The ENR is built on former cropland and is divided into five cells; a Buffer Cell (55 ha), Flow-way Cell 1 (525 ha), Flow-way Cell 2 (414 ha), Polishing Cell 3 (404 ha), and Polishing Cell 4 (146 ha). Construction was completed and the site was flooded in September 1993, however, release of treated water did not begin until August 1994 when an operating permit was granted by the EPA. The Buffer Cell distributes inflow to two independent, parallel treatment trains (Cells 1&3 and 2&4). Cell 1 and Cell 2 are naturally revegetated cattail marshes where most of the phosphorus removal is expected to occur. Cell 3 (a planted mixed marsh) and Cell 4 (a periphyton/submerged macrophyte community) are polishing cells for final reduction of phosphorus levels. Since flow-through operation began, 7,186 ha-m of water has passed through the system. Initial observations indicate that the outflow total phosphorus concentrations, on average, have been about five times lower than the inflow concentrations (ca. 100 to 200 mg /L). The project resulted in 66 tons of phosphorus removal over a 5-year period with the average cost of **\$106/lbs P-removed**.

4.1.2 Spring Lake P-removal Project

Spring Lake, Michigan is a eutrophic, submerged river mouth lake that drains into the Grand River about 1km upstream from Lake Michigan. Spring Lake has some of the highest phosphorus concentrations in western Michigan. For example, the USEPA has set a TP water quality goal of 15 ppb for the western Michigan ecoregion (USEPA 2000). However, during ice-free periods from 1999 through 2002, TP concentrations in Spring Lake averaged 100 ppb, and ranged from 6 to 631 ppb (Progressive AE 2002), far in excess of USEPA standards. Given the high phosphorus concentrations in the lake, and especially the high concentrations measured near the sediment layer during summer months, it was believed that internal loading may be an important process in Spring Lake. As a consequence, research was conducted in 2003 by AWRI to evaluate the importance of internal loading and the effectiveness of alum in reducing internal loading in Spring Lake, Michigan. The result from investigations indicated that internal loading accounted for between 55 and 65% of the total phosphorus entering the lake water column on an annual basis and that an alum application of 24 mg aluminum/L was extremely effective at reducing TP release from the sediments (Steinman et al. 2003, 2004), but P release rates were no different at alum concentrations of 15 mg alum/L than at concentrations of 25 mg/L in a 2004 study.

A whole-lake alum treatment was applied to eutrophic Spring Lake during October and November 2005. Eight months later, an ecological assessment of the lake was performed and compared with data collected in 2003 and 2004. Field measurements showed reduced soluble reactive phosphorus (SRP) and total phosphorus (TP) concentrations in the water column the summer after the alum application, but chlorophyll levels and irradiance profiles were not significantly affected. Total

macroinvertebrate density declined significantly in 2006 compared with 2004, with chaoborids and oligochaetes experiencing the greatest reductions.

Internal phosphorus release rates, measured using sediment cores incubated in the laboratory, ranged from 0.052 to 0.877 mg TP/m²-d under anaerobic conditions. These internal loading rates were significantly lower than those measured in 2003 at three out of four sites. Mean porewater SRP concentrations were lower in 2006 than in 2003 and the P fraction in the sediment was also significantly lower in 2006 compared with 2003. Overall, these results indicate that the alum treatment effectively reduced internal P loading in Spring Lake. However, water column phosphorus concentrations remain high in this system, presumably due to high external loading levels, and may account for the high chlorophyll levels. An integrated watershed management approach that includes reducing internal and external inputs of P is necessary to address the cultural eutrophication of Spring Lake.

The Spring Lake Board paid \$1.3 million to pump more than 1 million gallons of aluminum sulfate, or alum, into much of the 1,298-acre lake in late 2005. The treatment was aimed at reducing the amount of phosphorus in the lake, which fueled massive algae blooms that made the water's surface look like it was covered with bright green paint. In the two summers since the alum treatment, there have been no major algae blooms on the lake, water clarity has improved and phosphorus concentrations have dropped by more than 50 percent. The external phosphorus loading, including loading estimates from tributaries, atmosphere, stormwater, septic systems, waterfowl, and lawn fertilizer, was estimated by Lauber in 1999. Internal load (based on estimates from the current study) accounted for 56% (low), 66% (medium), or 62% (high) of the total phosphorus load to Spring Lake. The average

total phosphorus loading was estimated at 9 tons/yr, and the cost of the project to remove 50% of phosphorus was calculated as **\$131/lbs P-removed**.

4.1.3 Onondaga Lake Improvement Project

Onondaga Lake is located along the northern side of the City of Syracuse in Onondaga County, New York. The lake covers an area of 4.6 square miles (11.9 square kilometers). The lake receives water from a drainage basin of 248 square miles (648 square kilometers), located almost entirely within Onondaga County. Onondaga Lake was one of the most polluted lakes in the United States. The lake has had a number of domestic and industrial pollution problems relating to population growth and industrialization in Syracuse over the last century and when the Amended Consent Judgment was drafted, the Metropolitan Syracuse Wastewater Treatment Plant was considered to be a major source of phosphorus to the lake. The Onondaga County Department of Water Environment Protection implemented a pilot project in 2000 to evaluate phosphorus treatment technologies. The pilot project concluded that high-rate flocculated settling could reduce phosphorus in Metro's discharge to levels of 0.12mg/L as a 12-month rolling average. The full-scale phosphorus treatment facility was completed in 2004 and by 2012 Onondaga County must reduce the phosphorus discharges to 0.02mg/L, a result they will achieve with the addition of tertiary treatment (filtration).

The construction of the plant upgrade was completed at a cost of \$130 million. Upon completion of the METRO improvements, effluent ammonia concentrations have been reduced to less than 2 mg/L during cold weather operating conditions and effluent phosphorus concentrations have been reduced from approximately 0.6mg/L to less than 0.12mg/L

The total project capital cost was \$128,313,664 and the high rate flocculated settling (HRFS) for phosphorus removal O&M cost was \$3,821,000/year, therefore the total annual economic cost (TAEC) is \$15 million by using an equation below.

$$TACE = Cca * CRF + Ca$$

Where Cca is the capital cost, Ca is the annualized O&M cost, and CRF is the capital recovery factor, which is calculated by the following relation (Tsagarakis et al, 2003), $CRF = r(1+r)^t / (1+r)^t - 1$ where r is the Opportunity Cost of Capital (OCC); and t is the economic life. For WWTP facilities, the economic life is generally taken to be 20years and the CRF is 8.72% when the OCC is equal to 6% (Tsagarakis et al, 2003). The plant treats an average monthly flow of 84 million gallons per day which takes influent phosphorus of 0.75 mg/L per day and brings it down to 0.12mg/L per day that reduces phosphorus of 73 tons per year. From the estimate of the TAEC above, the unit cost of TP removal was **\$93/lbs P-removed**.

4.1.4 Ozark Stream

Algal blooms occurred frequently in Ozark streams due to urbanization that accelerated stream bank erosion. The City of Springfield (MO) and Greene County completed a project to restore degraded streams by removing drainage tunnels and reconstructing the stream corridor. In the 1990s, the James River Arm of Table Rock Lake in Missouri had frequent algal bloom events. In response, the Table Rock Lake Water Quality, Inc was formed and instrumental in formalizing and implementing a plan to improve the quality of the James River. TMDL values of 0.075 mg/L of P and 1.5 mg/L in-stream TN were approved in May, 2001 and BMPs including riparian corridor restoration and septic tank cleanouts were performed to meet the non-point

source goals. For point source pollution, the City of Springfield Southwest Treatment Plant reduced the average P discharge to 0.5 mg/L.

By the Ward Branch Study, it was estimated that the erosion would liberate 93lbs of P per 1,000 feet of channel per year and the TP load in the stream was 175 lbs that was 53 percent of the P load in the stream. Therefore a 100-foot wide buffer with woody vegetation for the first 50 feet next to the stream and a 50 foot grass filter outside the woody area were used for the bank erosion, and it yielded 50 percent removal efficiency. \$15,000 was estimated for an average installation cost including 3-5gallon tree, shrubs, native grass seeding, erosion control, and grading and it indicates that a 100-foot wide grass and tree buffer would cost \$20 per linear foot to install and an additional \$140 per linear foot to maintain for a 50 year period. The amount of P removed during the 50 year design life was estimated at 0.58 lbs per foot of buffer, and the cost efficiency was calculated at **\$278/lbs P**. For stream stabilization using geomorphic and bioengineering approaches, the cost of \$269 per linear foot was estimated and the cost efficiency was **\$188 /lbs P** annually for a 50-year cycle which is the most cost-effective methods of preventing phosphorus from entering lake as shown in this study. The cost of the projects of non-point source phosphorus control is higher than point source control projects as shown in Table 4.1.

Table 4.1: Cost of projects.

Project (Used method)		Cost (\$/lbs P-removed)
Natural Removal	Everglades (Wetlands)	106.06
	Spring Lake (Alum)	131.13
WWTPs	Onondaga WWTP (HRFS)	93.4
Combination	Ozark Stream (A/S & Alum + BMP)	205.3 (avg.)

4.2 Estimation of Costs of Phosphorus Removal in Waste Water Treatment Facilities

The marginal costs were estimated for the installation of phosphorus removal in point source wastewater treatment plants (WWTP), in five different plant capacities, from 1million gallons per day (MGD) to 100 MGD, and three strategies, basic Activated Sludge (AS) process with chemical addition, anoxic/oxic (A/O) arrangement of the AS process, and the anaerobic/aerobic/oxic (A/A/O) arrangement of the AS process (Jiang et al, 2005). The effluent concentrations from the plants were limited to 2.0 mg/L, 1.0 mg/L, 0.5 mg/L, 0.13 mg/L, and 0.05 mg/L, and additional unit processes, such as a clarifiers, sand filters, or ultra-filters were added to achieve the lower effluent concentrations by removing particulate matter from the effluent and hence remove the adsorbed phosphorus.

The costs of upgrading a facility included both a capital cost and an operations and maintenance (O&M) cost estimated using the algorithm of EPA (1998) including component costs for energy, chemical, sludge disposal, labor, maintenance, and insurance. The amounts of labor are estimated from Estimating Water Treatment Costs (USEPA, 1979), and maintenance and insurance are estimated according to Detailed Costing Document for the Centralized Wastewater Treatment Industry (USEPA, 1998). The total construction costs are divided into eight components; excavation and site work, manufactured equipment, concrete, steel, labor, piping and valves, electrical equipment and instrumentation, and housing.

The Total Annual Economic Cost is the sum of the annualized capital cost and the annualized O&M costs (Tsarakis et al, 2003) as the equation shown in the cost of Onondaga WWTP project. To achieve an effluent TP limit of 2mg/L, a set of alum feed equipment added to the basic AS design with a fiber-glass reinforced polymer

(FRP) tank with 15 days of storage. Compared with the A/O and A/A/O configurations, the AS + Al process appears more economical, since the incremental TAEC and the unit cost of TP removal are only 30 to 50 percent of those of two alternatives (Table 4.2). To meet the TP limit of 1mg/L, more alum is needed in the AS + Al design. For the A/O and A/A/O alternatives, some alum is also needed in order to lower the effluent TP concentration. The unit costs of TP removal in the three configurations decreased with the plant capacity, and the cost difference between the A/O and A/A/O configurations diminished quickly as the plant capacity increases and becomes almost negligible when the plant capacity approaches 100 MGD. When the effluent TP is to be lower than 0.5 mg/L, more alum is added and a regular sand filter is installed to further remove solids with a rapid mixing and flocculation tank for the addition of polymer, wash-water storage tank (WWST), filter backwash pumping facilities, and a wash-water surge basin. The filter must be backwashed when the solids retained within it exceed a threshold (Qasim et al, 2000). The cost of the AS + Al + F configuration are the lowest of three options, although the difference nearly disappears as plant capacity increases. More alum is needed to attain an effluent TP limit of 0.13mg/L, and the A/O + Al + F design becomes the lowest, as a result of the lower chemical and energy consumption and lower amounts of labor required as the plant capacity rises above 10 MGD. To attain the effluent TP below 0.05mg/L, ultra-filtration with an additional clarifier for sedimentation of the alum sludge is adopted in all three configurations to reduce the effluent total suspended solid concentrations to below 1mg/L.

Table 4.2: Unit cost of phosphorus removal (\$/lbs TP).

Capacity (MGD)	1	10	20	50	100
Effluent 2mg TP/L					
AS +Al	14.0	4.6	4.1	3.7	3.6
A/O	27.8	12.4	10.6	9.2	8.5
A/A/O	33.0	13.2	11.1	9.4	8.9
Effluent 1mg TP/L					
AS +Al	12.9	6.8	6.4	6.1	6.0
A/O +Al	30.9	16.1	14.3	12.9	12.2
A/A/O +Al	39.5	17.1	15.0	13.2	12.5
Effluent 0.5mg TP/L					
AS +Al +F	88.6	32.5	27.9	25.4	24.8
A/O +Al +F	107.7	39.7	34.0	30.4	29.3
A/A/O +Al +F	122.3	40.5	34.5	30.5	29.6
Effluent 0.13mg TP/L					
AS +Al +F	113.6	62.7	58.6	56.8	55.9
A/O +Al +F	121.8	59.1	53.6	50.5	49.5
A/A/O +Al +F	125.9	59.5	54.1	50.5	50.0
Effluent 0.05mg TP/L					
AS +Al +S +F +UF	175.9	90.9	83.2	75.9	73.6
A/O +S +Al +F +UF	189.1	94.1	85.0	76.8	74.1
A/A/O +Al +S +F +UF	192.3	93.6	84.5	76.4	73.6

From Table 4.2, AS + Al is the most economical option when TP targets are between 0.5 and 2.0 mg/L. However, when the TP target is less than 0.13mg/L, the AS + Al + F design is the most economical for a small plant that has a 1 MGD capacity although A/A/O + Al + F processes are more cost-effective when the plants have

bigger capacities than 10MGD. For a TP target of 0.05mg/L, the AS + Al + S + F + UF process is just a little bit more economical than the other alternatives.

4.3 Estimation of Costs of Phosphorus Removal by Best Management Practice

Selection of Implementation Strategies/Alternatives

The reduction of phosphorus entering Spring Lake of 3,035 lbs/yr was estimated assuming the implementation of the recommended practices below. The costs of these BMPs are also shown in Table 4.3.

Table 4.3: Cost of BMPs (Source: Spring Lake Watershed Plan, Spring Lake Watershed Committee, July 2008).

Practice		Unit Cost (\$)	Total Cost (\$)	P-removed (lb/yr)	Cost of P-removed* (\$/lb)
Gully and megarill erosion control					
WASCOB**	50 structures	1,800	90,000	400	23
Grade stabilization (GS)	20 structures	4,500	90,000	20	450
Diversions	40 structures	1,100	44,000	40	110
Stream bank stabilization					
Streambank stabilization (SBS)	5,000 ft	30	150,000	281	53
Forested gully erosion control					
Grade stabilization /Brush checks	25 structures	700	17,500	50	35
Cropland sheet and rill erosion control					
Terrace -underground outlet	20,000 ft	3	60,000	240	25
Grassed waterway	2,000 ft		3,000	4	75
Conversion to no-till	2,000 acres	30	60,000	2000	6
Total			454,500	3,035	Average 107

* Project cost per lbs of phosphorus removed over a 10-year lifespan except conversion to no-till is over a 5-year lifespan

** Water and sediments control basins (WASCOB)

To meet the TMDL regulation, phosphorus load should be reduced by treating point source through WWTPs or by decreasing non-point source load through BMPs. For selecting a P treatment method between WWTP and BMP, cost is the most important factor that should be evaluated. 0.5mg/L WWTP effluent concentration was chosen to be compared with BMP cost (Figure 4.1). P removal costs in BMPs, and 1 and 10 MGD WWTPs were not significantly different ($p>0.05$), but when costs of 1 MGD WWTPs and BMPs except the highest costs for both were compared, the costs of BMPs were much lower than WWTPs and the cost difference were significant ($p<0.05$).

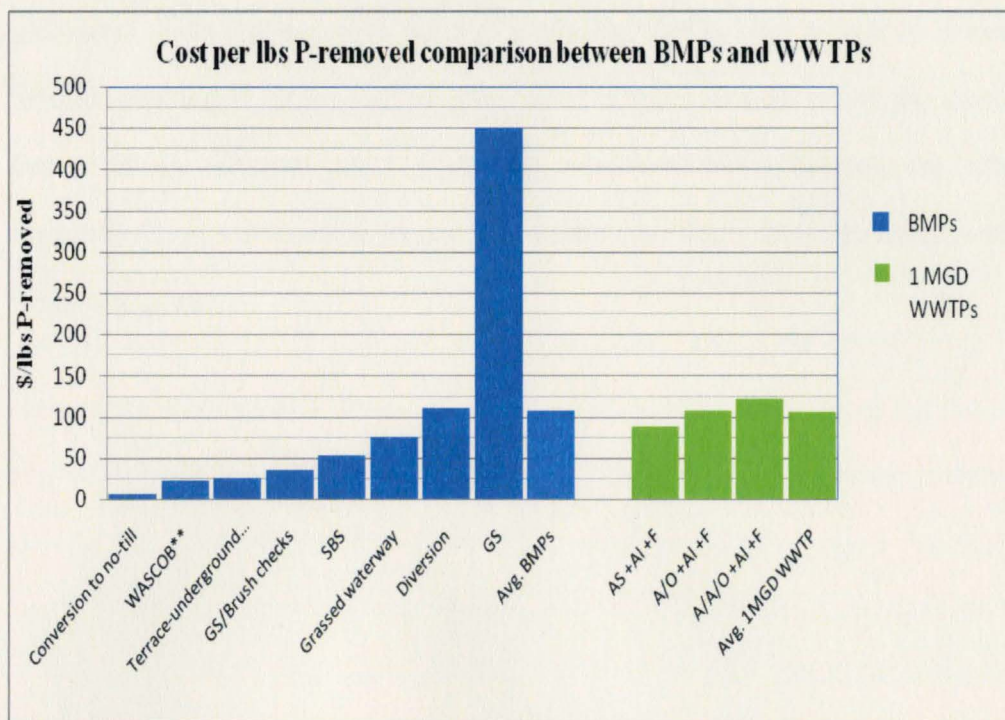


Figure 4.1: P removal cost comparison between BMPs, and 1 MGD WWTPs (0.5mgP/L effluent concentration) (\$/lbs P-removed)

For the RS2 construction, total cost including alum, mulch, labor and equipment was \$3,680. From the study of P absorption capacity of water treatment residual

(WTR), 1750 mmol P/kg WTR adsorption capacity was estimated (Haustein, G.K., 2000). From the adsorption capacity, the P-removal cost of RS2 can be calculated as **\$1.8/lbs P** (see Appendix 2 for the calculation). However, it should be emphasized that the installation was a prototype and expenses would be expected to increase when done with equipment that would allow larger scale installations.

From Table 4.1 and Figure 4.1, it was found that the P-removal costs of BMPs and WWTPs were around \$100/lbs P-removed, and not significantly different. However, the cost range of P-removal among the BMPs was wide from \$1.8/lbs P to \$450/lbs P. In this range, RS2 was ranked first as the lowest P-removal cost based on very preliminary information. From the result, RS2 has shown that it may be a cost-effective method to remove non-point source P which satisfies one of the two crucial factors of an effective BMP. While the nutrient-removal-efficiency, the other important factor, examined in chapter 3, has shown positive results, the study is still very preliminary.

CHAPTER 5
SUMMARY OF NUTRIENT REMOVAL IN MISSISSIPPI WATERSHEDS
AND FUTURE WORK

Soil P losses from agriculture are one of the biggest sources of eutrophication in surface waters and P losses through subsurface flow are significant as surface P losses and cannot be ignored (Turner and Haygarth, 2000). For BMP selection, the two most important factors are effectiveness and cost. The Reactive Stream Stabilization (RS2) structure was developed to stabilize the stream bank, and remove N and prevent subsurface P losses from agricultural lands. As it was designed, soils in the reactive barrier contain substantially greater amount of aluminum than the surrounding area and high concentrations of TOC for denitrification. Expected concerns of P accumulation in the barrier and influences of the added TOC on the stream cannot be observed from this research. At this point, P and N reductions are not as high as the results of previous field tests at CSU but it is still considerable. From this research, the design objectives of RS2 have been achieved and we expect continued improvement in removal efficacy. Therefore, RS2 should be seen as an important P load reduction BMP. The cost information provided in this report can be used to provide a value of the stream stabilization with respect to other non-point source P reduction strategies. Further research will be conducted to quantify the effectiveness and value of reactive stream stabilization for meeting the non-point source component of current and future TMDL regulations.

CHAPTER 6

REFERENCES

- Beckett, R. and Hart, B. T. (1993) *Use of field flow fractionation technique to characterize aquatic particles, colloids, and macromolecules*. In: Buffle, J. and van Leeuwen, H. P. (eds) *Environmental Particles*, IUPAC Analytical Chemistry Division, Lewis Press, New York, pp 165-205.
- Bennett, E. M., Carpenter, S. R., and Caraco, N. F. (2001) *Human impact on erodible phosphorus and eutrophication: A global perspective*. *BioScience* 51: 227-234
- Biswas, B. K. et al. (2008) *Removal and recovery of phosphorus from water by means of adsorption onto orange waste gel loaded with zirconium*. *Technol.* 99, 8685-8690.
- Breeuwsma, A., Rijerink, J. G. A., and Schoumans, O. F. (1995) *Impact of manure on accumulation and leaching of phosphate in areas of intensive livestock farming*. p.239-249. In: Steele, K. (eds) *Animal waste and the land-water interface*, Lewis Publishers-CRC Press, NY
- Brown, R. E. (2007) *Onondaga County's "State of the Art" Ammonia and Phosphorus Removal Project at the Metropolitan Syracuse WWTP*. Department of Water Environment Protection, Onondaga County, New York.
- Burkholder, J. M., Noga, E. J., Hobbs, C. W., Glasgow, H. B. Jr. and Smith, S. A. (1992) *New 'phantom' dinoflagellate is the causative agent of major estuarine fish kills*. *Nature* 358: 407-410
- Busman, L., Lamb, J., Randall, G., Rehm, G., and Schmitt, M. (2002) *The Nature of Phosphorus in Soils, Phosphorus in the Agricultural Environment*, University of Minnesota
- Carpenter, S. R. (2008) *Proc. Natl. Acad. Sci. USA* 105: 11039-11040
- Carpenter, S. R., (2005) *Eutrophication of aquatic ecosystems; Bistability and soil phosphorus*. *Natl. Acad. Sci. USA* 102: 10002-10005
- Carpenter, S. R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N. and Smith, V. H. (1998) *Ecol. Appl.* 8: 559-568
- CDPHE (1999) *Chatfield Reservoir Control Regulation. Regulation No.73*. Colorado Department of Public Health and Environment Water Quality Control Commission.
- Chimney, M. J. and Foforth, G. (2006) *History and description of the Everglades Nutrient Removal Project, a subtropical constructed wetland in south Florida (USA)*. *Eco. Eng.* 27, 268-278.
- Committee on the Mississippi River and the Clean Water Act (2008), *Mississippi River Water Quality and the Clean Water Act: Progress, Challenges, and Opportunities*. National Research Council
- Cooke, G. D., Welch, E. B., Peterson, S. A. and Newroth, P. R. (1993) *Restoration & Management of Lakes & Reservoirs*. Lewis, Boca Raton, FL

- Devlin, D. L., McVay, K., Pierzynski, G. M., and Janssen, K. (2002) *Best Management Practices for Phosphorus*. Kansas State University, Agricultural Experiment Station and Cooperative Extension Service
- Dove, E., Johnson, K. and Keener, M. (2008) *The Value of Protecting Ozark Streams; An Economic Evaluation of Stream Bank Stability for Phosphorus Reduction*. Watershed Center, Olsson Associates.
- Elliott, H. A., O'Connor, G. A., Lub, P., and Brinton, S. (2002) *Influence of Water Treatment Residuals on Phosphorus Solubility and Leaching*. Waste Management Technical Report, J. Environ. Qual. 31:1362-1369, ASA, CSSA, SSSA, Agric. and Biol. Eng. Dep., Pennsylvania State Univ. and Soil and Water Sci. Dep., Univ. of Florida
- EPA (1991) *Guidance for Water Quality Based Decisions: The TMDL Process*. EPA-440-4-91-001, Office of Water
- EPA (1999) *40 CFR Part 130, Proposed Revisions to the Water Quality Planning and Management Regulation*. Federal Register, 64:162, Aug. 23, 1999
- EPA (1999) *Protocol for Developing Nutrient TMDLs*. EPA 841-B-99-007. Office of Water (4503 F), United States Environmental Protection Agency, Washington D. C.
- EPA (2006) *Total Maximum Daily Load, Tuscumbia River Canal Bridge Creek, Elam Creek in the North Independent Streams Basin of Mississippi Alcorn and Prentiss Counties, Mississippi*. USEPA Region 4, Atlanta, Georgia.
- EPA (2007) *Total Maximum Daily Loads (TMDLs) for the Bear Creek Watershed and Tilda Bogue Watershed in the Big Black River Basin of Mississippi to address Biological Impairment due to Nutrients, Organic Enrichment and Low Dissolved Oxygen*. U.S. EPA Region 4
- EPA (2007) *National Nutrient Strategy*.
www.epa.gov/waterscience/criteria/nutrient/strategy/.
- EPA (2007) *Total Maximum Daily Load for the Fourteen Mile Creek Watershed in the Big Black River Basin of Mississippi to address Biological Impairment due to Nutrients, Organic Enrichment and Low Dissolved Oxygen*. USEPA Region 4, Atlanta, Georgia.
- EPA (2007) *Total Maximum Daily Load for the Bear Creek Watershed in the Big Black River Basin of Mississippi to address Biological Impairment due to Nutrients, Organic Enrichment and Low Dissolved Oxygen*. USEPA Region 4, Atlanta, Georgia.
- EPA (2007) *Watershed-based National Pollutant Discharge Elimination System (NPDES) Permitting Technical Guidance*. EPA 833-B-07-004. Office of Wastewater Management Water Permits Division.
- EPA (2007) *Total Maximum Daily Load for Mattubby Creek Watershed in the Tombigbee River Basin of Mississippi to address Biological Impairment due to Nutrients, Organic Enrichment/Low Dissolved Oxygen*. USEPA Region 4, Atlanta, Georgia.
- EPA (2007) *Total Maximum Daily Load for The Town Creek Watershed in the Tombigbee River Basin of Mississippi to address Biological Impairment due to Nutrients*. USEPA Region 4, Atlanta, Georgia.
- EPA (2007) *Total Maximum Daily Load for The Noxubee River Watershed in the Tombigbee River Basin of Mississippi to address Biological Impairment due to Nutrients, Organic Enrichment and Low Dissolved Oxygen*. USEPA Region 4, Atlanta, Georgia.
- EPA (2009) *National Water Quality Inventory: Report to Congress 2004 Reporting Cycle*. EPA-841-R-08-001, Office of Water, Washington D.C

- Fixen, P. E. and Grove, J. H. (1990) *Testing soils for phosphorus*. In: Westerman, R. L. (eds) *Soil Testing and Plant Analysis*, SSSA, Madison, WI.
- Frossard, E., Condron, L., Oberson, A., Sinaj, S. and Fardeau, J. C. (2000) *Process governing phosphorus availability in temperate soils*. J. Environ. Qual. 29: 15-23
- Frothingham, K. M. (2008) *Evaluation of stability threshold analysis as a cursory method of screening potential streambank stabilization techniques*. Appl. Geography, 28:124-133
- Gallimore, L.E., Basta, N. T., Storm, D. E., Payton, M. E., Huhnke, R. H., and Smolen, M. D. (1999) *Water treatment residual to reduce nutrients in surface runoff from agricultural land*. J. Environ. Qual. 28:1474-1478
- Gerstein, J.M. and R.R. Harris (2005) *Protocol for Monitoring the Effectiveness of Bank Stabilization Restoration*. University of California, Center for Forestry, Berkeley, CA. 24 pp
- Green, C. J., Johnson, P., Allen, V.G., and Crossland, S. L. (2005) *Treatment Technologies for Phosphorus Removal from Water Derived from Cattle Feedyards*. Plant and Soil Science Department and Agricultural & Applied Economics Department, Texas Tech University.
- Harrison, A. F. (1987) *Soil Organic Phosphorus: A review of world literature*. CABI
- Haustein, G.K., Daniel, T. C., Miller, D. M., Moore, P. A. Jr., and McNew, R. W. (2000) *Aluminum-containing residuals influence high-phosphorus soils and runoff water quality*. J. Environ. Qual. 29:1954-1959
- Haygarth, P. M. and Jarvis, S. C. (2002) *Agriculture, Hydrology and Water Quality*, CABI
- Huang, W. et al. (2008) *Phosphoate removal from wastewater using red mud*. J. Hazard. Mater. 158, 35-42.
- Hubbard, L.C., Biedenharn, D.S., and Ashby, S.L. (2003) *Assessment of Environmental and Economic Benefits Associated with Streambank Stabilization and Phosphorus Retention*. Water Quality Research Program Technical Notes Collection, ERDC WQTN-AM-14, Vicksburg, MS
- Ippolito, J. A., Barbaricka, K. A., Heila, D. M., Chandlerb, J. P., and Redenteb, E. F. (2003) *Phosphorus Retention Mechanisms of a Water Treatment Residual*. Waste Management Technical Report, J. Environ. Qual. 32:1857-1864, Department of Soil and Crop Sciences and Department of Forest, Rangeland, and Watershed Stewardship, Colorado State University
- Jiang, M.B. Beck, R.G. Cummings, K. Rowles, and D. Russell (2005) *Estimation of Costs of Phosphorus Removal in Wastewater Treatment Facilities: Adaptation of Existing Facilities*. Water Policy Working Paper 2005-011.
- John Nurminen Foundation (2007) *Eutrophication of the Baltic Sea and Blue-Green Algae*. The Clean Baltic Sea Project, John Nurminen Foundation.
- Lenntech (2008) *Phosphorus removal from wastewater*. Water Treatment & Air Purification Holding B.V., Lenntech, Netherlands.
- Littau, S. E. and Engelhart, W. G. (1990) *Microwave Sample Preparation for Total Nitrogen and Phosphorus Determination*. Presented at the 32nd Rocky Mountain Conference, CEM Innovators in Microwave Technology.
- Maguire, R. O. and Sims, J. T. (2002) *Measuring Agronomic and Environmental Soil Phosphorus Saturation and Predicting Phosphorus Leaching with Mehlich 3*, Soil Sci. Soc. Am. J. 66:2033-2039, Department of Plant and Soil Sci., Univ. of Delaware, Newark, DE

- McCullah, J. and Gray, D. (2005) *Environmentally Sensitive Channel- and Bank-Protection Measures*. NCHRP Report 544, Transportation Research Board of the National Academies, National Cooperative Highway Research Program
- Macleod, C. and Haygarth, P. M. (2003) *A Review of the Significance of Non-point Source Agricultural Phosphorus to Surface Water*. IGER, Devon, UK
- MDEQ (2007) *Mississippi's Nonpoint Source Management Program*, Annual Report, Prepared Pursuant to Section 319 of the Clean Water Act
- MDEQ (2008) *Total Maximum Daily Load; Total Nitrogen, Total Phosphorus, and Organic Enrichment/Low Dissolved Oxygen for a Segment of the Coldwater River*. Jackson, MS
- MDE. (2006) *Maryland's 2006 TMDL Implementation Guidance for Local Governments*. The Maryland of the Environment, Baltimore, Maryland.
- MFC (2008) *Mississippi's Best Management Practices*. 4th edition, The Mississippi Forestry Commission Publication No.107
- Michigan United Conservation Clubs (1997) *Stream Bank Stabilization*
- Millennium Ecosystem Assessment (2005) *Synthesis Report*, Island, Washington DC, <http://www.MAweb.org>
- Miller, S. (2008) Onondaga Lake Improvement Project. Onondaga County Department of Water Environment Protection, New York. www.ongov.net/lake/index.htm
- Mississippi Soil and Water Conservation Commission, *Agricultural Best Management Practices for Water Quality in Mississippi*. C9994866-99, EPA
- Mulla, D. J., Birr, A. S., Kitchen, N., and David, M. (2005) *Evaluating the effectiveness of agricultural management practices at reducing nutrient losses to surface waters*. Pp. 171-193 in *Proceedings of the Gulf Hypoxia and Local Water Quality Concerns Workshop*, Iowa State University
- Nash, S. D., Hannah, M., Halliwell, D., and Murdoch, C. (2000) *Factors affecting phosphorus transfer from a pasture based grazing system*. J. Environ. Qual. 29: 1160-1165.
- Nett, M. T., Locke, M. A., and Pennington, D. A. (2004) *Water Quality Assessments in the Mississippi Delta: Regional Solutions, National Scope*. ACS Symposium Series 877
- North Carolina Wildlife Resource Commission, *Streambank Erosion*. Stream Notes, Vol. 1, No. 2
- Novotny, V. (2002) *Water Quality: Diffuse Pollution and Watershed Management*. 2nd Edition, John Wiley & Sons
- ODNR. (2000) *Riprap Revetment*. Ohio Stream Management Guide No. 16, The Ohio Department of Natural Resources, Division of Water
- Oldham, L. (2008) *Phosphorus in Mississippi Soils*. Mississippi State University Extension Service
- Park, J. K., Wang, J. and Novotny, G. (1997) *Wastewater Characterization for Evaluation of Biological Phosphorus Removal*. Research Report 174. The Wisconsin Department of Natural Resource.
- Park, W. H. and Polprasert, C. (2008) *Roles of oyster shells in an integrated constructed wetland system designed for P removal*. Ecol. Eng. 34, 50-56.
- Pierzynski, G. M. (2000) *Methods of Phosphorus Analysis for Soils, Sediments, Residuals, and Waters*, Southern Cooperative Series Bulletin No. 396 http://www.soil.ncsu.edu/sera17/publications/sera17-2/pm_cover.htm
- Reddy, K. R., Kadlec, R. H. and Chimney, M. J. (2006) *The Everglades Nutrient Removal Project*. Ecol. Eng. 27, 265-267.

- Rybicki, S. M. (2004) *New Technologies of Phosphorus Removal from Wastewater*. Ul. Warszawka 24; 31-155 Kraków.
- Sadlon, N.P. (1993) *Soil Bioengineering: A Natural Approach to Stream Bank Stabilization*. USGA Green Section Record
- Schindler, D. W., et al. (2008) *Eutrophication of lakes cannot be controlled by reducing nitrogen input: results of a 37-year whole-ecosystem experiment*. Proc. Natl. Acad. Sci. USA 105: 11253-11258
- SEPA, *Best Management Practices*. Scottish Environment Protection Agency, UK <http://apps.sepa.org.uk>
- Sharpley, A. N. and Rekolainen, S. (1997) *Phosphorus in Agriculture and Its Environmental Implications*. In: Tunney, H. and Wallingford, O. X. (eds) *Phosphorus Loss from Soil to Water*, CABI
- Sims, J. T. (2000) *Soil Test Phosphorus: Mehlich 3* In: Pierzynski, G. M. (eds) *Method of Phosphorus Analysis for Soils, Sediments, Residuals, And Waters*, Southern Cooperative Bulletin No. 396
- Skirrow, R. (2006) *Streambank stabilization using bioengineering and biotechnical methods*. Alberta Infrastructure and Transportation, prepared for Annual Conference of the Transportation Association of Canada Charlottetown, Prince Edward Island
- Smith, C., Williams, J. (2007) *BMP Economic Considerations*. Department of Agricultural Economics, KSU
- Spring Lake Watershed Planning Committee (2008) Spring Lake Watershed Plan. McDonough County SWCD office, Jackson Macomb, Illinois.
- Steinman, A., Rediske, R. and Nemeth, L. (2004) *Internal Phosphorus Loading in Spring Lake: Year 2*. AWRI MR-2004-5. Annis Water Resources Institute, Muskegon, Michigan.
- Steinman, A., Rediske, R. and Reddy, K. R. (2004) *The Reduction of Internal Phosphorus Loading Using Alum in Spring Lake, Michigan*. J. Environ. Qual. 33:2040-2048.
- Turner, B. L. and Haygarth, P. M. (2000) *Phosphorus Forms and Concentrations in Leachate under Four Grassland Soil Types*. Soil Sci. Soc. Am. J. 64:1090-1099 Dep. of Geography, Royal Holloway, Univ. of London, Egham, Surrey, UK
- Turner, B. L. and Haygarth, P. M. (2002) *Organic phosphorus characterization by phosphatase hydrolysable phosphorus techniques: applications to soil extracts and runoff waters*. In: Whitton, B. A. and Hernandez, I. (eds) *Phosphatases in the Environment*. Kluwer Academic Press, The Netherlands (in press)
- US Army Corps Engineering (2006) Upper Mississippi River System Environmental Design Handbook
- Virginia Tech. (2006) *TMDL Implementation-Characteristics of Successful Projects, Final Report*. EPA Project X7-83156301-0. VT-BSE Document No. 2006-0003. The Center for TMDL and Watershed Studies at Virginia Tech.
- Watson, C. C., Thornton, C. I., Carlson, K. H., Bledsoe, B. P., and Robeson, M. D. (2002), *Demonstration Erosion Control Monitoring Site 2002 Evaluation*. Colorado State University
- Watson, C. C., Carlson, K. H., and Jordan, B. A. (2006) *Delta Headwaters Project Monitoring Sites 2006 Evaluation*. Cottonwood Research LLC, Fort Collins, CO
- Watson, M. and Mullen R. (2007) *Understanding Soil Tests for Plant-Available Phosphorus*. School of Environment and Natural Resources, Ohio State University
- Wilson, M. A. and Carpenter, S. R. (1999) Ecol. Appl. 9: 772-783

Woodward-Clyde (1992) *Nonpoint Source Management Plan for Chatfield Reservoir, Colorado*. Woodward-Clyde Consultants, Denver, Colorado.

APPENDIX

1. Calculation of OM and alum in trench:

OM (v/v): $(75 \text{ bags} * 1.5 \text{ ft}^3) / 600 \text{ ft}^3 = 0.187$

Alum (v/v): $(150 \text{ bags} * 0.81 \text{ ft}^3) / 600 \text{ ft}^3 = 0.202$

Alum (w/w): $0.086 \text{ Al/Alum} = 0.017$

2. Calculation of P removal cost of RS2

Construction cost: alum: \$1,500, mulch: \$300, labor: \$1,000 and equipment: \$800

Total construction cost: \$3,680

Volume of trench: 600 ft^3

Density of alum: 2.7 kg/L

Weight of alum in trench: 9267.44 kg

Weight of Al in trench: $9267.44 \text{ kg} * 0.086 \text{ Al/alum} = 797 \text{ kg}$

WTR (4.7 % Al) adsorption capacity (Haustein, 2000): 1750 mmol P/kg

$= 54.25 \text{ g P/kg} = 1161.7 \text{ g P/kg Al}$

RS2 P-removal cost: $\$3,680 / \{(1161.7 \text{ g P/kg Al}) * (797 \text{ kg Al}) * (2.21 \text{ lbs/kg}) / (1000 \text{ g/kg})\} = \$1.81/\text{lbs P}$

Table 7.1: Soil fractions and characteristics in RS2 study area and control area

		RS2 study area				Control
		1-A	1-B	1-C	1-D	1-E
Field	sand	0.271	0.369	0.765	0.442	
	silt	8.334	4.312	5.716	5.423	
	clay	1.395	5.319	3.519	4.135	
		Silty Clay	Silt Loam	Silty Clay	Silty Clay Loam	Silty Clay
		2-A	2-B	2-C	2-D	2-E
RS2 Barrier (16"deep)	0.022	0.249	0.044	0.201	0.387	
	7.930	5.707	5.618	6.061	5.538	
	2.048	4.044	4.338	3.738	4.075	
		Silt Loam	Silty Clay	Silty Clay	Silty Clay Loam	Silty Clay
		3-A	3-B	3-C	3-D	3-E
Bank	0.018	0.037	0.386	0.566	0.919	
	5.384	5.624	4.835	5.858	5.418	
	4.598	4.339	4.779	3.576	3.663	
		Silty Clay	Silty Clay	Silty Clay	Silty Clay Loam	Silty Clay Loam

Table 7.2: Concentrations, standard errors (SE) and 95% confidence intervals (CI) of soil aluminum (mg/g) in RS2 study area and control area

	Date	Aluminum (mg/g)		Average
		Sample1 05/02/09	Sample2 07/03/09	
Field	1-A	0.798	1.247	1.022
	1-B	0.532	0.317	0.425
	1-C	0.454	0.573	0.513
	1-D	0.760	0.706	0.733
	Mean	0.673		
	SE	0.099		
	95%CI	0.195		
RS2 Barrier (16"deep)	2-A	0.645	1.845	1.245
	2-B	1.864	1.269	1.566
	2-C	2.419	1.780	2.100
	2-D	5.196	2.006	3.601
	Mean	2.128		
	CV	0.490		
	SE	0.476		
Bank	3-A	0.645	0.501	0.573
	3-B	0.222	0.440	0.331
	3-C	0.454	0.727	0.590
	3-D	0.222	0.471	0.346
	Mean	0.460		
	SE	0.062		
	95%CI	0.123		
Control	1-E	0.609	0.440	0.525
	2-E	0.395	0.460	0.428
	3-E	0.567	0.720	0.643
	Mean	0.532		
	SE	0.049		
	95%CI	0.097		

Table 7.3: Concentrations, standard errors (SE) and 95% confidence intervals (CI) of soil total phosphorus (TP) (mg/g) in RS2 study area and control area

		TP (mg/g)		
		Sample1	Sample2	Average
		05/02/09	07/03/09	
Field	1-A	0.605	0.713	0.659
	1-B	0.262	0.184	0.223
	1-C	0.484	0.246	0.365
	1-D	0.487	0.328	0.407
	Mean	0.414		
	SE	0.067		
	95%CI	0.130		
RS2 Barrier (16"deep)	2-A-a	0.161	0.431	0.296
	2-B-a	0.282	0.430	0.356
	2-C-a	0.544	0.327	0.436
	2-D-a	0.343	0.532	0.438
	Mean	0.381		
	SE	0.046		
	95%CI	0.089		
RS2 Barrier (36"deep)	2-A-b	0.307		0.307
	2-B-b	0.390		0.390
	2-C-b	0.308		0.308
	2-D-b	0.410		0.410
	Mean	0.354		
	SE	0.027		
	95%CI	0.053		
Bank	3-A	0.121	0.327	0.224
	3-B	0.222	0.430	0.326
	3-C	0.363	0.246	0.304
	3-D	0.222	0.430	0.326
	Mean	0.295		
	SE	0.039		
	95%CI	0.077		
Control	1-E	0.355	0.430	0.392
	2-E	0.324	0.614	0.469
	3-E	0.223	1.008	0.615
	Mean	0.492		
	SE	0.116		
	95%CI	0.227		

Table 7.4: Concentrations, standard errors (SE) and 95% confidence intervals (CI) of soil Mehlich-3 phosphorus (mg/g) in RS2 study area and control area

	Date	Mehlich-3 P (mg/g)		
		Sample1 05/02/09	Sample2 07/03/09	Average
Field	1-A	0.063	0.044	0.053
	1-B		0.042	0.042
	1-C	0.056	0.037	0.047
	1-D	0.034	0.047	0.041
	Mean	0.047		
	SE	0.004		
	95%CI	0.008		
RS2 Barrier (16"deep)	2-A	0.034	0.035	0.035
	2-B	0.054	0.065	0.059
	2-C	0.052	0.080	0.066
	2-D	0.038	0.047	0.043
	Mean	0.051		
	SE	0.006		
	95%CI	0.011		
RS2 Barrier (36"deep)	2-A-b	0.061		0.061
	2-B-b	0.091		0.091
	2-C-b	0.062		0.062
	2-D-b	0.058		0.058
	Mean	0.068		
	SE	0.008		
	95%CI	0.015		
Bank	3-A	0.029	0.012	0.021
	3-B		0.003	0.003
	3-C	0.036	0.026	0.031
	3-D	0.004	0.040	0.022
	Mean	0.022		
	SE	0.006		
	95%CI	0.011		
Control	1-E	0.043	0.133	0.088
	2-E	0.033	0.049	0.041
	3-E	0.042	0.036	0.039
	Mean	0.056		
	SE	0.016		
	95%CI	0.030		

Table 7.5: Concentrations, standard errors (SE) and 95% confidence intervals (CI) of soil total nitrogen (TN) (mg/g) in RS2 study area and control area

	Date	TN (mg/g)		Average
		Sample1 05/02/09	Sample2 07/03/09	
Field	1-A	17.244	12.453	14.848
	1-B	7.882	9.929	8.905
	1-C	8.367	9.977	9.172
	1-D	7.369	8.969	8.169
	Mean	10.274		
	SE	1.142		
	95%CI	2.238		
RS2 Barrier (16"deep)	2-A	11.621	11.293	11.457
	2-B	8.787	10.772	9.779
	2-C	7.892	10.045	8.969
	2-D	7.588	10.138	8.863
	Mean	9.767		
	SE	0.599		
	95%CI	1.175		
RS2 Barrier (36"deep)	2-A-b	8.168		8.168
	2-B-b	8.497		8.497
	2-C-b	7.427		7.427
	2-D-b	7.350		7.350
	Mean	7.861		
	SE	0.281		
	95%CI	0.551		
Bank	3-A	10.236	11.961	11.099
	3-B	7.562	11.965	9.763
	3-C	9.374	9.819	9.596
	3-D	5.772	9.180	7.476
	Mean	9.484		
	SE	0.739		
	95%CI	1.448		
Control	1-E	10.300	10.513	10.407
	2-E	8.580	10.101	9.341
	3-E	8.120	9.844	8.982
	Mean	9.577		
	SE	0.403		
	95%CI	0.789		

Table 7.6: Concentrations, standard errors (SE) and 95% confidence intervals (CI) of total phosphorus (TP) and dissolved reactive phosphorus (DRP) (mg/L) in waters from monitoring wells and stream

Sample #	Location	TP (mg/L)	DRP (mg/L)
LB1	Field Well 25'	—	—
LB3	Filed Well 75'	0.340	0.030
LB5	Field Well 90'	0.260	0.040
Mean		0.300	0.035
SE		0.040	0.005
95%CI		0.078	0.010
LB2	Bank Well 25'	0.180	0.010
LB4	Bank Well 75'	0.360	0.050
LB6	Bank Well 90'	0.080	0.030
Mean		0.207	0.030
SE		0.082	0.012
95%CI		0.161	0.023
Upst		0.420	0.120
Midst-1		0.170	0.030
Midst-2		0.330	0.020
Dwst		0.390	0.020

Table 7.7: Concentrations, standard errors (SE) and 95% confidence intervals (CI) of total nitrogen (TN) and nitrate (mg/L) in waters from monitoring wells and stream

Sample #	Location	TN (mg/L)	NO ₃ - (mg/L)
LB1	Field Well 25'	—	—
LB3	Filed Well 75'	1.280	0.600
LB5	Field Well 90'	2.280	1.300
Mean		1.780	0.950
SE		0.500	0.350
95%CI		0.980	0.686
LB2	Bank Well 25'	0.920	0.800
LB4	Bank Well 75'	0.640	0.200
LB6	Bank Well 90'	1.860	0.400
Mean		1.140	0.467
SE		0.369	0.176
95%CI		0.723	0.346
Upst		0.640	0.500
Midst-1		0.540	0.300
Midst-2		0.510	0.300
Dwst		0.390	0.300

Table 7.8: Concentrations, standard Errors (SE) and 95% confidence intervals (CI) of total organic carbon (TOC) and in waters from monitoring wells and stream

Sample #	Location	TOC (mg/L)
LB1	Field Well 25'	—
LB3	Filed Well 75'	0.253
LB5	Field Well 90'	1.106
Mean		0.680
SE		0.427
95%CI		0.836
LB2	Bank Well 25'	5.550
LB4	Bank Well 75'	7.500
LB6	Bank Well 90'	1.000
Mean		4.683
SE		1.926
95%CI		3.775
Upst		5.070
Midst-1		4.750
Midst-2		4.530
Dwst		3.700