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Assessing the efficiency of alternative best management practices to reduce nonpoint source pollution in the broiler production region of Louisiana

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ASSESSING THE EFFICIENCY OF ALTERNATIVE BEST MANAGEMENT PRACTICES TO REDUCE NONPOINT SOURCE POLLUTION IN THE BROILER PRODUCTION REGION OF LOUISIANA

A Thesis

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List of Abbreviations

AEU	Animal Equivalent Unit
AFO	Animal Feeding Operation
AVGWLF	ArcView Generalized Watershed Loading Function
BMP	Best Management Practices
CAC	Command and Control
CAFO	Concentrated Animal Feeding Operation
CRP	Conservation Reserve Program
CWA	Clean Water Act
EQIP	Environmental Quality Incentive Program
EPA	Environmental Protection Agency
FBCP	Farm Bill Conservation Program
FWP	Fish and Wildlife Propagation
GA	Genetic Algorithm
GIS	Geographic Information System
GWLF-E	Generalized Watershed Loading Function Enhanced
HSPF	Hydraulic Simulation Program - Fortran
k	Soil Erosion Factor
LBPR	Louisiana Broiler Production Region
LDEQ	Louisiana Department of Environmental Quality
L-S	Slope Length Factor
NOAA	National Ocean and Atmospheric Administration

NPS	Nonpoint Source
NRCS	National Resource Conservation Service
NPDES	National Pollution Discharge Elimination System
PCR	Primary Contact Recreation
PRediCT	Pollution Reduction Comparison Tool
PS	Point Source
RCWP	Rural Clean Water Program
RHS	Right Hand Side
SCR	Secondary Contact Recreation
SWAT	Soil and Water Assessment Tool
SWMM	Storm Water Management Model
TMDL	Total Maximum Daily Load
USDA	United States Department of Agriculture
USLE	Universal Soil Loss Equation
WQA	Water Quality Act
WQMP	Louisiana Water Quality Management Plan

Abstract

The Louisiana broiler production region is located in North Central and Northwestern Louisiana. The region consists of twelve parishes in Northwestern and North Central Louisiana. The broiler production region is a significant contributor of nonpoint source (NPS) pollution to nearby waterways. This pollution is a consequence of sediment, nitrogen and phosphorus runoff caused by agricultural production. NPS pollution is difficult to mitigate due to uncertainties in its point of origin as well as a host of other factors ranging from rainfall to topographical parameters. Best Management Practices (BMPs) have been shown to be a reliable method for reducing nonpoint source pollution emanating from agricultural production. To reduce pollutants, several BMPs have been recommended, specific to crops and regions, by the Natural Resource Conservation Service of the United States Department of Agriculture (NRCS/USDA) and U.S. Environmental Protection Agency (EPA). Successful implementation of BMPs for water quality improvement requires careful study of both nonpoint pollution sources and their effectiveness in a given spatial situation. These assessments are being conducted for several watersheds throughout the United States; however, many watersheds in Louisiana remain unexamined. This study focuses on two watersheds in the broiler production region of Louisiana and utilizes a GIS based simulation program to determine the best least cost solution for the application of BMPs in the study region. Analyses were conducted under alternative climate change and BMP effectiveness scenarios. Results indicate that it is cost effective to implement nutrient management to reduce phosphorus pollution.

Chapter 1. Introduction

1.1 Background

Water quality has become a major concern in the United States and throughout the world. The Clean Water Act (CWA) of 1972 laid the groundwork for several programs to improve water quality; however, according to the Environmental Protection Agency, over 40% of assessed waterways do not achieve minimum requirements for their intended use (USEPA, 2008).

Under the National Pollution Discharge Elimination System (NPDES) program, all point source (PS) polluters, such as municipal and industrial waste facilities, are required to obtain permits, which are managed by the EPA and state environmental agencies. The CWA requires states to determine a Total Maximum Daily Load (TMDL) for each watershed that does not meet its intended use. The NPDES program is widely recognized as effectively reducing point source pollution and restoring waterways to their designated uses throughout the United States. However, due to their diffuse nature, nonpoint source polluters, which are exemplified by emissions from mobile sources, leaching or runoff from agricultural lands and runoff from residential areas and construction sites, remain an unresolved cause of water quality problems, despite the determination of TMDLs (USEPA, 2003). Agricultural runoff has been found to be the largest single contributor to nonpoint source pollution in rural watersheds, contributing an estimated 65% of the nitrogen pollution to the Gulf of Mexico (USEPA, 2000).

Agriculture is the major source of nonpoint pollution in northern Louisiana. While fertilizers have become necessary for modern agricultural production, they can leach nutrients, such as nitrogen and phosphorus, into surrounding waterways when applied improperly. Nutrient runoff results in eutrophication when it reaches nearby waterways, which often leads to hypoxia. These hypoxic zones are a growing problem in the Gulf of Mexico, threatening gulf ecosystems and the many nearby industries dependent on marine life (Hall, 2009).

A diverse range of structural and management methods known as best management practices (BMPs) are widely used to control NPS runoff. Implementation of BMPs at critical locations throughout various watersheds have been shown to improve water quality in waterways compromised by NPS (Zhen et al., 2004). However, BMPs are being implemented without sufficient studies at the farm or watershed level to determine which combination of BMPs is most effective (NRCS, 2004).

When determining which BMPs to utilize in a region, cost and farmers' willingness to adopt these practices are important factors to consider. Farmers or agricultural producers who are not likely to adopt expensive BMPs often absorb implementation costs. Moreover, farm managers are interested in maximizing profits while societal and environmental institutions are focused on improving water quality. These public groups are not likely to be concerned with pollution reduction costs unless implementation of these practices causes them economic burden. However, achieving the least cost solution is often in concert with both public and private interests (Gitau et al., 2004).

The key challenge of structuring an effective BMP program targeted at reducing NPS pollution is achieving a maximum reduction in pollutant loading at a minimum cost (Giri et al., 2012). Selection and placement of BMPs have been shown to be nearly three times more cost effective than targeting methods of specified pollutants (Arabi et al., 2006). Once BMPs have been implemented, pollutant reduction from that site can be satisfactorily measured over time. However, predetermining the impact of BMPs on a specific site is generally more complicated (Gitau et al., 2004).

Over the past several years, a multitude of models and simulation programs have been developed to predict the best combination of BMPs in a given watershed. Modeling techniques include linear programming, Monte Carlo simulation, scatter search and sorted genetic algorithms. Geographic information system (GIS) based simulation software includes the Soil and Water Assessment Tool (SWAT), Mapshed, the Pollution Reduction Comparison Tool (PRedICT), the Storm Water Management Model (SWMM) and the Hydraulic Simulation Program - Fortran (HSPF). Arabi et al. (2006) used SWAT and a genetic algorithm (GA) to optimize BMPs for watersheds in Indiana. Mishra et al. (2007) employed SWAT to identify areas of high sediment yield and determine structural designs to minimize them. Kaini et al. (2012) utilized a single objective optimal control model in concert with SWAT and a GA to determine optimal BMP placement for the Silver Creek watershed in Illinois.

In this study, we utilize Mapshed simulation software in conjunction with an optimization model to determine a cost-effective BMP combination for the Chenerie Creek and Bayou Desiard, two watersheds within the broiler production region. Multiple studies have utilized Mapshed, or its predecessor the ArcView Generalized Watershed Loading Function (AVGWLF), in combination with various optimization techniques to determine optimal BMP placement (McGarety el al., 2005; Markel et al., 2007; Georgas et al., 2009). This software package is a useful tool which can be utilized to reduce nutrient (nitrogen and phosphorus) and sediment loads in waterways and help them reach their predetermined TMDL goals.

1.2 Problem Statement

Recent literature indicates concern over the inability of previous pollution reduction efforts to identify and reduce NPS polluters. While PS pollution has been largely reduced in the United States, NPS remains a challenge to environmental regulators, as it is difficult to identify and costly to monitor sources due to their diffuse nature. Further problems include challenges introduced by topographical, hydrological and climatic factors and their influence over the flow of pollutants. Agricultural runoff has been identified as a major contributor to NPS pollution. BMPs have been shown to reduce effluent runoff from agricultural production. However, the factors that dictate the optimal BMPs to utilize in a specific region vary drastically over a small area, making precise measurement at the watershed and sub-watershed levels necessary for ideal implementation. This research utilizes simulation software to determine the effectiveness of several BMPs in the Chenerie Creek and Bayou Desiard watersheds, two watersheds located in the Louisiana Broiler Production Region (LBPR). The results of this analysis are analyzed, along with implementation cost information for each BMP, to determine the most cost-effective BMP (or combination of BMPs) in the area.

1.3 Objectives

The study's main objective is to identify the most cost-effective suite of BMPs to reduce phosphorus loadings in the study area, based on agricultural, climatic, hydrological and topographical data.

Specifically, we aim to:

1. Simulate effluent runoff in the Ouachita watershed by utilizing the data in the Mapshed software package.
2. Analyze the data to determine the reduction coefficient of each BMP in the watershed.
3. Compare this data with cost of implementation data for each BMP to determine the most cost-effective BMP or combination of BMPs for the study region.

1.4 Overview of Thesis

The thesis is organized as follows: Chapter 1 details the project's background and outlines the objectives. Chapter 2 provides a literature review, which covers the history of water quality policy in the United Sates and highlights empirical studies of BMP efficiency and the role of optimization and GIS in BMP studies**.** Chapter 3 contains the data and methods used in this study. The results of the analysis are provided in Chapter 4. Finally, Chapter 5 summarizes the implications and conclusions drawn from this analysis.

Chapter 2. Literature Review

2.1 Water Policy: A brief history

2.1.1 Federal Water Policy

The first government regulation establishing any type of limitation on water pollution began with the Refuse Act of 1899. The purpose of this act was not to ensure clean drinking water or preserve the quality of fisheries but to prevent impediments to navigation. This legislation implies that some rivers had become so overfilled with solid waste that it impaired the ability of ships to navigate commonly used routes and waterways. While this is an archaic law with little practical use in present day policy, it serves as a reminder of the humble beginnings of water pollution policies and how badly polluted the waterways of the United States once were (Freeman, 2000).

Presently, the primary legislation governing water pollution in the United States is the Clean Water Act, initially passed in 1948 (Copeland, 2013). This was the first federal regulation to deal directly with more modern instances of water pollution. This legislation enabled the federal government to conduct research dealing with water quality problems and loan funds to local governments for the building of sewage treatment plants. However, no water quality standards were established and no forms of enforcement were implemented.

The CWA was amended in 1956 and updated in 1965 with the establishment of the Water Quality Act (WQA). The 1956 amendments established an allocation of funds for federal grants, which could be used to cover up to 55% of the construction costs of municipal sewage treatment plants. The amendment also allowed the government to convene meetings between interested parties if serious pollution problems occurred along interstate waterways. These revisions again failed to mandate effluent limits at the individual, watershed, or state level. The Water Quality Act of 1965 sought to remedy this failure by asserting that states must set minimum water quality standards for interstate waterways. To enforce these minimum standards, states would determine the maximum allowable discharge of various pollutants and then distribute permits to major polluters. The basis for permit distribution and the punishments for violating those permits were left to the state's discretion. While the establishment of water quality standards was an important step in the progress of water policy, the Water Quality Act of 1965 was ultimately a failure due to the costs of monitoring and regulating the waterways as well as a varying dedication among states to water quality control (Freeman, 2000).

The Cuyahoga river fire of 1969 was cause for water policy change and led to a major revision of the CWA in 1972. Water quality issues were also a significant motivation for the establishment of the Environmental Protection Agency (EPA) in 1970 (Fisher-Vanden et al., 2013). The goals outlined in the CWA were: 1) the attainment of fishable and swimmable waters by July 1, 1983 and 2) the elimination of all discharges of pollutants into navigable waterways. The establishment of goals, methods and accountability represented a significant change from earlier federal policy (Freeman, 2000). While these deadlines were not met in many areas of the country and have been postponed through several amendments, their influence on future water policy should not be underestimated (King, 2005).

The CWA was revised several times throughout the 1970s and 1980s. The first major revision of the CWA occurred in 1972 as mentioned above. The 1972 revisions substantially increased federal subsidies, established new goals and deadlines for pollution removal and established new regulation and enforcement methods for municipal waste treatment plants. The 1972 revisions also shifted responsibilities for issuing water quality permits to federal authorities. The CWA was subsequently updated in 1977. The 1977 act extended some deadlines established in the 1972 provisions and made clearer delineations between conventional pollutants and toxic water pollutants. The CWA amendments of the 1970s deal largely with PS pollution; however, they do have some minor provisions for NPS. The section dealing with NPS calls for the establishment of area-wide waste treatment management plans (Freeman, 2000).

The 1987 amendments to the WQA are the first federal legislation to seriously address sources of NPS and NPS mitigation. This amendment establishes that states are responsible for addressing NPS problems within their borders. It stipulates that states must identify NPS sources, establish water quality goals and implement management practices to meet these goals in state NPS assessment reports and state management programs. These plans must identify significant sources of NPS and BMPs to diminish these sources. The 1987 amendment also authorizes the EPA to provide grants to assist with the implementation of BMPs approved by the EPA (James, 2011).

The 1987 amendments to the WQA were the last major amendments to the WQA or CWA; however, there have been several important policy programs related to agricultural runoff and NPS since that time. The Rural Clean Water Program (RCWP) was conducted from 1980 to 1990. The program's stated goals were to: 1) improve water quality in the project area in the most cost-effective manner, 2) assist farmers in reducing NPS water pollutants in order to meet water quality goals and 3) develop and test programs, policies and procedures for the control of agricultural NPS pollution. The program funded twenty-one test projects across the U.S., which implemented BMPs and monitored their effectiveness. The RCWP helped improve targeting and use of BMPs in the U.S.

Section 303(d) of the CWA requires states to identify lakes, rivers and streams that do not meet current water quality standards and requires municipal and industrial polluters to implement technology-based controls to mitigate the pollution causing these impairments. For each impaired waterway, states are required to establish TMDLs, which set maximum levels of pollution for each water body, which they then submit to the EPA for approval. If states fail to establish satisfactory TMDLs, the EPA is allowed to set a priority list of waterways for each state and establish its own TMDLs. Establishing TMDLs requires quantitatively assessing both the amount of pollution and the need for pollution reduction in a given waterway as well as establishing the sources of pollution. TMDLs are applicable to both NPS and PS sources. While these stipulations exist in the initial 1972 CWA, difficulties related to NPS and a lack of EPA funding to pursue these programs detracted from the establishment of TMDLs. After being largely overlooked for more than two decades, several lawsuits by environmental groups led the EPA to propose new rules and guidelines for monitoring and assessing TMDLs in 1997. Congress eventually passed these proposals into law in 2000. Since that time, the EPA has been establishing TMDLs for priority waterways in several states in accordance with the new guidelines (Copeland, 2003).

In order to grasp the true meaning of Section 303(d) of the CWA, it is important to define TMDLs and understand how they are established. The EPA defines a TMDL as a written plan and analysis established to ensure that a waterbody will attain and maintain water quality standards, including consideration of existing pollutant loads and reasonably foreseeable increases in pollutant loads. It is intended to provide an opportunity to compare relative contributions from all sources and consider technical and economic trade-offs between point and nonpoint sources (USEPA, 2012). The stated purpose of establishing each TMDL is to set in motion a series of actions that allocate pollutants in such a way that water quality standards are achieved. Each TMDL outlines maximum allowable pollutant loads to achieve water quality standards for defined critical conditions. Each TMDL must specify the pollutant for which it is established and the amount that may be present to meet water quality standards. The TMDL must also specify the amount the waterbody deviates from the load required to attain water quality standards. The TMDL must take into consideration all point sources, nonpoint sources and consideration for seasonal variations. Each TMDL must allocate pollutant loadings to specific point sources (for example, sewer overflows or abandoned mines) as well as allocations for estimates of nonpoint pollutants. It must also include a margin of safety to account for uncertainty and lack of knowledge as well as considerations for future growth (USEPA, 2012).

The Food Security Act of 1985 (also known as the 1985 Farm Bill) established the Conservation Reserve Program (CRP). The goals of the CRP program were to reduce soil erosion, increase and improve wildlife habitats, protect the nation's long-term capability to produce food and fiber, provide income support for farmers to curb the production of surplus commodities, protect ground and surface water by reducing runoff and sediment and to help clean lakes, rivers, streams and ponds. The program allows farmers to enter into 10-15 year contracts with the USDA to take highly erodible lands out of production and receive rental payments for returning the land to permanent vegetative cover (Glaser, 2012).

The Environmental Quality Incentive Program (EQIP) is a program created under the 1996 Farm Bill. The initial annual funding for the program was $200 million, but that figure has increased steadily, with annual funding reaching $1.8 billion in the year 2012. The program was created to assist famers and livestock producers in making environmental and conservation improvements. Under EQIP, landowners establish and implement conservation plans for which they receive cost share or incentive payments. The goal of this program is to select projects that maximize the benefit of payments made under EQIP. Emphasis is placed on planning to identify current problems and practices capable of addressing these problems (USEPA, 2013).

The 2002 Farm Bill Conservation Provisions (FBCP) provided technical and financial assistance to farmers interested in conservation and improvement of natural resources. The bill introduced or updated several funding and incentive programs for BMP implementation. The FBCPs include an array of programs that target different

BMPs and conservation practices and provide assistance through incentive payment and cost share programs (USEPA, 2003).

In 2008, Congress adopted the Farm Security and Rural Investment Act. This act, alternatively known as the “Farm Bill,” established programs to provide assistance to farmers and ranchers implementing BMPs to reduce NPS pollution, restore wetlands and improve wildlife habitat. The Farm Bill also incentivizes agricultural landholders to participate in several other programs aimed at increasing the utilization of BMPs on their land (LDEQ, 2012).

2.1.2 Louisiana State Water Policy

In the state of Louisiana, the primary document addressing water quality is the Louisiana Water Quality Management Plan (WQMP). The plan was developed in accordance with the policies laid out in the CWA. The WQMP is designed and implemented by the Louisiana Department of Environmental Quality (LDEQ). The stated goal of the WQMP is to ensure the waters of the state meet established water quality standards and thereby maintain all designated uses (LDEQ, 2004).

The CWA mandates that the governor of each state submit an NPS management plan to the EPA. This plan must address: (1) a description of BMPs to be implemented by the state to reduce NPS, (2) a description of management programs utilized to achieve implementation of BMPs, (3) a schedule of milestones to achieve implementation of BMPs, (4) a certification by the Attorney General of Louisiana that the state water pollution control agency has adequate authority to implement the above policies, (5) a description of federal and state assistance that will be utilized to implement the state’s

NPS management program and (6) an identification of other federal financial assistance or development projects the state will review for their effects on the water quality and consistency with the state's NPS management program. Louisiana received approval for its NPS Management Plan from the EPA on November 21, 2012 (LDEQ, 2012).

The Louisiana NPS Management Plan details ongoing and future water quality projects in the state of Louisiana. The stated goal is to reduce NPS impairments in at least 40 water bodies by October 2016. The report also documents recent water quality improvements undertaken by the state in the years preceding the NPS plan. Previously adopted goals (2005) included reducing the number of waterways on the impaired water bodies list by 25% for three different categories. These categories were primary contact recreation (PCR), secondary contact recreation (SCR) and fish and wildlife propagation (FWP). This goal was to be achieved by the end of 2012. While the LDEQ was successful at meeting the goals for PCR and SCR, it restored only 8 of the proposed 77 waterways for FWP. FWP waterways are the primary water bodies impaired by nutrient and sediment loadings (LDEQ, 2012).

In addition to detailing past efforts to control NPS pollution, the plan also outlines the state's efforts to identify and control waterways impaired by NPS pollution. This plan includes an effort to abate known NPS water quality impairments, identify and address new impaired waterways and threatened waterways through the development of TMDLs and manage and implement NPS programs efficiently and effectively, including financial management and the periodic review and evaluation of NPS management programs using environmental and functional measures of success (LDEQ, 2012).

Louisiana also releases an annual NPS report to update interested parties on their goals and achievements for the past year. According to the 2012 report, 23 impaired waterways have been fully restored in the past 12 years. Louisiana also estimates that it mitigated 519 million pounds of nitrogen, 129 million pounds of phosphorus and 89 million pounds of sediment from government-funded projects in 2012. The state also developed 12 implementation plans, identified 20 priority areas for BMP placement and monitored water quality at 14 sites downstream of locations where BMPs had been introduced. While Louisiana has made strides toward achieving water quality goals by identifying impaired watersheds and implementing BMPS, it still has more than 300 impaired waterways and will, in all likelihood, be working to restore its waterways for the next several decades (LDEQ, 2012).

2.2 BMP Efficiency

BMP efficiency has been the focus of hundreds, if not thousands of studies over the past thirty years (Evans et al., 2012). While a comprehensive storm water BMP database exists, and a similar agricultural BMP database was undertaken by the EPA, the agricultural database was placed on hold before its release to the public (Wieland et al., 2009). Several independent literature reviews and meta-analyses have been conducted to evaluate the pollutant reduction and cost efficiencies of many different agricultural BMPs (Harmel et al., 2006; Wieland et al., 2009; Merriman et al., 2009; Yagow et al., 2002; Evans et al., 2012). These analyses draw on numerous sources, from a combination of previous literature reviews (Evans et al., 2012) to a meta-analysis of over 100 site specific BMP studies (Merriman et al., 2009). The remainder of this section will provide a description of the methods used by each of the BMP meta-analyses as well as the information each analysis provides about the BMPs considered in this study.

Wieland et al. (2009) analyzed the efficiency of BMPs to reduce nutrients and sediment specifically tailored for use in the Chesapeake Bay. This study relies heavily upon a literature review conducted by Simpson et al. (2007), which also focused on the Chesapeake Bay. Simpson et al. (2007) utilize a literature review of current studies as well as an "adaptive management approach" which allows for the application of the best applicable science and the best professional judgment to further adapt the estimated efficiencies derived from the literature review. The Wieland et al. (2009) study summarizes and updates the 2007 study and is referred whenever it reveals pertinent new data. Merriman et al. (2009) compiled a BMP efficiency database with the goal of developing a BMP efficiency tool. They considered a range of sources including some unpublished sources (the study consisted of 18% unpublished sources and 82% published sources). This database reviews a wide range of studies including lab studies, field studies, paired watershed studies and modeling studies. This database averages these sources to find mean BMP efficiencies. Yagow et al. (2002) developed a BMP database of published literature for comparison of BMP efficacies in nutrient load and concentration. This database initially reviewed 596 articles, including only articles that offered primary research and results from field-monitored studies. After considering 596 articles for these criteria, 168 articles were incorporated into the database. After the initial formulation, the database was updated regularly until 2006. Evans et al. (2012) reached efficiency figures for different categories of BMPs after reviewing the work of Yagow et al. (2002), Ritter et al. (2001), Susquehanna River Basin (1998) and U.S. EPA (1990).

The goal of Evans et al. (2012) is not to create an in-depth literature review database, but baseline BMP efficiencies for PRedICT, a BMP assessment tool. Unfortunately, these reviews do not contain efficiencies for all BMPs across all pollutants. Whenever a study or efficacy is omitted for a certain BMP, it can be assumed that no figures were available from that particular study. Further complicating comparison is a lack of homogeneity across practice names and a lack of consistency even within a well-defined BMP. All of the aforementioned articles attempt to address this problem by assessing BMP suites instead of individual BMPs. This alone may account for some of the variability in BMP efficiency estimates.

The term "cover crop" refers to the practice of planting crops including grasses, legumes and forbs for seasonal cover and other conservation practices. Cover crops can also reduce erosion from wind and water, increase soil organic matter content, capture and recycle nutrients in the soil profile, suppress weeds and increase biodiversity (NRCS, 2013). Common examples of cover crops include ryegrass, legumes, sorghum, wheat, rapeseed and barley (EPA, 2012). Simpson et al. (2007), utilizing a weighted literature review (75% of literature review coefficients), find that the reduction efficiencies for cover crops were 26% of N loadings for coastal plains and 20% of N loadings for non-coastal plains. Merriman et al. (2009) find that cover crops reduce an average of 66% nitrogen, 67% of the total phosphorus and 70% of the total sediment in the area in which they are implemented. The Virginia Tech agricultural BMP database (Yagow et al., 2002) reports that cover crops give a phosphorus reduction of 48%. Evans et al. (2012) recommend that efficiencies of 25% nitrogen reduction, 36% phosphorus reduction and 25% sediment reduction be used when assessing the effectiveness of cover crops.

Conservation crop rotation refers to the practice of growing crops in a planned sequence on the same field. This can improve the soil quality, reduce erosion and manage the balance of nutrients (NRCS, 2013). Merriman et al. (2009) found the average BMP efficiency for conservation cover crops to be 67% for nitrogen, 60% for phosphorus and 72% for sediment. The Virginia Tech BMP database estimates the range for conservation crop rotation 6.8% efficiency for N, 39.9% efficiency for P and 38.1 to 55.4% efficiency for sediment reduction. Evans et al. (2012) recommend BMP efficiencies of 8% for nitrogen, 22% for phosphorus and 30% for sediment.

Conservation tillage refers to the practice of managing the amount, orientation and distribution of crop and other plant residue on the soil surface year round, limiting soil disturbance activities to those necessary to place nutrients, condition residue and plant crops. Tillage can take many forms including conventional till, no-till and mulch tillage. Conservation tillage is broadly defined as tillage that leaves a minimum of 30% of the soil surface covered by crop residue (NRCS, 2013). Harmel et al. (2006) compiled the results of 40 studies analyzing the effectiveness of N and P reduction using different types of conservation tillage practices in different areas of the country. The range for the median total N coefficient is 2%-82% and the range for median total P coefficient is -12% to 40% depending on the method used. Merriman et al. (2009) find that the average reduction of total P in the application area is 55%, the average reduction in total N is 53% and the average reduction of total sediment is 66%. Simpson et al. (2007) report conservation tillage reduction coefficients of 8% for nitrogen, 22% for phosphorus and 30% for sediment. The Virginia Tech BMP database (Yagow et al., 2002) finds that conservation tillage reduces nitrogen loadings by an average of 68.2% to 87.5%, phosphorus loadings by an average of 18% to 92% and sediment loadings by an average of 22.6% to 67.3% depending upon the technique. Evans et al. (2012) find that conservation tillage reduction coefficients are best estimated at 50% for nitrogen, 38% for phosphorus and 64% for sediment.

A grade stabilization structure is used to control the grade and head cutting in natural or artificial channels. These structures are used to prevent the formation or advancement of gullies. These structures improve water quality by reducing sediment and sediment bound pollutants (NRCS, 2013). The Virginia Tech BMP database (Yagow et al., 2002) find that grade stabilization structures reduce nitrogen by an average of 56.1%, phosphorus by an average of 60.4% and sediment by an average of 82.2% in areas where they are installed.

Nutrient management is a commonly utilized agricultural BMP characterized by a variety of different techniques. These techniques include varying the fertilizer form and rate, varying nutrient application methods and timing, treating soils and manure to reduce the availability and mobility of nutrients and developing a comprehensive farm-wide plan to manage nutrients from all sources (NRCS, 2013). A nutrient management plan is developed to optimize crop yields while minimizing the amount of nutrients leaching from the farm. This is achieved by finding the optimal nutrient balance so that (ideally) nutrients are neither over- nor under-applied (Evans et al., 2012). The Merriman et al. (2009) meta-analysis found the mean value of nutrient reduction coefficients for a nutrient management plan to be 10% for nitrogen and 48% for phosphorus. The Virginia Tech BMP database lists the average nitrogen reduction coefficient as 40.7% and average phosphorus reduction coefficients of -19%. Evans et al. (2012) estimate that nutrient efficiency reduction coefficients are 70% for N and 28% for P. Sediment values are not given for nutrient management plans because the plans are aimed at managing applied nutrients and therefore do not reduce sedimentation runoff.

Retirement of agricultural land refers to the practice of returning agricultural land to a state of vegetative or forested cover. This can include conversion of agricultural land to wetlands or forests (Evans et al., 2012). This can also include establishing conservation cover defined as perennial vegetative cover to protect soil and water resources on land retired from agricultural production. In many cases, the land retirement is administered through the Conservation Reserve Program (CRP). This program pays farmers yearly rent (for a contract period of 10-15 years) to remove environmentally sensitive land from agricultural production and plant species that will improve environmental health and quality (NRCS, 2013). Simpson et al. (2009) find that, in the Chesapeake Bay Watershed, converting agricultural land to wetlands has an efficiency ranging from 7%-25% depending on area characteristics, a phosphorus efficiency range of 12%-50% depending on area characteristics and a sediment efficiency of 15% regardless of area characteristics. Merriman et al. (2009) find wetlands to have an average nitrogen reduction rate of 64% and an average phosphorus reduction rate of 72%. Evans et al. (2012) estimate the coefficients for the retirement of agricultural land to have a nitrogen reduction of 95%, a phosphorus reduction of 95% and a sediment reduction of 95%.

Vegetative buffers (also referred to as riparian buffers, grassed waterways or filter strips) are permanent strips of stiff, dense vegetation established along the general contour of slopes or across concentrated flow areas (NRCS, 2013). Simpson et al. (2007) estimated that riparian forested buffers reduce total N by an average of 38%, total P by an average of 40% and total sediment by an average of 53.3% when considered over a range of land-use types. Merriman et al. (2009) found that filter strips reduce total N by an average of 54%, total P by an average of 57% and total sediment by an average of 56% in the regions in which they are applied. The Virginia Tech BMP database (Yagow et al., 2002) finds that vegetative buffers have a range of P reduction from 3.6% to 25.5% depending on the type of vegetative buffer. Evans et al. (2012) find that vegetative buffers provide reduction coefficients of 64% for nitrogen, 52% for phosphorus and 58% for sediment.

Fencing refers to the practice of constructing a barrier to facilitate the movements of animals, people or vehicles (NRCS, 2013). For the Chesapeake Bay, Wieland et al. (2009) estimate the reduction efficiencies to be 25% for total nitrogen, 30% for total phosphorus and 40% for total sediment based on suggestions from previous literature (Simpson et al., 2007). The Merriman et al. (2009) literature review finds that the mean reduction efficiencies for fencing are 78% for nitrogen, 75% for phosphorus and 83% for sediment. Evans et al. (2012) find that streambank fencing has efficiencies of 56% for nitrogen, 78% for phosphorus and 76% for sediment.

Streambank stabilization structures refer to treatments used to stabilize and protect the banks of streams or constructed channels and shorelines of lakes, reservoirs and estuaries (NRCS, 2013). Merriman et al. (2009) estimate that streambank stabilization structures have a nitrogen efficiency of 78%, a phosphorus efficiency of

76% and a sediment efficiency of 83%. Evans et al. (2012) find that streambank stabilization has nutrient and sediment efficiencies of 95%.

The wide range of reduction in BMP coefficients is not provided to suggest that BMP effectiveness cannot be determined or that these coefficients cannot be estimated for a given watershed. These variations highlight the fact that BMP efficiency is site specific and will depend on soil, topography, crops and vegetative cover, climate, management and maintenance. This variation among analysis and meta-analysis is presented to underscore the need for modeling at the watershed level. As the next section highlights, BMP effectiveness estimates have been combined with local BMP cost data and implemented in several watershed level studies to improve the efficacy of BMPs in the area.

2.3 Optimization and GIS in Determining BMP Cost Effectiveness

Cost-effective NPS reduction in agriculture relies upon the correct selection and placement of BMPs within a given watershed. Factors such as land use, soil variety, topography, hydrology, meteorology and interaction with other BMPs all determine the effectiveness of installed BMPs. Because these factors vary throughout different watersheds, site-specific BMPs are required to reduce NPS runoff in the most efficient manner. To determine which combination of BMPs is best for a given watershed, alternative BMP scenarios must be considered (Veith, 2004).

Several studies have reported the effectiveness of various BMPs at reducing nutrient loads. The amount by which a BMP reduces the nutrient loading is known as the "BMP reduction factor." These factors differ among nutrients for any given BMP and vice versa. Studies range in their assessment of the effectiveness of each BMP, largely because the scale of the test area (e.g. plot, field, farm, watershed) and aforementioned environmental factors vary greatly among studies. However, a generally accepted range of the BMP reduction factor can often be determined (Rao, 2009).

The use of GIS-based runoff simulation modeling coupled with an optimization algorithm to estimate the placement of BMPs for nutrient reduction has been explored extensively (Gitau et al., 2004; Veith et al., 2004; Kaini et al. 2012; Alminagorta et al., 2012). Simulation-based modeling incorporates scientific knowledge to quantify site and BMP specific response. Optimization allows for variation in spatial factors across a multitude of variables and circumstances. Through the use of optimization algorithms, BMP interaction as well as a range of site-dependent characteristics can be assessed (Veith, 2004).

Computer models have long been used to simulate environmental and meteorological occurrences. Arcview's GIS software provides graphical support for these simulation models and extracts data from digital maps. GIS software also prepares data in the form utilized by most simulation software (Abbaspour et al., 2007). The use of GIS software has become relatively widespread due to the inherent advantages of manipulating spatial data in GIS. The Mapshed simulation software manipulates GIS shape and grid files as well as other non-spatial data to estimate NPS runoff (Evans et al., 2012).

The term "model" refers to a set of equations or algorithms that are used to simulate a physical system. A multitude of watershed simulation models are available to water quality researchers including: the GWLF model (Haith et al., 1987), the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998), the Erosion Productivity Impact Calculator (EPIC) model (Williams et al., 1984), the Hydrologic Simulation Program Fortran (HSPF) model used by the Environmental Protection Agency (Donigian et al., 1984), the Spatially Referenced Regressions on Watershed Attributes (SPARROW) model (Smith et al., 1997), the Soil Moisture Distribution and Routing (SMDR) model (Zollweg et al., 1996) and the Long-Term Hydrologic Impact Assessment (L-THIA) model (Bhaduri et al., 2000). Models vary in their complexity and assessment capabilities. More complex models require a larger amount of data and make fewer assumptions. It is generally recommended that the simplest model that will sufficiently identify BMP placement be used. However, the model must be capable of quantifying the potential response of the given watershed to site-specific changes. In an EPA-sponsored study, Shoemaker et al. (2005) provide a comprehensive overview of more than 65 watershed modeling programs, providing detailed information about model type, level of complexity and water quality factors assessed by each model. This study found that existing models can simulate the dominant pollutant types and water bodies using available technology.

For this study, we will utilize the Generalized Watershed Loading Function-Enhanced (GWLF-E). GWLF has been utilized to predict nutrient loads in the Delaware River (Schneiderman et al., 2002) as well as evaluate BMPs in the San Jaqoiun River Valley (Cryer et al., 2001) and the Big Cypress Creek Watershed (Santhi et al., 2006). This model has also been used in watershed analysis in the Hudson River watershed (Lee et al., 2000), the NYC water supply watersheds (Schneiderman et al., 2002) and the

Chesapeake Bay watershed (Lee et al., 2000). Evans et al. integrated GWLF with economic models for cost analysis in a 2002 study of watersheds in Pennsylvania.

The use of optimization in combination with an NPS pollutant runoff model has been shown to improve BMP cost-effectiveness. Ancev (2003) determined that simulation-recommended BMP changes reduced phosphorus loadings in the Eucha-Spavinaw watershed near Tulsa, OK. Srivastava et al. (2002) demonstrated a 56% reduction in pollutant loading and a 109% increase in net profits through the use of a simulation model with an optimization algorithm. Veith et al. (2003) used a GIS model combined with a genetic algorithm to reduce NPS pollutant flows in a 1,014-ha watershed in Virginia.

Several studies have been performed about the cost of reducing pollutants in watersheds throughout the United States. In a study of the Louisiana dairy production region, Hall (2009) estimated the cost of reducing one pound of nitrogen to be $14.60, one pound of phosphorus to be $238.47 and one pound of sediment to be $0.44. The total cost of reduction in the watershed was $37.3 million. This cost occurred by adopting a combination of cover crops, conservation tillage, riparian buffer, critical area planting, nutrient management, vegetative buffer and prescribed grazing. The estimated cost per unit of pollutant with the BMPs currently adopted in the watershed was $70.51 per pound of nitrogen, $819.39 per pound of phosphorus and $1.18 per pound of sediment. The total cost of adoption for the watershed with the current suite of BMPs was $107.7 million.

For two watersheds in Indiana, Arabi et al. (2006) found that combining a watershed-modeling tool with an optimization procedure provided improved cost efficiencies. In the first watershed included in the study, Arabi et al. (2006) determined that the same amount of pollutants could be reduced for a cost of $165,370 as were currently being reduced for a cost $414,690. For the same watershed, this study also determined that for the cost of $414,690, nearly three times the amount of pollutants could be removed than under a targeting scenario with the same cost. For the second watershed included in the study, Arabi et al. (2006) determined that five times the amount of pollutants could be reduced using an optimization model in place of a targeting model for the cost of $60,610.

Maringati et al. (2011) also used an optimization procedure in concert with a watershed-modeling tool to estimate pollution in north central Indiana. Their goal was to achieve maximum pollutant reduction while minimizing cost. They found a range of cost solutions from $25-$275/ha that provided pollutant reductions of 23%-49% for nitrogen, 37%-76% for phosphorus and 45%-83% for sediment.

Alminagorta et al. (2012) use a linear optimization program to determine the most cost-effective BMPs for phosphorus reduction in Echo Reservoir, Utah. For each of the three sub-watersheds included in this study (Chalk Creek, Weber River Below and Weber River Above Wanship), it is determined that nutrient management is a cost-effective BMP. Protected grazing land and streambank stabilization are also found to be cost-effective BMPs in Chalk Creek. The total cost of reduction in Chalk Creek is $367,000 for a total phosphorus reduction of 4.4 (metric) tons and a unit cost of reduction of $83.81/kg. The total cost of reduction in Weber River Below Wanship is $158,000 for a total reduction of 0.9 tons and a unit reduction cost of $167.73/kg. The total cost of reduction for Weber River Above Wanship is $460,000 for a total reduction of 2.7 tons of phosphorus and a unit reduction cost of $167.45/kg.

Gitau et al. (2004) examined the cost of reducing phosphorus loading at the farm level using an optimization procedure coupled with a GA and a watershed-modeling tool. They found an optimal solution using four BMPs, contour strip cropping, a nutrient management plan, riparian forest buffer and a strip cropping nutrient management plan combination. The target phosphorus reduction set for the optimization procedure was 60% of the 1,471 kg of estimated runoff under a scenario with no BMPs. The total phosphorus reduced in this study was 884 kg for a cost of $1,430. The unit reduction cost for phosphorus under this BMP scenario was $1.62/ kg.

Kaini et al. (2012) use a GA and a watershed modeling tool to estimate costs for 20%, 40% and 60% pollutant load reductions for a sub-watershed in Illinois. For a 20% load reduction scenario, 552,586 kg of nitrogen, 108,524 kg of phosphorus and 20,978 tons of sediment are reduced for a cost of $1.036 million. The unit cost of reduction under this scenario is $1.87/kg for nitrogen, $9.55/kg for phosphorus and $49.39/ton for phosphorus. For a 40% load reduction scenario, 420,760 kg of nitrogen, 81,691 kg of phosphorus and 21,294 tons of sediment are reduced for $1.494 million. The unit cost of reduction under this scenario is $3.55/kg for nitrogen, $18.29 kg for phosphorus and $70.16 per ton of sediment. Under a 60% reduction scenario, 296,247 kg of nitrogen, 57,865 kg of phosphorus and 20,398 tons of sediment were reduced for a cost of $7.461 million. The unit cost of reduction under this scenario is $25.18/kg of nitrogen, $128.94/kg of phosphorus and $365.77/ton of sediment.

Chapter 3. Data and Methodology

3.1 Data and Study Area

3.1.1 Study Area

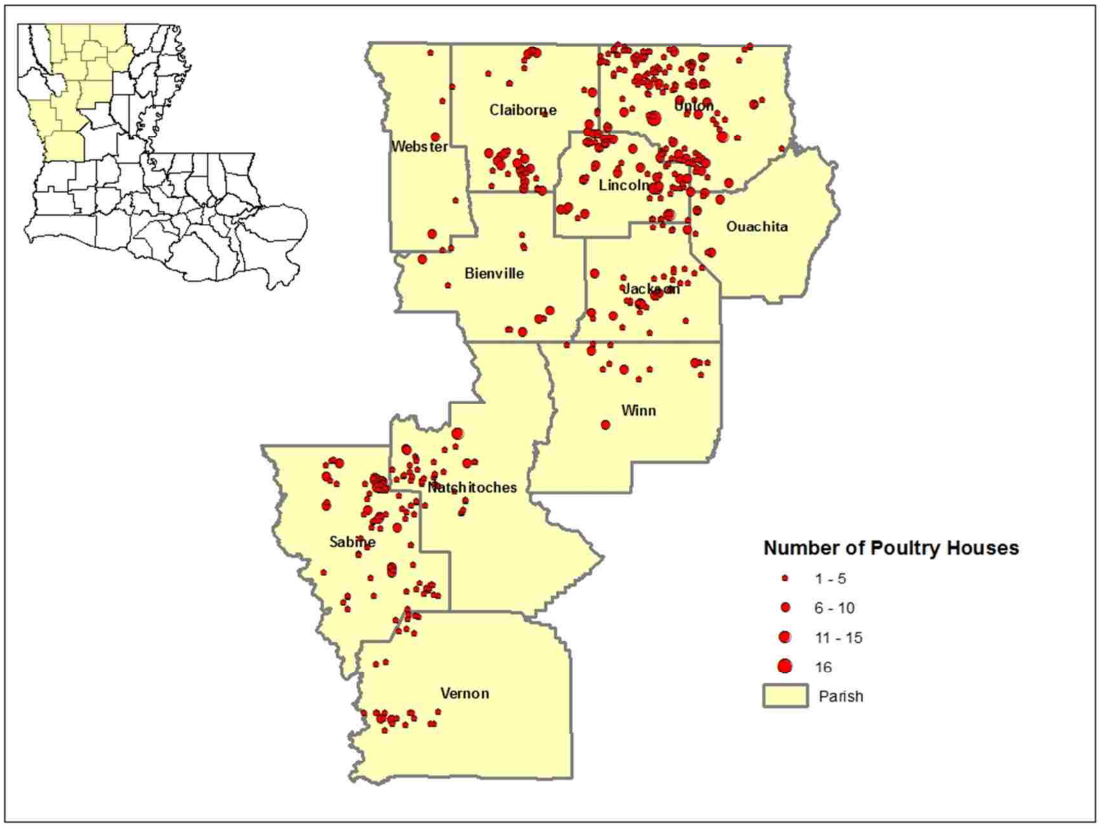


Figure 3.1 Louisiana Broiler Production Region

This study investigates runoff from agriculture in the broiler production region of Louisiana, picture in Figure 3.1. This region, located in north central and northwestern Louisiana, has a high concentration of broiler production. Poultry production is Louisiana's largest animal industry. It contributes $1.5 billion to the state's economy. Broiler production makes up a large portion of Louisiana's poultry production industry. In 2012, broiler producers produced 912.7 million pounds of broiler meat with a gross farm value of $876.1 million (LSU AgCenter, 2012). Louisiana parishes with a large concentration of broiler production include Bienville, Claiborne, Jackson, Lincoln, Natchitoches, Ouachita, Red River, Sabine, Union, Vernon, Webster and Winn. These parishes form the region known as the Louisiana Broiler Production Region (LBPR). Due to the structure of the underlying watershed, data on Bossier, Caldwell, De Soto, Grant and Rapides parishes was also included. The tributaries in this region are part of the Ouachita River Basin, which feeds the Mississippi River. This study area was chosen because it has several watersheds from the Louisiana DEQ's list of priority watersheds and has not yet been comprehensively studied with respect to BMPs (LDEQ, 2013).

From within the study area, we selected the Ouachita River Basin. This basin is located primarily within the broiler production region and contains several impaired waterways. The main water body in this basin is the Ouachita River. The Ouachita River's source is found in the Ouachita Mountains located in west-central Arkansas. The Ouachita River flows through northern Louisiana and empties into the Tensas and Black Rivers, which feed the Red River, which in turn feeds the Mississippi River. The Ouachita River Basin covers 16,100 kilometers of Louisiana. The land in this area is primarily utilized for agriculture and forestry, with the agricultural lands lying in the flat Mississippi flood plain and the forested lands lying in the hills between the Red River and Ouachita River.

Within the Ouachita River Basin, one watershed from the LDEQ's list of priority watersheds has been selected for analysis. The focus of this study is the Lower Ouachita (HUC: 08040207) sub-basin. The Lower Ouachita lies in Caldwell, Catahoula, Concordia, Jackson, La Salle, Morehouse, Ouachita and Union parishes in northern Louisiana. This sub-basin contains several impaired watersheds that lie within the LBPR. Within the Lower Ouachita sub-basin we chose to focus on the Cheniere Creek (Figure 3.2) (HUC: 0804020701) and Bayou Desiard (Figure 3.3) (HUC: 0804020702) watersheds. These water bodies are listed as impaired by the EPA and lie entirely within the Louisiana broiler production region (EPA, 2013).

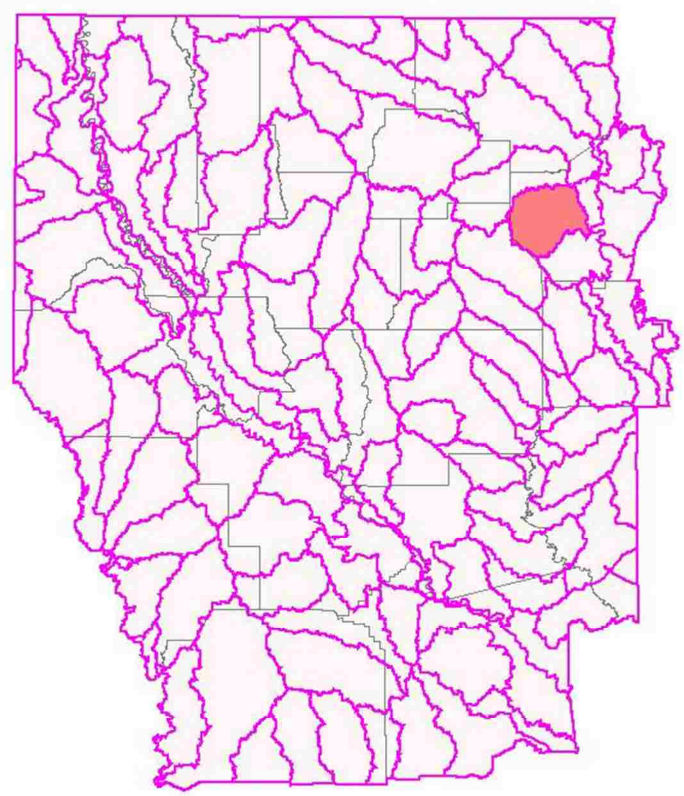


Figure 3.2 Map of Cheneire Creek Watershed

The Cheniere Creek watershed, highlighted in Figure 3.2, is primarily located in Ouachita Parish with a small portion in Jackson Parish. It covers an area of 38,800 hectares and centers around Cheniere Creek, which flows between the Ouachita River and Cheniere Break Lake. The crop production area in this watershed measures 5,492 hectares with a streambank length of 6,700 meters in agricultural land. While Cheniere Creek does appear on the EPA's list of impaired watersheds, no TMDL has been determined for this watershed. The EPA has, however, determined that one of the causes of impairment in this watershed is organic enrichment and oxygen depletion. This can be reduced by adopting practices that reduce nutrient and sediment loadings in the waterbody.

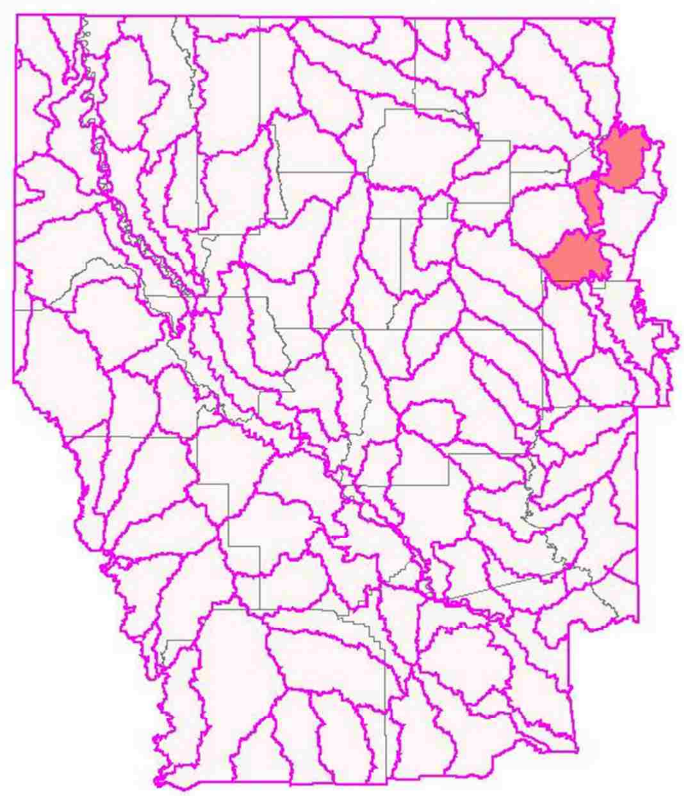


Figure 3.3 Map of the Bayou Desiard Watershed

The Bayou Desiard watershed, highlighted in Figure 3.3, is also primarily located in Ouachita Parish with small portions in Jackson and Caldwell parishes. It covers an area of 56,806 hectares and centers around Bayou Desiard and Lake Bartholomew**.** The crop production area in the watershed measures 10,629 hectares with 42,000 meters of waterfront land. Both the LDEQ and EPA have listed Bayou Desiard as an impaired waterway. Unlike Cheniere Creek, Bayou Desiard has an established TMDL. The TMDL asserts that Bayou Desiard does not meet fish and wildlife standards. The cause of impairment has been listed as low dissolved oxygen levels as well as organic enrichment. Further studies have shown that all of these loadings are the result of NPS loadings with none of the loadings resulting from PS polluters.

3.1.2 GIS Layers and Cost Data

Mapshed, the GIS based watershed modeling tool used to simulate watershed characteristics, requires several data layers to estimate nonpoint source loading and BMP effectiveness on a given watershed. These GIS layers were collected from a number of sources and transformed in order to meet the specifications of the program.

Several shape (or vector) and grid layers are required by Mapshed. The Basin layer shows the boundaries of one or more watersheds where the modeling is being performed. This layer is acquired from the Louisiana water mapping service (http://sslmaps.tamu.edu/website/srwp/Louisiana/viewer.htm) and has been clipped so that only the portions of watersheds in Louisiana are assessed. The county layer is a polygon layer, which shows the parish boundaries and is not used to perform any calculations. The land use/cover layer is a grid layer, which uses 16 distinct land use/cover types to help estimate nutrient flows throughout the watershed. These layers were attained from the Louisiana GIS CD (http://atlas.lsu.edu). The stream layer contains line features of stream segments for the study area. The stream layer was acquired from the USGS. The surface elevation (topography) layer is a grid layer, which is used to calculate slope-related data used in the model. It has been obtained from the Louisiana statewide GIS server (\\gid-store.lsu.edu\gis). The physiographic province layer contains areas with different hydraulic parameters. These parameters are warm rain erosion rate, cool rain erosion rate and groundwater recession rate. This layer was digitized from a USGS map of physiographic regions throughout Louisiana. The layers listed above were all obtained in the format required by Mapshed. However, several layers were obtained in a format not compatible with Mapshed and were manipulated in order to meet with Mapshed's formatting requirements.

The animal feeding operation (AFO) layer contains information on the location of farms as well as animal populations by type. Point shape files contain the location of poultry houses and dairy farms. The poultry houses were digitized from a DOQQ file provided as a base map in ArcGIS 10.3. The dairy farm locations were obtained from the Department of Health and Hospitals. Animal totals were obtained from the LSU Agricultural Summary's five-year summary, which provides agricultural data for the years 2006-2010. The summary provides yearly totals, which are then averaged over five years. Animal totals are averaged over a five-year period to minimize the effect of single year market fluctuations, which may drastically alter the number of animals in a parish for an individual year. We selected the range of 2006-2010 because it represents the most current period in which weather data was available for the selected watershed.

The soil layer contains information on various soil properties such as hydraulic group, erodibility factor and water holding capacity. The map of soil type and soil area was obtained from the Louisiana GIS CD. The hydraulic group, erodibility factor and water holding capacity were procured from Louisiana state soil surveys (which contain soil information by parish). Soil areas often contain more than one soil type. For each soil area, the three soil properties listed above are calculated by multiplying the properties of the individual soil types by the percentage of each soil in the soil area. The percentages of soil types in a soil area were also acquired from the Louisiana state soil survey. A soil grid layer, Soil Phosphorus (Soil-P), is used to estimate the phosphorus content of sediment runoff to nearby waterways. This layer was obtained from the soils lab at the LSU Department of Plant, Environmental and Soil Sciences.

The weather layer contains point layers of the location of each individual watershed. In this study, eight weather stations are included in the model. Each weather station is linked to a table, which contains data on maximum and minimum temperatures as well as precipitation for that weather station, for the longest time period during which data is available. If more than one weather station is within the watershed, the mean daily temperature and precipitation are used. If no weather stations are within a watershed, the means of the two closest weather stations to that watersheds center are used. Data for this layer were obtained from the National Ocean and Atmospheric Administration's (NOAA) online climatic database (http://www.ncdc.noaa.gov/cdo-web/search). Mapshed requires that data be consecutive for every day of the year with no missing values. In cases where NOAA data contained missing values, estimates were made by averaging the previous and next day's totals. Temperature data were multiplied by 0.18 and then added to the number 32 [(temp*9/50)+32] to change tenths of degrees centigrade into degrees Fahrenheit. Precipitation was divided by 254 to change tenths of a millimeter into inches [prcp/(2.54*100)].

Cost data were obtained from data the NRCS provided on cost share payments made via the Environmental Quality Incentives Program (EQIP) to recipients in Louisiana in 2013. In many cases, one type of BMP may have more than one relevant cost associated with it. For BMPs with multiple relevant costs, an average of all relevant costs in the area is taken. This is consistent with the GWLF-E model, which takes into account the range of different practices that may fall under a single BMP heading. Figures obtained from the NRCS were often in acres (with respect to farmland) and linear feet (with respect to streambanks). Where applicable, cost values given in acres were transformed into hectares by multiplying the values by 2.47, and cost values given in linear feet were multiplied by 3.28 to put them in terms of meters.

Grade stabilization structures present a special case because they are costed and applied in terms of individual structures rather than on a per acre basis. To address this and allow grade stabilization to be compared to other BMPs, they are prorated on a per-hectare basis. To achieve this, it is assumed that, on average, four grade stabilization structures will be applied every 100 acres. This is consistent with observed behavior in the area and confirmed by a Louisiana NRCS agent. To calculate the per hectare cost, the average cost of one grade stabilization structure is divided by 25 to spread the cost over the 25 acres that the grade stabilization structure covers. The per-acre cost is then multiplied by 2.47 to put the cost figure in terms of hectares. Costs for all of the BMPs investigated in this study can be found in Table 3.1.

Table 3.1 BMP cost per land unit

BMP	$/ hectare	$/ meter
Cover Crop	$182.32	-
Conservation Tillage	$71.93	-
Conservation Crop Rotation	$26.82	-
Grade Stabilization Structure	$363.65	-
Nutrient Management	$41.57	-
Agland Retirement	$152.98	-
Vegetative Buffer	-	$18.88
Fencing	-	$5.62
Streambank Stabilization	-	$86.38

3.2 Watershed Modeling

Nonpoint source pollution from agriculture is recognized as the leading cause of water impairment in the United States. Due to its diffuse nature, NPS pollution sources are difficult to detect and costly to monitor. BMPs have been devised, through years of development, to mitigate NPS pollution; however, correct spatial placement of BMPs is essential for pollution mitigation. Moreover, determining the most cost-effective combination of BMPs to reach predetermined daily loadings is essential when dealing with agricultural producers and public policy makers on ever-decreasing budgets.

To aid in determining the spatial placement and most cost-effective combination of BMPs to meet pollution reduction targets, watershed simulation models have been developed. These models range in their complexity, but all of them require broad temporal and spatial data that must be assembled, analyzed and interpreted. Computer modeling has seen significant improvements in the past several decades, with increases in computing technology and the development of GIS software. These models are now recognized as essential tools for NPS pollution mitigation.

The Pennsylvania Department of Environmental Protection has developed one such watershed model in concert with Pennsylvania State University to enable NPS simulation in Pennsylvania. Though originally developed for Pennsylvania, the model was designed to be adapted to other states and geographic regions. This GIS based modeling program is known as the Generalized Watershed Loading Function-Enhanced (GWLF-E) and is an updated version of early AVGWLF and GWLF models. AVGWLF has been updated and renamed Mapshed. In addition to updating AVGWLF, the latest version (Mapshed) runs in an open source GIS program named Map Windows. Older versions of AVGWLF utilized ArcView's GIS software, which is expensive. For this project, we used Arcview GIS 10.3 to format the data, as it allows more flexibility than Map Windows and was available via Louisiana State University's GIS laboratory. The original program, developed for TMDL projects in Pennsylvania, has been adapted for watersheds in the LBPR.

The procedure used in the GWLF-E phase of this research are as follows: (1) Identify the parishes in the production region which overlay the related watershed, (2) gather environmental and demographic data (weather, soil type, AFOs, etc.) for the watershed, (3) reformat and input compiled data into GWLF-E computer module using Arcview GIS, (4) identify impaired watersheds in the LBPR and (5) simulate nutrient and sediment runoff at different levels of BMP adoption throughout the selected watersheds.

GWLF-E is used in place of costly onsite monitoring to simulate phosphorus, nitrogen and sediment runoff. Additionally, GWLF-E contains algorithms to simulate pathogen loadings. GWLF-E is a distributed/ lumped parameter watershed model, meaning that it is distributed in surface loading, considering various land use cover scenarios but a lumped parameter model in sub-surface loading. The model is continuous with respect to weather, utilizing daily inputs. Erosion and sediment yield calculations are estimated on a monthly basis and combined with transport capacity, based on watershed size and daily runoff, to determine sediment loadings (Evans et al., 2012). Dissolved phosphorus and nitrogen coefficients are applied to surface runoff to determine surface nutrient losses. Subsurface losses are calculated by using phosphorus and nitrogen coefficients for shallow groundwater. These monthly loadings are then averaged into yearly loadings, which are utilized to determine average loadings over the entire 10-year period.

This analysis focuses on two watersheds in the Lower Ouachita sub-basin, both of which lie in the LBPR. The EPA lists both of these watersheds as impaired. The data layers for each watershed are analyzed individually for spatial accuracy. Mapshed utilizes these data layers to create input files for use in the GWLF-E model over a given time period and growing season. For this study, the years 2001-2010 were selected for the

Chenerie Creek watershed and the years 2003-2012 were selected for the Bayou Desiard watershed. These are the most current ten-year periods for which all necessary data are available for each watershed. The crop-growing season is selected as April through October, which is consistent with the crop-growing season in Louisiana. GWLF-E takes these input files and simulates the runoff of sediment and nutrients (nitrogen and phosphorus) for a watershed using the process detailed above.

Coefficients for both wet and dry years are calculated to estimate the effect that drought years and years with surplus rainfall have on runoff and BMP effectiveness. Drought and surplus rainfall are determined by summing the total amount of rainfall in each watershed for a given year. The total rainfall for each year is then compared to total rainfall for all other years in the study period. For the Chenerie Creek watershed, 2004 was the year with the highest rainfall with 68.37 inches of rainfall and 2010 was the year with the lowest rainfall with 36.11 inches of rainfall. For the Bayou Desiard watershed, 2004 was the year with the highest rainfall with 70.13 inches of rainfall and 2005 was the year with the lowest rainfall with 33.25 inches of rainfall.

To estimate BMP effectiveness, Mapshed’s BMP land coverage scenario editor is utilized. This scenario editor allows the manipulation of the area of agricultural land or streambank length (depending on the nature of the BMP) that is designated to a specific BMP. Land coverage is manipulated as a percentage of existing farmland, which is calculated by Mapshed based on input data. Streambank based BMPs are manipulated based on portions of agricultural stream length. This parameter can be manipulated by the tenth of a kilometer; however, for consistency, agricultural stream length application is manipulated as a percentage of total agricultural stream length. The phosphorus, nitrogen and sediment reduction parameters for each BMP can be manipulated using Mapshed's rural BMP efficiency editor. In addition, estimates were obtained for a 10% increase in each load reduction coefficient and a 10% decrease for each load reduction coefficient for each BMP, thus creating a range of reduction. One hundred and fifty simulations are run for each BMP in each watershed. This allows each BMP to be simulated at 2% steps in land or stream coverage scenarios, for normal, increased and decreased BMP reduction parameters. Each simulation in Mapshed yields an output summary in .csv (spreadsheet) format. These spreadsheet summaries contain, among other statistics, average monthly loading estimates of phosphorus, nitrogen and sediment. Output spreadsheets are reformatted using an R program that results in a summary spreadsheet for each BMP with phosphorus, nitrogen and sediment loadings at different levels of BMP adoption. A separate summary spreadsheet is created for each BMP at 10% increased reduction rates and 10% decreased reduction rates.

3.3 BMP Reduction Coefficients and Optimization Programming

BMP effectiveness is determined by a "BMP reduction coefficient." These coefficients are representative of the amount of nutrient or sediment reduction provided by a one unit (hectare for field based and meter for stream-based BMPs) increase in BMP adoption. These coefficients are used to quantify BMP effectiveness in the optimization program.

To obtain effectiveness coefficients, regression analysis is performed on the simulation output. Each simulation output is subtracted from a baseline simulation with no BMP coverage to obtain the amount of nutrient reduction at each level of adoption for each BMP. The amount of total agricultural land or streambank length is calculated at 2% intervals, creating a list of corresponding land coverage for each BMP. The amount of nutrient reduction for each level of adoption is then regressed on the amount of land associated with its coverage level. This yields the nutrient reduction coefficient, which indicates how many kilograms (or metric tons for sediment) are reduced per unit of land.

An optimization model is then utilized to determine the ideal land coverage, at the least cost, for different levels of pollutant reduction. The linear programming procedure is detailed below in Figure 3.4. The goal of this optimization program is to minimize cost while maximizing pollutant reduction. To achieve this, constraints are placed on scarce resources as well as minimum requirements for nutrient reduction rates. Phosphorus was chosen as the primary nutrient for reduction because it is recognized as the primary chemical contributing to water pollution, eutrophication and hypoxia in the Gulf of Mexico. Nitrogen and sediment reduction were also targeted as secondary goals. In each watershed (as well as in wet and dry years), phosphorus reductions of 10%, 15%, 20% and 30% (where feasible) were analyzed. Maximum feasible reductions (determined as a percentage of total phosphorus reduction) were also considered across both watersheds.

Additional constraints were placed on maximum land usage for each BMP. Agricultural land (Agland) based BMPs are restricted to agricultural land in the watershed, and streambank BMPs are restricted to the total stream embankments in **agricultural areas (these figures are taken from GWLF-E, which derives them from the**

$$Min \sum_{i=1}^{j} c_i B_i$$

$Subject\ to,$

$$Nitrogen: \sum_{i=1}^{j} n_i B_i \geq 0$$

$$Sediment: \sum_{i=1}^{j} s_i B_i \geq 0$$

$$Phosphorus: \sum_{i=1}^{j} p_i B_i \geq \alpha I_p$$

$$Other: \textstyle\sum_{i=1}^{j} o_{i,k} B_i \leq R_k, for\ all\ k = \ 1, \dots \dots, K$$

$$B_i \geq 0$$

$where: c_i = Cost\ of\ BMP\ i$

$B_i\ = BMP\ i$

$c_i = Cost\ of\ BMP\ i$

$n_i = Nitrogen\ reduced\ by\ BMP\ i$

$s_i = Sediment\ reduced\ by\ BMP\ i$

$p_i = Phosphorus\ reduced\ by\ BMP\ i$

$\alpha = Some\ fraction\ of\ total\ phosphorus$

$I_p = Total\ phosphorus\ loading$

$o_{i,k} = Land\ unit\ covered\ by\ BMP\ i\ for\ land\ use\ k$

$R_k = Maximum\ allowable\ land\ useage\ for\ use\ k$

Figure 3.4 Optimization Procedure

land use cover map). Agland retirement was further restricted to 10% of all agricultural land, as it is impractical to retire too much agricultural land in one area. Furthermore, it was found that approximately 7% of farmland in the area had been placed under a conservation reserve program in the year 2007 (USDA, 2013). Vegetative buffer was restricted to 30% of all streambank area in agricultural lands, as an adoption rate of greater than 30% was deemed to be highly unlikely by local NRCS agents.

Chapter 4. Results

Results for the most cost-effective set of BMPs are presented for the two watersheds under normal, wet and dry weather scenarios. Increasing targeted pollutant reduction levels also affected the ideal combination of BMPs as well as the overall costs of implementation. As expected, decreasing the efficiency of every BMP resulted in higher costs and lower levels of pollutant reduction. Increasing BMP efficiency had the opposite effect. Wet years produced more runoff and generally resulted in higher amounts of nutrient and sediment load reduction from BMP adoption. Dry years produced less overall runoff and generally resulted in lower amounts of nutrient and sediment load reduction from BMP adoption.

4.1 Chenerie Creek

The most cost-effective BMPs in Chenerie Creek, at a target phosphorus reduction rate of 10%, were nutrient management plan and vegetative buffer. The baseline pollutant loading in this watershed with no BMP adoption was 394.4 metric tons (all “tons” referred to in the results and conclusion sections are metric tons) of nitrogen, 48.8 tons of phosphorus and 1,400 tons of sediment. The total cost of implementing these BMPs was $68,346. This resulted in a total nitrogen reduction of 13.2 tons, a total phosphorus reduction of 4.8 tons and a total sediment reduction of 1,800 tons. The cost per kilogram of reduction for nitrogen was $5.13, $14.30 for phosphorus and $20.59 per ton for sediment. Calculations for sediment reduction do not include the cost of nutrient management, which does not reduce sediment runoff. The total land utilized in this BMP scenario was 700 ha (used for nutrient management) and two kilometer (used for vegetative buffer). Examining scenarios with 10% reduced and 10% increased BMP efficiency increases the total cost of implementation to $89,900 under the reduced efficiency scenario and reduced the cost to $56,150 under the increased efficiency scenario. The total amount of pollutants reduced was 13.4 tons of nitrogen, 4.8 tons of phosphorus and 1,600 tons of sediment under the reduced efficiency scenario and 13.1 tons of nitrogen, 4.8 tons of phosphorus and 2,000 tons of sediment under the increased efficiency scenario. The cost per unit of reduction under the decreased efficiency scenario is $6.19/kg for nitrogen, $17.35/kg for phosphorus and $22.73/ton for sediment. For an increased BMP efficiency scenario, the cost per unit of reduction was $4.27/kg for nitrogen, $11.75/kg for phosphorus and $18.81/ton for sediment. The ideal combination of BMPs remains unchanged with land coverage being increased to 1,100 ha under a nutrient management plan for the reduced scenario and decreased to 400 ha under a nutrient management plan for an increased scenario. A summary of total adoption costs at different phosphorus target levels for standard, reduced and increased BMP efficiency can be found in Table 4.1. A summary of BMPs adopted and agland usage can be found in Table 4.2. For all tables, results for 10% decreased coefficients are represented by D10 and 10% increased coefficients are represented by U10.

For different levels of phosphorus reduction, the price per kg of each nutrient varies. As phosphorus reduction increases, so does the price per kg. The most cost-effective BMP in this watershed, on a per hectare basis, is vegetative buffer. However, at the 10% reduction level, given the vegetative buffer implementation constraint of 30% of total streambanks, vegetative buffer is not capable of meeting the reduction goal. Because of this, nutrient management plan also enters the solution, even though it is less cost efficient on a per hectare basis. As the proportion of nutrient management to vegetative buffer begins to increase, the price per kg of reduction also increases. At lower target levels of phosphorus reduction, sediment is only reduced by one BMP (nutrient management plan) and the price per ton remains constant. Moving from 20% to 30% phosphorus reduction scenarios, the total cost increases by 636% while the total phosphorus reduction increases by only 50%. This price spike is caused by several less cost-effective BMPs entering the model.

Table 4.1 Summary of Total Pollutant Reduction Costs at Different Levels of Targeted Phosphorus Reduction for Chenerie Creek

Scenario	Cost ($1000)	Reduction			Cost/ Unit		
		N (tons)	P (tons)	S (1000 tons)	N ($/kg)	P($/kg)	S($/ton)
10%	68.3	13.1	4.8	1.8	$5.14	$14.30	$20.59
10% D10	82.9	13.4	4.8	1.7	$6.19	$17.35	$22.73
10% U10	56.2	13.1	4.8	2.0	$4.27	$11.75	$18.81
15%	136.3	20.7	7.2	1.8	$6.58	$19.02	$20.59
15% D10	157.6	20.7	7.2	1.7	$7.61	$22.00	$22.73
15% U10	118.4	20.6	7.2	2.0	$5.74	$16.52	$18.81
20%	204.2	28.1	9.6	1.8	$7.26	$21.37	$20.59
20% D10	232.4	28.0	9.6	1.6	$8.29	$24.32	$22.73
20% U10	180.7	28.1	9.6	2.0	$6.42	$18.91	$18.81
30%	1,538.8	41.6	14.3	9.4	$37.01	$107.35	$157.73
30% U10	713.5	44.6	14.3	5.4	$15.98	$49.78	$102.33
Max (31%)	1,873.8	41.9	14.8	11.2	$44.77	$126.51	$166.15
Max D10 (28%)	1,900.8	37.6	13.4	10.3	$50.57	$142.08	$184.59
Max U10 (34%)	1,900.7	45.8	16.2	12.4	$41.50	$117.00	$152.63

Table 4.2 Summary of BMPs Adopted and Land Use in Chenerie Creek

Scenario	Grade Stabilization (1000 ha)	Nutrient Management (1000 ha)	Agland Retirement (1000 ha)	Vegetative Buffer (km)	Fencing (km)
10%	0.0	0.7	0.0	2.0	0.0
10% D10	0.0	1.0	0.0	2.0	0.0
10% U10	0.0	0.4	0.0	2.0	0.0
15%	0.0	2.4	0.0	2.0	0.0
15% D10	0.0	2.9	0.0	2.0	0.0
15% U10	0.0	1.9	0.0	2.0	0.0
20%	0.0	4.0	0.0	2.0	0.0
20% D10	0.0	4.7	0.0	2.0	0.0
20% U10	0.0	3.4	0.0	2.0	0.0
30%	3.7	1.3	0.5	2.0	4.7
30% U10	1.1	3.8	0.5	2.0	4.7
Max (31%)	4.7	0.2	0.5	2.0	4.7
Max D10 (28%)	4.8	0.1	0.5	2.0	4.7
Max U10 (34%)	4.8	0.1	0.5	2.0	4.7

In Chenerie Creek, the optimal combination of BMPs to achieve a 10% phosphorus reduction level is nutrient management plan and vegetative buffer. Vegetative buffer is constrained to two km by the vegetative buffer constraint, while nutrient management continues to be implemented, at higher and higher levels, until a 30% reduction scenario is desired. To achieve a 30% reduction goal, more BMPs including grade stabilization, agland retirement and streambank fencing also enter the solution, while the amount of land devoted to nutrient management decreases. These BMPs enter the optimal solution because, as the target phosphorus amount increases, the land constraint becomes binding, and BMPs with higher per hectare reduction coefficients enter the solution, despite being less cost efficient (on a per hectare basis). This causes the price spike at the 30% adoption level noted in Table 4.1.

Table 4.3 highlights the shadow prices for the right hand side constraints. The shadow price for phosphorus at each reduction level indicates the price of reducing one extra kilogram of phosphorus. This price remains constant for 10%-20% reduction scenarios, as the price to increase a kilogram of phosphorus reduction is always dependent on increasing only one BMP, nutrient management. Over this range, a one meter increase in vegetative buffer area is always decreasing the same amount of nutrient management so the shadow price for relaxing the vegetative buffer constraint also remains constant. As less cost-effective BMPs enter the solution at the 30% reduction level, shadow prices begin to change. The price of reducing an extra kilogram of phosphorus increases from $28.44 to $701.27. This price change is caused by the introduction of less cost-effective BMPs and the reduction of a more cost-effective BMP, nutrient management, as the total agland constraint becomes binding. The shadow price for vegetative buffer also increases, as an extra meter of vegetative buffer would reduce reliance on less cost-effective BMPs.

Reduced costs for each BMP, highlighted in Table 4.4, show the cost of alternatives to the optimal solution. For instance, if one hectare of cover crops is forced into the solution, the total cost will increase by $136.79. The reduced costs also reveal which BMPs are likely to enter the model at greater reduction rates as well as indicating cost-effectiveness at each reduction level. This can change at different reduction levels as land constraint becomes more binding and model focus shifts from per hectare cost-effectiveness to per hectare load reduction effectiveness. An example of this is grade stabilization, which is much less cost-effective at 20% phosphorus reduction rates than conservation crop rotation, but more effective at the 30% reduction level. This change occurs as the total agland constraint becomes binding and grade stabilization is selected for its higher per hectare reduction coefficient. Per hectare reduction coefficients can be found in appendix A.

Table 4.3 Shadow Prices of Constraints in Chenerie Creek

Scenario	Phosphorus	Agland	Streambank	Agland Retirement	Vegetative Buffer
10%	$28.44	$0.00	$0.00	$0.00	-$33.59
10% D10	$31.28	$0.00	$0.00	$0.00	-$33.11
10% U10	$26.07	$0.00	$0.00	$0.00	-$34.03
15%	$28.44	$0.00	$0.00	$0.00	-$33.59
15% D10	$31.28	$0.00	$0.00	$0.00	-$33.11
15% U10	$26.07	$0.00	$0.00	$0.00	-$34.03
20%	$28.44	$0.00	$0.00	$0.00	-$33.59
20% D10	$31.28	$0.00	$0.00	$0.00	-$33.11
20% U10	$26.07	$0.00	$0.00	$0.00	-$34.03
30%	$701.27	-$983.66	-$0.15	-$996.60	-$1,274.89
30% U10	$621.18	-$949.14	-$0.02	-$876.65	-$1,241.86
Max (31%)	$701.27	-$983.66	-$0.15	-$996.60	-$1,274.89
Max D10 (28%)	$805.09	-$1,028.45	-$0.34	-$1,035.62	-$1,318.74
Max U10 (34%)	$621.18	-$949.14	-$0.02	-$876.65	-$1,241.86

Table 4.4 Reduced Costs of BMPs in Chenerie Creek

Phosphorus Reduction	Cover Crops	Conservation Tillage	Conservation Crop Rotation	Grade Stabilization	Nutrient Management	Agland Retirement	Vegitative Buffer	Fencing	Streambank Stabilization
10%	$136.79	$51.89	$17.71	$309.02	$0.00	$66.48	$0.00	$5.39	$86.09
10% D10	$137.25	$51.89	$17.81	$309.56	$0.00	$66.84	$0.00	$5.39	$86.10
10% U10	$136.41	$51.89	$17.64	$308.56	$0.00	$69.94	$0.00	$5.38	$86.10
15%	$136.79	$51.89	$17.71	$309.02	$0.00	$66.48	$0.00	$5.39	$86.09
15% D10	$137.25	$51.89	$17.81	$309.56	$0.00	$66.84	$0.00	$5.39	$86.10
15% U10	$136.41	$51.89	$17.64	$308.56	$0.00	$69.94	$0.00	$5.38	$86.10
20%	$136.79	$51.89	$17.71	$309.02	$0.00	$66.48	$0.00	$5.39	$86.09
20% D10	$137.25	$51.89	$17.81	$309.56	$0.00	$66.84	$0.00	$5.39	$86.10
20% U10	$136.41	$51.89	$17.64	$308.56	$0.00	$69.94	$0.00	$5.38	$86.10
30%	$43.22	$561.58	$785.77	$0.00	$0.00	$0.00	$0.00	$0.00	$79.51
30% U10	$37.47	$543.69	$757.16	$0.00	$0.00	$0.00	$0.00	$0.00	$79.83
Max (31%)	$43.22	$561.58	$785.77	$0.00	$0.00	$0.00	$0.00	$0.00	$79.51
Max D10 (28%)	$50.69	$584.78	$823.26	$0.00	$0.00	$0.00	$0.00	$0.00	$79.48
Max U10 (34%)	$37.47	$543.69	$757.16	$0.00	$0.00	$0.00	$0.00	$0.00	$79.83

4.2 Bayou Desiard

In Bayou Desiard, the most cost-effective BMP for the targeted phosphorus reduction goal of 10% was nutrient management**.** Total baseline loadings for each pollutant with no BMP adoption were 561.2 tons of nitrogen, 54.6 tons of phosphorus and 29,100 tons of sediment. The total cost to achieve a 10% reduction using nutrient management was $137,000. The amount of pollutant reduction achieved at this cost was 16.3 tons of nitrogen, 5.4 tons of phosphorus and zero tons of sediment. The cost per kg of nitrogen was $8.43 and the cost per kg of phosphorus was $25.23. Under this phosphorus reduction scenario, 3,300 ha of land were placed under a nutrient management plan. The maximum possible phosphorus reduction in Bayou Desiard was 56%. The total cost to achieve this level of phosphorus reduction was $3.9 million. The maximum amount of pollutant reduction that could occur in Bayou Desiard, given the constraints of the model, was 83.9 tons of nitrogen, 30 tons of phosphorus and 17,200 tons of sediment. The BMPs selected to achieve this level of reduction were grade stabilization, nutrient management, agland retirement, vegetative buffer, fencing and streambank stabilization. A summary of total adoption costs at different phosphorus target levels for standard, reduced and increased BMP efficiency is presented in Table 4.5. BMP adoption at different target levels of phosphorus reduction is summarized in Table 4.6.

As in Chenerie Creek, when phosphorus target levels (and overall pollutant reduction levels) increase, the cost of total reduction also increases. These costs will rise in equal proportion to the amount of pollutant reduced as long as the suite of BMPs selected remains the same. Since the proportion of reduction and costs are increased at the same rate, the unit cost of reduction remains the same. For Bayou Desiard, this occurs at target reduction rates of 10%-30%. Moving to reduction rates above 30%, previously less efficient BMPs enter the solution and total cost as well as unit price increase dramatically with far less improvement in total pollutants reduced. A notable exception in this case is sediment. Because no sediment is reduced under the most cost-effective BMP, nutrient management, sediment prices do not appear until other BMPs enter the solution.

Table 4.5 Summary of Total Pollutant Reduction Costs at Different Levels of Targeted Phosphorus Reduction for Bayou Desiard

Scenario	Cost ($1000)	Reduction			Cost/ Unit		
		N (tons)	P (tons)	S (1000 tons)	N ($/kg)	P($/kg)	S($/ton)
10%	137.7	16.3	5.5	0.0	$8.43	$25.23	$0.00
10% D10	151.4	16.1	5.5	0.0	$9.41	$27.75	$0.00
10% U10	126.2	16.3	5.5	0.0	$7.73	$23.13	$0.00
15%	206.6	24.4	8.2	0.0	$8.43	$25.23	$0.00
15% D10	227.2	24.2	8.2	0.0	$9.41	$27.75	$0.00
15% U10	189.3	24.8	8.2	0.0	$7.64	$23.13	$0.00
20%	275.4	32.7	10.9	0.0	$8.43	$25.23	$0.00
20% D10	303.0	32.2	10.9	0.0	$9.41	$27.75	$0.00
20% U10	252.4	33.1	10.9	0.0	$7.64	$23.13	$0.00
30%	413.1	49.0	16.4	0.0	$8.43	$25.23	$0.00
30% D10	467.5	48.5	16.4	0.2	$9.64	$28.55	$104.82
30% U10	378.7	49.6	16.4	0.0	$7.64	$23.13	$0.00
50%	2,262.6	82.3	27.3	11.1	$27.51	$82.91	$183.54
50% D10	5,937.7	75.0	27.3	16.4	$79.12	$217.58	$362.42
50% U10	979.5	88.2	27.3	16.7	$11.11	$35.89	$86.10
Max (56%)	3,886.9	83.9	30.0	17.2	$46.30	$129.48	$224.75
Max U10 (60%)	3,922.3	91.4	32.7	18.9	$42.90	$119.77	$206.62

Table 4.6 Summary of BMPs Adopted and Land Use in Bayou Desiard

Scenario	Grade Stabilization (1000 ha)	Nutrient Management (1000 ha)	Agland Retirement (1000 ha)	Vegetative Buffer (km)	Fencing (km)	Streambank Stabilization (km)
10%	0.0	3.3	0.00	0.0	0.0	0.0
10% D10	0.0	3.6	0.0	0.0	0.0	0.0
10% U10	0.0	3.0	0.0	0.0	0.0	0.0
15%	0.0	4.0	0.0	0.0	0.0	0.0
15% D10	0.0	5.5	0.0	0.0	0.0	0.0
15% U10	0.0	4.6	0.0	0.0	0.0	0.0
20%	0.0	6.6	0.0	0.0	0.0	0.0
20% D10	0.0	7.3	0.0	0.0	0.0	0.0
20% U10	0.0	6.1	0.0	0.0	0.0	0.0
30%	0.0	9.9	0.0	0.0	0.0	0.0
30% D10	0.0	10.6	0.0	1.4	0.0	0.0
30% U10	0.0	9.1	0.0	0.0	0.0	0.0
50%	4.4	5.5	1.1	12.6	29.4	0.0
50% D10	9.6	0.0	1.1	12.6	6.0	23.4
50% U10	0.1	9.5	1.1	12.6	29.4	0.0
Max (56%)	9.1	0.5	1.1	12.6	29.4	0.0
Max U10 (60%)	9.1	0.4	1.1	12.6	29.4	0.0

As nutrient management is the most cost-effective BMP, it is the sole BMP selected until 50% target phosphorus reduction levels are achieved. At a 50% reduction level, the amount of land placed under a nutrient management plan drops, as the minimum phosphorus reduction constraint becomes more binding. At this high level of reduction overall cost efficiency is no longer the most important factor in deciding which BMPs enter the solution. BMPs that reduce higher levels of pollutants per hectare enter the solution, in place of more cost-efficient BMPs.

Under reduced and increased BMP efficiency scenarios, the ideal combination of BMPs remained largely the same. Under a reduced BMP efficiency scenario, at a 30% phosphorus reduction target, nutrient management is bound by the maximum agland usage constraint and another BMP (vegetative buffer) is forced to enter the solution. Altering BMP efficiencies effectively tightens and relaxes the constraints. While the optimal combination is usually the same, changing the constraints occasionally changes the optimal solution. Taking note of which BMPs enter or leave the solution under these altered efficiency scenarios is important in the event that load reduction estimates for the standard coefficients underestimate or overestimate actual pollutant reduction in the watershed.

Table 4.7 summarizes shadow prices in Bayou Desiard. Shadow prices for phosphorus in Bayou Desiard remain constant at $25.23 between 10%-30% reduction levels. As more BMPs are required to meet higher levels of phosphorus reduction, the marginal cost of phosphorus increases to $595.19 per kg of reduction. As less cost-effective BMPs are forced to enter the solution due to higher per hectare efficiency rates, shadow prices increase dramatically. As target phosphorus levels are increased, more constraints become binding and the cost of each constraint is revealed. At the 50% reduction level, placing an extra ha of farmland under agland retirement would reduce total costs by $939.17. Relaxing the vegetative buffer constraint by one meter would reduce the total cost by $186.30.

Table 4.7 Shadow Prices of Constraints in Bayou Desiard

Scenario	Phosphorus	Agland	Streambank	Agland Retirement	Vegetative Buffer
10%	$25.23	$0.00	$0.00	$0.00	$0.00
10% D10	$27.75	$0.00	$0.00	$0.00	$0.00
10% U10	$23.13	$0.00	$0.00	$0.00	$0.00
15%	$25.23	$0.00	$0.00	$0.00	$0.00
15% D10	$27.75	$0.00	$0.00	$0.00	$0.00
15% U10	$23.13	$0.00	$0.00	$0.00	$0.00
20%	$25.23	$0.00	$0.00	$0.00	$0.00
20% D10	$27.75	$0.00	$0.00	$0.00	$0.00
20% U10	$23.13	$0.00	$0.00	$0.00	$0.00
30%	$25.23	$0.00	$0.00	$0.00	$0.00
30% D10	$56.76	-$43.45	$0.00	$0.00	$0.00
30% U10	$23.13	$0.00	$0.00	$0.00	$0.00
50%	$595.19	-$939.18	-$15.01	-$959.64	-$186.30
50% D10	$12,201.19	-$23,544.70	-$373.46	-$14,023.37	-$3,665.63
50% U10	$539.16	-$927.62	-$15.08	-$869.39	-$183.91
Max (56%)	$595.19	-$939.18	-$15.01	-$959.64	-$186.30
Max U10 (60%)	$539.16	-$927.62	-$15.08	-$869.39	-$183.91

The reduced cost of each BMP, summarized in Table 4.8, is the cost of forcing the adoption of BMPs not selected by the model into one hectare of land. This can be an indicator of which BMPs not selected by the model enter at higher reduction levels. Vegetative buffer has a very low reduced cost and, in the reduced BMP efficiency scenario, it enters the solution before any other BMP. In general, BMPs with lower reduced costs enter the model more rapidly. However, this is not always the case. For example, the reduced cost of cover crops is $112.23 and the reduced cost of grade stabilization is $251.15. However, when considering high phosphorus reduction demands, grade stabilization enters the optimal solution and cover crops do not. This selection can be attributed to grade stabilization's higher per hectare phosphorus reduction coefficient. Reduced costs are also indicators of alternative solutions. For example, at the 10% phosphorus reduction level the reduced cost for conservation tillage is $30.94. The interpretation of this is that if, in Bayou Desiard, one hectare of land was placed under conservation tillage it would increase the total cost for achieving the same level of phosphorus reduction by $30.94. This increase in cost occurs because conservation tillage is being used in place of a more cost-efficient BMP in the hectare of land in which it is adopted. While conservation tillage is still reducing some phosphorus, making the reduced cost of conservation tillage less than the total cost of adopting one hectare of land under conservation tillage ($71.93), using conservation tillage will force more total cropland to be placed under some BMP, increasing the total cost of mitigation in the watershed.

Table 4.8 Reduced Costs of BMPs in Bayou Desiard

Scenario	Cover Crops	Conservation Tillage	Conservation Crop Rotation	Grade Stabilization	Nutrient Management	Agland Retirement	Vegetative Buffer	Fencing	Streambank Stabilization
10%	$112.23	$30.94	$6.55	$251.15	$0.00	$66.00	$0.16	$1.26	$80.97
10% D10	$112.03	$30.71	$6.83	$251.51	$0.00	$67.18	$0.11	$1.26	$80.97
10% U10	$136.16	$51.78	$17.59	$308.26	$0.00	$69.33	$9.53	$4.73	$85.35
15%	$112.23	$30.94	$6.55	$251.15	$0.00	$66.00	$0.16	$1.26	$80.97
15% D10	$137.00	$51.78	$17.76	$309.27	$0.00	$67.18	$9.65	$4.76	$85.33
15% U10	$136.16	$51.78	$17.59	$308.26	$0.00	$69.33	$9.53	$4.73	$85.35
20%	$112.23	$30.94	$6.55	$251.15	$0.00	$66.00	$0.16	$1.26	$80.97
20% D10	$137.00	$51.78	$17.76	$309.27	$0.00	$67.18	$9.65	$4.76	$85.33
20% U10	$136.16	$51.78	$17.59	$308.26	$0.00	$69.33	$9.53	$4.73	$85.35
30%	$112.23	$30.94	$6.55	$251.15	$0.00	$66.00	$0.16	$1.26	$80.97
30% D10	$133.09	$74.18	$51.73	$295.88	$0.00	$20.96	$0.00	$3.86	$84.24
30% U10	$136.16	$51.78	$17.59	$308.26	$0.00	$69.33	$9.53	$4.73	$85.35
50%	$41.61	$535.95	$750.03	$0.00	$0.00	$0.00	$0.00	$0.00	$76.33
50% D10	$3,803.40	$14,761.69	$19,586.83	$0.00	$5,308.98	$0.00	$0.00	$0.00	$0.00
50% U10	$33.88	$529.99	$739.23	$0.00	$0.00	$0.00	$0.00	$0.00	$77.55
Max (56%)	$41.61	$535.95	$750.03	$0.00	$0.00	$0.00	$0.00	$0.00	$76.33
Max U10 (60%)	$33.88	$529.99	$739.23	$0.00	$0.00	$0.00	$0.00	$0.00	$77.55

4.3 Wet and Dry Years in Chenerie Creek

In addition to the analysis of the effects of BMPs in years with average rainfall, BMPs were also analyzed in years with the highest and lowest amount of rainfall (of the years included in this study). In Chenerie Creek, the year with the highest rainfall was 2004 and the year with the lowest rainfall was 2010. In 2004, the baseline loadings with no BMPs were 522.4 tons of nitrogen, 60.6 tons of phosphorus and 18,100 tons of sediment. In 2010, the baseline loadings were 262.3 tons of nitrogen, 33.1 tons of phosphorus and 8,900 tons of sediment. The cost to reduce 10% of the total phosphorus in 2004 was \$113,000, while the cost to reduce 10% of the total phosphorus in 2010 was \$135,000. The total amount of pollutants reduced at this cost was 18.7 tons of nitrogen, 6.1 tons of phosphorus and 2,300 tons of sediment for 2004, and 10.4 tons of nitrogen, 3.3 tons of phosphorus and 1,100 tons of sediment for 2010. The cost per kilogram of reduction was \$6.02 for nitrogen and \$18.64 for phosphorus in 2004 and \$12.91 for nitrogen and \$40.71 for phosphorus in 2010. The cost per ton of sediment reduction was \$16.16 in 2004 and \$34.66 in 2010. The most cost-effective combination of BMPs in 2004 and 2010 was nutrient management and vegetative buffer. The total land utilization in a wet year (2004) was 1,800 ha under a nutrient management plan and two kilometers of streambank under vegetative buffer. For a dry year (2010), the optimal land utilization to achieve a 10% phosphorus reduction was 2,300 ha adopting a nutrient management plan and two kilometers of streambank converted to vegetative buffer.

The maximum percentage of phosphorus able to be reduced, given the model constraints, was 28% for 2004 and 24% for 2010. These reductions were achieved at a cost of \$2.2 million in 2004 and \$1.9 million in 2010. The unit cost for maximum pollutant reduction in 2004 was \$45.49/kg of nitrogen, \$131.40/kg of phosphorus and \$135.73/ton of sediment. In 2010 the cost for the maximum pollutant reduction was \$80.64/kg of nitrogen, \$238.84/kg of phosphorus and \$279.62/ton of sediment. The total load reductions achieved at these costs were 49 tons of nitrogen, 17 tons of phosphorus and 14,800 tons of sediment in 2004 and 23.4 tons of nitrogen, 7.9 tons of phosphorus and 6,700 tons of sediment in 2010. In 2004, the most cost-effective combination of BMPs to achieve maximum nutrient reduction was grade stabilization structure, agland retirement, vegetative buffer, fencing and streambank stabilization. This combination remained the same for 2010 with the exception of nutrient management replacing streambank stabilization. A summary of costs and total pollutant reduction for a wet year scenario can be found in Table 4.9. A summary of adopted BMPs and their land usage for a wet year scenario can be found in Table 4.10.

As phosphorus reduction targets increase, so do the costs of reduction. For 10%-20% target phosphorus reduction levels, the ideal combination of BMPs is nutrient management and vegetative buffer. The most cost-effective BMP for phosphorus reduction is vegetative buffer. However, this BMP is not effective enough to reduce 10% of the total phosphorus runoff in the watershed before it is bound by the maximum vegetative buffer constraint. Because of this, the next most cost-effective BMP, nutrient management, enters the solution. As the proportion of nutrient management to vegetative buffer increases in the watershed, cost efficiency per kg of nutrient decreases and total unit cost increases. As higher desired levels of reduction are achieved and less efficient BMPs begin to enter the solution, both total price and unit price dramatically increase.

Table 4.9 Summary of Total Pollutant Reduction Costs at Different Levels of Targeted Phosphorus Reduction for Chenerie Creek in a Wet Year (2004)

	Cost ($1000)		Reduction			Cost/ Unit	
Scenario		N (ton)	P (ton)	S (1000 ton)	N ($/kg)	P($/kg)	S($/ton)
10%	113.0	18.7	6.1	2.3	$6.02	$18.64	$16.16
10% D10	127.1	18.7	6.1	2.1	$6.81	$20.96	$17.84
10% U10	101.3	18.8	6.1	2.6	$5.38	$16.71	$14.76
15%	180.5	28.4	9.1	2.3	$6.36	$19.85	$16.16
15% D10	201.3	28.2	9.1	2.1	$7.15	$22.14	$17.84
15% U10	163.1	28.6	9.1	2.6	$5.71	$17.94	$14.76
20%	248.0	38.0	12.1	2.3	$6.52	$20.46	$16.16
20% D10	289.6	39.0	12.1	2.6	$7.42	$23.89	$26.81
20% U10	225.0	38.3	12.1	2.6	$5.88	$18.56	$14.76
Max (28%)	2,230.2	49.0	17.0	14.8	$45.49	$131.40	$135.73
Max D10 (25%)	1,864.9	43.9	15.2	12.9	$42.46	$123.06	$144.26
Max U10 (30%)	1,766.2	53.4	18.2	14.8	$33.08	$97.13	$117.66

As observed in the analysis of average rainfall years in both watersheds, the model initially chooses an ideal set of cost-effective BMPs and utilizes them over an ever-broadening area until these BMPs are limited by some constraint and other BMPs are forced to enter the solution. In this case, the most cost-effective BMP combination at lower levels of pollutant reduction is nutrient management and vegetative buffer. Vegetative buffer is immediately constrained by the maximum vegetative buffer constraint. Nutrient management continues to be applied to more and more agricultural land until it can no longer meet the desired phosphorus reduction levels. At this point, costlier BMPs with higher nutrient/ hectare reduction coefficients enter the solution and the total agricultural land placed under nutrient management planning decreases, as the total agricultural land constraint becomes more binding. At the maximum phosphorus reduction level, nutrient management is excluded from the optimal solution, which is achieved through a combination of grade stabilization, agland retirement, vegetative buffer, fencing and streambank stabilization.

Table 4.10 Summary of BMPs Adopted and Land Use in Chenerie Creek in a Wet Year (2004)

Scenario	Grade Stabilization (1000 ha)	Nutrient Management (1000 ha)	Agland Retirement (1000 ha)	Vegetative Buffer (km)	Fencing (km)	Streambank Stabilization (km)
10%	0.0	1.8	0.0	2.0	0.0	0.0
10% D10	0.0	2.1	0.0	2.0	0.0	0.0
10% U10	0.0	1.5	0.0	2.0	0.0	0.0
15%	0.0	3.4	0.0	2.0	0.0	0.0
15% D10	0.0	3.9	0.0	2.0	0.0	0.0
15% U10	0.0	3.0	0.0	2.0	0.0	0.0
20%	0.0	5.1	0.0	2.0	0.0	0.0
20% D10	0.0	5.3	0.2	2.0	0.0	0.0
20% U10	0.0	4.5	0.0	2.0	0.0	0.0
Max (28%)	4.9	0.0	0.5	2.0	1.2	3.5
Max D10 (25%)	4.7	0.3	0.5	2.0	4.7	0.0
Max U10 (30%)	4.5	0.5	0.5	2.0	0.0	0.0

The shadow prices, summarized in Table 4.11, remain constant for this scenario between 10%-20% phosphorus reduction levels. At the maximum reduction rates, the shadow price jumps to more than $36,000. Given these constraints, it is very expensive to reduce an extra kilogram of phosphorus at this level of nutrient reduction. However, the agland, agland retirement and vegetative buffer shadow prices are also extremely high. The implication of these shadow prices is that if, at high nutrient reduction levels, it were possible to relax the Right Hand Side (RHS) constraints by one land unit, the reduction in total cost would be substantial.

Table 4.11 Shadow Prices of Constraints for Chenerie Creek in a Wet Year (2004)

Scenario	Phosphorus	Agland	Streambank	Agland Retirement	Vegetative Buffer
10%	$22.27	$0.00	$0.00	$0.00	-$10.94
10% D10	$24.50	$0.00	$0.00	$0.00	-$10.67
10% U10	$20.42	$0.00	$0.00	$0.00	-$11.19
15%	$22.27	$0.00	$0.00	$0.00	-$10.94
15% D10	$24.50	$0.00	$0.00	$0.00	-$10.67
15% U10	$20.42	$0.00	$0.00	$0.00	-$11.19
20%	$22.27	$0.00	$0.00	$0.00	-$10.94
20% D10	$61.50	-$62.79	$0.00	$0.00	-$55.28
20% U10	$20.42	$0.00	$0.00	$0.00	-$11.19
Max (28%)	$36,676.58	-$89,409.77	-$362.67	-$52,578.57	-$48,721.51
Max D10 (25%)	$636.47	-$1,038.45	-$0.12	-$1,041.55	-$748.50
Max U10 (30%)	$490.82	-$957.88	$0.00	-$881.08	-$703.96

Reduced costs for each decision variable are shown in Table 4.12. These costs remain the same under 10%-20% phosphorus reduction scenarios. These prices highlight the costs of choosing a BMP not selected in the optimal solution. At phosphorus reduction levels between 10%-20%, conservation crop rotation is the cheapest BMP not selected by the model. However, at higher levels of desired phosphorus reduction, phosphorus reduction efficiency is more critical to the optimal solution than cost efficiency.

Table 4.12 Reduced Costs of BMPs for Chenerie Creek in a Wet Year (2004)

Scenario	Cover Crops	Conservation Tillage	Conservation Crop Rotation	Grade Stabilization	Nutrient Management	Agland Retirement	Vegetative Buffer	Fencing	Streambank Stabilization
10%	$136.89	$51.94	$18.01	$309.13	$0.00	$66.66	$0.00	$5.40	$86.11
10% D10	$137.35	$51.94	$17.83	$309.68	$0.00	$67.02	$0.00	$5.40	$86.11
10% U10	$136.51	$51.94	$17.66	$308.68	$0.00	$70.12	$0.00	$5.39	$86.12
15%	$136.89	$51.94	$18.01	$309.13	$0.00	$66.66	$0.00	$5.40	$86.11
15% D10	$137.35	$51.94	$17.83	$309.68	$0.00	$67.02	$0.00	$5.40	$86.11
15% U10	$136.51	$51.94	$17.66	$308.68	$0.00	$70.12	$0.00	$5.39	$86.12
20%	$136.89	$51.94	$18.01	$309.13	$0.00	$66.66	$0.00	$5.40	$86.11
20% D10	$132.21	$84.53	$67.03	$290.95	$0.00	$0.00	$0.00	$5.07	$85.71
20% U10	$136.51	$51.94	$17.66	$308.68	$0.00	$70.12	$0.00	$5.39	$86.12
Max (28%)	$14,781.03	$56,564.79	$74,918.46	$0.00	$20,991.19	$0.00	$0.00	$0.00	$0.00
Max D10 (25%)	$52.36	$591.08	$831.59	$0.00	$0.00	$0.00	$0.00	$0.00	$79.52
Max U10 (30%)	$38.93	$549.25	$764.44	$0.00	$0.00	$0.00	$0.00	$0.19	$80.05

Total cost and unit cost reduction figure for a dry year scenario in Chenerie Creek are presented in Table 4.13. The minimum cost combination of BMPs for low levels of phosphorus reduction in a dry year was nutrient management plan and vegetative buffer. Once again, as the proportion of the less cost-effective BMP, nutrient management, increases in comparison to the most cost-effective BMP, vegetative buffer, total costs increase faster than total reductions, causing unit costs to increase. In this weather scenario, agland retirement and fencing are forced to enter the solution to achieve a 20% phosphorus reduction. While this does increase the unit reduction cost for all pollutants, only sediment prices increase by more than 100%. The dramatic increase in sediment is due to the fact that nutrient management is not included in the calculation of $/ton of sediment, which causes sediment prices to be more sensitive to the introduction of less cost-effective BMPs. The introduction of agland retirement and streambank fencing causes only a modest increase in total and unit prices of nutrient reduction. This shows that these BMPs can be utilized in this scenario without doubling the price of load reduction.

A summary of land use at each target level of phosphorus reduction is presented in Table 4.14. Nutrient management and vegetative buffer are the most cost-efficient BMPs at lower levels of phosphorus reduction. However, due to lower reduction per hectare coefficients in a dry year, a more diverse suite of BMPs is forced to enter the solution at a 20% phosphorus reduction level. Agland retirement, which has the highest overall reduction coefficient of 1.8 kg/hectare, enters the solution and is bound by the maximum agland retirement constraint. To achieve the desired level of phosphorus reduction, streambank fencing is also forced to enter the solution. As we move to the maximum possible phosphorus reduction, in this case 24% of total phosphorus loadings, grade stabilization also enters the solution. Grade stabilization has a higher phosphorus reduction per hectare efficiency (1.5 kg/hectare) than nutrient management (0.88 kg/hectare), which forces it into the solution, reducing the amount of total agland which can be placed under the more cost-efficient nutrient management plan.

Table 4.13 Summary of Total Pollutant Reduction Costs at Different Levels of Targeted Phosphorus Reduction for Chenerie Creek in a Dry Year (2010)

Scenario	Cost ($1000)		Reduction			Cost/ Unit	
		N (ton)	P (ton)	S (1000 ton)	N ($/kg)	P($/kg)	S($/ton)
10%	134.7	10.4	3.3	1.1	$12.91	$40.71	$34.66
10% D10	150.9	10.4	3.3	1.0	$14.56	$45.62	$38.27
10% U10	121.1	10.5	3.3	1.2	$11.56	$36.61	$31.67
15%	213.0	15.8	5.0	1.1	$13.52	$42.93	$34.66
15% D10	237.1	15.6	5.0	1.0	$15.18	$47.78	$38.27
15% U10	192.9	15.9	5.0	1.2	$12.17	$38.88	$31.67
20%	337.1	22.9	6.6	1.7	$14.71	$50.95	$73.91
20% D10	1,165.5	20.9	6.6	4.0	$55.90	$176.17	$266.29
20% U10	264.7	21.2	6.6	1.2	$12.46	$40.01	$31.69
Max (24%)	1,892.1	23.5	7.9	6.7	$80.64	$238.34	$279.62
Max D10 (21%)	1,613.4	21.0	6.9	5.3	$76.92	$232.26	$297.06
Max U10 (26%)	1,810.5	25.6	8.6	7.1	$70.69	$210.51	$253.32

Table 4.14 Summary of BMPs Adopted and Land Use for Chenerie Creek in a Dry Year (2010)

Scenario	Grade Stabilization (1000 ha)	Nutrient Management (1000 ha)	Agland Retirement (1000 ha)	Vegetative Buffer (km)	Fencing (km)
10%	0.0	2.3	0.0	2.0	0.0
10% D10	0.0	2.7	0.0	2.0	0.0
10% U10	0.0	2.0	0.0	2.0	0.0
15%	0.0	4.2	0.0	2.0	0.0
15% D10	0.0	4.8	0.0	2.0	0.0
15% U10	0.0	3.7	0.0	2.0	0.0
20%	0.0	4.9	0.5	2.0	1.7
20% D10	2.5	2.4	0.5	2.0	4.7
20% U10	0.0	5.5	0.0	2.0	0.0
Max (24%)	4.8	0.2	0.5	2.0	4.7
Max D10 (21%)	3.9	1.0	0.5	2.0	4.7
Max U10 (26%)	4.5	0.4	0.5	2.0	4.7

Shadow prices and reduced costs for the dry year scenario in Chenerie Creek remain constant for phosphorus reduction targets of 10%-15%. At 20%, shadow prices increase steeply as less cost-effective BMPs enter the solution in order to meet the increased phosphorus demands. At this level of reduction, reduced costs also change, in some cases increasing dramatically and in some cases decreasing slightly. This change is largely attributable to the per hectare reduction coefficient of each BMP. BMPs with higher per hectare reduction coefficients will have a decrease in reduced costs, while those with lower per hectare reduction coefficients will have an increase in reduced costs. At higher levels of reduction, more gains could be made by relaxing some of the constraints. If the agland retirement constraint were allowed to increase by one hectare at the 20% level of phosphorus reduction, it would reduce total costs by $743.67. If the vegetative buffer constraint were relaxed by one hectare at this level of phosphorus reduction, total savings would be $551.03. High shadow prices for RHS constraints at high phosphorus reduction scenarios underscore possible economic gains of relaxing the RHS constraints at these reduction levels. Shadow prices and reduced costs for a dry year scenario in Chenerie Creek are summarized in table 4.15 and 4.16, respectively.

Table 4.15 Shadow Prices of Constraints for Chenerie Creek in a Dry Year (2010)

Scenario	Phosphorus	Agland	Streambank	Agland Retirement	Vegetative Buffer
10%	$47.36	$0.00	$0.00	$0.00	-$10.94
10% D10	$52.10	$0.00	$0.00	$0.00	-$10.66
10% U10	$43.41	$0.00	$0.00	$0.00	-$11.19
15%	$47.36	$0.00	$0.00	$0.00	-$10.94
15% D10	$52.10	$0.00	$0.00	$0.00	-$10.66
15% U10	$43.41	$0.00	$0.00	$0.00	-$11.19
20%	$905.25	-$753.10	$0.00	-$743.67	-$551.03
20% D10	$1,354.08	-$1,039.04	-$1.93	-$1,041.90	-$747.01
20% U10	$43.41	$0.00	$0.00	$0.00	-$11.19
Max (24%)	$1,179.11	-$993.50	-$1.70	-$1,002.34	-$721.74
Max D10 (21%)	$1,354.08	-$1,039.04	-$1.93	-$1,041.90	-$747.01
Max U10 (26%)	$1,044.19	-$958.39	-$1.53	-$881.34	-$702.71

Table 4.16 Reduced Costs of BMPs for Chenerie Creek in a Dry Year (2010)

Phosphorus Reduction	Cover Crops	Conservation Tillage	Conservation Crop Rotation	Grade Stabilization	Nutrient Management	Agland Retirement	Vegitative Buffer	Fencing	Streambank Stabilization
10%	$136.90	$51.94	$17.74	$309.14	$0.00	$66.67	$0.00	$5.33	$86.02
10% D10	$137.35	$51.94	$17.83	$309.68	$0.00	$67.04	$0.00	$5.33	$86.03
10% U10	$136.52	$51.94	$17.66	$308.69	$0.00	$70.13	$0.00	$5.32	$86.03
15%	$136.90	$51.94	$17.74	$309.14	$0.00	$66.67	$0.00	$5.33	$86.02
15% D10	$137.35	$51.94	$17.83	$309.68	$0.00	$67.04	$0.00	$5.33	$86.03
15% U10	$136.52	$51.94	$17.66	$308.69	$0.00	$70.13	$0.00	$5.32	$86.03
20%	$67.13	$442.98	$606.27	$74.80	$0.00	$0.00	$0.00	$0.00	$79.53
20% D10	$52.45	$591.45	$832.08	$0.00	$0.00	$0.00	$0.00	$0.00	$79.13
20% U10	$136.52	$51.94	$17.66	$308.69	$0.00	$70.13	$0.00	$5.32	$86.03
Max (24%)	$44.87	$567.81	$794.14	$0.00	$0.00	$0.00	$0.00	$0.00	$79.15
Max D10 (21%)	$52.45	$591.45	$832.08	$0.00	$0.00	$0.00	$0.00	$0.00	$79.13
Max U10 (26%)	$39.01	$549.58	$764.87	$0.00	$0.00	$0.00	$0.00	$0.00	$79.59

4.4 Wet and Dry Years in Bayou Desiard

The year with the highest total rainfall in Bayou Desiard was also 2004; however, the year with the lowest rainfall was 2005. Total estimated pollutant loadings in 2004 with no BMP adoption were 841.8 tons of nitrogen, 85.4 tons of phosphorus and 41,100 tons of sediment and 334.2 tons of nitrogen, 27 tons of phosphorus and 17,600 tons of sediment in 2010. In 2004, the total cost to mitigate 10% of the phosphorus loading was $133,200, while in 2005 it was $154,000. The BMP adopted at these costs was nutrient management for both years. The total pollutant reductions achieved for these costs were 26.2 tons of nitrogen, 8.5 tons of phosphorus and zero tons for sediment in 2004, and 8.7 tons of nitrogen, 2.7 tons of phosphorus and zero tons for sediment in 2005. The cost per unit of reduction was $5.16/kg for nitrogen and $15.6/kg for phosphorus in 2004 and $17.66/kg of nitrogen and $57.33/ kg of phosphorus in 2005. The amount of agland placed under nutrient management was 3,200 ha in 2004 and 3,700 ha in 2005.

The maximum amount of phosphorus reduction that could occur under the wet year scenario for Bayou Desiard was 57%. The maximum phosphorus reduction for a dry year scenario was 50%. The total pollutant reduction, with a goal of maximum phosphorus reduction, was 150.8 tons of nitrogen, 48.7 tons of phosphorus and 25,600 tons of phosphorus in a wet year and 31 tons of nitrogen, 13.5 tons of phosphorus and 9,600 tons of sediment. The total cost of these reductions was $1.8 million for a wet year scenario and $4.8 million for a dry year scenario. The unit reduction cost under a wet year scenario was $26.33/ kg of nitrogen, $81.62/ kg of phosphorus and $155.10 per ton of sediment. The unit reduction cost under a dry year scenario was $155.65/ kg of nitrogen, $357.87/ kg of phosphorus and $500.39/ ton of sediment. The BMPs adopted to achieve these reductions and costs in a wet year were grade stabilization structure, nutrient management, agland retirement, vegetative buffer and streambank fencing. The same suite of BMPs was adopted to achieve maximum phosphorus reduction in a dry year with the exception of streambank stabilization being adopted and nutrient management being excluded. Total cost and land use for Bayou Desiard in a wet year are highlighted in Tables 4.17 and 4.18, respectively.

Table 4.17 Summary of Total Pollutant Reduction Costs at Different Levels of Targeted Phosphorus Reduction Bayou Desiard in a Wet Year (2004)

Scenario	Cost ($1000)	Reduction			Cost/ Unit		
		N (tons)	P (tons)	S (1000 tons)	N ($/kg)	P($/kg)	S($/ton)
10%	133.2	26.2	8.5	0.0	$5.16	$15.60	$0.00
10% D10	146.5	25.8	8.5	0.0	$5.68	$17.16	$0.00
10% U10	122.1	26.5	8.5	0.0	$4.61	$14.30	$0.00
15%	199.8	39.2	12.8	0.0	$5.09	$15.60	$0.00
15% D10	219.8	38.7	12.8	0.0	$5.68	$17.16	$0.00
15% U10	183.1	39.7	12.8	0.0	$4.61	$14.30	$0.00
20%	266.4	52.3	17.1	0.0	$5.09	$15.60	$0.00
20% D10	293.0	51.6	17.1	0.0	$5.68	$17.16	$0.00
20% U10	244.2	52.9	17.1	0.0	$4.61	$14.30	$0.00
30%	399.6	78.5	25.6	0.0	$5.09	$15.60	$0.00
30% D10	439.5	77.4	25.6	0.0	$5.68	$17.16	$0.00
30% U10	366.3	79.4	25.6	0.0	$4.61	$14.30	$0.00
50%	1,810.4	139.8	42.7	13.5	$12.95	$42.41	$112.91
50% D10	3,581.4	132.2	42.7	21.0	$27.09	$83.89	$167.65
50% U10	839.0	146.6	42.7	7.1	$5.72	$19.65	$61.81
Max (57%)	3,972.3	150.9	48.7	25.5	$26.33	$81.62	$155.10
Max D10 (51%)	3,943.2	133.8	43.5	22.8	$29.48	$90.55	$172.23
Max U10 (62%)	3,957.8	164.2	52.9	27.8	$24.10	$74.76	$142.16

The minimum cost under a wet year scenario is achieved by adopting a nutrient management at lower levels of target phosphorus reduction. This solution remains valid until phosphorus reduction rates become 50%. At 50%, a host of other BMPs enter the optimal solution, resulting in a 353% total price increase. This comes at a 67% increase of phosphorus reduction and a 78% increase in nitrogen reduction. As phosphorus targets are increased to their maximum level, total price increases by 119% for a 14% increase in phosphorus reduction and an 8% increase in nitrogen reduction.

Table 4.18 Summary of BMPs Adopted and Land Use for Bayou Desiard in a Wet Year (2004)

Scenario	Grade Stabilization (1000 ha)	Nutrient Management (1000 ha)	Agland Retirement (1000 ha)	Vegitative Buffer (km)	Fencing (km)
10%	0.0	3.2	0.0	0.0	0.0
10% D10	0.0	3.5	0.0	0.0	0.0
10% U10	0.0	2.9	0.0	0.0	0.0
15%	0.0	4.8	0.0	0.0	0.0
15% D10	0.0	5.3	0.0	0.0	0.0
15% U10	0.0	4.4	0.0	0.0	0.0
20%	0.0	6.4	0.0	0.0	0.0
20% D10	0.0	7.0	0.0	0.0	0.0
20% U10	0.0	5.9	0.0	0.0	0.0
30%	0.0	9.6	0.0	0.0	0.0
30% D10	0.0	10.6	0.0	0.0	0.0
30% U10	0.0	8.8	0.0	0.0	0.0
50%	2.6	6.9	1.1	12.6	29.4
50% D10	8.1	1.4	1.1	12.6	29.4
50% U10	0.0	9.6	1.1	12.6	7.3
Max (51%)	9.3	0.2	1.1	12.6	29.4
Max D10 (55%)	9.3	0.3	1.1	12.6	29.4
Max U10 (57%)	9.3	0.3	1.1	12.6	29.4

The most cost-effective BMP for this weather scenario is nutrient management. The model chooses this BMP for the optimal solution until the constraint for phosphorus reduction is placed at 50% of the initial loading. At this level of phosphorus reduction, grade stabilization, agland retirement, vegetative buffer and fencing all enter the solution. Agland retirement and grade stabilization both enter the solution because they have higher per hectare reduction coefficients than nutrient management. This reduces the total agland which can be used for nutrient management and increases cost. The agland BMPs alone cannot achieve the phosphorus target so vegetative buffer (which is constrained by the vegetative buffer constraint) as well as fencing enter the solution.

Shadow prices for the wet year scenario in Bayou Desiard, summarized in Table 4.19, remain constant for phosphorus reduction targets between 10%-30%. Marginal costs for land use constraints are not applicable, because these constraints are not yet binding at 10%-30% phosphorus reduction levels. As higher reduction targets are achieved, marginal costs increase. The shadow price of phosphorus increases from $15.60 at the 30% phosphorus rate to $361.50 at the 50% phosphorus reduction rate. This sharp increase is caused by less cost-effective BMPs being selected by the model due to their high mitigation per land unit coefficient. The marginal costs of the agland retirement and vegetative buffer constraints are also high at this level, increasing to $950.44 and $187.74, respectively, indicating potential gains could be made from relaxing these constraints.

Table 4.19 Shadow Prices of Constraints for Bayou Desiard in a Wet Year (2004)

Scenario	Phosphorus	Agland	Streambank	Agland Retirement	Vegetative Buffer
10%	$15.60	$0.00	$0.00	$0.00	$0.00
10% D10	$17.16	$0.00	$0.00	$0.00	$0.00
10% U10	$14.30	$0.00	$0.00	$0.00	$0.00
15%	$15.60	$0.00	$0.00	$0.00	$0.00
15% D10	$17.16	$0.00	$0.00	$0.00	$0.00
15% U10	$14.30	$0.00	$0.00	$0.00	$0.00
20%	$15.60	$0.00	$0.00	$0.00	$0.00
20% D10	$17.16	$0.00	$0.00	$0.00	$0.00
20% U10	$14.30	$0.00	$0.00	$0.00	$0.00
30%	$15.60	$0.00	$0.00	$0.00	$0.00
30% D10	$17.16	$0.00	$0.00	$0.00	$0.00
30% U10	$14.30	$0.00	$0.00	$0.00	$0.00
50%	$361.70	-$922.48	-$10.74	-$950.04	-$187.74
50% D10	$423.73	-$985.15	-$11.56	-$988.95	-$198.50
50% U10	$112.17	-$284.58	$0.00	-$221.22	-$54.75
Max (51%)	$361.70	-$922.48	-$10.74	-$950.04	-$187.74
Max D10 (55%)	$423.73	-$985.15	-$11.56	-$988.95	-$198.50
Max U10 (57%)	$327.69	-$911.26	-$10.80	-$860.33	-$185.43

The reduced cost for each BMP, shown in Table 4.20, highlights the cost of alternatives to the optimal solution at each level of phosphorus reduction. In general, the lower the reduced cost, the more likely the BMP will enter into the solution as target phosphorus levels are increased. However, this is not always the case. Sometimes, to achieve higher levels of phosphorus reduction given the land constraints, it becomes necessary to utilize BMPs which have a higher pollutant reduction costs but also higher pollutant reduction coefficients.

Table 4.20 Reduced Costs of BMPs for Bayou Desiard in a Wet Year (2004)

Phosphorus Reduction	Cover Crops	Conservation Tillage	Conservation Crop Rotation	Grade Stabilization	Nutrient Management	Agland Retirement	Vegetative Buffer	Fencing	Streambank Stabilization
10%	$112.17	$30.97	$6.58	$251.24	$0.00	$65.63	$0.17	$1.86	$81.71
10% D10	$111.92	$30.70	$6.83	$251.47	$0.00	$66.85	$0.10	$1.85	$81.70
10% U10	$110.75	$30.36	$5.91	$249.83	$0.00	$4.11	$9.49	$1.73	$81.80
15%	$136.35	$51.70	$17.63	$308.19	$0.00	$65.63	$9.50	$4.91	$85.52
15% D10	$111.92	$30.70	$6.83	$251.47	$0.00	$66.85	$0.10	$1.85	$81.70
15% U10	$110.75	$30.36	$5.91	$249.83	$0.00	$4.11	$9.49	$1.73	$81.80
20%	$136.35	$51.70	$17.63	$308.19	$0.00	$65.63	$9.50	$4.91	$85.52
20% D10	$111.92	$30.70	$6.83	$251.47	$0.00	$66.85	$0.10	$1.85	$81.70
20% U10	$110.75	$30.36	$5.91	$249.83	$0.00	$4.11	$0.00	$1.73	$81.80
30%	$136.35	$51.70	$17.63	$308.19	$0.00	$65.63	$9.50	$4.91	$85.52
30% D10	$111.92	$30.70	$6.83	$251.47	$0.00	$66.85	$0.10	$1.85	$81.70
30% U10	$110.75	$30.36	$5.91	$249.83	$0.00	$4.11	$0.00	$1.73	$81.80
50%	$38.75	$525.34	$736.09	$0.00	$0.00	$0.00	$0.00	$0.00	$77.24
50% D10	$43.47	$557.52	$787.18	$0.00	$0.00	$0.00	$0.00	$0.00	$77.10
50% U10	$103.24	$197.81	$238.67	$211.83	$0.00	$0.00	$0.00	$0.00	$79.89
Max (51%)	$38.75	$525.34	$736.09	$0.00	$0.00	$0.00	$0.00	$0.00	$77.24
Max D10 (55%)	$43.47	$557.52	$787.18	$0.00	$0.00	$0.00	$0.00	$0.00	$77.10
Max U10 (57%)	$31.16	$519.58	$725.60	$0.00	$0.00	$0.00	$0.00	$0.00	$78.22

As in both the average rainfall and the high rainfall years for Bayou Desiard, nutrient management is the most cost-effective BMP at lower levels of phosphorus reduction. In the case of a low rainfall year, nutrient management remains the only BMP selected by the model until 30% phosphorus levels are targeted. This results in constant unit costs for nitrogen and phosphorus between 10%-20% phosphorus reduction levels. At a 30% phosphorus reduction level, prices increase at a faster rate than nutrient reduction, as a less efficient BMP, vegetative buffer, enters the model. When phosphorus targets are increased to 50%, the maximum amount of phosphorus reduction feasible given the constraints, total price increases by a factor of 5.2. This price increase is the result of several less cost-efficient BMPs with greater per unit reduction rates entering the model.

Under a dry year scenario, as in other rainfall scenarios for this BMP, nutrient management is the first BMP selected by the model. As desired pollutant reduction is increased, the land covered by this BMP also increases. At 30% phosphorus reduction levels, nutrient management is constrained by the maximum agland constraint and vegetative buffer enters the model. At the maximum level of BMP reduction, BMPs with higher nutrient reduction per land unit are forced to enter the model to achieve the desired level of nutrient reduction. These BMPs are grade stabilization, agland retirement, fencing and streambank stabilization. Nutrient management is forced out of the solution due to the scarcity of agland while vegetative buffer remains in the optimal solution because it is the most cost-effective streambank BMP. Total and unit costs for a dry year scenario in Bayou Desiard are highlighted in Table 4.21. A summary of BMP adoption and land use is presented in Table 4.22.

Table 4.21 Summary of Total Pollutant Reduction Costs at Different Levels of Targeted Phosphorus Reduction for Bayou Desiard in a Dry Year (2005)

Scenario	Cost ($1000)	Reduction			Cost/ Unit		
		N (tons)	P (tons)	S (1000 tons)	N ($/kg)	P($/kg)	S($/ton)
10%	154.5	8.7	2.7	0.0	$17.66	$57.33	$0.00
10% D10	170.0	8.6	2.7	0.0	$19.70	$63.06	$0.00
10% U10	141.7	8.8	2.7	0.0	$16.01	$52.55	$0.00
15%	231.8	13.1	4.0	0.0	$17.66	$57.33	$0.00
15% D10	255.0	12.9	4.0	0.0	$19.70	$63.06	$0.00
15% U10	212.5	13.2	4.0	0.0	$16.01	$52.55	$0.00
20%	309.1	17.5	5.4	0.0	$17.66	$57.33	$0.00
20% D10	340.0	17.3	5.4	0.0	$19.70	$63.06	$0.00
20% U10	283.3	17.7	5.4	0.0	$16.01	$52.55	$0.00
30%	486.6	26.2	8.1	0.2	$18.59	$60.17	$188.34
30% D10	583.6	25.7	8.1	0.7	$22.73	$72.16	$208.11
30% U10	425.0	26.5	8.1	0.0	$16.01	$52.55	$0.00
50%	4,823.6	31.0	13.5	9.6	$155.65	$357.87	$500.39
50% U10	2,534.7	37.1	13.5	7.2	$68.28	$188.05	$322.79
Max D10 (48%)	1,908.8	31.6	10.8	4.9	$60.34	$177.02	$333.12
Max U10 (54%)	3,953.6	33.7	14.6	10.2	$117.26	$271.59	$386.68

Shadow prices for a dry year in Bayou Desiard are highlighted in Table 4.23. Under this rainfall scenario, the marginal cost of phosphorus reduction remains constant from 10%-20% levels of phosphorus reduction, as only one decision variable has entered the solution. At higher levels of phosphorus reduction, more BMPs enter the model and more constraints become binding, causing the marginal cost of phosphorus to increase. At 50%, the maximum phosphorus reduction level, the marginal cost is very high. This price is the result of reducing phosphorus at levels close to the maximum amount that can be reduced in the watershed. At this level of phosphorus reduction, relaxing the agland retirement and vegetative buffer constraints by one hectare and one meter, respectively, results in cost decreases of $8,00 and $1,900. These prices represent the potential economic gains of reducing the constraints by one unit.

Table 4.22 Summary of BMPs Adopted and Land Use for Bayou Desiard in a Dry Year (2005)

Scenario	Grade Stabilization (1000 ha)	Nutrient Management (1000 ha)	Agland Retirement (1000 ha)	Vegetative Buffer (km)	Fencing (km)	Streambank Stabilization (km)
10%	0.0	3.7	0.0	0.0	0.0	0.0
10% D10	0.0	4.1	0.0	0.0	0.0	0.0
10% U10	0.0	3.4	0.0	0.0	0.0	0.0
15%	0.0	5.6	0.0	0.0	0.0	0.0
15% D10	0.0	6.1	0.0	0.0	0.0	0.0
15% U10	0.0	5.1	0.0	0.0	0.0	0.0
20%	0.0	7.4	0.0	0.0	0.0	0.0
20% D10	0.0	8.2	0.0	0.0	0.0	0.0
20% U10	0.0	6.8	0.0	0.0	0.0	0.0
30%	0.0	10.6	0.0	2.4	0.0	0.0
30% D10	0.0	10.6	0.0	7.5	0.0	0.0
30% U10	0.0	10.2	0.0	0.0	0.0	0.0
50%	9.6	0.0	1.1	12.6	19.8	9.6
50% U10	4.9	4.7	1.1	12.6	29.4	0.0
Max D10 (48%)	2.9	6.6	1.1	12.6	29.4	0.0
Max U10 (54%)	9.3	0.2	1.1	12.6	29.4	0.0

Table 4.23 Shadow Prices of Constraints for Bayou Desiard in a Dry Year (2005)

Scenario	Phosphorus	Agland	Streambank	CRP	Vegetative Buffer
10%	$57.33	$0.00	$0.00	$0.00	$0.00
10% D10	$63.06	$0.00	$0.00	$0.00	$0.00
10% U10	$52.55	$0.00	$0.00	$0.00	$0.00
15%	$57.33	$0.00	$0.00	$0.00	$0.00
15% D10	$63.06	$0.00	$0.00	$0.00	$0.00
15% U10	$52.55	$0.00	$0.00	$0.00	$0.00
20%	$57.33	$0.00	$0.00	$0.00	$0.00
20% D10	$63.06	$0.00	$0.00	$0.00	$0.00
20% U10	$52.55	$0.00	$0.00	$0.00	$0.00
30%	$117.97	-$43.98	$0.00	$0.00	$0.00
30% D10	$131.22	-$44.93	$0.00	$0.00	$0.00
30% U10	$52.55	$0.00	$0.00	$0.00	$0.00
50%	$14,401.78	-$13,271.46	-$370.14	-$8,049.25	-$1,915.36
50% U10	$1,315.84	-$999.41	-$32.41	-$908.87	-$178.69
Max D10 (48%)	$1,710.64	-$1,086.18	-$34.39	-$1,052.22	-$192.81
Max U10 (54%)	$1,315.84	-$999.41	-$32.41	-$908.87	-$178.69

The reduced costs for different phosphorus reduction scenarios, highlighted in Table 4.24, represent the cost of alternative BMPs that are not selected in the optimal solution. As in other watersheds and rainfall scenarios, BMPs that have low reduced costs are likely to enter the model first. However, as higher desired phosphorus levels are targeted, BMPs with higher per hectare reduction coefficients are chosen over those with more cost-effective per hectare rates.

Table 4.24 Reduced Costs of BMPs for Bayou Desiard in a Dry Year (2005)

Scenario	Cover Crops	Conservation Tillage	Conservation Crop Rotation	Grade Stabilization	Nutrient Management	Agland Retirement	Vegetative Buffer	Fencing	Streambank Stabilization
10%	$118.07	$35.62	$9.02	$264.01	$0.00	$15.22	$2.27	$1.86	$79.42
10% D10	$137.78	$52.13	$17.92	$310.20	$0.00	$68.51	$9.80	$1.85	$84.59
10% U10	$117.74	$35.87	$8.88	$264.86	$0.00	$20.89	$2.46	$1.73	$79.78
15%	$118.07	$35.62	$9.02	$264.01	$0.00	$15.22	$2.27	$4.91	$79.42
15% D10	$137.78	$52.13	$17.92	$310.20	$0.00	$68.51	$9.80	$1.85	$84.59
15% U10	$117.74	$35.87	$8.88	$264.86	$0.00	$20.89	$2.46	$1.73	$79.78
20%	$118.07	$35.62	$9.02	$264.01	$0.00	$15.22	$2.27	$4.91	$79.42
20% D10	$137.78	$52.13	$17.92	$310.20	$0.00	$68.51	$9.80	$1.85	$84.59
20% U10	$117.74	$35.87	$8.88	$264.86	$0.00	$20.89	$2.46	$1.73	$79.78
30%	$133.72	$75.17	$52.29	$295.94	$0.00	$21.06	$0.00	$4.91	$82.64
30% D10	$134.58	$75.67	$53.22	$297.37	$0.00	$22.15	$0.00	$1.85	$82.66
30% U10	$117.74	$35.87	$8.88	$264.86	$0.00	$20.89	$2.46	$1.73	$79.78
50%	$2,151.86	$8,370.56	$11,037.92	$0.00	$2,869.04	$0.00	$0.00	$0.00	$0.00
50% U10	$45.85	$575.68	$799.06	$0.00	$0.00	$0.00	$0.00	$0.00	$74.87
Max D10 (48%)	$60.31	$621.14	$871.37	$0.00	$0.00	$0.00	$0.00	$0.00	$72.23
Max U10 (54%)	$45.85	$575.68	$799.06	$0.00	$0.00	$0.00	$0.00	$0.00	$74.87

4.7 Model Self Calibration

To provide some calibration and accuracy assurance, the GWLF-E model was rerun with the ideal combination of BMPs at phosphorus reduction levels before and after the kinks in the unit price curves. These phosphorus reduction levels are 20% and 30% for Chenerie Creek and 30% and 50% for Bayou Desiard. These results were then compared with the predicted nutrient reduction levels under each ideal BMP scenario.

The predicted reductions in Chenerie Creek under the ideal BMP combination scenario were 28.1 tons of nitrogen, 9.6 tons of phosphorus and 1,843 tons of sediment at the 20% phosphorus reduction level and 41.6 tons of nitrogen, 14.3 tons of phosphorus and 9,423 tons of sediment at the 30% phosphorus reduction level. The model estimated that the ideal combination of BMPs at the 20% level in Chenerie Creek reduced 29.6 tons of nitrogen, 9.7 tons of phosphorus and 1,832 tons of sediment at the 20% phosphorus reduction level and 37.1 tons of nitrogen, 12.3 tons of phosphorus and 8,232 tons of sediment at the 30% phosphorus reduction level.

In Bayou Desiard, the predicted reductions for a 30% target phosphorus reduction rate were 49 tons of nitrogen, 16.4 tons of phosphorus and zero tons of sediment. The predicted reductions for a 50% target phosphorus reduction rate were 82.3 tons of nitrogen, 27.3 tons of phosphorus and 11,074 tons of sediment. The model estimated that the ideal combination of BMPs at the 30% level would reduce 49.3 tons of nitrogen, 16.5 tons of phosphorus and zero tons of sediment. At the 50% reduction level, the model estimated that the ideal combination of BMPs would reduce 72.7 tons of nitrogen, 21.5 tons of phosphorus and 6,213 tons of sediment.

Chapter 5. Summary and Conclusions

5.1 Summary

Growing public concern about water quality in the United States has led interest groups and policy makers to become increasingly focused on the state of the nation's waterways. With point source pollution largely controlled in the United States under the NPDES rules, nonpoint sources have become the focus of water pollution mitigation efforts under the EPA's TMDL program. Runoff from agricultural lands has been cited as the primary cause of nonpoint source pollution. Suites of BMPs have been developed to reduce nonpoint runoff from a range of sources.

Nonpoint source pollution emanates from many points, making it difficult to mitigate. It is costly to locate, monitor and regulate the origins of nonpoint source pollution. To address this issue, GIS modeling of impaired watersheds has become the accepted procedure for pollutant reduction efforts. These models take broad spatial and environmental factors into account when estimating the nonpoint source runoff affecting the watershed. They are also capable of modeling the mitigating effects of BMP adoption on watersheds. When combined with an optimization procedure, these models can be used to determine the most cost-effective BMPs in a given watershed.

In this analysis, the GIS based watershed modeling software Mapshed is utilized to estimate nonpoint source runoff and BMP effectiveness in the Louisiana Broiler Production Region. We selected two watersheds from the EPA's list of impaired watersheds in this region: Chenerie Creek and Bayou Desiard.

For most phosphorus reduction scenarios, the ideal combination of BMPs was vegetative buffer and nutrient management plan for Cheneire Creek and nutrient management plan for Bayou Desiard. In general, pollutant reduction in Bayou Desiard was more costly than in Chenerie Creek. This is largely due to the fact that vegetative buffer had a higher per hectare reduction coefficient in Chenerie Creek, making it the most cost-effective BMP for that watershed. BMPs in wet years generally had higher pollutant reduction coefficients than average years, which had higher pollutant reduction coefficients than dry years. However, there is also more pollutant runoff in wet years than average years and more pollutant runoff in average years than dry years. This leads to higher total costs in wet years than average years and higher total costs in average years than dry years.

One notable exception occurred in Chenerie Creek. In Chenerie Creek, the vegetative buffer nutrient reduction coefficient is higher in an average year than in a wet year. This causes total costs to be higher in all scenarios for the wet year and the per kilogram costs to be higher for phosphorus in all scenarios, except for the maximum phosphorus reduction scenario. While this result is unexpected, it is possible that oversaturation of the ground water makes vegetative buffer less effective in a substantially wet year than in an average year. It is also possible that creeks overflow in wet years, causing vegetative buffers to be less effective than in normal or dry years.

The wet year phenomenon is important for policy implications. While wet years have higher reduction coefficients and, in general, it costs less to reduce the same percentage of pollutants in a wet year than an average year, it is important to remember that total loadings are still increased at every level. If BMPs are initially implemented in a series of dry years, they may tend to overstate BMP performance because fewer pollutants are leaching from the fields than in an average or wet year. This may result in TMDLs initially being met, but eventually being violated. Even if the BMP is implemented in an average year, a series of wet years may temporarily overwhelm the system with excess runoff. Single events such as extremely heavy rainfall may also temporarily reduce the effectiveness of certain BMPs due to oversaturation, while increasing runoff. Results for average, wet and dry years as well as reduced and increased BMP efficiency coefficients are highlighted in Figure 5.1.

5.2 Policy Implications

The goal of this study was to identify the most cost-efficient BMPs in two watersheds in the LBPR, given certain existing constraints. The results should aid policy makers, state (LDAF and LDEQ) and federal agencies (NRCS) about which BMPs to encourage farm managers to adopt. Cost sharing is a common method of encouraging agricultural BMPs throughout the United States. If policy-making agencies are unaware of the most cost-effective BMPs in an area, they may encourage incorrect BMP adoption. Informing policy makers and farm managers which BMPs are the most cost-efficient is the ultimate motivation behind this study and others like it.

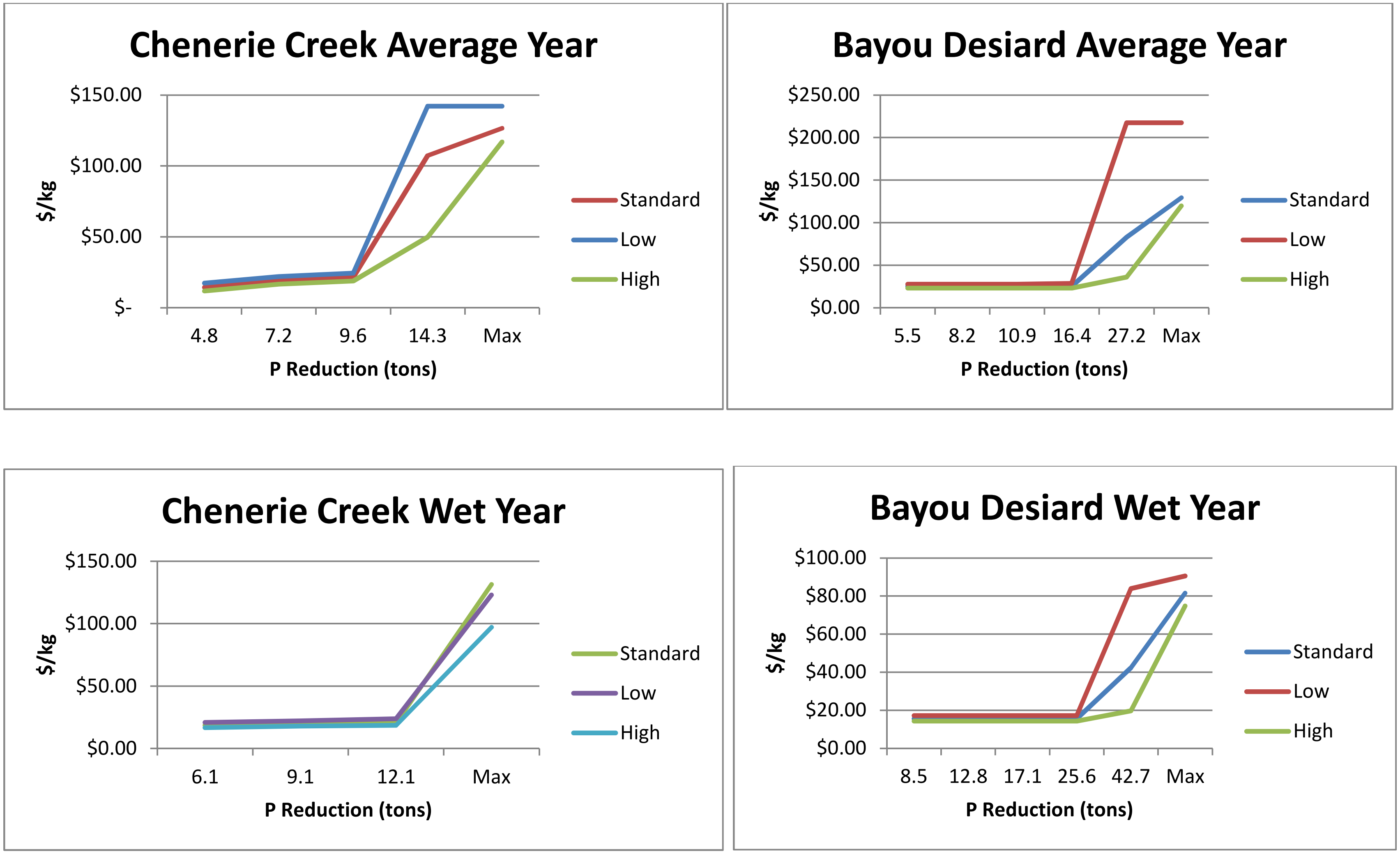
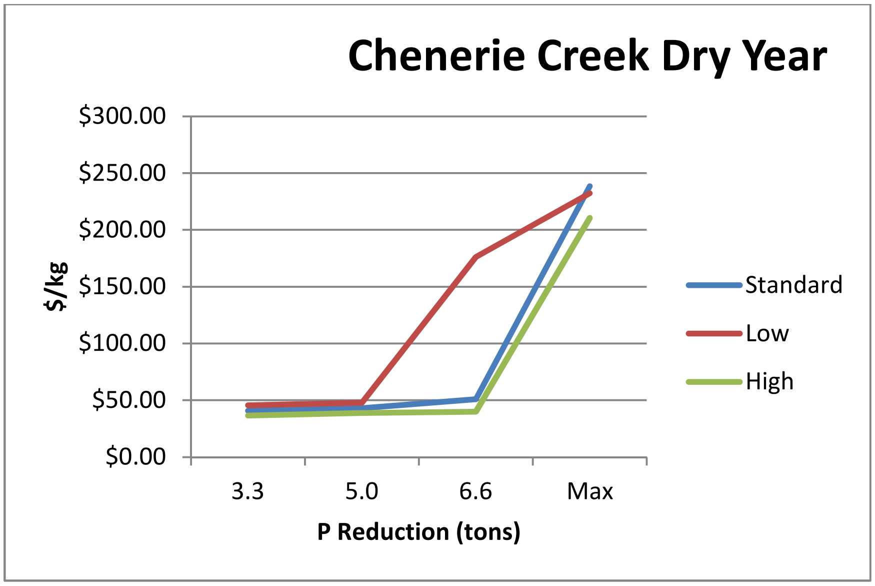


Figure 5.1 Unit Cost of Phosphorus Reduction



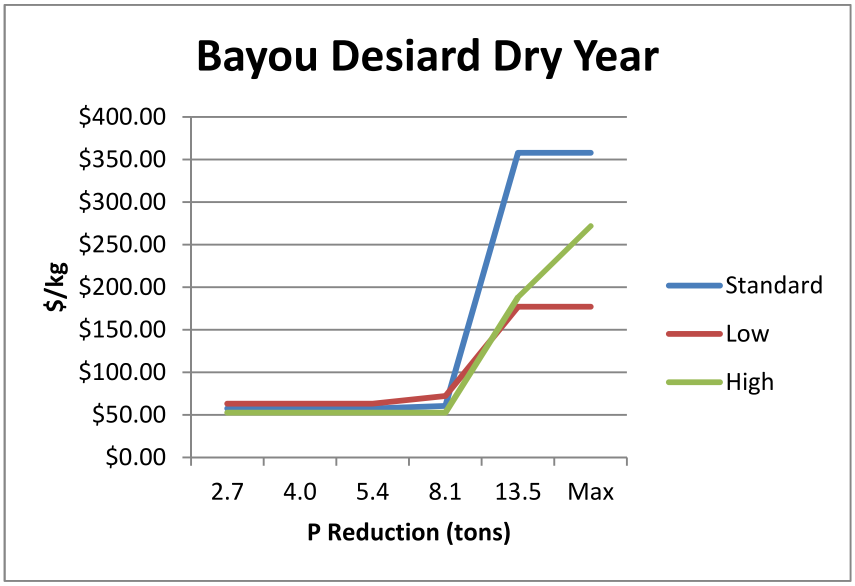


Figure 5.1 Contd

Kinked pollutant reduction unit price curves, as shown in Figure 5.1, have important policy implications. In both watersheds, for average, wet and dry years, the model initially selects one or two of the most cost-efficient BMPs. As desired levels of phosphorus loadings increase, the model is forced to select a range of more costly BMPs, causing a price spike in the total and unit reduction costs. In the best scenario, policy makers would be able to operate in the range where marginal phosphorus costs are relatively steady. However, if it is necessary to go beyond that range, the model is eventually forced to select a range of more costly BMPs, causing a price spike in total unit reduction costs. In the best scenario, policy makers would be able to operate in the range where marginal phosphorus costs are relatively steady. However, if it is necessary to go beyond that range, the policy maker may be able to offset some costs by utilizing the shadow prices of the constraints.

The shadow prices of the constraints inform policy makers of how much the total cost could be reduced if the constraint were relaxed by one unit. These marginal prices also increase as the total and marginal costs of pollutant reduction increase. While it is impractical to relax the agland or stream length constraints, it may be possible to relax the agland retirement and vegetative buffer constraints. Retiring too much agricultural land is not practical, but in an area with excessive runoff, it may be useful to retire more than 10% of the total agland. At high reduction levels, the shadow price of the agland retirement constraint is often much higher than the current price paid to farmers to retire agricultural land. If more reduction is desired, it may be possible to pay farmers a higher rate in order to retire more of their land.

Furthermore, vegetative buffer was a cost-effective BMP in both study regions, and it may be more practical to expand its usage beyond its constraints. LCES and NRCS agents who are familiar with the study area indicated that most farmers are not willing to adopt vegetative buffers at levels above 30% (Jim Hendrix, personal communication). However, the NRCS currently only offers payments for the cost of BMP implementation.

If cost-effective gains are to be made, it may be worthwhile to offer landowners a subsidy beyond BMP implementation costs but below the shadow price of relaxing the constraint. While implementing subsidy mechanisms will require knowledge of the farm managers' willingness to accept values for these practices, which is beyond the scope of this study, it also is important to understand the potential benefits and efficiency gains when considering different policy tools.

The reduced costs of BMPs not selected by the model also play an important part in a policy maker's decisions. For a host of different reasons, farmers may not be willing to adopt the most cost-effective BMPs. It is important for policy makers to know the cost of viable alternatives to the optimal solution. With this information, they will be able to determine whether to offer farmers further incentives to adopt the most cost-effective BMPs or encourage farmers to implement a less cost-effective BMP that they may be more willing to implement. Although this may not provide the best solution from an efficiency standpoint, a second-best solution may offer a viable alternative. Under either scenario, it is important for policy makers to have reliable estimates of the prices they are facing.

5.3 Further Research and Study Limitations

This study utilized GIS software to simulate runoff and BMP effectiveness. While GIS modeling has become the accepted method for BMP effectiveness studies, these models do have their limitations. Ideally, GIS software would be able to identify which segments of the watershed produce the greatest runoff. This would allow ideal placement of BMPs in a given watershed. However, this requires studying BMPs at an extremely small spatial scale, which necessitates detailed spatial information as well as several million simulations, both of which were beyond the time frame of this study.

It is sometimes practical to combine BMPs on the same piece of land. For example, nutrient management could easily be combined with any BMP except agland retirement. It may also be possible to combine cover crops, conservation tillage and conservation crop rotation. However, these scenarios present unique modeling challenges. One potential problem is the interaction effect between each BMP. As noted under the dry year scenario, BMPs are less effective when there is less runoff. If one BMP is already reducing runoff, it is likely that another BMP applied to the same piece of land will not be reducing at full capacity. While data from future BMP studies may be used to estimate the combined effects of BMPs, Mapshed currently does not allow any combination of BMPs to be placed on the same land segment. Estimating the combined effect of BMPs also requires thousands more simulation runs. With improvements in computer processing and automated simulation programs, it may be possible to overcome this problem in the near future.

Model calibration is an important aspect of dealing with uncertainty introduced by the model. Taking pollutant loading measurements for each watershed and comparing them with the output produced by the model helps to increase model accuracy. Under Louisiana’s newly approved TMDL plan, this runoff data will become available. Unfortunately, nutrient and sediment loadings are not currently available for either watershed considered in this study.

Future studies utilizing improved software able to take into account BMP combinations as well as more detailed spatial accuracy will help to improve our knowledge of BMP efficiency. As more information about current loadings in Louisiana water bodies is made available under the Louisiana NPS reduction program, current models can be better calibrated to reflect real-world data. This study and others like it represent the first step in reducing nonpoint source pollution in a cost-effective manner. Studies about farmers' adoption of and willingness to pay for these practices are the logical next step to meet pollution reduction goals across the United States. Combining studies about BMP cost-effectiveness with farmers' willingness to pay are important steps for restoring the nation's water ways and reducing nonpoint source pollution.

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Appendix A Regression Summary

Table A.1 Sample Data Table for Cover Crops in Chenerie Creek

	Amount of Pollutant Reduced			
% of Agland Covered	S (ton)	N (kg)	P (kg)	Hectares Covered
2	81.06	273.13	175.85	109.84
4	162.14	546.23	351.72	219.68
6	243.23	819.37	527.59	329.52
8	324.29	1092.52	703.44	439.36
10	405.35	1365.65	879.3	549.2
12	486.43	1638.76	1055.16	659.04
14	567.5	1911.89	1231.02	768.88
16	648.59	2185.02	1406.87	878.72
18	729.65	2458.16	1582.72	988.56
20	810.74	2731.29	1758.57	1098.4
22	891.8	3004.41	1934.44	1208.24
24	972.88	3277.52	2110.32	1318.08
26	1053.93	3550.65	2286.16	1427.92
28	1135.01	3823.83	2462.01	1537.76
30	1216.09	4096.93	2637.89	1647.6
32	1297.18	4370.06	2813.73	1757.44
34	1378.24	4643.17	2989.59	1867.28
36	1459.32	4916.3	3165.47	1977.12
38	1540.4	5189.46	3341.33	2086.96
40	1621.48	5462.58	3517.19	2196.8
42	1702.56	5735.71	3693.03	2306.64
44	1783.63	6008.83	3868.92	2416.48
46	1864.69	6281.96	4044.76	2526.32

Table A.1 Contd.

48	1945.76	6555.11	4220.61	2636.16
50	2026.85	6828.22	4396.46	2746
52	2107.92	7101.36	4572.34	2855.84
54	2188.99	7374.46	4748.21	2965.68
56	2270.06	7647.61	4924.07	3075.52
58	2351.15	7920.76	5099.92	3185.36
60	2432.22	8193.85	5275.77	3295.2
62	2513.29	8466.99	5451.62	3405.04
64	2594.38	8740.11	5627.49	3514.88
66	2675.44	9013.25	5803.36	3624.72
68	2756.5	9286.39	5979.21	3734.56
70	2837.59	9559.53	6155.08	3844.4
72	2918.67	9832.64	6330.93	3954.24
74	2999.74	10105.77	6506.77	4064.08
76	3080.82	10378.89	6682.64	4173.92
78	3161.9	10652.04	6858.51	4283.76
80	3242.96	10925.16	7034.37	4393.6
82	3324.04	11198.29	7210.22	4503.44
84	3405.1	11471.42	7386.07	4613.28
86	3486.18	11744.55	7561.94	4723.12
88	3567.25	12017.69	7737.8	4832.96
90	3648.32	12290.79	7913.65	4942.8
92	3729.41	12563.93	8089.51	5052.64
94	3810.48	12837.07	8265.37	5162.48
96	3891.56	13110.19	8441.25	5272.32
98	3972.64	13383.33	8617.1	5382.16
100	4053.71	13656.46	8792.96	5492

$$N = 0 + 2.486607\beta_2 + \epsilon$$

$$P = 0 + 1.601048\beta_2 + \epsilon$$

$$S = 0 + .73811\beta_2 + \epsilon$$

$Where$:

$N = kg\ of\ nitrogen\ reduction$

$P = kg\ of\ phosphorus\ reduction$

$S = tons\ of\ sediment\ reduction$

$\beta_2 = hectares\ of\ land$

$\epsilon = error\ term$

Figure A.1 Regression Sample for Cover Crops in Chenerie Creek

Table A.2 Regression Coefficients for Chenerie Creek

BMP	N (kg/ha)	P (kg/ha)	S (ton/ha)
Cover Crop	2.48661	1.60105	0.73811
Conservation Tillage	0.68596	0.70446	0.63267
Conservation Crop Rotation	0.42938	0.32045	0.33774
Grade Stabilization	4.80173	1.92126	1.72929
Nutrient Management	4.53491	1.46198	0.0
Agland Retirement	14.85573	3.04199	2.00345
Vegetative Buffer	4.9642645	1.84511585	0.91702566
Fencing	0.00927834	0.00822724	0.0250256
Streambank Stabilization	0.01572029	0.01000867	0.03131719

Table A.3 Regression Coefficients for Bayou Desiard

BMP	N (kg/ha)	P (kg/ha)	S (ton/ha)
Cover Crop	2.71147859	1.8143604	0.51605684
Conservation Tillage	0.74799598	0.7983174	0.44233465
Conservation Crop Rotation	0.46749857	0.36287049	0.23591171
Grade Stabilization	5.26607	2.18892	1.21538
Nutrient Management	4.93029882	1.64779215	0.0
Agland Retirement	16.1509721	3.4472873	1.40072474
Vegetative Buffer	1.25158	0.36993	0.19917
Fencing	0.02723	0.03466	0.07393
Streambank Stabilization	0.04608	0.04211	0.09218

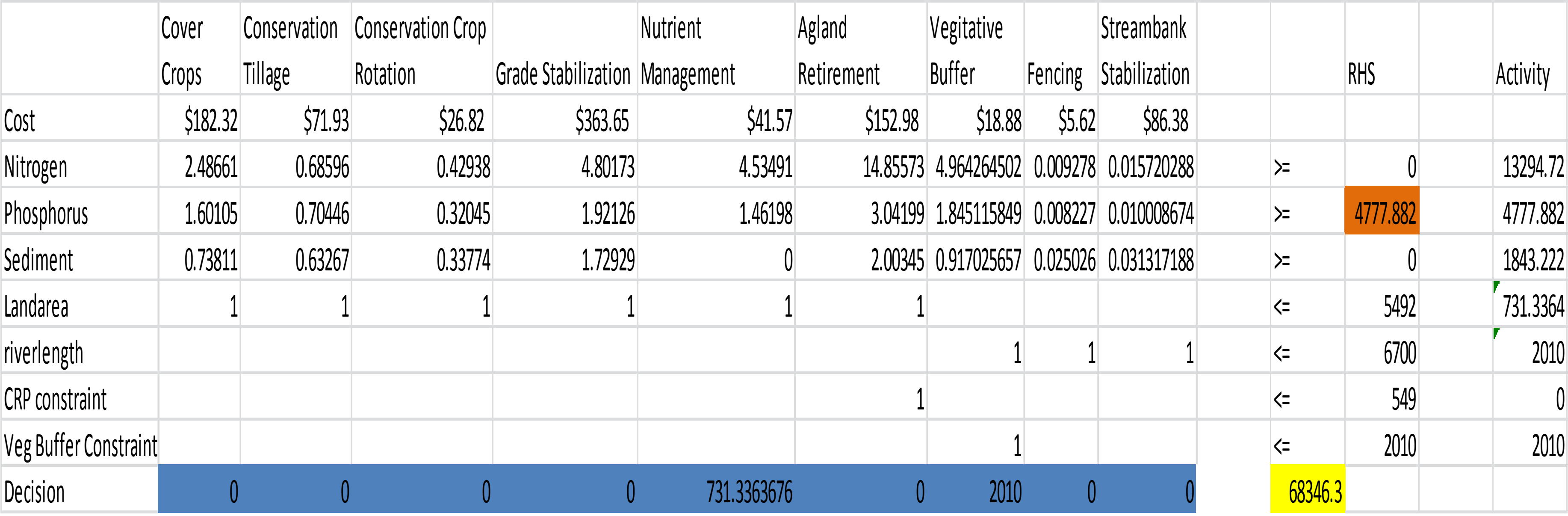
Table A.4 Regression Coefficients for Chenerie Creek in Wet and Dry Years

	2004 (Wet)			2010 (Dry)		
BMP	N (kg/ha)	P (kg/ha)	S (ton/ha)	N (kg/ha)	P (kg/ha)	S (ton/ha)
Cover Crop	3.16591	2.03975	0.94063	1.51988	0.95917	0.4384
Conservation Tillage	0.87335	0.89749	0.80625	0.41928	0.42203	0.37577
Conservation Crop Rotation	0.52965	0.39584	0.41724	0.26205	0.19183	0.20041
Grade Stabilization	6.11348	2.4477	2.20375	2.93494	1.151	1.02712
Nutrient Management	5.9301	1.86659	0.0	2.82394	0.87785	0.0
Agland Retirement	19.42618	3.87553	2.55312	9.25082	1.82242	1.18995
Vegetative Buffer	4.009	1.33881	1.16863	1.92183	0.62956	0.54467
Fencing	0.01119	0.01004	0.03036	0.00692	0.00621	0.01877
Streambank Stabilization	0.019	0.01224	0.038	0.01175	0.00757	0.02349

Table A.5 Regression Coefficients for Bayou Desiard in Wet and Dry Years

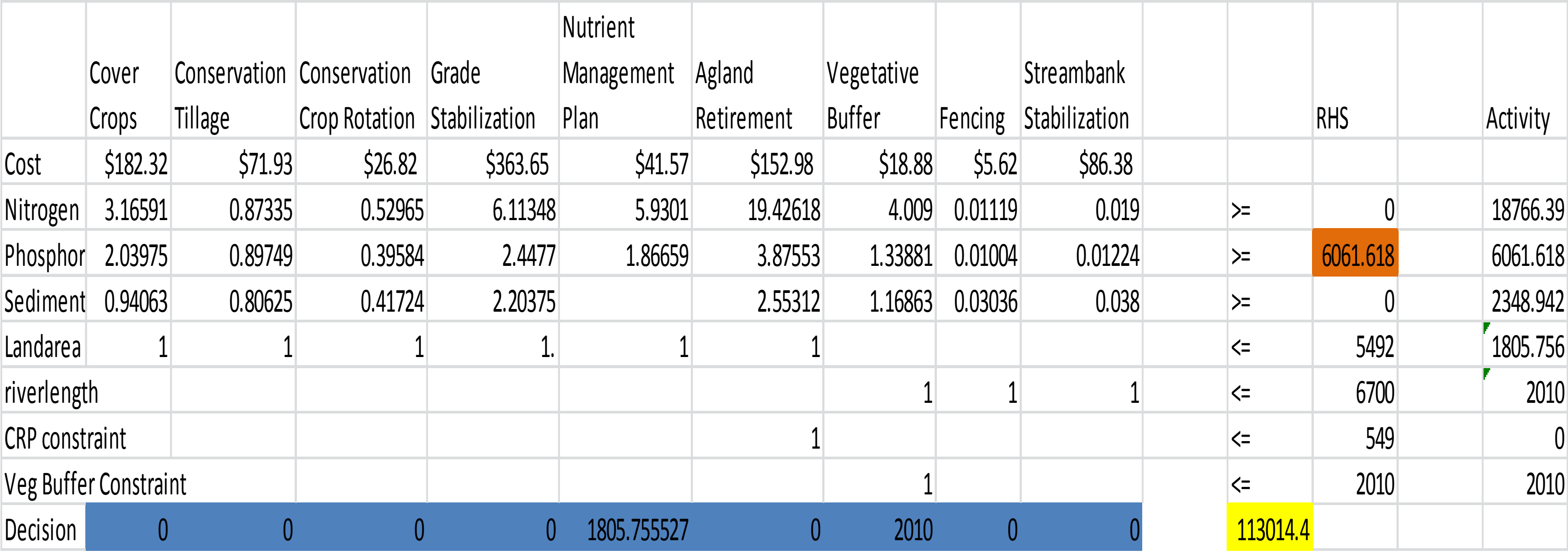
	2004 (Wet)			2005 (Dry)		
BMP	N (kg/ha)	P (kg/ha)	S (ton/ha)	N (kg/ha)	P (kg/ha)	S (ton/ha)
Cover Crop	5.05672	2.94737	0.76344	0.85279	0.78476	0.25996
Conservation Tillage	1.39496	1.29684	0.65437	0.23525	0.34529	0.22282
Conservation Crop Rotation	0.87185	0.58948	0.349	0.14703	0.15695	0.11884
Grade Stabilization	9.82086	3.55583	1.79799	1.65623	0.94677	0.61223
Nutrient Management	8.16597	2.66537	0.0	2.35356	0.72519	0.0
Agland Retirement	26.7506	5.60001	2.07218	7.70994	1.49104	0.7056
Vegetative Buffer	2.20682	0.60095	0.29464	0.49299	0.16001	0.10033
Fencing	0.03555	0.04523	0.09648	0.02051	0.02609	0.05566
Streambank Stabilization	0.06015	0.05495	0.1203	0.0347	0.0317	0.0694

Appendix B: Optimization Matrix Examples and Cost per Hectare Reduction Figures



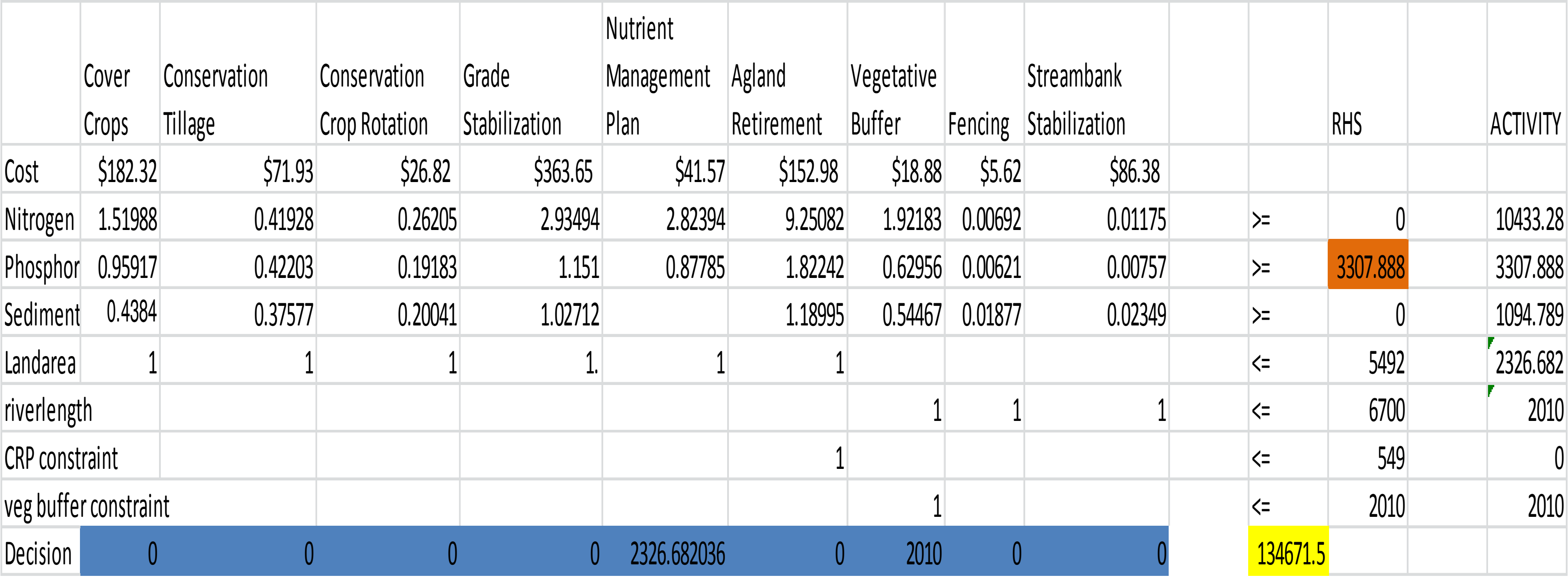
	Cover Crops	Conservation Tillage	Conservation Crop Rotation	Grade Stabilization	Nutrient Management	Agland Retirement	Vegitative Buffer	Fencing	Streambank Stabilization			RHS		Activity
Cost	$182.32	$71.93	$26.82	$363.65	$41.57	$152.98	$18.88	$5.62	$86.38					
Nitrogen	2.48661	0.68596	0.42938	4.80173	4.53491	14.85573	4.964264502	0.009278	0.015720288		>=	0		13294.72
Phosphorus	1.60105	0.70446	0.32045	1.92126	1.46198	3.04199	1.845115849	0.008227	0.010008674		>=	4777.882		4777.882
Sediment	0.73811	0.63267	0.33774	1.72929	0	2.00345	0.917025657	0.025026	0.031317188		>=	0		1843.222
Landarea	1	1	1	1	1	1					<=	5492		731.3364
riverlength							1	1	1		<=	6700		2010
CRP constraint						1					<=	549		0
Veg Buffer Constraint							1				<=	2010		2010
Decision	0	0	0	0	731.3363676	0	2010	0	0		68346.3			

Figure B.1 Optimization Matrix for Chenerie Creek at 10% Phosphorus Reduction



	Cover Crops	Conservation Tillage	Conservation Crop Rotation	Grade Stabilization	Nutrient Management Plan	Agland Retirement	Vegetative Buffer	Fencing	Streambank Stabilization			RHS		Activity
Cost	$182.32	$71.93	$26.82	$363.65	$41.57	$152.98	$18.88	$5.62	$86.38					
Nitrogen	3.16591	0.87335	0.52965	6.11348	5.9301	19.42618	4.009	0.01119	0.019		>=	0		18766.39
Phosphor	2.03975	0.89749	0.39584	2.4477	1.86659	3.87553	1.33881	0.01004	0.01224		>=	6061.618		6061.618
Sediment	0.94063	0.80625	0.41724	2.20375		2.55312	1.16863	0.03036	0.038		>=	0		2348.942
Landarea	1	1	1	1.	1	1					<=	5492		1805.756
riverlength							1	1	1		<=	6700		2010
CRP constraint						1					<=	549		0
Veg Buffer Constraint							1				<=	2010		2010
Decision	0	0	0	0	1805.755527	0	2010	0	0		113014.4			

Figure B.2 Optimization Matrix for Chenerie Creek at 10% Phosphorus Reduction in a Wet Year



	Cover Crops	Conservation Tillage	Conservation Crop Rotation	Grade Stabilization	Nutrient Management Plan	Agland Retirement	Vegetative Buffer	Fencing	Streambank Stabilization			RHS		ACTIVITY
Cost	$182.32	$71.93	$26.82	$363.65	$41.57	$152.98	$18.88	$5.62	$86.38					
Nitrogen	1.51988	0.41928	0.26205	2.93494	2.82394	9.25082	1.92183	0.00692	0.01175		>=	0		10433.28
Phosphor	0.95917	0.42203	0.19183	1.151	0.87785	1.82242	0.62956	0.00621	0.00757		>=	3307.888		3307.888
Sediment	0.4384	0.37577	0.20041	1.02712		1.18995	0.54467	0.01877	0.02349		>=	0		1094.789
Landarea	1	1	1	1.	1	1					<=	5492		2326.682
riverlength							1	1	1		<=	6700		2010
CRP constraint						1					<=	549		0
veg buffer constraint							1				<=	2010		2010
Decision	0	0	0	0	2326.682036	0	2010	0	0		134671.5			

Figure B.3 Optimization Matrix for Chenerie Creek at 10% Phosphorus Reduction in a Dry Year

Table B.1 Per Hectare Unit Reduction Costs for BMPs in Chenerie Creek

BMP	N ($/kg)	P ($/kg)	S ($/ton)
Cover Crop	$73.32	$113.88	$247.01
Conservation Tillage	$104.86	$102.10	$113.69
Conservation Crop Rotation	$62.47	$83.71	$79.42
Grade Stabilization Structure	$75.73	$189.28	$210.29
Nutrient Management	$9.17	$28.44	$0.00
Agland Retirement	$10.30	$50.29	$76.36
Vegetative buffer	$3.80	$10.23	$20.58
Fencing	$605.68	$683.06	$224.56
Streambank Stabilization	$5,494.73	$8,630.39	$2,758.19

Table B.2 Per Hectare Unit Reduction Costs for BMPs in Bayou Desiard

BMP	N ($/kg)	P ($/kg)	S ($/ton)
Cover Crop	$67.24	$100.49	$353.30
Conservation Tillage	$96.16	$90.10	$162.61
Conservation Crop Rotation	$57.38	$73.92	$113.70
Grade Stabilization Structure	$69.06	$166.13	$299.21
Nutrient Management	$8.43	$25.23	$0.00
Agland Retirement	$9.47	$44.38	$109.21
Vegetative buffer	$15.08	$51.03	$94.78
Fencing	$206.41	$162.15	$76.02
Streambank Stabilization	$1,874.52	$2,051.47	$937.06

Table B.3 Per Hectare Unit Reduction Costs for BMPs in Chenerie Creek for a Wet Year

BMP	N ($/kg)	P ($/kg)	S ($/ton)
Cover Crop	$57.59	$89.38	$193.83
Conservation Tillage	$82.36	$80.14	$89.21
Conservation Crop Rotation	$50.65	$67.76	$64.29
Grade Stabilization Structure	$59.48	$148.57	$165.01
Nutrient Management	$7.01	$22.27	$0.00
Agland Retirement	$7.87	$39.47	$59.92
Vegetative buffer	$4.71	$14.10	$16.15
Fencing	$502.37	$559.65	$185.08
Streambank Stabilization	$4,546.88	$7,055.14	$2,273.34

Table B.4 Per Hectare Unit Reduction Costs for BMPs in Chenerie Creek for a Dry Year

BMP	N ($/kg)	P ($/kg)	S ($/ton)
Cover Crop	$36.06	$61.86	$238.82
Conservation Tillage	$51.56	$55.46	$109.92
Conservation Crop Rotation	$30.77	$45.51	$76.86
Grade Stabilization Structure	$37.03	$102.27	$202.25
Nutrient Management	$5.09	$15.60	$0.00
Agland Retirement	$5.72	$27.32	$73.83
Vegetative buffer	$8.55	$31.41	$64.07
Fencing	$158.10	$124.25	$58.25
Streambank Stabilization	$1,436.02	$1,572.00	$718.01

Table B.5 Per Hectare Unit Reduction Costs for BMPs in Bayou Desiard for a Wet Year

BMP	N ($/kg)	P ($/kg)	S ($/ton)
Cover Crop	$119.96	$190.08	$415.88
Conservation Tillage	$171.55	$170.43	$191.41
Conservation Crop Rotation	$102.36	$139.83	$133.84
Grade Stabilization Structure	$123.90	$315.94	$354.05
Nutrient Management	$14.72	$47.36	$0.00
Agland Retirement	$16.54	$83.94	$128.56
Vegetative buffer	$9.82	$29.98	$34.66
Fencing	$812.41	$905.25	$299.36
Streambank Stabilization	$7,353.77	$11,412.44	$3,677.22

Table B.6 Per Hectare Unit Reduction Costs for BMPs in Bayou Desiard for a Dry Year

BMP	N ($/kg)	P ($/kg)	S ($/ton)
Cover Crop	$213.80	$232.33	$701.36
Conservation Tillage	$305.74	$208.31	$322.80
Conservation Crop Rotation	$182.44	$170.91	$225.72
Grade Stabilization Structure	$219.57	$384.10	$593.97
Nutrient Management	$17.66	$57.33	$0.00
Agland Retirement	$19.84	$102.60	$216.81
Vegetative buffer	$38.29	$117.97	$188.15
Fencing	$274.05	$215.39	$100.97
Streambank Stabilization	$2,489.22	$2,725.00	$1,244.62

Appendix C GIS Layers

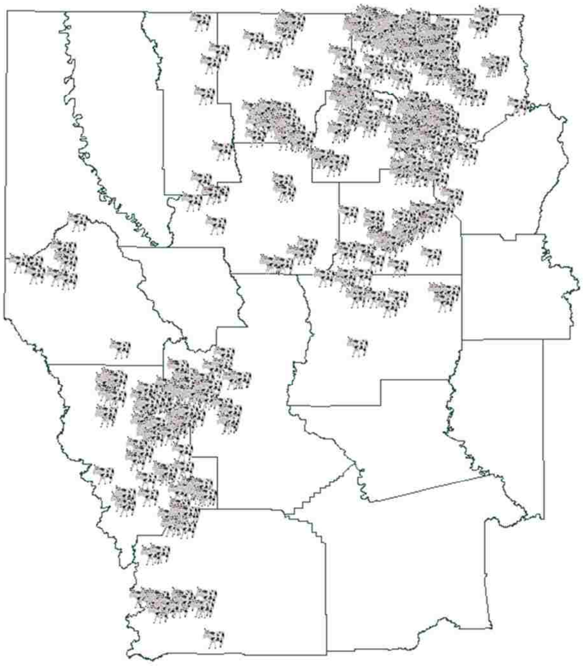


Figure C.1 AFO Layers

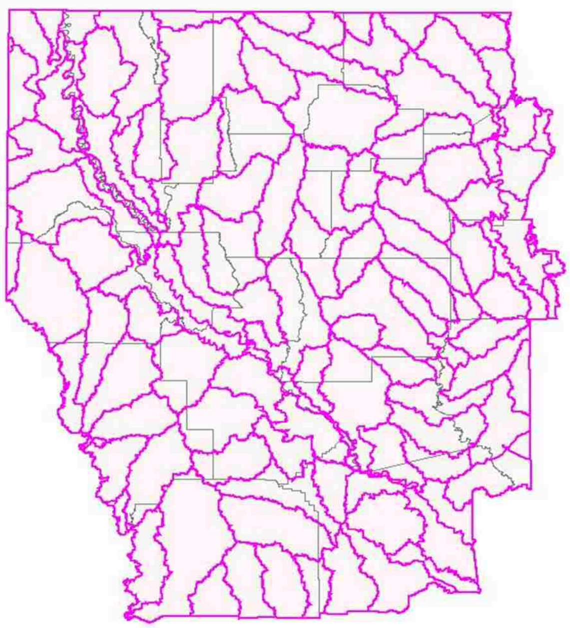


Figure C.2 Basin Layer

Figure C.3 County Layer

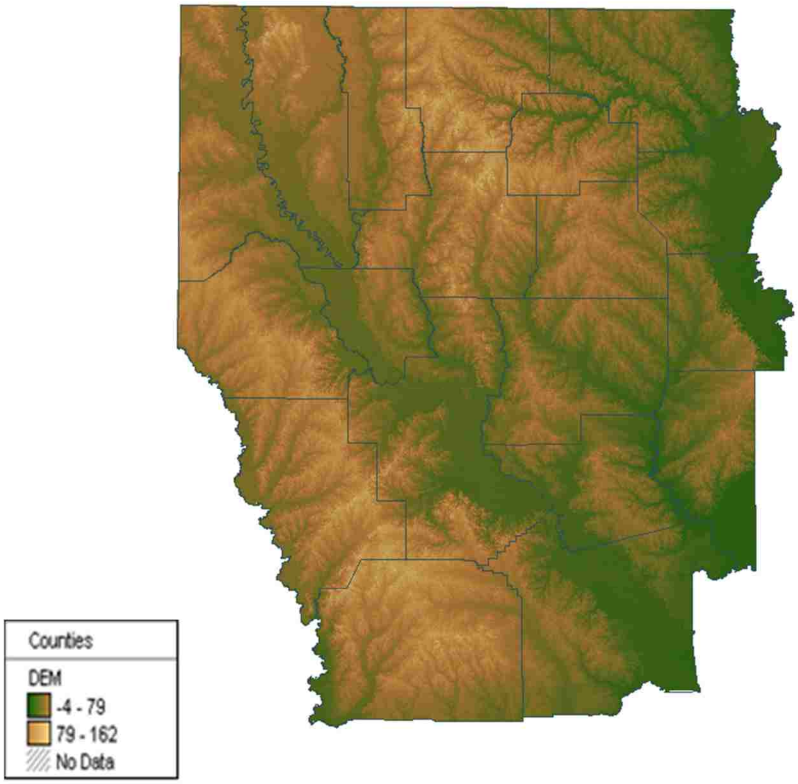


Figure C.4 DEM Layer

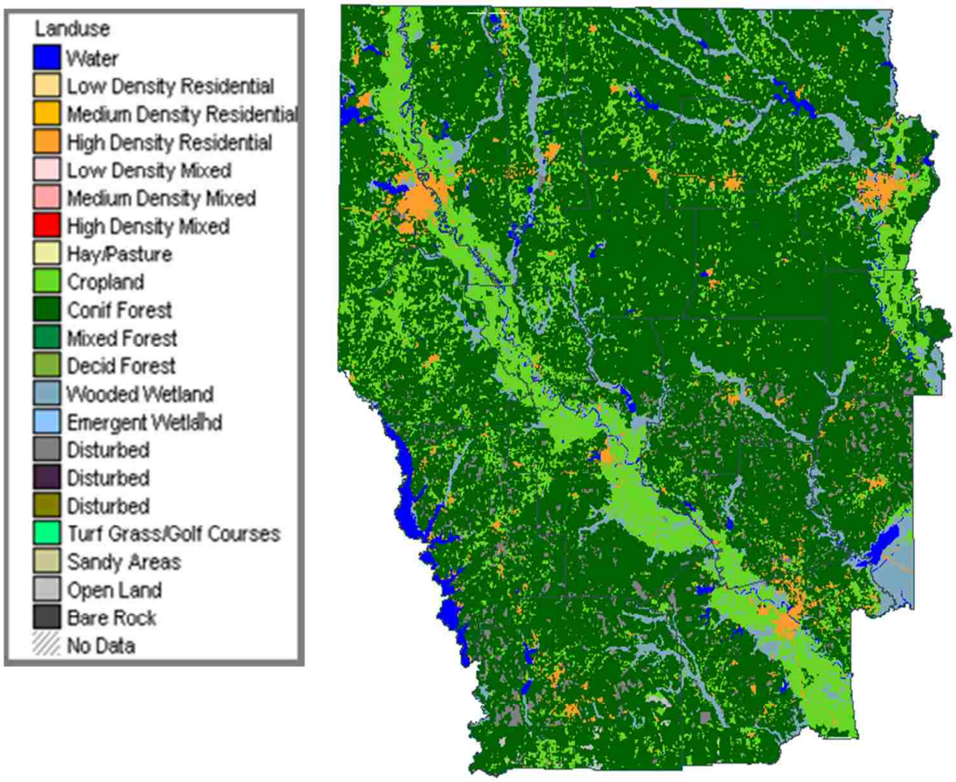


Figure C.5 Land Use Layer

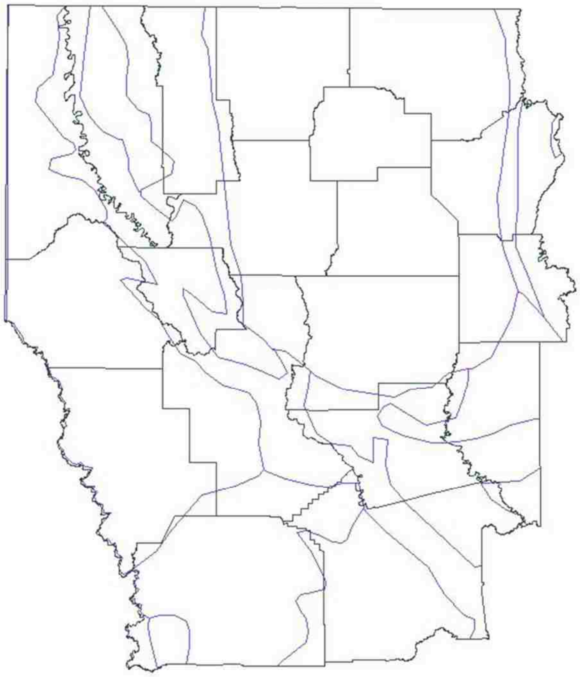


Figure C.6 Physiographic Province Layer

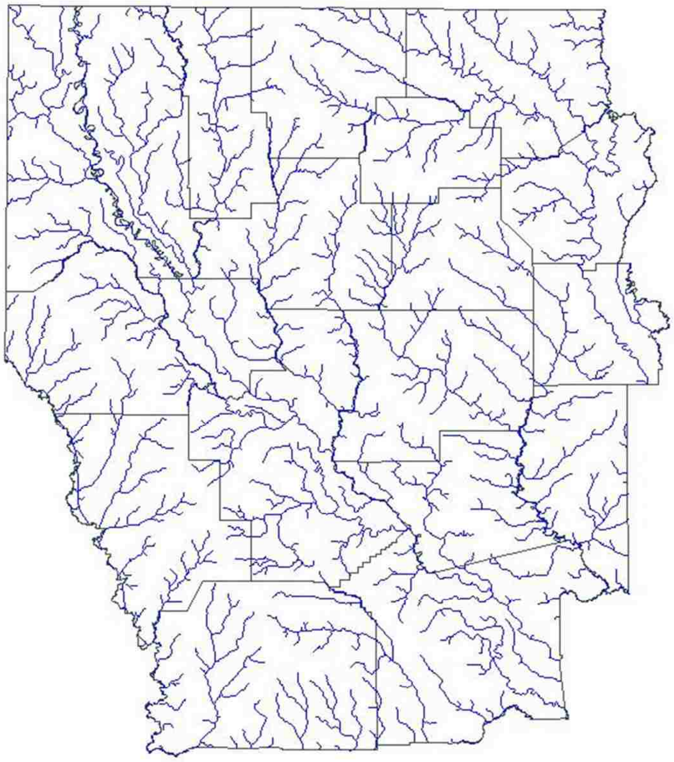


Figure C.7 River Layer

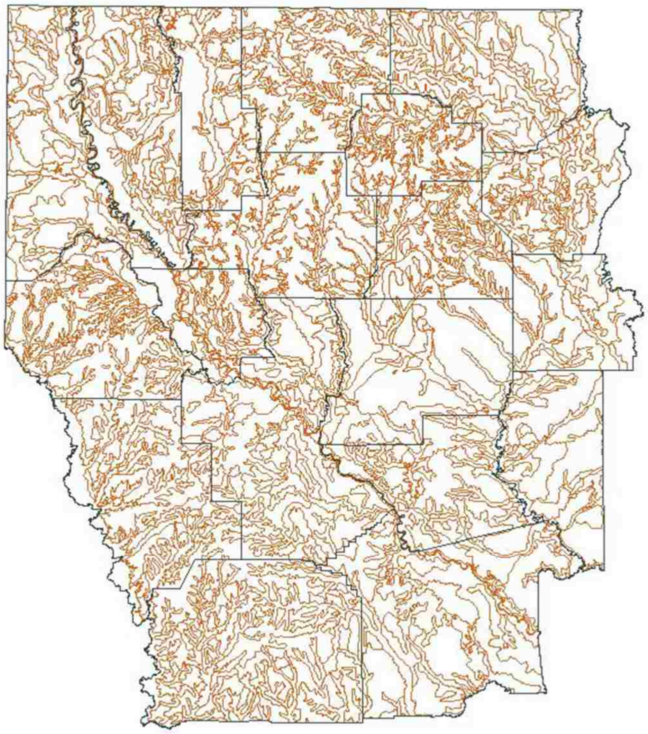


Figure C.8 Soil Layer

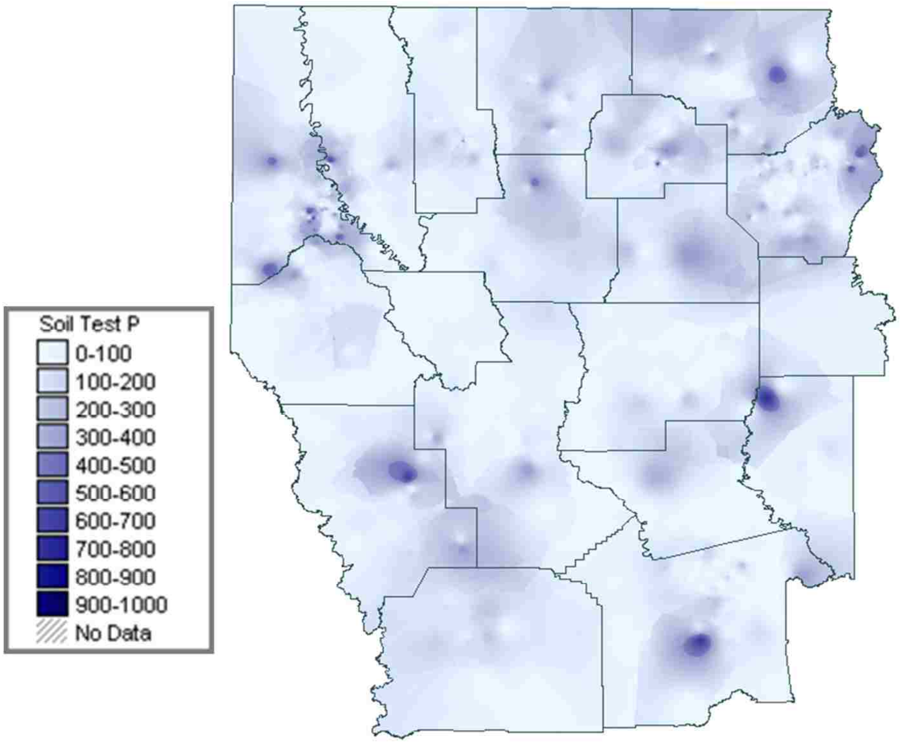


Figure C.9 Soil Test P Layer

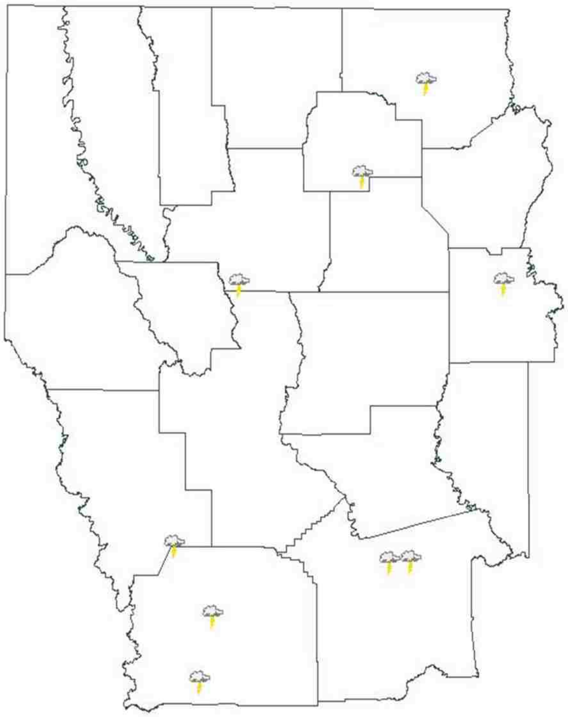


Figure C.10 Weather Layer

Vita

Bryan Gottshall was born and raised in Pennsylvania. He attended Mercy College in New York and attained a Bachelor of Science in music industry and technology. During this time, he co-founded and facilitated a small studio production and live sound company. After graduating from Mercy College, he worked as a staff engineer at Downtown Recording Studios in New York City. He also worked as a freelance engineer, recording several albums and continuing to mix live shows. After leaving the studio, he joined the Agricultural Economics department of Louisiana State University master's program. He hopes his new career will help play a positive role in environmental, agricultural and developmental economics.