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By Margaret McCahon Kalcic

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For the degree of Doctor of Philosophy

Is approved by the final examining committee:

Jane Frankenberger
Chair

Indrajeet Chaubey

Linda Prokopy

Laura Bowling

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Approved by Major Professor(s): Indrajeet Chaubey

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Approved by: Bernard Engel 09/24/2013
Head of the Graduate Program Date

# ADAPTIVE TARGETING: ENGAGING FARMERS TO ASSESS PERCEPTIONS AND IMPROVE WATERSHED MODELING, SPATIAL OPTIMIZATION, AND ADOPTION OF AGRICULTURAL CONSERVATION PRACTICES

A Dissertation

Submitted to the Faculty

of

Purdue University

by

Margaret McCahon Kalcic

In Partial Fulfillment of the

Requirements for the Degree

of

Doctor of Philosophy

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Purdue University

West Lafayette, Indiana

To Andy, my love

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I want to express my gratitude for so many who invested time and effort into helping me complete this work. To my advisors, Dr. Jane Frankenberger and Dr. Indrajeet Chaubey, I thank you for your encouragement, wisdom, and support in helping me find a project and complete my studies. And thank you to my committee members, Dr. Linda Prokopy and Dr. Laura Bowling, for your thoughtful guidance. I could never have completed the human dimensions work without Dr. Prokopy's support!

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# TABLE OF CONTENTS

APPENDICES

# LIST OF TABLES

Table Page

# LIST OF FIGURES

Figure Page

# ABSTRACT

Kalcic, Margaret McCahon. Ph.D., Purdue University, December 2013. Adaptive Targeting: Engaging Farmers to Assess Perceptions and Improve Watershed Modeling, Optimization, and Adoption of Agricultural Conservation Practices. Major Professors: Jane Frankenberger and Indrajeet Chaubey.

Targeting agricultural conservation practices to farmland that has the greatest impact on surface water quality has received wide support from scientists and watershed managers. The targeting approach has, however, been politically contentious as many believe farmers will oppose the approach on grounds such as privacy invasion and unfair distribution of government incentives. Targeting conservation practices using complex optimization models has become common in the scientific community, and yet targeted results are underutilized in practice because of difficulties such as knowledge transfer and absence of a political framework for their use. For targeting to be successful, it must be politically supported in concept and practically demonstrated in implementation. In this work I have conducted an interdisciplinary study and targeting experiment that brings together the human dimensions of targeting with the engineering tools of watershed modeling and spatial optimization to demonstrate an adaptive targeting approach. The approach is adaptive in its involvement of stakeholders, namely farmers and landowners, in the targeting process. Fourteen farmers were engaged through in-depth interviews about their farmland, conservation practices, and opinions on targeting of conservation. Interviews and the targeting experiment were conducted in 2012-2013 in two small west-central Indiana watersheds – the Little Pine watershed (56 km$^2$) and Little Wea watershed (45 km$^2$).

There was general support for the targeting approach among farmers interviewed, despite wide variation in farmer views of conservation and government programs. Farmer views of differing conservation practices varied as well, supporting a flexible targeting approach where farmers are consulted prior to targeting conservation on their lands. The watershed modeling and spatial optimization approach tailored to farm boundaries was a suitable tool for targeting field scale practices at the watershed scale. Conservation practices represented in the Soil and Water Assessment Tool (SWAT) varied in effectiveness of reducing total nitrogen, total phosphorus, and sediment from reaching surface waters. Grassed waterways, filter strips, and strategically cited wildlife habitats had the greatest efficiency in lands with little existing conservation, and cover crops and wetlands were capable of intercepting nutrients and sediments other practices could not reach. The adaptive targeting experiment resulted in a stated intention to adopt 35% of all targeted recommendations across ten farms. Interviews clearly improved the targeting approach, provided an avenue for knowledge transfer, and built trust with farmers.

# CHAPTER 1. INTRODUCTION

Agricultural intensification has provided a food surplus benefiting humans worldwide. Yet increased agricultural production has many unintended consequences, also called externalities: accelerated soil erosion degrades water quality (Lal, 1998) and damages the soil's ability to sustain crop yields (Pimentel et al., 1995); fertilizer applications lead to nitrogen and phosphorus runoff that harms aquatic ecosystems through algal blooms and hypoxic conditions in lakes and coastal regions (Conley et al., 2009); and pesticides can harm both upland and aquatic ecosystems (Matson et al., 1997). These contaminants, referred to as nonpoint source pollution, are of particular importance to downstream water quality.

Farmers and landowners can reduce or capture nonpoint source pollutants by using conservation practices, also referred to as best management practices for agriculture. Some conservation practices address the rate or timing of fertilization, pesticide application, and tillage practices. Others are structural practices such as constructed wetlands and vegetated buffers that are capable of capturing pollutants between the farm fields (source) and streams or rivers (Dinnes et al., 2002).

In the United States, implementation of conservation practices is generally not regulated by the government, but rather reflects a voluntary decision on the part of the farmer or landowner. Government incentives are available through voluntary enrollment to encourage adoption of conservation practices. Unfortunately, past research has shown that incentives are not likely to achieve efficient pollution reductions (Nowak et al., 2006; Diebel et al., 2008). The reason is two-fold: the first is a physical vulnerability of the land - some farmland is more vulnerable to generating nonpoint source pollution than other lands (e.g. soil type and slope) - and the second concerns the human dimensions of land management - some farmers and landowners will choose not to use conservation practices on vulnerable farmland.

This land vulnerability is due to a combination of physical characteristics and human land management drives disproportionality, the concept that a portion of managed farmland contributes a disproportionately large amount to environmental and land degradation (Nowak et al., 2006). When land vulnerability and management behaviors of farmers are combined, they lead to an even greater skewed distribution nonpoint source loading to waterways (Nowak et al., 2006). If some farmers managing these vulnerable lands are less likely to seek government support, the resulting environmental degradation may mask any conservation good done by others.

For this reason, many scientists and water managers have long supported the concept of targeting conservation practices to locations where they can do the most good at the watershed scale (e.g. Hession and Shanholtz, 1988; Crumpton, 2001; Heathwaite et al., 2005; Diebel et al., 2008; Diebel et al., 2009; Tuppad et al., 2010). The act of targeting can take many forms, including prioritizing conservation to vulnerable lands (e.g. Tuppad et al., 2010), to locations with greatest potential for improvement (e.g. Maringanti et al., 2011), as well as to suitable locations for a given practice (e.g. Tomer et al., 2009). Tools used to conduct targeting range from geospatial analyses to watershed models and optimization approaches.

Although conceptually appealing, targeting has not often been used. Some anticipate a targeting approach will be opposed by farmers and landowners (Arbuckle, 2012), who may view it as unfair or unnecessary government intrusion. Indeed, many farmers are concerned about the perceived excessive regulation of farming (Ahnstrom et al., 2008), and some farmers are known to hold negative views of government programs (Reimer et al., 2011). Economic incentives generally help farmers initiate conservation efforts, but may not lead to sustained conservation (Ahnstrom et al., 2008). Government funding may not be appealing to all farmers, including those with a stewardship ethic who may not be motivated to conserve lands for financial reasons (Greiner et al., 2009). Yet to date, there is little evidence that farmers do resist the targeting approach (Arbuckle, 2012), and many researchers are calling for a flexible targeting approach (Nowak et al., 2006; Ahnstrom et al., 2008; Reimer et al., 2011).

In this work I seek to design a flexible and adaptive targeting approach and implement it using the best watershed modeling and spatial optimization tools available in two small Indiana watersheds. Stakeholder participation, in this case interactions with farmers and landowners, is an important part of an adaptive approach, as it will likely increase fairness, lead to wiser, more efficient solutions, and better decisions, and be viewed more favorably by farmers (Tuler and Webler, 1999 ; Lauber and Knuth, 2000; Beierle, 2002; Dietz and Stern, 2008). Since farmers and landowners control the sources of nonpoint source pollution, it is important that any plan for conservation involve producers and seek to be a pleasant process for them. Building good relationships and trust between producers and conservation programs is a critical part of countering nonpoint source pollution, and even more so when dealing with targeted solutions. Engaging these producers is necessary to adapt targeted solutions so they have the highest chance of adoption in agricultural landscapes.

## 1.1 Goals and Objectives

The overall goal of this work was to develop an adaptive targeting approach that is acceptable to farmers and landowners and increase adoption of optimal conservation in their lands. This approach was demonstrated in what will be referred to as the *targeting experiment*.

The first objective was to better understand farmer perceptions of targeting, and how these relate to their conservation behavior, beliefs about the natural environment, and distrust of government programming. Tasks involved (1) review of the literature on farmer perceptions of conservation, (2) design and implementation of farmer interviews, (3) transcription of interviews, (4) qualitative analysis to understand interactions among conservation adoption, views of the natural environment and conservation programming, and the perception of targeting, and (5) identification of farmer interest in, trust of, and response to the overall targeting experiment. Tasks are documented in chapters 2 and 5.

The second objective was to create an appropriate watershed modeling and spatial optimization framework capable of optimizing the placement of conservation practices in the case study watersheds. This objective required several tasks for extending the Soil and Water Assessment Tool (SWAT), the chosen watershed model, in numerous ways: (1) defining the model's smallest spatial units, hydrologic response units (HRUs) by socially meaningful boundaries so that inputs and outputs are mapped directly to individual farm fields; (2) evaluating the SWAT model's effectiveness at predicting streamflow and water quality in the case study watersheds; (3) ensuring proper simulation of subsurface tile drainage abundant in the study watersheds; and (4) representing in SWAT six conservation practices that have potential to influence water quality and are common in the case study watersheds. Additional tasks were required to extend the chosen spatial optimization approach, the NSGA-II genetic algorithm: (5) allowing for numerous conservation practices in each HRU; (6) constraining future scenarios such that existing conservation practices persist; (7) constraining future scenarios to farmer preferences for future conservation; (8) creating appropriate objective functions, cost and a water quality index; and (9) selecting an optimal generation and corresponding optimal set of conservation practices by applying a threshold for each HRU. These tasks are documented in chapters 3 and 4.

The third and final objective was to evaluate the adaptive targeting approach as demonstrated in the targeting experiment. The spatial optimization approach developed in the second objective was implemented in the case study watersheds, and results were brought back to farmers in follow-up interviews. The approach was evaluated by the following rubrics: (1) optimality of current farmer adoption of conservation, which, if nearly optimal in the absence of targeting, could imply that targeting has little more to offer; (2) comparisons between unconstrained targeting and constrained targeting, which is more acceptable to farmers; (3) farmer assessment of optimality of the targeted practices; (4) farmer intention to adopt targeted practices, which shows the expected impact of the approach in farmer decision-making; and (5) farmer recommendations for the approach. These tasks are the focus of chapter 5.

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# CHAPTER 2. FARMER PERCEPTIONS OF TARGETING CONSERVATION PRACTICES IN TWO MIDWESTERN WATERSHEDS

## 2.1 Abstract

Watershed managers have largely embraced targeting of agricultural conservation as a way to strategically manage nonpoint source pollution from agricultural lands, yet practical implementation of targeted solutions has lagged. Successful targeting may require support from farmers and landowners, whose lands would be targeted for conservation. Recent quantitative work has found that farmers in Iowa generally support targeting, but could not probe into the reason for these views. In this work a qualitative approach was employed, using farmer interviews in Indiana to better understand farmers' views on targeting. Interviews discussed adoption of a number of conservation practices on farmers' lands, as well as identified farmers' views on targeting, disproportionality, and monetary incentives. Results show consistent support for the targeting approach across all interviews, despite dramatic differences in farmers' views of land stewardship, their views about disproportionality of water quality impacts, and their trust of government programs. While the theoretical concept of targeting was palatable to all farmers, most farmers raised concerns related to targeting's practical implementation, including the need for flexibility and the image of the entity performing targeting.

## 2.2 Introduction

Agricultural production in the Midwest USA provides enormous benefits to humans worldwide, yet intensification of agricultural activities also threatens water quality and environmental resources through nonpoint source pollution, such as soil erosion, nutrients, and pesticides. Soil erosion degrades farmland and damages water quality, nitrogen and phosphorus runoff can harm aquatic ecosystems through algal blooms and hypoxic conditions in lakes and coastal regions (Conley et al., 2009), and pesticides are responsible for upland and aquatic ecological harm (Matson et al., 1997).

Nonpoint source pollution can be mitigated by installation of agricultural conservation practices, also called best management practices. Conservation practices include on-field nutrient or pesticide management plans, and tillage practices, as well as off-farm structures like constructed wetlands and riparian buffers intended to intercept pollutants before they reach lotic (riverine) ecosystems (Dinnes et al., 2002). Many government programs encourage farmers to adopt conservation practices with incentives available for voluntary enrollment. However, these incentives may fail to efficiently reduce agricultural pollution of surface waters, as farmers may choose not to adopt conservation on the most vulnerable farmlands (Nowak et al., 2006; Diebel et al., 2008).

Disproportionality underlies farmland vulnerability and is a primary motivation behind targeting of conservation practices to the most vulnerable locations in the landscape (Reimer et al., 2011; Arbuckle, 2012). Disproportionality can be defined as the situation in which a small portion of farmland is responsible for a disproportionately large amount of environmental degradation (Nowak et al., 2006). Land vulnerability is a function of both physical vulnerability of farmland (e.g. soil type and slope) as well as the human dimensions of land management. Interdisciplinary research has shown both the vulnerability of land and the behaviors of farmers lead to a skewed distribution of water quality impacts, especially phosphorus and sediment loading to waterways (Nowak et al., 2006). Therefore, some farmers managing the most vulnerable lands will also be the least likely to seek government support, and the conservation good done by many may be masked by the poor land management of a few.

Many scientists and water managers have supported the targeting of conservation practices to the most effective locations (e.g. Hession and Shanholtz, 1988; Crumpton, 2001; Heathwaite et al., 2005; Diebel et al., 2008; Diebel et al., 2009; Tuppad et al., 2010). Targeting can take many forms, including prioritization of conservation to the most vulnerable lands, also called “hotspots” (e.g. Tuppad et al., 2010), to locations with the highest potential for improvement (e.g. Maringanti et al., 2011), as well as to sites where a given practice makes the most sense (e.g. Tomer et al., 2009). Targeting tools range from geospatial analyses to more complicated watershed models and optimization approaches.

While targeting of government funds for conservation is conceptually appealing, it has not often been done and is commonly viewed as politically contentious. In fact, in the 2002 Farm Bill, conservation programming was shifted away from cost-effectiveness and traditional targeting tools (Claassen, 2007). Targeting efforts led by the Natural Resource Conservation Service (NRCS), such as the Mississippi River Basin Healthy Watersheds Initiative (MRBI) in the 2008 Farm Bill (Farm Bill, 2008), focus on targeting fairly large watersheds for conservation efforts. Yet targeting watersheds may fail to produce optimal conservation as soils, slopes, and land management within these watersheds may be quite diverse. In addition, conservation practices are generally implemented at the field scale by farmers operating at the field scale. Therefore, field scale targeting of conservation practices may be optimal.

In order for field scale targeting to be successful, not only would appropriate policies be needed, but support from farmers and landowners would also be required, as they are decision-makers on targeted lands. Arbuckle (2012) studied farmer views of targeting through a quantitative survey of select Iowa farmers, and found general support for a targeting approach. His survey could not, however, explore why most farmers supported targeting, or why a significant and vocal minority opposed the approach. Work is needed to better understand how farmers view the targeting approach

### 2.2.1 Farmer views related to targeting conservation practices

While little research has focused directly on farmer views of targeting, many studies have explored related farmer views on conservation and stewardship of the land. Arbuckle (2012) found that most farmers support targeting, and these farmers may be characterized by greater awareness of disproportionality and the environment than those who oppose targeting. However, a significant minority of farmers had deep-seated concerns about government intrusion (Arbuckle, 2012). Based on previous work, of greatest interest for this study were the relationship between stewardship ethic, concerns about government intrusion, attitudes towards incentives, and support for a targeting approach.

#### 2.2.1.1 Stewardship ethic

Farmers in the US generally view themselves as good stewards of the land and desire to be considered good stewards by others (Ahnstrom et al., 2008). Stewardship of the land may be motivated intrinsically by an attachment to the land, a desire to pass on the land to future generations, an identity of what it means to be a good farmer, and a general sense of responsibility to the family, community, or others (Ryan et al., 2003; Reimer et al., 2011; McGuire et al., 2013). While farmer behaviors are driven by diverse goals, those with a stewardship ethic have been found to have greater motivation for conservation (Greiner et al., 2009). It is possible that farmers with greater stewardship ethic would better understand the need for increased conservation and therefore be more amenable to the targeting approach.

#### 2.2.1.2 Concerns about government intrusion

Many farmers are concerned about perceived excessive regulation of farming (Ahnstrom et al., 2008). A portion of farmers in Indiana is known to hold negative views of government programs, and may be unwilling to participate in these programs in the absence of incentives (Reimer et al., 2011). Some farmers in Indiana and Iowa who are more motivated by finances and production and less motivated by conservation also have greater concern about government intrusion (Arbuckle, 2013; Reimer et al., 2011). Therefore it is possible that farmers who have greater concern about government intrusion would be less likely to have adopted many conservation practices and participate in government programs, and would be more likely to resist a targeting approach.

#### 2.2.1.3 Views of government incentives

Economic incentives have been shown to help farmers initiate conservation efforts, but they are not necessarily helpful in changing attitudes or leading to sustained conservation (Ahnstrom et al., 2008). While farms experience economic stresses like all businesses, farmers' greatest goals and motivations may not be financial in nature (Greiner et al., 2009). In fact, farmers who have adopted few conservation practices may be more motivated by incentives, while others may be motivated to adopt conservation for intrinsic reasons, such as recognition by peers, or a stewardship ethic of care for the environment (Greiner et al., 2009). For instance, some Michigan farmers had strong intrinsic motivations to conserve streams and riparian buffers (Ryan et al., 2003). There is some concern that incentives may actually hinder conservation of stewardship farmers, who are intrinsically motivated to conserve and do not require monetary incentives (Greiner et al., 2009; Reimer et al., 2011). It is likely that farmer views of incentives relate to their views of an approach that targets those incentives to priority farmland.

### 2.2.2 Overall goal

The purpose of this study is to better understand farmer views of a targeting approach to conservation programming. Qualitative analysis of in-depth interviews using the grounded theory approach provides a conceptual framework for understanding interactions among conservation adoption, views of the natural environment and conservation programming, and the perception of targeting in this pilot work.

## 2.3 Materials and Methods

### 2.3.1 Qualitative analysis approach

Individual farmer interviews were used in this work to provide rich qualitative data on farmer opinions and conservation. Analysis of qualitative data allows the researcher to better understand the relationships between beliefs, attitudes, and external characteristics that drive behavior such as adoption of conservation (Kaplowitz and Hoehn, 2001). An especially useful tool in preliminary or pilot work, qualitative work such as interviews and focus groups can lay the foundation for subsequent quantitative methods (Kaplowitz and Hoehn, 2001; Prokopy, 2011). Qualitative research is generally intended to understand a particular community or sub-group. In this work, results are not intended to be generalizable, yet themes may be transferrable to similar people or groups and can be used as a conceptual framework for future efforts.

### 2.3.2 Study area

Interviews were conducted with farmers in two watersheds in west-central Indiana, which were selected based on the presence of local watershed conservation and research efforts. Watershed 1, the Little Pine Creek watershed near Montmorenci, Indiana, is 56 $km^2$ in size, while Watershed 2, the Little Wea Creek watershed at South Raub, Indiana, is 45 $km^2$ in size. Both watersheds are primarily agricultural land use with corn and soybeans as the predominant crops covering approximately 70% of the lands.

### 2.3.3 Interview guide

The interview guide was developed as part of a larger adaptive targeting study. The first part of the adaptive targeting experiment involved a set of baseline interviews in winter of 2012 in which farmers provided information on current conservation efforts, as well as presented their preferences for future conservation. Participants knew that the information they provided would be used to develop targeted conservation practice recommendations on their lands. Only qualitative data from the baseline interviews were used in this work. Follow-up interviews were conducted in winter of 2013 with the majority of participants in order to provide them with recommendations and discuss their intentions to adopt targeted practices. All aspects of the interview approach were approved by Purdue University's Institutional Review Board.

Because this work was placed within the context of a targeting study, participants took the interviews quite seriously, and discussion of targeting was practical and tangible. Support for targeting may be expected to depend somewhat on the type of targeting approach utilized, and farmers may not view all approaches equally. Therefore, participants were asked about their trust of computer models used for targeting, the limitations of these models, and what other data or supplementary information would be necessary for successful targeting. Views of computer models as targeting tools were included in the qualitative analysis under the broader concept of support for the targeting approach.

Interview prompts were designed to cover the topics of disproportionality, support for the targeting approach, views on conservation, and views of incentives. Specific prompts are shown in Table 2.1 alongside the opinion they were designed to elucidate. Several questions were asked that were similar to those asked in a previous Iowa survey (Arbuckle, 2012). To better understand farmer views on conservation and incentives, the interview prompt led the farmer through a discussion of eleven conservation practices. These practices were selected for inclusion either because they were commonly used in the county or because they had potential to impact water quality. For each practice, the farmer was asked whether he had used this practice in the past or present, and whether he would consider using the practice in the future if "given an incentive to do so." Maps of the study area were included at the field scale and farmers were encouraged to draw locations of conservation practices and specific land management issues on the maps. While maps were limited to the study area, conservation in farmers' lands outside the study area was also considered for the qualitative analysis.

### 2.3.4 Interview response

The aim was to find and interview as many farmers operating in the two study watersheds as possible. Potential interviewees were selected from public records based on land ownership in the study area of at least 20 hectares, and public access to addresses and phone numbers. Contact was made first by an introductory letter, then by phone, and those who were interested scheduled an interview. A total of 70 contacts were sent the letter, and only 42 households were reached by phone, as many of the phone numbers were discontinued. Out of the 42, 13 were determined to actively farm, 22 were non-farming landowners, 3 did not actually own land in the study area, and in 4 cases the contact was refused by a family member who gave no information. Of these 13 farmers, 12 accepted the interview, while the last was unable to take an interview because he was busy preparing the fields for planting and a family member had already been interviewed about his lands. Two landowners retired from farming for a decade but still involved in the farming operation on their lands were asked if they would participate in the interview and accepted.

Table 2.1 Interview prompts on a variety of opinions related to support for the targeting approach, motivations for adoption of conservation, and disproportionality of farm environmental impacts.

| Interview prompts | Opinions learned |
|---|---|
| What kinds of incentives are appealing to you? What kinds of incentives do not appeal to you? | Views of incentives |
| Do you think some farmers contribute more to water quality problems than others? Why or why not? | Belief or disbelief in disproportionality |
| How do you think farmers should take responsibility for water quality preservation? | Belief or disbelief in disproportionality<br>Sense of stewardship or responsibility |
| Do you think conservation practices should be targeted to locations where they are most effective? | Support for the targeting approach |
| Should conservation practices be prioritized in locations where they do the most good for water quality at the least cost? Why do you think this? | Support for the targeting approach |
| Do you think conservation funding should be higher for land that is most vulnerable to soil and water quality problems? Why or why not? | Feeling of unfairness in the targeting approach<br>Support for targeting approach |
| In my research, I am using a landscape-scale model to find optimal locations for conservation practices in this area. Do you think computer models can effectively identify good locations for conservation practices? What would increase your trust in these models? | Trust of targeting tools |
| How would you feel if you were told that you had the opportunity to be compensated for adopting an optimal conservation practice on your farm? How would you likely respond? | Feeling of unfairness in the targeting approach |
| If I find that your land may be optimal for a conservation practice that you expressed an interest in during this study, would you like me to contact you for a second interview? | Refusing contact of a conservation professional |

A total of fourteen farmers were interviewed, but only twelve were included, because two were employees on Purdue University farms. These two were not included in this analysis to ensure there was no bias in the sample. The remaining twelve were split evenly in the two watersheds. Overall, the response rate of those individuals who were reached by phone, were active farmers, and were asked if they would consider an interview, was nearly 100%, although only 60% of those contacted by letter were reachable by phone.

Not only was the response rate high, the percentage of agricultural lands covered by the interviews in the two watersheds was fairly sizable as well. In Watershed 1, 34% of the land (1900 hectares) was covered by the interviews, although two of the interviews were conducted with operators of university farms. In Watershed 2, 32% of the land (1440 hectares) was covered. The majority of the study area not covered by the interviews is most likely rented by farmers who do not own at least 20 hectares within the watersheds, or did not have contact information in the public domain that could be used to make successful contact.

Interviews were conducted in January-March of 2012, prior to spring planting. Interview length was 1.5-4 hours, including significant time spent locating conservation practices and structures in the farm lands.

### 2.3.5 Coding interview data

Interviews were taped and transcribed verbatim. Transcripts were coded using the grounded theory approach (Corbin and Strauss, 1990; Miles and Huberman, 1994) with the aid of the NVivo 9 software. Coding took place iteratively, beginning with a large set of codes that encompassed all aspects of the interviews, and then narrowing to codes that were dominant among a number of farmers and most relevant to the research questions. Inter-coder reliability where a second researcher independently coded three interviews was evaluated at an early stage of coding. Although the sample size was small, the sample was fairly homogeneous (in terms of age, race, occupation, and geographic location), and saturation was reached for the topics discussed in this work (Mason, 2010).

### 2.3.6 Grouping farmers based on conservation practice adoption

Farmers were divided into three groups based on their level of conservation practice adoption, similar to a method used in Reimer et al. (2011). In that work, farmers who had adopted few conservation practices on their farms tended to have a "farm as business" motivation, meaning they focused primarily on the profit of the farming operation, often to the detriment of the natural environment. Environmentally-motivated farmers were much more likely to be in the medium or high adoption groups.

Here, similar groupings were created based on adoption of seven practices as shown in Table 2.2. Criteria were developed to define adoption of a given practice, so that results could be reported consistently across all farmers. Adoption of each conservation practice was determined not only by whether or not a farmer stated he adopted a practice, but also by careful examination of the farmer's statements about the practices on his farm. Resulting adoption groups were: low adopters, who currently have in place 0-2 (out of 7) conservation practices on their farms; medium adopters: who currently have in place 3-4 conservation practices; and high adopters: who currently have in place 5-7 conservation practices.

## 2.4 Results and Discussion

### 2.4.1 Farmer characteristics and adoption

All twelve interviewees were Caucasian male. They were, on average, 63 years of age, and their length of farming career was, on average, 39 years, ranging from 27 to 54 years. All farmers grew row crops, primarily corn and soybeans, with three farms including winter wheat or alfalfa in crop rotations. Livestock on the farms included five farms with a small number of beef cattle grazing on pasture lands, and two farms with hog operations. Most farmers reported having livestock operations in the past. Farm size ranged from approximately 80 to 4,000 hectares, with a mean of 750 and a median of 450 hectares. Both retired farmers were in the high adopter group, while both major livestock owners were in the low adopter group. At least one farmer served on a local conservation board.

Table 2.2 Selected conservation practices for inclusion in interviews, and the criteria used to determine farmer adoption in this work.

| Conservation practice standard (NRCS number) | Criteria for determining whether practice has been adopted |
|---|---|
| Continuous no-tillage (329) | Farmer has at least one field that is maintained continuously throughout the rotation with no-till. Other forms of conservation tillage were not considered in this category. |
| Cover crops (340) | Farmer currently plants at least one field each year with a cover crop that is in place through the winter. Cover crop varieties include, but are not limited to, winter wheat, cereal rye, and tillage radishes. |
| Filter strip (393) | A strip of vegetation is maintained alongside an open waterway, which may or may not have been funded or meet the width requirement for conservation funding. |
| Grassed waterway (412) | Farmer currently maintains grassed waterways on the farm. Farmer may or may not be receiving CRP payments, but waterways should be maintained in grass vegetation, and be located within or adjacent to farm fields. |
| Restoration and management of rare or declining habitats (643) | Farmer has grown prairie grasses on his land or received an incentive to establish a wildlife habitat (aside from buffer strips, grassed waterways, and wetlands). |
| Upland wildlife habitat management (645) | Farmer provides any habitat during the wildlife nesting season by not mowing grassed waterways, buffer strips, etc. April 1 – August 1, or has created habitats or food plots other than prairie grasses in uplands. |
| Wetland restoration/creation (657/658) | Farmer has taken farmland or pastureland out of production to restore or create a wetland. Such a project would most likely receive conservation funding. |

### 2.4.2 Qualitative coding by adoption groups

Based on current conservation adoption rates, four farmers were low adopters, three were medium adopters, and five were high adopters (Table 2.3). Low adopters had few conservation practices besides grassed waterways, which were present on all farms in the study. All farmers viewed grassed waterways as critical to prevent excessive soil erosion in the most vulnerable lands and maintain manageability of the land. Continuous no-tillage and filter strips were common in the medium and high adopter groups. Filter strips generally required removing land from production along streams and ditches, and no-tillage was seen as beneficial to soil formation but potentially harmful to crop yields. High adopters used most or all conservation practices, even the two landowners who owned fairly small farms. Farmers in the sample displayed a wide range of adoption behavior, which was described well by the three adoption groups.

Qualitative codes were developed and then used to compare views across adoption groups. Qualitative coding resulted in a final set of 29 codes, which were used to categorize farmer perceptions of conservation programming, views of incentives, personal sense of stewardship, belief in disproportionality, support of targeting conservation, and ideas about the role of computer models in targeting efforts. Codes and descriptions are shown in Table 2.4.

Dominant codes for each farmer are shown by category and adoption group in Table 2.5. A number of differences arise between low adopters and high adopters, while medium adopters, as may be expected, often walk the line between the groups. Primary differences between low adopters and high adopters were that only low adopters expressed distrust of conservation programming, and no low adopters had high levels of positive interaction with conservation planners, while medium and high adopters had high levels of interaction with conservation planners. Concern about government intrusion in this sample, therefore, tracked well with farmers of lower stewardship ethic.

Table 2.3 Number of farmers adopting conservation practices in the past and present, grouped by adoption behavior.

| | **Low adopter** (0-2 CPs out of 7, 4 farmers) | **Medium adopter** (3-4 CPs out of 7, 3 farmers) | **High adopter** (5-7 CPs out of 7, 5 farmers) |
|---|---|---|---|
| Continuous no-tillage | 0 | 2 | 4 |
| Cover crops | 0 | 0 | 3 |
| Filter strips | 1 | 3 | 4 |
| Grassed waterways | 4 | 3 | 5 |
| Restoration and management of rare or declining habitats | 0 | 0 | 4 |
| Uplands wildlife habitat management | 1 | 1 | 4 |
| Wetland restoration/creation | 0 | 0 | 2 |

Table 2.4 Final codes with descriptions.

| **Codes** | **Description** |
|---|---|
| *Views of the targeting approach* | |
| Agree | Farmer agrees in the concept of targeting through conservation programming. |
| Most good | Farmer emphasizes that targeting is prioritizing projects that do the most good, or emphasis on “biggest bang for the buck.” |
| Strong interest | Farmer shows strong interest in hearing about practices targeted on his lands. |
| Difficult | Farmer expresses that targeting will be difficult to implement or offers suggestions for successful implementation. |
| Objectives | Farmer comments on what the objectives of targeting should be (e.g. water quality vs. education/community values). |
| Unfair | Farmer perceives, to some extent, that targeting is unfair to those farmers not benefiting directly from targeted use of conservation funding. |
| *Views of computer models used for targeting* | |
| Helpful | Farmer approves of using a computer model to target conservation practices. |
| In-field inspection | Farmer emphasizes the importance of supplementing computer model results with in-field inspection. |
| Inputs | Farmer emphasizes that his trust in the computer model depends on using the correct inputs (e.g. current conservation practices on the land). |
| Bias | Farmer expresses concern over computer modeling that is performed by a “biased” source, such as the government. |
| *Views of disproportionality of farmers' impacts* | |
| Caring | Farmer expresses a belief in disproportionality driven by some farmers caring less about conserving but rather caring solely about economic bottom line. |
| Management | Farmer expresses a belief in disproportionality driven by different farm management practices (e.g. conservation tillage vs. conventional tillage). |
| Resources | Farmer expresses a belief in disproportionality as driven by some farmers’ inability to conserve due to tight resources (e.g. large farm, lack of funds). |
| Land | Farmer expresses a belief in disproportionality as driven by different land characteristics (e.g. slope, soil type). |
| Disbelief | Statements reveal that a farmer does not agree with the concept of disproportionality, or evades the question. |

Table 2.4 Continued.

| **Codes** | **Description** |
|---|---|
| *Views of conservation programming* | |
| Interact | Farmer mentions positive interaction with conservation-oriented professionals (e.g. soil and water conservation district). |
| Distrust | Farmer appears to distrust or dislike government programs or conservation programming (e.g. emphasis on “red tape”). |
| Problems | Farmer identifies issues with conservation programming that serve as a barrier to conservation (e.g. eligibility, requirements). |
| *Views of conservation practice incentives* | |
| Help | Incentives help conservation to take place (includes “enable” and “motivate”). |
| Enable | Incentives are a means to achieve conservation farmers already view as a priority, but cannot currently fund. |
| Motivate | Incentives are the primary motivation for conservation interest; farmer suggests his actions are drive by the presence of an incentive, rather than an inherent interest in conservation. |
| Don't help | Incentives don’t necessarily help conservation efforts (includes “unnecessary” and “unwanted”). |
| Unnecessary | Farmer suggests that he would conserve regardless of incentives, either because conservation is important to him, or because incentives would be insufficient reason to conserve. |
| Unwanted | Farmer suggests that incentives are unattractive, either because the government should limit its spending, or the farmer doesn’t want to be involved in something regulated by the government. |
| *Stewardship ethic* | |
| Responsible | Farmer expresses a sense of responsibility for environmental impacts of his farm. |
| Responsible to Community | Farmer expresses a sense of responsibility to the local community, or society as whole, in regards to farm management practices. |
| Steward | Farmer’s statements evoke a general sense of environmental stewardship. |
| Not responsible | Farmer expresses that he’s already doing enough conservation, or is not responsible for his farm’s environmental impacts. |
| Others responsible | Farmer defers question of responsibility by indicating that others (besides farmers) are responsible for minimizing environmental impacts (e.g. townspeople who over-fertilize their lawns). |

Table 2.5 Farmer perceptions of conservation programming, targeting, and related concepts, divided by current conservation practice adoption level. See Table 2.4 for code descriptions. Numbers in parentheses indicate the number of farmers in the adoption group expressing that view. Italics indicate results differing most across adoption groups. (+) and (-) indicate positive and negative views, respectively.

| **Low adopter** (0-2 CPs out of 7, 4 farmers) | **Medium adopter** (3-4 CPs out of 7, 3 farmers) | **High adopter** (5-7 CPs out of 7, 5 farmers) |
|---|---|---|
| Views of the **targeting approach** | | |
| (+) Agree (4/4) | (+) Agree (3/3) | (+) Agree (5/5) |
| (+) Most good (4/4) | (+) Most good (2/3) | (+) Most good (4/5) |
| (+) Strong interest (3/4) | (+) Strong interest (2/3) | (+) Strong interest (1/5) |
| | *(-) Difficult (2/3)* | *(-) Difficult (2/5)* |
| | *(-) Objectives (1/3)* | *(-) Objectives (2/5)* |
| | | *(-) Unfair (1/5)* |
| Views of **computer models** used for targeting | | |
| (+) Helpful (4/4) | (+) Helpful (2/3) | (+) Helpful (4/5) |
| In-field inspection (1/4) | In-field inspection (2/3) | In-field inspection (3/5) |
| *(-) Inputs (2/4)* | *(-) Inputs (1/3)* | |
| *(-) Bias (2/4)* | | |
| Views of **disproportionality** of farmers' impacts | | |
| (+) Caring (2/4) | (+) Caring (1/3) | (+) Caring (4/5) |
| (+) Management (2/4) | (+) Management (2/3) | (+) Management (5/5) |
| Resources (1/4) | Resources (1/3) | |
| Land (1/4) | Land (2/3) | Land (3/5) |
| *(-) Disbelief (1/4)* | | |
| Views of **conservation programming** | | |
| | *(+) Interact (3/3)* | *(+) Interact (4/5)* |
| *(-) Distrust (2/4)* | | |
| (-) Problems (1/4) | (-) Problems (1/3) | (-) Problems (1/5) |
| Views of conservation practice **incentives** | | |
| (+) Help (2/4) | (+) Help (3/3) | (+) Help (4/5) |
| (+) Enable (1/4) | (+) Enable (2/3) | (+) Enable (1/5) |
| (+) Motivate (2/4) | (+) Motivate (1/3) | (+) Motivate (4/5) |
| (-) Don't help (2/4) | (-) Don't help (1/3) | (-) Don't help (1/5) |
| *(-) Unnecessary (2/4)* | *(-) Unnecessary (1/3)* | |
| (-) Unwanted (2/4) | (-) Unwanted (1/3) | (-) Unwanted (1/5) |
| **Stewardship** ethic | | |
| (+) Responsible (1/4) | (+) Responsible (2/3) | (+) Responsible (3/5) |
| (+) Community (1/4) | (+) Community (2/3) | (+) Community (2/5) |
| (+) Steward (1/4) | (+) Steward (2/3) | (+) Steward (2/5) |
| *(-) Others responsible (2/4)* | *(-) Others responsible (1/3)* | |
| *(-) Not responsible (1/4)* | | |

Major differences and similarities in farmer views by adoption group are elaborated in the following sections. Many quotations are indexed by adoption group to protect the identity of individual participants.

### 2.4.3 Farmer views of targeting

#### 2.4.3.1 Support for the targeting approach

All farmers showed support for the targeting approach, sharing the opinion that government funds should be spent efficiently, and were generally in favor of conservation funding being higher for lands most vulnerable to soil and water quality degradation. This is consistent with Arbuckle's work (2012), which found farmers generally in favor of the targeting approach.

The primary reason farmers expressed for their support of targeting was a desire for conservation programming to do the most good for the least cost. As one said,

> "Well, biggest bang for the buck. We don't have unlimited funds to spend, either personally, or businesses, or the government, any of us. So we have to do the most for the least amount of money."

Some farmers expressed a willingness to forego government funding if there is a greater need elsewhere: "Even though it [government funding] might not funnel to my own farm, but if there's a farm out there that's losing soil at a terribly high rate, I think the money should go there, get that stopped, help that person.." Many farmers emphasized the importance of prioritizing conservation to the most vulnerable areas:

> "Fix the bad and gaping wound before you worry about the scratch on the finger sort of thing. You can always come back to that later on."

> "I think the more highly eroded [lands] should get first choice [for government funding] to be allocated to those first. Take care of the worst problems first…as money becomes available you can move on down to the less problematic areas."

> "All other factors being equal, you put your money where it does the most conservation good."

The three adoption groups all appeared to support the targeting approach equally, though some high adopters with greater stewardship ethic were able to articulate a clear sense of responsibility for their farms' impacts, as discussed in the section on stewardship ethic. They extended responsibility for land beyond water quality protection, highlighting the importance of community responsibility, especially to neighboring farmlands that may be degraded by poor management on their own farm. "If my farm is causing problems with water quality and if I control that, the people downstream from me are benefiting from that." One farmer lamented difficulties he has with a neighbor who "does not care" about conservation and is "creating damage beyond their farm." Another suggested that conservation could be prioritized to locations where it could be most visible to the community, so that "for public education it might do more good."

In some cases, it was not clear whether the farmer was speaking of targeting as a prioritization of government funds, or rather an action a farmer would take in the course of personal conservation planning. Questions were designed to ensure distribution of government funds were discussed, but it may be relevant to further explore farmer views of personal versus government targeting in future work. While all farmers supported prioritizing conservation efforts where they do the most good, they may have different perspectives on the role of government funding and intervention.

#### 2.4.3.2 Interest in targeting results

While only six farmers showed strong interest in hearing about an opportunity to implement targeted conservation on their land, all 12 farmers showed some level of interest, and each was amenable to scheduling a follow-up interview after the targeting experiment was completed. Low adoption farmers may be expected to be more wary of targeting and the act of being targeted, and therefore to have low interest in the study, or even refuse to be contacted in the first place. However, of the six farmers that expressed a strong interest in hearing about targeted results, surprisingly, half of these were in the low adopter group. One low adopter responded to a prompt asking how he would feel if his land were targeted with the following comment: “It would be interesting, it could be helpful…I would look and say, okay, what’d you find, where is it, what’s your idea of what can be done to it?” A high adopter responded with “Okay, let’s talk about it. I wouldn’t throw a person off the place, nor would I sign something in the first five seconds either.” One medium adopter expressed great enthusiasm for hearing about the results, and another shared that he felt he could receive some valuable feedback from the project. Throughout most interviews, farmers would mention difficult or degraded lands, point them out on the map, and ask for feedback specifically for managing those areas. The high level of engagement and interest expressed by low adopting farmers is an encouraging finding. Even those farmers who are wary of government and conservation programming may be willing to receive advice from conservation professionals if they first establish a connection and build trust through interviews. Successful interviewing may depend on asking farmers about what practices they are interested in doing, and which lands they feel are in the most need of conservation.

#### 2.4.3.3 Difficulties and suggestions for targeting

A number of medium and high adopters emphasized potential difficulties with the targeting approach as well as suggestions for improving it. Their concerns, which are delineated below, shed light on the problems that farmers think need to be solved in order to effectively use the targeting approach. It was initially surprising that medium and high adopters expressed these views, rather than low adopters, none of whom expressed such concerns. But, since high adopters are more involved in conservation programming than low adopters, it is reasonable that they would have had greater experience implementing conservation and more exposure to potential difficulties of targeting conservation.

One difficulty some farmers mentioned was that many farmers do not see a need for targeting conservation to vulnerable locations. One high adopter that saw a need for targeting spoke candidly of his peers, stating that “the big problem with targeting is that so many of the operators, these farmers, actually operate over all the different ranges of [land vulnerability], and they tend not to adjust their practices just because it would be more beneficial on one place than another." Such management is likely a result of growing farm size (for example, the average size among these farmers was 750 ha), as well, creating an environment in which operators are strapped for both time and resources and find it difficult to tailor land management practices to land vulnerability. While this farmer clearly understood a need for targeting conservation, many farmers may not see this need and may indeed resist a targeting approach.

Another difficulty with targeting that was raised by a number of farmers is their resistance to an outside entity overseeing the targeting process and the expectation that such an entity would have a homogenizing lens, targeting without recognition of the uniqueness of each farm. "Every case needs to be evaluated individually on something like that [targeting]," one farmer commented, "it's not a one-size-fits-all thing." Some farmers raised the question of which metrics should be used in targeting efforts, challenging which objectives drive targeting programs, and how such objectives ought to be implemented. "It's hard to do all things with one judging scale."

A third source of difficulties raised by multiple farmers pertains to working with landowners on rental lands. Land rental was raised in more than one interview as an impediment to using conservation practices the farmer would like to use on rented land. One medium-adopter, when asked if filter strips were applicable to his farm, answered that they "definitely" were applicable to him "personally", but stated with frustration that "the landowner just wants that cash rent" and will not agree to installing filter strips along his open waterways "because I'm paying him more dollars per acre to farm it than…he could get from the government for leaving it in a filter strip."

One high adopter acknowledged the importance of targeting, especially as an education process, while recognizing that an effective targeting approach would be a lengthy and involved process of engaging farmers and landowners. He emphasized the importance of educating farmers and other stakeholders about targeted conservation efforts, giving them the tools they need to make good decisions. In his view, targeting done correctly would be an "education process," in which "various government agencies" and "owners, operators as well" should "sit down and discuss" the targeted results. His suggestion for gaining support was to show stakeholders exactly what the conservation would involve:

> "Throw that laptop open and say this is what we can do, this is what it would look like… You've got to have pictures, you've got to be able to make examples…. You need to be able to walk out to that point [location in the farm field] and say, based on most recent information, this project could be done for X amount of dollars."

His reason for such a hands-on approach was that implementing conservation "usually takes about 5 or 6 years to get going, and a lot of time spent one on one with individuals."

### 2.4.4 Farmer views of computer models used for targeting

#### 2.4.4.1 Models as helpful targeting tools

When asked if computer models could effectively identify good locations for conservation, most farmers – regardless of adoption group – responded favorably, stating that such models could be quite helpful. One low adopter explained that models are a way to bring many sources of information together: "Now if you've got all kinds of different things into it [the model]: soil types, topography…the whole nine yards, yeah it probably could help tremendously." A medium adopter was enthusiastic about the modeling taking place in the targeting study: "I'm trying to help you [by interviewing], and you're trying to help me [by targeting on my lands], so I feel it's a win-win deal…I feel like I might get some possible feedback from it." A high adopter thought that a computer model would aid the targeting process: "Well, probably, [it would be] quicker and easier than any other way [to target] that we have right now."

#### 2.4.4.2 Difficulties with computer models

Although farmers generally supported using computer models to identify good locations for conservation, half of all participants stressed the importance of on-site inspection prior to any decisions. One farmer stated: "I will trust nearly all of our technology, if before things are implemented there is a visual inspection." Another corroborated: "Well, I still think there has to be somebody [who] physically comes out and does an inspection." One reason for a visual inspection was to verify model inputs are correct, in the case of soil maps or elevation data, for instance. "I think there's going to be a lot of feet on the ground sort of stuff to go with them [model results]. I know this from over the years, with the soil maps…some of our older soil maps are not very accurate." While the model may not fit in every case, one farmer suggested it could be used to prioritize conservation: "I think that you're always going to have that one situation that doesn't fit the model. I think it's a starting point, but there's nothing quite like boots on the ground to figure it out, really. I guess you could prioritize based off of a computer study or model." Another reason for physical inspection would be to determine what conservation is already taking place in the field. This could then be put into the model. As one farmer commented, "The only thing the model can't do…is [determine] whether or not the person is already doing that [conservation practice]." Such a visual inspection would require the farmer's permission, and no questions were asked about whether they would allow this.

Finally, two low adopters shared considerable concern about potential bias or skew on the part of the individual running the computer model, which may relate to distrust of the government. One farmer would "feel more comfortable if it was an independent, university-type project" rather than conducted by the government. Another farmer, who has a substantial hog operation, stated concern over a modeler with bias against the livestock industry, and said he would trust the model based on "knowing who was doing it and what their objective was." He suggested "trying to avoid any conflict of interest with what you're doing," mentioning that "the livestock industry is struggling with people trying to change good practices for invalid reasons."

### 2.4.5 Farmer views of disproportionality

Agreement with the concept of disproportionality, or the acknowledgement that some farmlands contribute more to water quality problems than other lands, were fairly consistent across groups, with the exception of one low adopter. While he did not clearly express a belief in disproportionality – he evaded a question about whether some farmers contributed more to water quality problems than others – he *was* able to see that some conservation practices would be more relevant to some lands than others based on different soil types and slopes. He gave the example, “if you’ve got a flat prairie, and [the farmer] wants to put in a waterway that isn’t going to do any good, then why [should the government] fund it? If [the field is] rolling [sloping] enough that it needs a waterway, that’s where it should go to.”

While all groups understood that farm impacts are disproportional in the landscape, the responses of high and low adopters nonetheless differed notably. High adopters generally believed that poor management practices and a lack of care for the land contributed substantively to disproportionality, and they discussed these concerns with great fervor. Their strong responses included calls to conservation action, which were consistent with the high stewardship ethic shared by high adopters.

### 2.4.6 Farmer trust of conservation programming

One high adopter suggested a linkage between low interaction, lack of government trust, and low adoption, when explaining that farmers who are not well connected to conservation planners do not hear about conservation and do not trust the government. “Then of course there’s the thing that I haven’t mentioned before, the widespread distrust of anything held forth by any governmental agency; if its government then it’s got to be bad. There are guys that, maybe if they were connected through USDA or soil conservation service, they might at least listen….” While those with low government trust may not be able to communicate well with conservation staff, he suggests that they may, however, “come closer to trusting” and listening to someone who is “clearly not part of the government.”

#### 2.4.6.1 Interaction with conservation planners

The majority of medium and high adopters described significant and primarily positive interactions with conservation planners such as those working for the soil and water conservation district, consistent with the finding in Prokopy et al. (2008) that local interactions with conservation staff are frequently positively correlated with adoption. Some farmers mentioned conversations or consultations they had with conservation staff, and some were even personally involved with conservation programming (e.g. serving on local conservation boards).

#### 2.4.6.2 Distrust of conservation programming

Some low adopters distrusted conservation programming. Two of the four low adopters expressed significant distrust, suggesting that conservation practices were often impractical. When recalling a conversation with a conservation planner about fencing off a creek from cattle, one low adopter explained that he did not agree with the conservation planner because such a conservation practices were infeasible. Another low adopter revealed distrust in government programs in general, emphasizing that the government cannot be trusted to perform unbiased work, because the government intentionally skews "grain reports and acreage reports to get the results they want…they do that just to control the grain market, in my opinion anyway." While government distrust may not be shared by medium and high adopters, they are aware of its existence in the population.

### 2.4.7 Farmer views of incentives

Farmers who had used specific conservation practices in the past or present were asked if they had ever received a financial incentive for these practices. The results are shown in Table 2.6. While each conservation practice had been incentivized for at least one farmer in the study area, two of the four low adopters had never received any form of government incentive. Farmers were not asked directly for their opinion on incentives in the interview script, though they were asked if they would consider using a practice if given "an appropriate incentive" to do so, and many chose to offer their opinions on incentives. Most high adopters had a more positive view of incentives than low adopters, but all adoption groups had some mix of perceptions. This is similar to findings in Prokopy et al. (2008) that positive views of adoption payments sometimes correlated with adoption, but frequently there is no statistically significant relationship.

Table 2.6 Primary views of the role of incentives by conservation practice, alongside incentives already received for those practices by adoption group. See Table 2.4 for code descriptions. Numbers following in parentheses indicate the number of farmers expressing that view. (+) and (-) indicate positive and negative views about incentives, respectively.

| **Conservation practice** | **Perceptions of incentives** **(no. of farmers expressing view)** | **Number of farmers who received incentives by adoption group** | | |
|---|---|---|---|---|
| | | **Low adopter** (0-2 CPs, 4 farmers) | **Medium adopter** (3-4 CPs, 3 farmers) | **High adopter** (5-7 CPs, 5 farmers) |
| Continuous no-tillage | (+) help (1/12)<br>(-) unnecessary (5/12)<br>(-) unwanted (1/12) | 1 | 0 | 2 |
| Cover crops | (+) help (3/12)<br>(-) unnecessary (1/12) | 0 | 0 | 1 |
| Filter strips | (+) motivate (1/12)<br>(-) unwanted (1/12) | 0 | 2 | 2 |
| Grassed waterways | (+) motivate (1/12)<br>(-) unnecessary (3/12) | 2 | 2 | 4 |
| Habitat practices (includes both Restoration and management of rare or declining habitats and Upland wildlife habitat management) | (+) help (2/12)<br>(+) motivate (2/12) | 0 | 1 | 5 |
| Created wetlands | (+) help (3/12)<br>(+) motivate (1/12) | 0 | 0 | 1 |

While each adoption group held a wide range of views on the role of incentives, the perception of incentives for each individual conservation practice (Table 2.6) depends on the nature of each practice. For continuous no-till, the majority of farmers believe incentives are unnecessary, either because farmers would use no-till without an incentive as they value its economic and soil-saving benefits in the first place, or because they would not use continuous no-till as they believe no-till is not compatible with their land or soil type and that an incentive would not be sufficient to make up for the resulting yield loss.

Three farmers also believed incentives to be unnecessary for implementation of grassed waterways, because they value waterways for soil erosion control. Two of these farmers have received incentives for grassed waterways in the past, so they were not opposed to receiving an incentive, but they would implement this practice whether or not an incentive was available. For the habitat practices and created wetlands, all comments about incentives were that they would be helpful or motivational for implementation of these practices. This finding is not surprising, since habitat practices and wetlands incur greater costs by removing productive land and provide few direct benefits to the farmer.

### 2.4.8 Breadth of stewardship ethic by farmers interviewed

Although all farmers supported targeting, their stewardship ethic varied widely. Stewardship views clearly tracked with adoption behavior. High adopters expressed clear stewardship views about responsibility for the natural environment, while other groups had a mixed response. The wide range of stewardship ethic present in the sample, from quite low to quite high stewardship ethic, makes their nearly universal support of the targeting approach all the more surprising.

#### 2.4.8.1 Responsibility and stewardship views of high adopters

A sense of personal responsibility and stewardship for the land characterized most high adopting farmers. When asked how farmers should take responsibility for water quality preservation, rather than refocusing blame for environmental degradation away from farmers, many high adopters held themselves—or farmers more broadly—responsible.

One high adopter admitted he, and all farmers, should use "closer scrutiny on the nutrients we apply and when we apply them." Another described farmer responsibility within a greater context of competition with economic factors:

> "[Farmers should] take it [water quality preservation] very seriously. I guess one of the things that bothers me about a good many farmers is that they don't see that as important. What they see is the economic picture, mostly presented to them by the salespeople, their equipment sales, seed sales, all that, and that's stressed so much and it also is heavily stressed in their finances – the bankers…and the agricultural economists, the number crunchers of every stripe who are reluctant to acknowledge anything that isn't financial."

High adopting farmers also recognized that using conservation practices enabled them to better care for the land, which aligned with their stewardship worldview. High adopters' sense of stewardship went beyond the economic bottom line, as can be seen in a statement made by one high adopter, who deviated somewhat from the others in his views of incentives, but shared their stewardship ethic: "Well, the reason you implement most of these [conservation practices] is because, you have this selfish attitude that you want this to be better, not because somebody's paying you to make it better, but because you want it better. This is the kind of attitude that I think we need to have." Stewardship, to him, is a "selfish" drive to protect farmland that causes him to make decisions against the economic bottom line that guides so many other farmers' choices. This "selfish" drive is an intrinsic motivation, and similar to Greiner and Gregg's (2011) suggestion that "conservation programs need to take advantage of farmers' stewardship ethic for maximum effectiveness and efficiency, and minimize the risk of crowding out intrinsic motivation and altruistic behaviors." This particular farmer may not respond well to or require extrinsic motivators such as incentives.

Similar to the findings of Reimer et al. (2012), a spiritual sense of responsibility to God was emphasized in more than one interview. While discussing his decision to restore a wetland, this same high adopting farmer revealed that his spiritual outlook shaped his stewardship ethic. The reason he pursued wetland restoration was to "put it back the way the Good Lord intended it to be." Another high adopter, when asked why he chose to implement conservation, highlighted his worldview and religious outlook as drivers to conserve: "It makes the most sense to me after my experience and training, and I guess I would say that, even some of it is my worldview. The compelling factor of stewardship, of caring for the land, and that even includes my religious outlook. Responsibility."

#### 2.4.8.2 Lack of responsibility and non-steward views of low adopters

Low adopters tended to have more non-steward views than other farmers. In particular, low adopters were likely to perceive that their current conservation level, low adoption, was sufficient to protect water quality. When asked how farmers should take responsibility for water quality preservation, one low adopter said that he thought farmers already take responsibility, citing as evidence their use of tile drainage that reduces surface runoff and conservation practices such as grassed waterways that reduce soil erosion. Tile drainage is not a conservation practice, though this farmer viewed it as protecting water qualtiy in some way. Regardless, tile drainage and grassed waterways are ubiquitous in the watershed, used in some capacity even by low adopters, so his statement implies that he believes low adopters are sufficiently protecting the environment. He went on to share that he has seen other conservation practices happening on his neighbor's land, but he does not think they are "feasible."

Another theme among some low adopters was the reassignment of blame for water quality protection away from farmers and onto other groups. The same low adopting farmer pointed out the water quality impacts of a university farm and local towns, as if to justify the environmental impacts of farmers: "So as far as I'm concerned, when Purdue University does stuff like that it's pretty tough to really say the farmer's doing things wrong." Another low adopter wrestled with the question and also pointed blame at non-farming sectors in defense of conventional farming practices: "Well, that's a tough question, because I don't think it's just farmers. Actually I think in general farmers or agriculture probably is less damaging to the water supply than industry and even home owners. There's probably more fertilizer and chemical dumped on yards in town per acre than what there is on a farm." While a number of players clearly contribute to non-point source pollution beyond farming, these and other comments by low adopters reveal a desire to justify inaction by blaming others, rather than assuming personal responsibility for their farm's impacts. This attitude stands in stark contrast to most views expressed by medium and high adopters.

## 2.5 Conclusions

While this qualitative analysis of farmer perceptions on targeting is exploratory and preliminary in nature, it points to several important considerations necessary to make the targeting approach successful in the Midwestern US.

Little opposition to and some clear support of the targeting approach was found among farmers with vastly differing adoption of conservation, awareness of the need for targeting referred to as disproportionality, stewardship ethic, and trust of conservation programming. Many farmers embraced their role as stewards of the natural environment, assumed blame for water quality degradation due to farming practices, and were strong proponents of allocating government funding to the farms in most need of it. Farmers were also amenable to receiving personal feedback on their farming practices through a larger adaptive targeting study, even those farmers with the least positive outlook on conservation and the government. Overall, these results corroborate Arbuckle's (2012) conclusion that "farmers are ready for the paradigm shift in conservation programming" known as targeting.

Support for the targeting approach in general should not mask the importance of conducting targeting in a way that is palatable to farmers. Farmers extended support to the tools of targeting, such as computer models and geospatial analysis. Yet farmers also recognized that design of a targeting program may be expected to encounter many difficulties. Many farmers are concerned about the aims of targeting, appropriate incentives, the objectives used, and the mechanics of modeling landscape vulnerability. There was overwhelming consensus among those interviewed that a computer model on its own would not be sufficient to truly target well, and that in-field inspection, one-on-one contact with farmers, and plenty of time for implementation would be needed.

Incentives, while necessary in many cases, may not be universally appreciated, and should vary among conservation practices.

Many farmers may not trust targeting if it is implemented by the government, and yet government subsidies may be required to achieve targeted results. Low adopting farmers who had concerns about government intrusion were wary of how targeting tools might be used and they emphasized the importance of an unbiased entity carrying out the actual targeting. Farmers with low current adoption of conservation practices may also have low stewardship ethic and distrust of conservation programming, and at the same time disproportionality would suggest that these farmers are likely to have the greatest need for targeted conservation. Perhaps partnerships between government and the academy, or local non-governmental groups, could help to reach farmers with greatest concern about government intrusion. Targeting efforts involving these farmers will be most effective if those carrying out the efforts build trust with the farmers prior to targeting and learn from the farmers about the practices they would consider implementing. This work suggests that targeting efforts should carefully take into account the image of the entity performing targeting. Transparency of the targeting process, such as clearly communicating modeling tools and objectives, may also influence farmer support.

Overall, this study showed that farmers hold a diverse set of views surrounding the nature of targeting efforts. Many suggestions point to the importance of a targeting approach that involves farmers in the act of targeting, and responds to their needs and concerns. Several of the most common themes – concerns about models representing in-field conditions, concerns about the objectives of targeting, an aversion to a one-size-fits-all approach, and a lack of trust between modeler and farmer – can be minimized when farmers are engaged meaningfully through interviews or focus groups. Ultimately, targeting may fail in its aims if it is not conducted in a way that is flexible to farmers' needs (Ahnstrom et al., 2008) and harnesses farmers' intrinsic motivations (Greiner et al., 2009; Reimer et al., 2011) as well as utilizes appropriate incentives.

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# CHAPTER 3. DEFINING SWAT HYDROLOGIC RESPONSE UNITS (HRUS) BY FIELD BOUNDARIES

## 3.1 Abstract

The Soil and Water Assessment Tool (SWAT) is widely used to relate farm management at the field scale to impacts on surface waters at the watershed scale. The hydrologic response unit (HRU) is the smallest spatial unit of the model. The standard HRU definition approach lumps all similar land uses, soils, and slopes within a subbasin based upon user-defined thresholds, and provides an efficient way to discretize large watersheds where simulation at the field scale may not be computationally feasible. In relatively smaller watersheds, however, defining HRUs to specific spatial locations bounded by property lines or field borders would often be advantageous, yet this is not currently possible within the ArcSWAT interface. In this work a simple approach is demonstrated that defines HRUs by field boundaries through addition of uniquely named soils to the SWAT usersoil database and creation of a field boundary layer with majority land use and soil attributes. Predictions of nitrogen, phosphorus, and sediment losses were compared in a case study watershed where SWAT was set up using both the standard HRU definition and field boundary approach. Watershed-scale results were reasonable and similar for both methods, but aggregating fields by majority soil type masked extreme high soil erosion predicted for a few soils. Field-scale results may be quite different due to choosing a majority soil type in each farm field. This approach is flexible and any shapefile boundary can be used to divide HRUs. A tool is currently under development that will automate the dataset and database preparation.

## 3.2 Introduction

The Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) is a hydrologic model widely used internationally and in the United States for water quality and natural resource management. SWAT is a flexible tool, capable of simulating the response of catchments ranging from small watersheds to large river basins as a function of management (e.g. implementation of conservation practices) and climate forcing. SWAT's ability to utilize detailed agricultural management makes it particularly well suited for simulating the response of agricultural watersheds. In addition, SWAT's open source programming makes it especially useful for research purposes and flexible for adaptations and continued model development (Gassman et al., 2007). Here, SWAT's open source framework is used to tailor the model for field-scale simulation by defining SWAT's hydrologic response units (HRUs) by crop field boundaries.

A SWAT model is set up using elevation and stream data to delineate subbasins within a watershed of interest. Subbasins are spatially distributed, and streamflow and associated contaminants are routed from one subbasin to another. The smallest spatial units, HRUs, are not distributed, may not be continuous, and there is no routing among them. Much of the SWAT simulation occurs at the HRU level, including impacts of agricultural management and conservation practices on crop production, hydrology, and water quality.

HRUs are normally defined by lumping similar land use, soil type, and optionally slope characteristics within a given subbasin based on user-defined thresholds for each category. This standard method permits the user to control the number of HRUs and achieve computational efficiency by applying a threshold of land area or percentage within a subbasin allowed for each HRU. In the case of relatively large watersheds and river basins, the standard HRU definition may be computationally the most effective. At the small watershed to field scale, however, individual land ownership may become an important consideration and field scale outputs and potentially inputs may be necessary depending upon simulation objectives.

Using SWAT with discretization at the field scale is an important step towards integrating the SWAT model with the human dimensions of watershed management. If SWAT model results are to be communicated to stakeholders such as farmers, landowners, or land managers, outputs should match socially meaningful area units such as parcels, fields, or even counties. While field discretized outputs address part of the need, field scale inputs require HRU definition using field boundaries.

A post-processing tool called Field_SWAT (Pai et al., 2011) effectively addresses a need for field-scale outputs from the SWAT model. Field_SWAT converts an existing model’s outputs from the HRU scale to the field-scale using a field boundary layer. The user inputs are the SWAT-created HRU raster and a field boundary shapefile, along with the particular SWAT outputs for the model to convert. The model takes these inputs, uses MATLAB’s (MATLAB, 2012) inpolygon function to determine which HRUs cells have their center within each farm field, and uses a statistical process, such as an area-weighted average of all HRU cells within a field, to aggregate HRU outputs to the field scale.

Field discretized inputs pose a more significant challenge for the SWAT modeling approach. While Field_SWAT can provide field-scale model outputs, it does not alter the standard method of HRU definition. There are applications where the SWAT model setup may need to take into account field boundaries. For example, most conservation practices in SWAT are represented at the HRU scale, and yet it may not be clear how to enter known practices on particular fields into the model if HRUs are discontinuous and lump together lands with many different owners. Similarly, if farm management practices such as fertilizer application and tillage are known at the field scale, the standard HRU definition would provide no means for altering them in the HRU management files. In these situations, field boundaries should be used to divide HRUs during the model setup stage, yet the standard HRU definition methods do not allow for HRU definition by field boundaries.

The goal of this work is to further extend the SWAT model’s usefulness through HRU definition by a farm field boundary layer. The approach is evaluated by comparison to the standard method of HRU definition in a relatively small case study watershed. Accuracy of simulated hydrology and water quality outputs are assessed using three years of measured data.

## 3.3 Methodology

### 3.3.1 Approach to HRU definition by field boundaries

#### 3.3.1.1 Common Land Unit (CLU) as field boundaries

The field boundary layer used in this work was the Common Land Unit (CLU) layer for agricultural land from the United States Department of Agriculture (USDA) Farm Service Agency (FSA). CLUs are defined as “the smallest unit of land that has a permanent, contiguous boundary, a common land cover and land management, a common owner and a common producer in agricultural land associated with USDA farm programs” (USDA FSA, 2012). A current CLU dataset with its attributes is only accessible by the FSA and its partnerships, but a version of the data stripped of all attributes distributed prior to the 2008 Farm Bill can be purchased by the public. The CLU layer was purchased from GISDataDepot (http://data.geocomm.com/readme/usda/clu.html). Note that CLUs are not the only field boundaries that could have been employed in the analysis. Field boundaries could be digitized manually using land use data, or county parcel data could be used as a proxy for field boundaries.

#### 3.3.1.2 Altering CLUs for use with SWAT

The CLU layer was altered slightly to make it better define field boundaries. To run SWAT using field boundaries, the land that is not contained within crop fields needs to be allocated. The CLU layer was altered to fill in holes, cinch small slivers between field boundaries, and eliminate the smallest parcels to reduce the total number of HRUs (Figure 3.1).

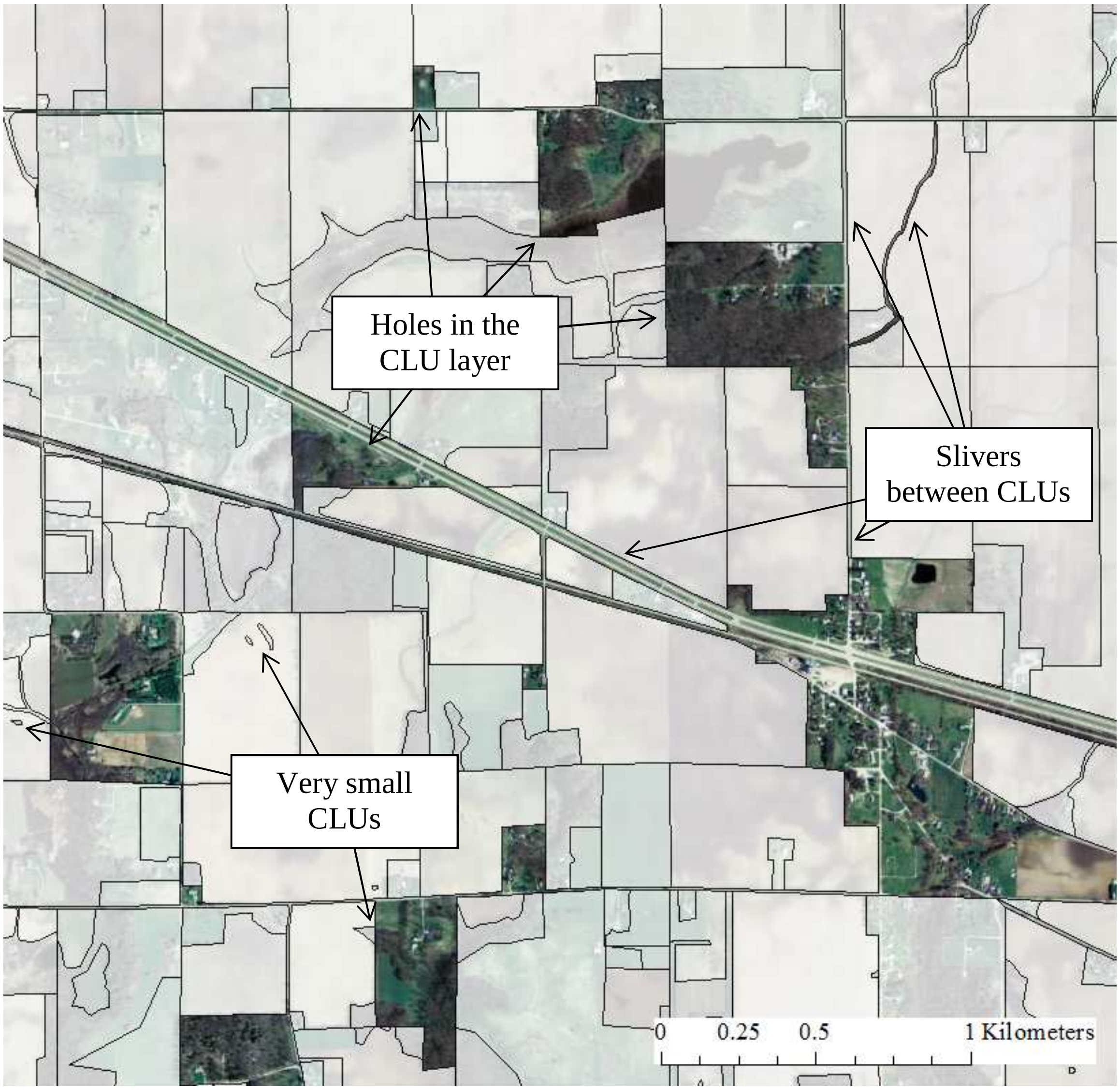

Figure 3.1 The CLU layer (semi-transparent white with black outlines) has holes, slivers between fields, and small HRUs due to roads and other non-farm land uses.

Holes in the CLU layer, especially along roadways, are to be expected since the layer was developed from agricultural parcel data. Holes were filled in so that there would be no missing information when the field boundary layer is used as soil and land use inputs in the HRU definition part of the SWAT model setup. Holes were filled through a union of the CLU layer with a polygon mask of the watershed. Yet most holes were connected to one another along roadways, and so the process created many slivers that connected distant parts of the watershed. This is a problem later when a majority land use and soil type are selected for each field, as the network of holes would all be assigned one land use and soil type. To break up this network, the narrowest field boundaries were cinched beforehand to split the network of holes into smaller distinct pieces. Finally, the smallest parcels were eliminated to decrease the total number of HRUs in the SWAT setup and thereby increase computational efficiency and simplicity of the model.

#### 3.3.1.3 Majority land use and soil type assigned to each field

In order to define one HRU as one field, each field needed to have one land use, one soil type, and one slope. Slope was not considered because a single slope was used in HRU definition to ensure HRUs were not fragmented within original field boundaries, but multiple slopes could be used if desired. In this work, the land use data was a National Agricultural Statistics Service (NASS) Cropland Data Layer (NASS, 2009), as a raster grid with land cover type attribute code. Soils data was the Soil Survey Geographic (SSURGO, 2005) Database, converted to a raster grid, with attribute of soil number called Mukey. Within each field boundary, the land use and soil type with the greatest number of cells was selected as the majority.

#### 3.3.1.4 Ensuring unique HRUs by assigning unique names to each field

The key to ensuring HRUs are defined by field boundaries is to assign a unique soil (or, alternatively, land use) name to every field in the study area. Majority land use and soil type are necessary, but not sufficient, for a one-to-one mapping of field to HRU, as fields with the same soil and land use in a given subbasin would still be automatically lumped into the same HRU. Therefore, field boundaries were kept separate by creating soils with unique names for every field. An alternate approach could have used uniquely named land uses instead, but there is currently an upper limit of a few hundred land uses that can be present in an ArcSWAT setup, which proved problematic even in the relatively small study watershed. This problem aside, an approach where unique crop names could be duplicated in separate SWAT subbasins would likely succeed as well.

Assigning unique soil names required addition of new soils to the SWAT database usersoil table. Lookup tables were created to map unique soil names to soil mukey. Each new soil name was added as an entry in the usersoil table with all attributes identical to the matching soil mukey except for the soil name (‘SNAM’). When HRUs are defined in the SWAT setup, the model sees each field as having a unique soil type.

### 3.3.2 Detailed methodology

This section describes in technical detail the main steps in pre-processing to obtain HRUs by field boundaries. Many steps took place in ArcGIS (ESRI, 2010). Work is currently underway to automate most of this process in python with a simple and easy to use tool.

In ArcMap, the CLU layer was pre-processed as follows. A polygon mask was digitized with a buffer around the study watershed and all layers were Clipped to the mask to reduce processing time. Slivers in the CLU layer were cinched using the Integrate tool in ArcToolbox with a 10 meter tolerance. Holes in the CLU layer were filled in using the Union tool on the CLU layer and the mask. Non-continuous features formed by the union tool were separated using the Feature to Polygon tool. Small CLUs were removed using the Select by Attributes tool from the new field boundary layer, selecting polygons with shape area less than 1 hectare, and using the Eliminate tool to merge them with larger polygons that share the longest boundary. Finally, the new field boundaries layer was saved as a shapefile. Now that the field boundaries layer had the final polygons used to define HRUs, soil and land use information were added to it.

Also in ArcMap, the majority soil and land use were assigned to each field as follows. The Zonal Statistics as Table tool was used, with the field boundary layer entered as the zone-defining layer, the feature ID (FID) as the field defining each zone, and the NASS land use as the raster that contains values for which to calculate a statistic. This table was populated a new attribute called Majority, which is the predominant land use in each field boundary. Join Field was used to join the new table to the field boundary layer, with input dataset as the field boundary layer, input join field as the FID, the output join field as the VALUE, and the field to join as Majority. The process was repeated for the SSURGO soils, and the attribute table was opened to confirm Majority and Majority_1 fields were joined properly, containing NASS land cover codes and SSURGO Mukey codes, respectively. Then Add Field allowed creation of a new field called Lookup with type "long" populated with FID values to be used in HRU definition. The attribute table was exported to create lookup tables and all records were saved in a textfile.

Lookup tables for soil and land use were created in Microsoft Excel and saved as .csv files. The field boundary lookup table was created by adding the textfile with field boundaries and editing in Excel to remove all columns except Lookup, Majority, and Majority_1. A lookup table for land use was created mapping each land use attribute code to the SWAT name for a given land use in the crop database (e.g. CORN and SOYB for corn and soybeans). A soil lookup table was created mapping soil Mukey to soil name in SWAT's usersoil database. The land use and soil lookup tables would already have been created to set up SWAT in the standard way. NASS land uses were primarily represented in the SWAT crop database already, so the lookup table was simple to create. In this work, the SSURGO Processing Tool for ArcSWAT (Sheshukov et al., 2011) was used to process SSURGO data to automatically create a soil lookup table and populate the usersoil database with SSURGO soil names.

A short MATLAB script was created to add unique soil types to the SWAT usersoil table. The script takes the lookup tables and usersoil database, adds a row to the usersoil database for every farm field, gives it a unique name based on the field's CLU Lookup number, and copies the rest of the soil information from the correct soil type in the usersoil table. Because soil names are type string, they must begin with a letter rather than a number, and so the program added an abbreviation for the watershed name 'LP' in front of the Lookup number to name the soils. This means an additional lookup table was required to map Lookup number to soil name. An updated usersoil table and lookup table were output as Excel spreadsheets, and the usersoil spreadsheet was appended to the usersoil table in the SWAT2012.mdb database using Microsoft Access. The database was saved under a new name in the project folder for the case study watershed.

Finally, the SWAT model was set up using field boundaries to define HRUs. In ArcSWAT, a new project was started, making sure to reference the updated SWAT2012.mdb in the project setup. The watershed was delineated as usual. Under Land Use/Soils/Slope Definition, the final field boundaries shapefile was entered, selecting the field Lookup and the crop and soil lookup tables for Land Use and Soils, respectively. The box was checked to create a shapefile of all HRUs for visualization purposes. Under HRU definition, a 0%/0%/0% threshold was used for lumping land uses, soils, and slopes, since the dataset was already preprocessed to lump them as desired. All remaining steps were unchanged by this HRU definition approach.

### 3.3.3 Case study watershed

A case study watershed was used to test the HRU definition by field boundary approach. Little Pine Creek watershed, located in west-central Indiana, is 56 $km^2$ in size, has corn and soybean production on 80% of its land, an average slope of 1.2%, and is characterized by poor soil drainage.

#### 3.3.3.1 Watershed modeling of two HRU definition approaches

Watershed models were set up for HRU definition by both the standard method and by field boundaries. Land use, soils, and slope definition was the only aspect that differed between the two approaches. In the standard approach, original NASS land use and SSURGO soils data were used to define HRUs. Slope definition was for only one slope class in both approaches. In the HRU by field boundary approach, the field boundary layer with majority land use and soil was used for both land use and soil definition. In both approaches, HRU definition used a 0%/0%/0% threshold so that all soil and land use data were retained in the model.

For both HRU definition approaches, watershed delineation used 10-meter elevation data (National Elevation Dataset) and burned in streams (National Hydrography Dataset). A stream threshold of 200 ha was used, as this led to a similar stream density to the National Hydrography dataset in the region of the case study watershed. An outlet point at the location of the gage station was added and selected as the watershed outlet. Weather data for the simulation were simulated, or in the case of precipitation and temperature, downloaded from the National Climate Data Center (NCDC). SWAT Model management and parameter changes

Once watershed models were set up for each HRU definition approach, several management and parameter changes were made to corn and soybean HRUs based on local knowledge of agriculture in this region. Fertilizer application rates were estimated from the Tri-state recommendations for 14 $m^3$/ha (160 bu/acre) corn yield and 4.4 $m^3$/ha (50 bushel/acre) soybean yield (Vitosh et al., Bulletin E-2567), which matched well the average crop yields for Tippecanoe County 2007-2012 (National Agricultural Statistics Service County Level Data). Nitrogen was applied as anhydrous ammonia, and phosphorus was applied in the form of di-ammonium phosphate (DAP), mono-ammonium phosphate (MAP), or ammonium polyphosphate (APP), which together have an average nitrogen to phosphorus ratio of 0.30. Phosphorus applications were assumed to take place in both spring and fall because it was determined that approximately half of farmers were applying phosphorus in the spring and half in the fall, and in order to maintain one management file for all farm fields, each farm field was given a split application, though in reality phosphorus would likely be applied all at one time.

Corn and soybeans lands were considered to be in a two-year rotation. On a year when soybeans were planted, soybeans were no-till planted on May 24 and harvested October 7. After soybean harvest, a chisel plowing on November 1 prepared the land for corn planting in the spring, and a fertilizer application of DAP/MAP/APP was applied on November 10 delivering 122 kg $P_2O_5$/ha and 19 kg $NH_3$/ha. On a year when corn was planted, nitrogen fertilizer was applied at 226 kg NH3/ha on April 22, disk plow tillage was performed on May 6, and corn was planted on May 6 and harvested on October 14.

In addition to crop management operations, tile drainage and associated parameters were altered to allow for the widespread presence of artificial subsurface drainage of the poorly drained soils in the watershed.  All corn and soybean HRUs with SSURGO drainage class of somewhat poorly drained, poorly drained, or very poorly drained, were assumed to have tile drainage.  Depth to the drains (DDRAIN) was assumed to be one meter, as is common in Indiana, and the tile drainage lag time (GDRAIN) was set to 48 hours.  In order to achieve any drain flow, the depth to impermeable layer (DEP_IMP) had to be raised from the default of six meters to 1.2 meters.  Indiana soils are generally known to have DEP_IMP less than the default, and so all un-drained cropland was given DEP_IMP of three meters.  To simulate tile drainage using the latest tile drainage routine in SWAT 579, the drainage flag (ITDRN) in the basins.bsn file was set to 1, and parameters in the new .sdr files were set as follows: Effective drain radius (RE_BSN) of 20 mm, distance between tiles (SDRAIN_BSN) of 20000 mm, Drainage coefficient (DRAIN_CO_BSN) of 10 mm/day, pump capacity (PC_BSN) of 0 mm/h, and multiplication factor between SWAT saturated hydraulic conductivity and lateral conductivity (LATKSATF_BSN) of 1.

#### 3.3.3.2 Comparing model effectiveness of two HRU definition approaches

The two methods for HRU definition were compared to one another and to measured data for a three year time period of 2009-2012.  Percentage of poorly drained soils and land uses were quantified, and also compared visually, to determine the impact of assigning one soil type and land use to each farm field.  Water balance for flows at the watershed outlet was compared using standard statistics for daily and monthly simulated and observed hydrograph goodness-of-fit – the coefficient of determination ($R^2$) and Nash-Sutcliffe coefficient ($E_{NS}$) (Engel et al., 2007) – as well as annual depth of streamflow and tile drainage over the watershed.  Nutrient and sediment concentrations and loads were compared against measured data using monthly $R^2$ and $E_{NS}$ values (only for the field boundaries approach), as well as standard summary statistics of daily mean, standard deviation, and range of extreme values.  Simulated loads of nitrate, total phosphorus, and sediment were taken from the output.rch file.  Corresponding observed daily nitrate, total phosphorus, and sediment loads were calculated from weekly measured concentrations using observed flows for days the samples were taken. Monthly observed loads were estimated using average daily flows over the month and average weekly nutrient and sediment concentrations. Simulated annual HRU-level total nitrogen, phosphorus, and sediment loading was obtained from the HRU output file, joined to the original HRU shapefiles, and displayed in ArcMap for visual comparison of the two approaches.

## 3.4 Results and Discussion

### 3.4.1 SWAT model setup by two HRU definition approaches

Both HRU definition approaches changed the number of HRUs, but the number of subbasins was 15 under both approaches. The standard method of HRU definition (with 0% thresholds for soil and land use) produced 960 HRUs, while the HRU definition by field boundaries produced 418. Most of the additional HRUs came from non-cropped lands, as corn and soybean HRUs from the two approaches totaled 356 and 320 HRUs, respectively. Figure 3.2 shows the results of different HRU definition approaches.

#### 3.4.1.1 Influence on soil type and land use

As a whole, the percent of land in corn and soybean land uses was higher under the field-based approach, primarily at the expense of grasslands (Table 3.1). This elimination was generally through croplands taking over roadways and easements (Figure 3.3), because CLUs narrower than 10 meters in width were integrated into adjacent CLUs. SWAT users commonly define threshold for soil and land use that may bias soil type and land use similarly. Two major roadways wide enough to resist integration with adjacent cropland were assigned a forested land use rather than grassed land use. So there is an apparent tradeoff in the current approach using CLUs – a larger integration leads to expansion of cropland borders at the expense of other land uses, while a smaller integration does not cinch slivers to break up the network of holes formed in the union of the CLU dataset with the watershed mask. Other ways to break up these parcels naturally could be implemented, such as digitizing natural breaks using ArcMap’s editor tool.

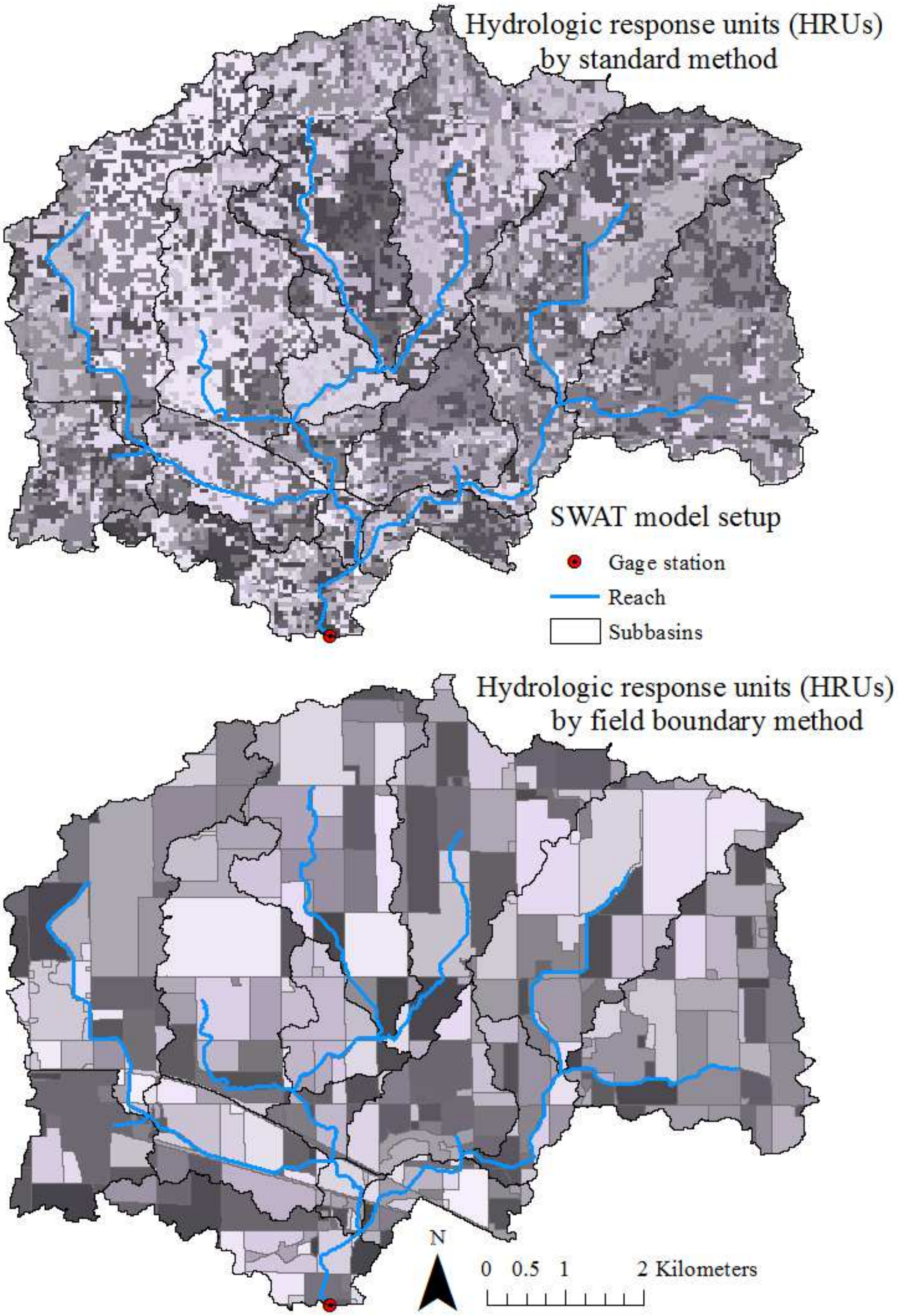

Figure 3.2 HRUs in the Little Pine Creek watershed using (top) the standard method (960 HRUs) and (bottom) the field-based method (418 HRUs). Each shade of gray represents one HRU. In the standard method one HRU may include many discontinuous polygons as shown by the dispersed pixels with the same gray color within a subbasin.

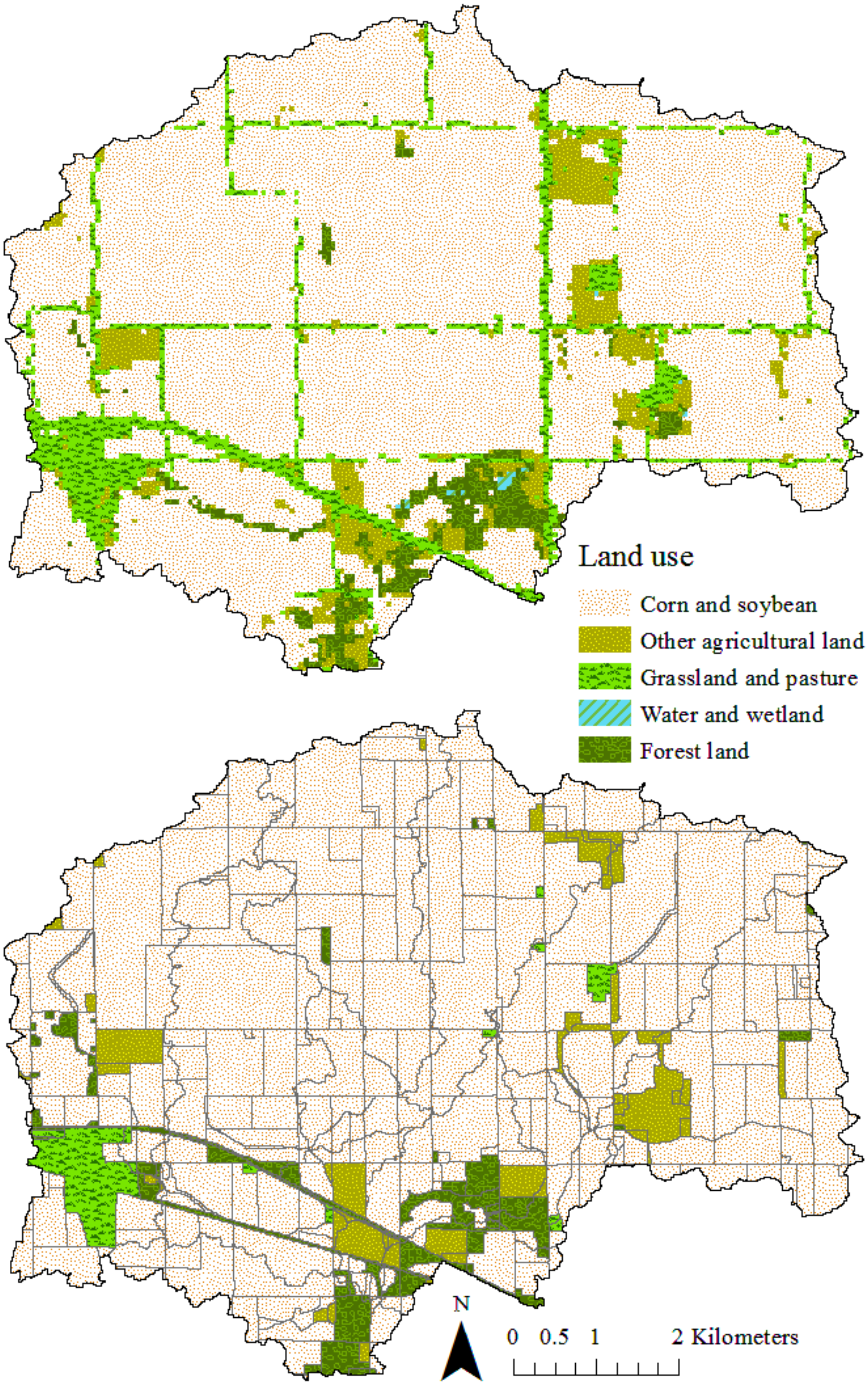

Figure 3.3 HRU land use by the standard HRU method (top) and the HRU by field boundary method (bottom). Many small non-cropland patches were eliminated, especially grass alongside roadways.

Soil type locations were altered much more drastically than land use (Figure 3.4), for two main reasons – first, the field boundary layer already took into account most land use changes in a heavily agricultural watershed, and second, soil polygons are smaller, more heterogeneous, and shaped with greater irregularity than land use polygons. Where many soil types existed in each farm field, selecting the majority soil provides surprisingly homogeneous soil typing in the field boundary approach. A vertical line separating soil types near the western edge of the watershed is located at a county border, where presumably two different surveyors made an assessment. It is encouraging to see from Table 3.1 that the prevalence of poorly drained soils is nearly identical in the two approaches. Yet Figure 3.5 reveals the loss of spatial heterogeneity in soil drainage class, and Figure 3.6 shows the estimate of tile-drained croplands. Especially notable is the distinction between excessively drained soils in the western part of the watershed and the primarily poorly drained soils elsewhere. The field boundary approach heightens that disparity such that a large, continuous portion of the watershed is excessively drained.

It is worthwhile to note that the 10-year average corn yields were similar in the two approaches, at 10.6 t/ha for the standard approach, 11.2 t/ha for the field boundary approach, and 10.1 t/ha estimated from Tippecanoe County yield data for 2007-2012 (National Agricultural Statistics Service County Level Data). Soybean yields were 2.4 t/ha, 2.6 t/ha, and 3.3 t/ha respectively. Both approaches reasonably estimate crop yields at the watershed scale.

Overall, it appears that the land use is fairly well preserved in the field boundary approach, and soil prevalence is similar, yet spatial heterogeneity of soils is vastly altered. From these alone it may be expected that the watershed-scale outputs of the two methods would be quite similar, while field-scale outputs would show greater divergence.

#### 3.4.1.2 Accuracy of simulated hydrology

Water balance and hydrology were quite reasonable for both approaches, despite using an uncalibrated model (Table 3.2). Daily or monthly $R^2$ above 0.6 and $E_{NS}$ above 0.5 are generally considered a good fit for streamflow simulations (Engel et al., 2007). Total depth of flow traveling through the watershed outlet of 0.36 m/y and 0.37 m/y corresponds very well to the measured value of 0.39 m/y. Overall both approaches lead to very reasonable estimation of water balance and hydrology at the daily and annual time scale.

Tile drainage accounted for roughly 35% of the total streamflow, which may be a little low for these heavily tile-drained lands. It is likely that some of the fields considered excessively well drained (Figure 3.5) have some level of tile drainage installed, and so the estimate of tile drains would be somewhat low. Also, there are some known issues with the depth to the impermeable layer parameter DEP_IMP, which could be limiting tile flows. Finally, the tile drainage parameters used in this work are reasonable guesses, but there has not been extensive analysis of their sensitivity as the drainage routine is fairly new in the SWAT model.

#### 3.4.1.3 Accuracy of simulated nutrients and sediment

Nitrogen, phosphorus, and sediment daily concentrations and loads at the watershed outlet were generally similar in the two approaches at the watershed scale (Table 3.3). These results are shown for all simulated days, and they did not differ considerably from summary statistics generated for (1) only those days with measured data or (2) monthly averages (Appendices I and J). The influence of turning off in-stream water quality modeling was insignificant as well, possibly due to the small size of the watershed and corresponding reach (Appendix K).

Table 3.1 Land uses and soils in Little Pine Creek watershed based on the two HRU definition methods.

| | **HRUs by standard method** | **HRUs by common land units** |
|---|---|---|
| **Percent of land use in watershed** | | |
| Corn | 47% | 51% |
| Soybean | 33% | 37% |
| Hay | 6% | 5% |
| Grass | 10% | 2% |
| Forest | 4% | 5% |
| Other | 1% | 0% |
| **Percent of soils in watershed** | | |
| Somewhat poorly drained | 41% | 41% |
| Poorly drained | 21% | 24% |
| Very poorly drained | 4% | 3% |
| Total poorly drained | 67% | 68% |
| Tile-drained (% of watershed area) | 53% | 59% |
| Tile-drained (% of cropland area) | 67% | 68% |

Table 3.2 Water balance and goodness-of-fit for simulated streamflow against measured gage data. Precipitation averaged 1.05 m/year during that period. The SWAT model was not calibrated in either method.

| | **Statistic** | **HRUs by standard method** | **HRUs by common land units** |
|---|---|---|---|
| **Flow at watershed outlet** | | | |
| Goodness-of-fit | $R^2$ *daily* | 0.76 | 0.76 |
| | $E_{NS}$ *daily* | 0.76 | 0.76 |
| | $R^2$ *monthly* | 0.85 | 0.86 |
| | $E_{NS}$ *monthly* | 0.83 | 0.84 |
| Total flow depth in m/y | *Annual average* | 0.36* | 0.37* |
| Tile flow in m/y | *Annual average* | 0.12 | 0.14 |

*Measured flow depth was 0.39 m/y for the three-year period in 2009-2012.

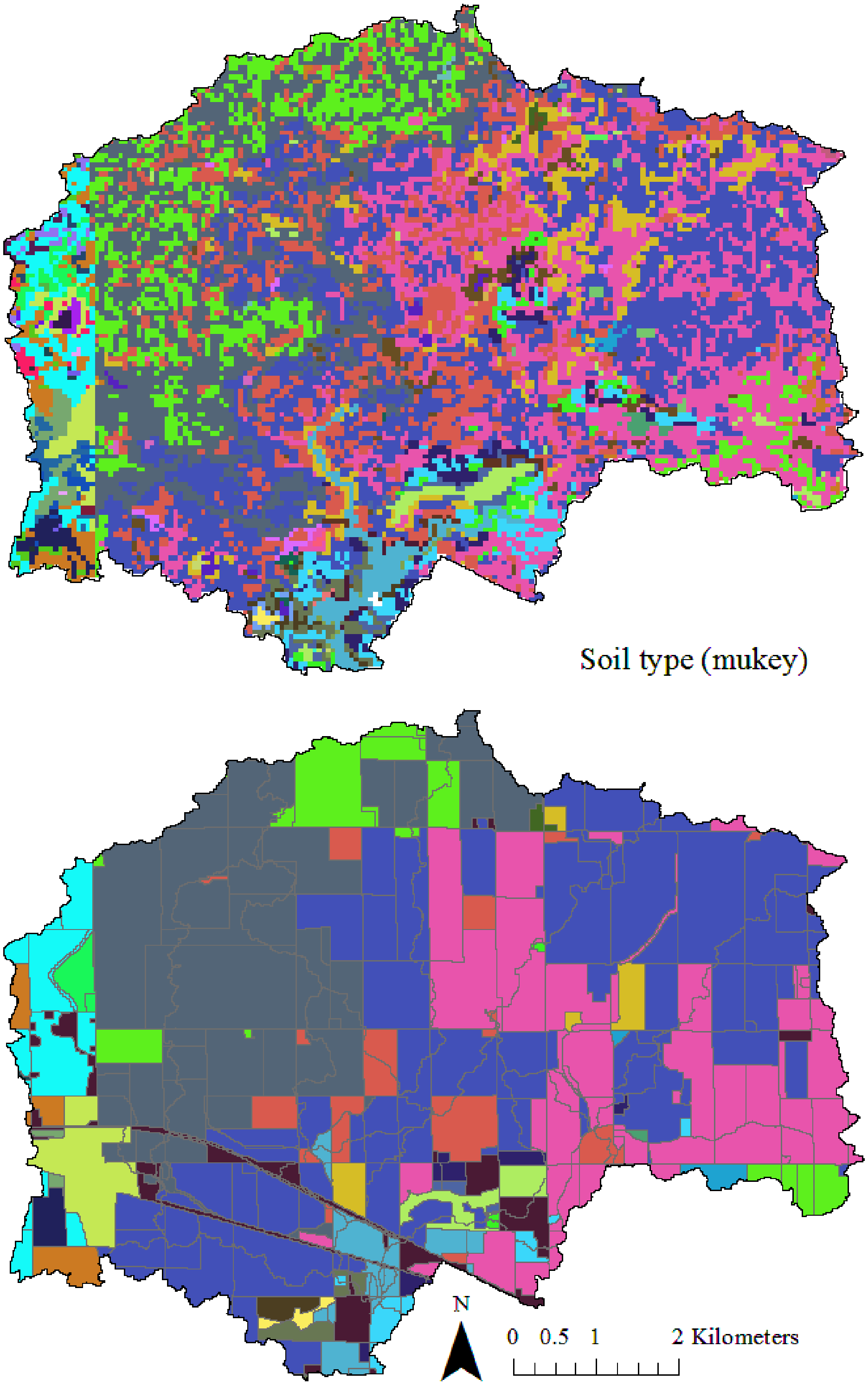

Figure 3.4 HRU soil type by the standard HRU method (top) and the HRU by field boundary method (bottom). The same color map is used for the two maps, showing the elimination of fine detail of spatially heterogeneous soil types.

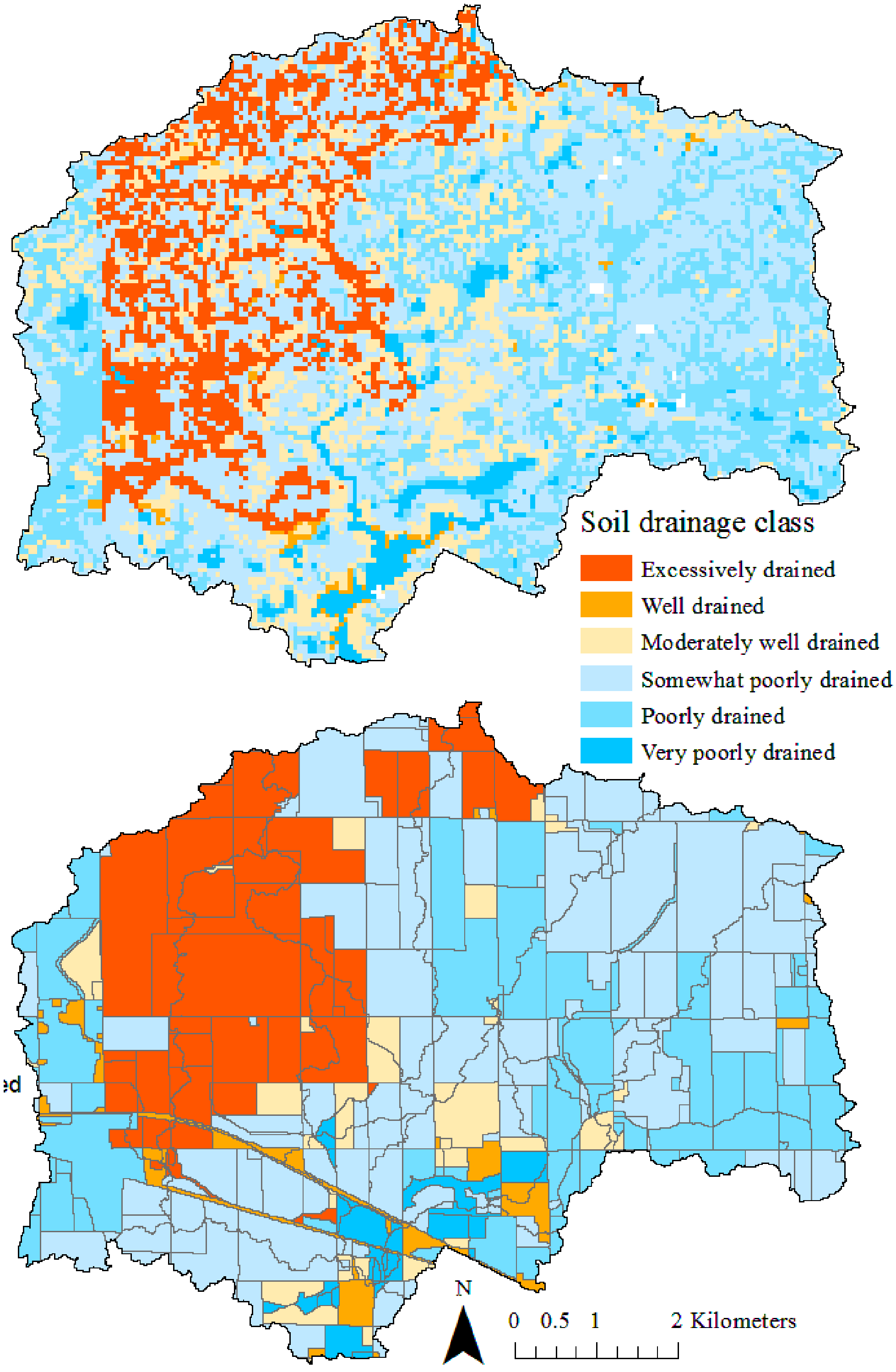

Figure 3.5 Soil drainage class for HRUs defined by the standard HRU method (top) and the HRU by field boundary method (bottom). Excessively drained soils were the majority soil drainage for much of the western part of the watershed, while most of the watershed had somewhat poorly drained soils.

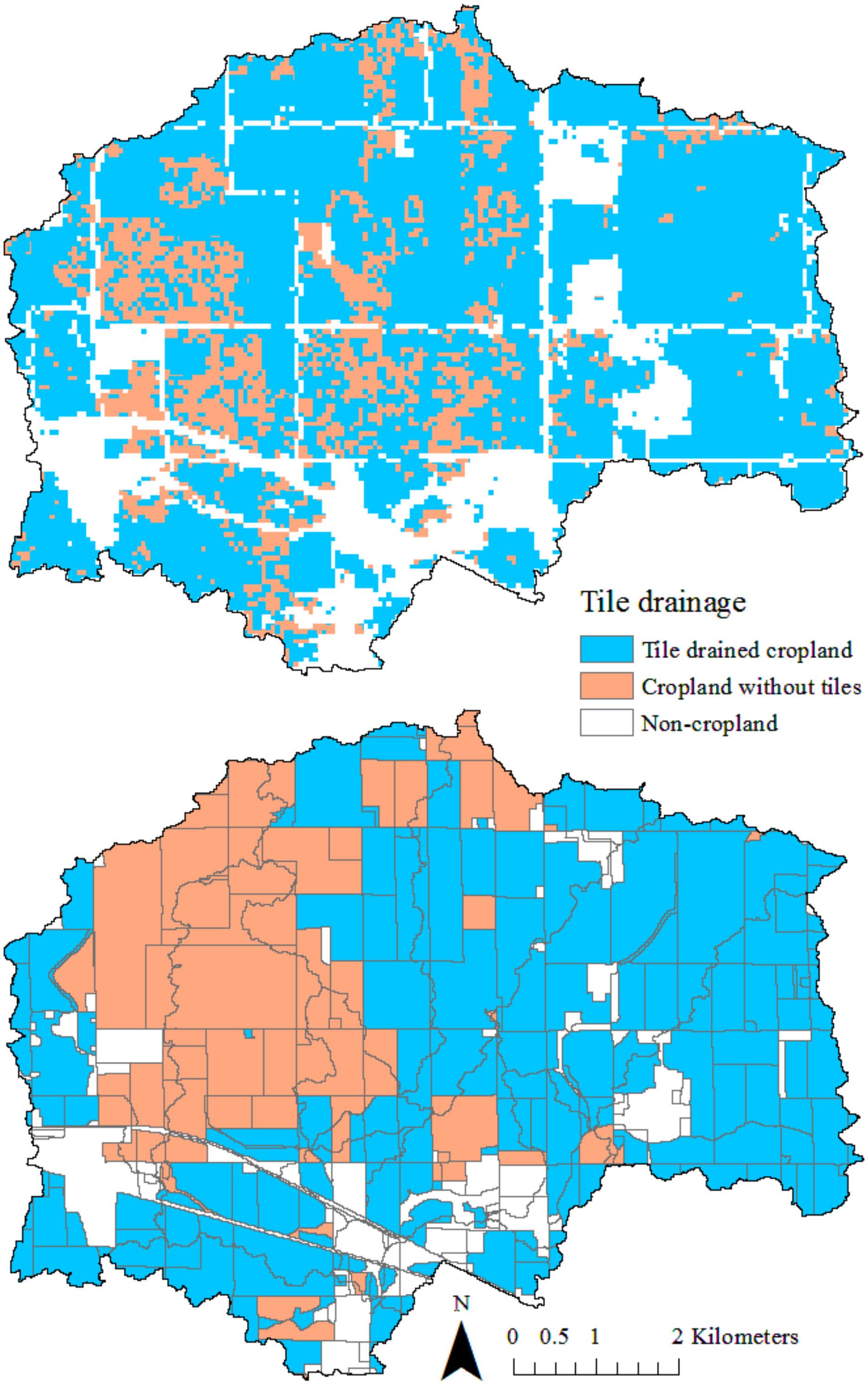

Figure 3.6 Estimate of tile-drained lands for HRUs defined by the standard HRU method (top) and the HRU by field boundary method (bottom).

Nitrate concentrations were somewhat lower yet with greater variability than the measured data. Measured water quality data showed that nitrate concentrations had fairly smoothed fluctuations, while simulated results for the daily timescale showed great spikes and drops according to precipitation (Appendix H). Nitrate is reported here because it, rather than total nitrogen, was measured at the watershed outlet. However, according to the SWAT simulation 75-78% of total nitrogen is delivered in the nitrate form, and 83-87% of all nitrate comes from tile drainage. So if total nitrogen data were available, the comparison may still prove similar. And if simulated tile drainage were greater, nitrate concentrations and loads from the SWAT simulations can be expected to closer match the measured data. Figure 3.7 shows the spatial distribution of total nitrogen losses from all HRUs by the two HRU definition methods. The magnitude of total nitrogen losses clearly followed the soil drainage class and presence of tile drainage.

Phosphorus loads and concentrations were predicted to be somewhat greater by the standard HRU definition approach compared to the field boundary approach and measured data. Surprisingly, sediment loading was similar for the two approaches, despite the difference in phosphorus loading. From Figures 3.8 and 3.9 it is clear that sediment and phosphorus export is less symmetrically distributed than nitrogen, as evidenced by the predominance of pollutant export in the lowest two or three categories on the five point scale (note that the scales are already built for skewed distributions, and they are similar for all pollutants, with the upper limit determined by the most extreme values in the sample). The field boundary approach shows fewer extremes of high phosphorus and sediment transport than the standard approach, presumably because these scarce highly erodible soil types were eliminated when selecting for majority soil type in each farm field.

Table 3.3 Nutrient and sediment balance summary statistics from output.rch comparing two HRU definition methods against measured data for 2009-2012.

| **Variable** | **Statistic *** | **HRUs by standard method** | **HRUs by common land units** | **Observed values (2009-2012)** |
|---|---|---|---|---|
| Nitrate-N concentration in mg/L | *Mean* | 4.53 | 3.94 | 6.64 |
| | *Standard deviation* | 6.53 | 5.99 | 4.01 |
| | *Minimum* | 0.00 | 0.00 | 0.03 |
| | *Maximum* | 42.2 | 37.9 | 23.2 |
| Nitrate-N loading in kg/d | *Mean* | 391 | 421 | 563 |
| | *Standard deviation* | 885 | 1060 | 995 |
| | *Minimum* | 0.00 | 0.00 | 0.01 |
| | *Maximum* | 8,530 | 10,400 | 6,360 |
| Total phosphorus (TP) concentration in mg/L | *Mean* | 0.21 | 0.09 | 0.14 |
| | *Standard deviation* | 0.23 | 0.11 | 0.13 |
| | *Minimum* | 0.00 | 0.00 | 0.00 |
| | *Maximum* | 1.44 | 0.51 | 0.89 |
| TP loading in kg/d | *Mean* | 29.1 | 13.0 | 12.5 |
| | *Standard deviation* | 102 | 42.1 | 43.6 |
| | *Minimum* | 0.00 | 0.00 | 0.00 |
| | *Maximum* | 1590 | 606 | 369 |
| Sediment concentration in mg/L | *Mean* | 42.7 | 35.3 | 21.5 |
| | *Standard deviation* | 56.3 | 56.9 | 33.1 |
| | *Minimum* | 0.00 | 0.00 | 1.20 |
| | *Maximum* | 433 | 494 | 261 |
| Sediment loading in kg/d | *Mean* | 6,710 | 6,490 | 4,240 |
| | *Standard deviation* | 25,800 | 26,900 | 21,700 |
| | *Minimum* | 0.00 | 0.00 | 1.08 |
| | *Maximum* | 403,000 | 426,000 | 215,000 |

*All statistics were calculated from daily loads and concentrations reaching the watershed outlet over the model evaluation period.

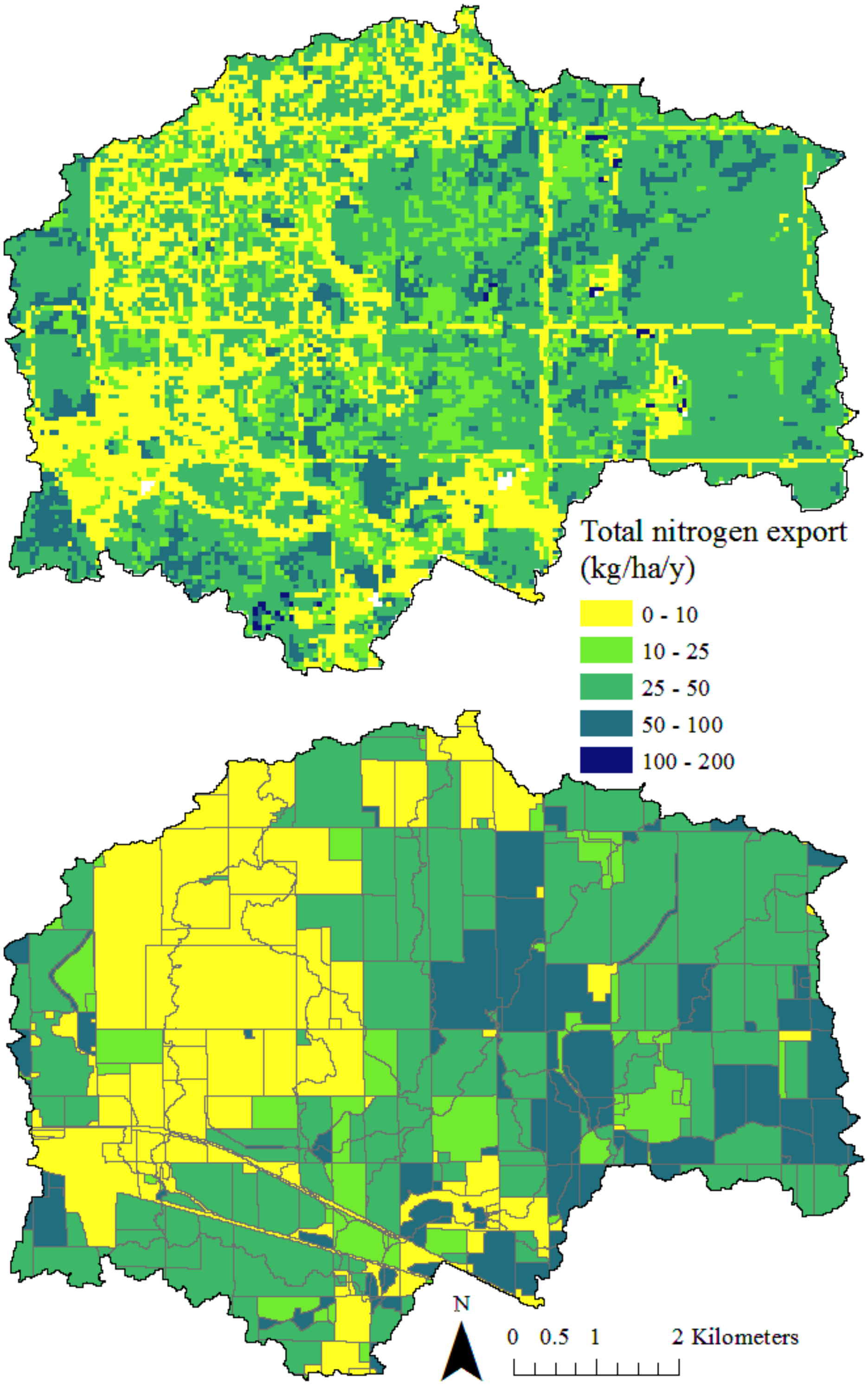

Figure 3.7 Annual average total nitrogen exported from HRUs defined by the standard HRU method (top) and the HRU by field boundary method (bottom). Total nitrogen losses were greatest from tile-drained lands, and much lower from excessively drained soils.

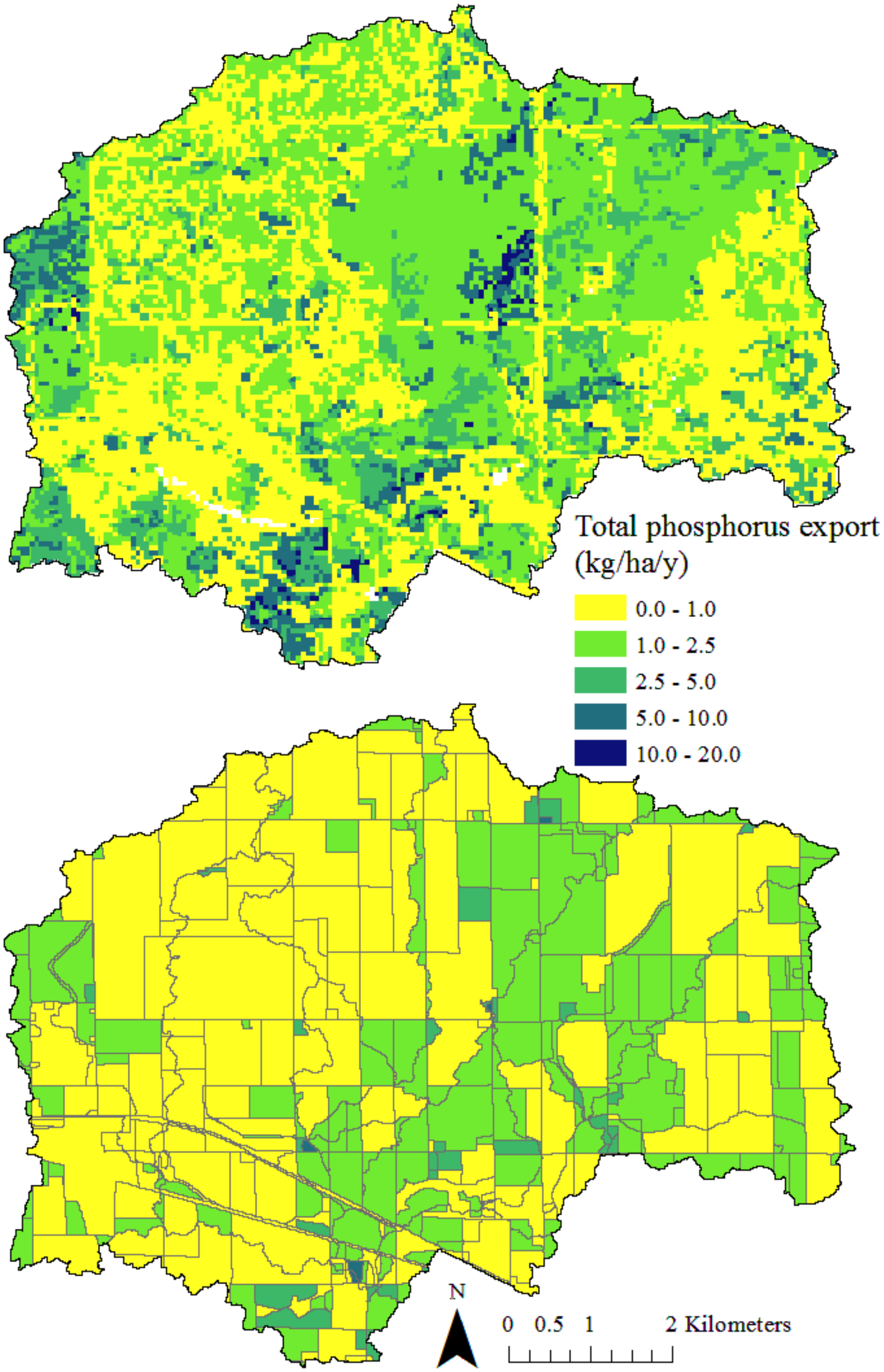

Figure 3.8 Annual average total phosphorus exported from HRUs defined by the standard HRU method (top) and the HRU by field boundary method (bottom). Phosphorus had the most skewed distribution of phosphorus, nitrogen, and sediment. The field boundary method masked the most extreme phosphorus losses.

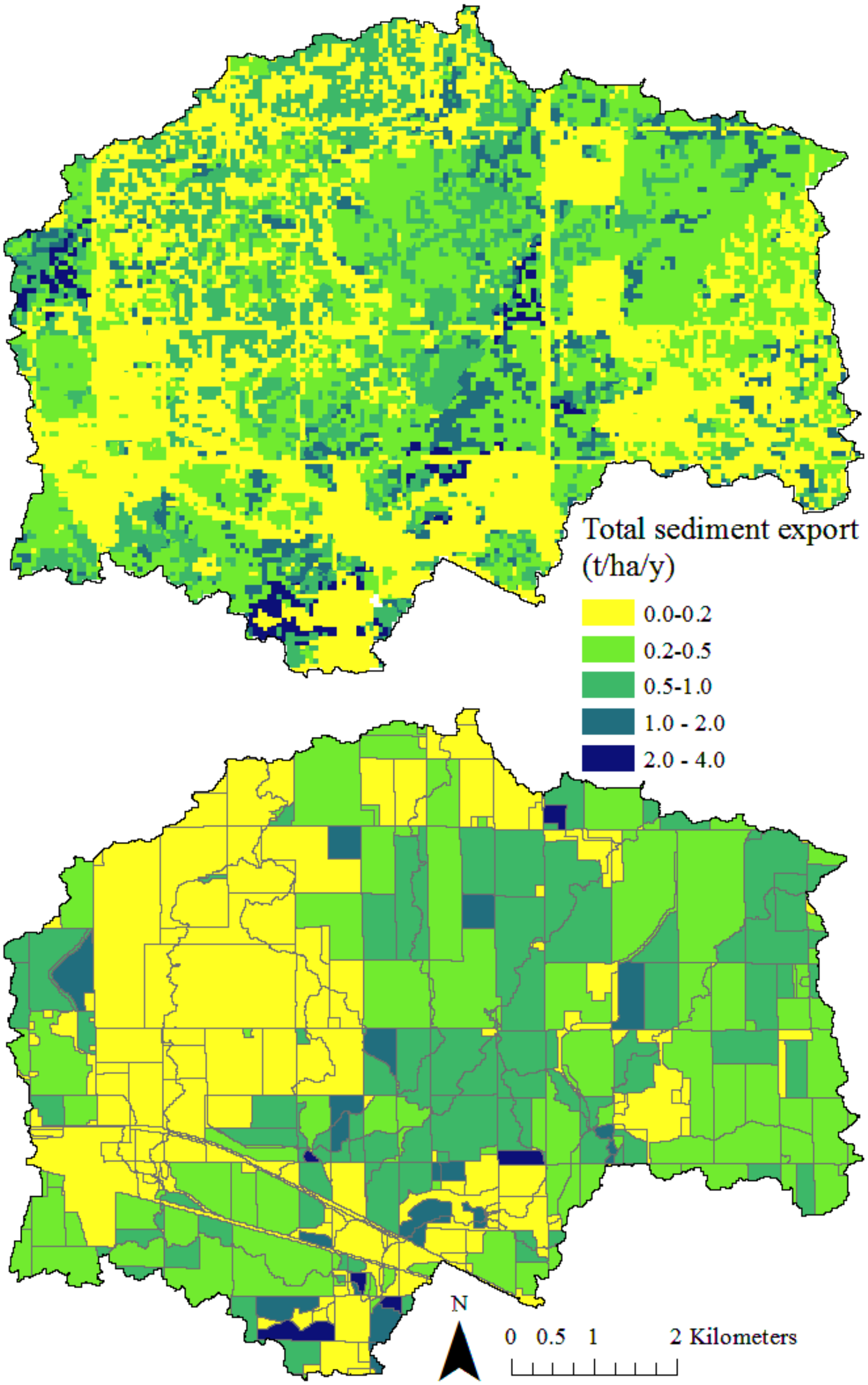

Figure 3.9 Annual average sediment exported from HRUs defined by the standard HRU method (top) and the HRU by field boundary method (bottom). Sediment losses were reduced from excessively drained soils, and greatest from poorly drained soils.

Nutrient and sediment losses generally performed well on measures of $R^2$ and $E_{NS}$. The field boundary approach for monthly average loads yielded $R^2$ of at least 0.6 for all nutrients and sediment, and $E_{NS}$ above 0.5 for nitrate and phosphorus. To explore the possible cause of poorer goodness-of-fit for sediment, a side experiment where current conservation practices known to exist in one-third of the watershed's cropland were added to the SWAT model (Appendix M). In this case the monthly sediment $E_{NS}$ rose from -0.3 to 0.2 as simulated sediment loading reduced by 19% in the watershed to 5,260.0 kg/d. These conservation practices over one-third of the watershed lowered sediment loading by roughly one-half of its overestimation. This finding confirms the suspicion that conservation practices present in the watershed but not simulated by the model could be the cause of over-estimated nutrients and sediments.

## 3.5 Conclusions

A simple new approach was demonstrated for defining hydrologic response units (HRUs) in the Soil and Water Assessment Tool (SWAT) by field boundaries, and a tool is being developed to make the approach more readily available to SWAT users. Field-discretized HRUs were defined by field boundaries through the addition of uniquely named soils to SWAT's usersoil database. Crop fields were assigned only one majority soil, despite the SSURGO soil layer having several soil types within a given crop field. In the future, there may be opportunities to use land use instead, which more closely matches the field boundary layer, and which would allow for subdivision of HRUs based on soils. This would require raising the upper limit on the number of land uses allowed in a SWAT setup. Using land use could also allow for multiple HRUs within each CLU based on soil type. While this limits an HRU to within one farmer's field, it is no longer a whole field, and the usefulness may diminish for some uses (e.g. spatial optimization of conservation practices).

This case study demonstrates just one possible approach to defining SWAT's HRUs by crop field boundaries. It is flexible approach in which a user can separate HRUs by any boundary shapefile. While basin-level water and nutrient balance were reasonable by this approach, field-scale outputs may be markedly different based on the size of field boundaries used due to selecting a majority soil in each crop field. Improvements can be made in how the lands outside the field polygons might be subdivided meaningfully to attain a reasonable number of HRUs that have distinct soils and land uses.

Defining HRUs by field boundaries increases the usability of the SWAT model for a number of small watershed and field scale applications, such as targeting at the field scale, as well as incorporating more detailed spatially explicit management and conservation practice information into the SWAT model. The approach had reasonable water, nitrogen, phosphorus, and sediment balance at the watershed scale, and performed in many ways similar to the standard model set up. This may extend the usability of SWAT to a broader range of uses, particularly applications to the human dimensions of watershed management, as well as stakeholders who desire to see model inputs and outputs correspond meaningfully to landowners. In applications such as targeting conservation practices, farm-scale results match the scale of management changes and most conservation practices, and may be more readily comprehended by farmers.

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# CHAPTER 4. SPATIAL OPTIMIZATION OF SIX CONSERVATION PRACTICES USING SWAT IN TILE-DRAINED AGRICULTURAL WATERSHEDS

## 4.1 Abstract

Targeting of agricultural conservation practices to the most effective locations in a watershed can promote wise use of conservation funds to protect surface waters from agricultural nonpoint source pollution. A spatial optimization procedure using the Soil and Water Assessment Tool was used to target six conservation practices widely used in the Midwest US: no-tillage, cereal rye cover crops, filter strips, grassed waterways, created wetlands, and restored prairie habitats. Two small, fairly flat, and heavily subsurface tile-drained watersheds in Tippecanoe County were used to demonstrate the targeting method, as well as to evaluate the model's representation of conservation practices in cost and water quality improvement, defined as export of total nitrogen, total phosphorus, and sediment from cropped fields. No-tillage was found to be the least effective at improving water quality in the flat study watersheds, while filter strips, grassed waterways, and habitats had the greatest cost-efficiency. Cover crops and wetlands made the greatest water quality improvement in lands with multiple existing conservation practices, and they also showed the greatest disparity in efficiency between the two watersheds. Spatial optimization resulted in similar optimal fronts for each watershed, with the greatest possible water quality improvement reduction of total pollutant loads by 70% to 80%, with nitrogen reduced by 50-60%, phosphorus by 90-95%, and sediment by at least 95%. Average pollutant loads could be reduced by 50-60% most efficiently, while the remaining 20% may drive up costs nearly ten-fold, and the final 20-30% reduction (especially of nitrogen) may not be obtainable by these conservation practices in their current representation and density of placement in the landscape.

## 4.2 Introduction

Scientists and watershed managers have long advocated a targeting approach to placement of conservation practices to protect surface waters from agricultural pollution, and researchers continue to refine these targeting approaches (e.g. Hession and Shanholtz, 1988; Crumpton, 2001; Heathwaite et al., 2005; Diebel et al., 2008; Diebel et al., 2009; Tuppad et al., 2010). Although widely recommended, targeting approaches have rarely been used to allocate conservation funds in the United States. Here many targeting approaches are reviewed, showing the need for the specific targeting approach demonstrated in this work.

### 4.2.1 Past targeting approaches

Targeting of conservation has taken many forms, from geospatial approaches to watershed-scale modeling. Generally the goal of individual targeting efforts falls under one of three categories. First, targeting "hotspots" in the watershed involves seeking to find and protect with conservation the spatial locations responsible for the greatest pollution. A second approach is targeting certain conservation practices to locations where a practice is most suitable. Finally, watershed modeling allows for targeting locations that have the greatest potential for or efficiency of water quality improvement. A number of past targeting studies are summarized below.

#### 4.2.1.1 Targeting hotpots

Many believe that water quality pollution is derived from hotspots in the landscape due to a combination of vulnerable lands and poor farm management (Nowak et al., 2006). Targeting these locations with conservation can protect farmland and water quality. Targeting hotspots is not a new idea; Hession and Shanholtz (1988) presented a targeting method for limiting soil erosion from critical source areas using a GIS methodology. More recently, Tuppad et al. (2010) employed a watershed modeling approach where subbasins with the greatest sediment yield were prioritized for reduced tillage, filter strips, and terraces in a Kansas watershed. Targeting conservation to hotspots is not limited to water quality pollution, but rather can extend to other conservation goals such as wildlife habitat protection for species diversity (Brown et al., 2009).

#### 4.2.1.2 Targeting conservation practices to suitable locations

Many targeting efforts have started with a conservation practice of interest and searched for the most suitable locations for that practice. A good example of this approach is locating suitable sites for wetland creation. Numerous wetland targeting studies have been conducted to strategically site constructed wetlands for greatest nitrate removal from agricultural tile drainage (Crumpton, 2001; Tomer et al., 2003; Kalcic et al., 2012; Tomer et al., 2013). All have been geospatial approaches, using data layers such as topography, land use, and locations of drainage ditches to select suitable wetland locations.

#### 4.2.1.3 Spatial optimization for greatest water quality improvement

Watershed modeling combined with spatial optimization is more complex than the other targeting methods, but potentially capable of achieving the most optimal conservation scenario for a watershed. Bekele and Nicklow (2005) performed a spatial optimization of land use and tillage to minimize nitrogen, phosphorus, sediment, and cost. Their optimization framework loosely coupled the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) with strength Pareto evolutionary algorithm 2 (SPEA2) (Zitzler et al., 2001), and had twelve land management options including no-tillage of corn and soybeans, along with perennial crops of sorghum, hay, pasture, and fescue grass. Many researchers (Maringanti et al., 2009; Maringanti et al., 2011; Rodriguez et al., 2011) have since employed spatial optimization of conservation practices through the coupling of SWAT and the non-dominated sorting genetic algorithm (NSGA-II) (Deb et al., 2002).

### 4.2.2 Spatial optimization using the Soil and Water Assessment Tool (SWAT)

Interest has grown in spatial optimization of numerous conservation practices using genetic algorithms and SWAT (e.g. Bekele and Nicklow, 2005; Maringanti et al., 2011) as greater computing resources make such computationally intensive approaches more feasible. SWAT is a watershed model commonly used to simulate the impact of land use and land management changes on water and water quality (Arnold et al., 1998). SWAT inputs include soil types, land use data, elevation data, climate data, and land management data. Within the model setup, a large watershed is delineated from elevation data and optional locations of rivers and streams. Several smaller subwatersheds are delineated within the large watershed, and the smallest spatial units are the hydrologic response units (HRUs) within subwatersheds.

Maringanti et al. (2009) developed an optimization method that has been replicated and is the basis for this work. They optimized the locations of filter strips, no-tillage, and nutrient management in an Arkansas watershed, minimizing cost as well as water quality impairment through three separate indices for phosphorus, nitrogen, and sediment export from each HRU. Maringanti et al. (2011) applied a similar method to an Indiana watershed, although they combined the three water quality indices into one aggregate pollutant value. Rodriguez et al. (2011) optimized the locations of pasture grazing practices, poultry litter management, and filter strips in an Arkansas watershed. These studies used a BMP tool to sever the dynamic linkage to the SWAT model and vastly decrease the computational time necessary for the optimization. While the BMP tool works well in the case where each HRU's outputs are being optimized, it may not lead to the most optimal solution at the watershed scale. In this work the dynamic linkage between SWAT and the genetic algorithm is retained so that the fitness of each individual is calculated using SWAT.

This methodology builds upon these studies in four primary ways: (1) several conservation practices are considered here that were not included in these works, such as cover crops and constructed wetlands; (2) the dynamic linkage with the SWAT model is retained so that optimization inputs are true SWAT estimates; (3) the HRUs are defined by field boundaries, which are more meaningful boundaries for conservation programs; (4) SWAT's new drainage routine more accurately models the tile drainage common in Corn Belt watersheds. Many of these distinctions are detailed in the following sections.

#### 4.2.2.1 Model representation of conservation practices

SWAT is capable of simulating a wide range of conservation practices commonly used in agricultural lands (Waidler et al., 2009). Simulating these practices frequently requires adjusting numerous parameters related to the design of a practice or its potential to impact hydrology and water quality. Arabi et al. (2008) provides recommendations on parameter choices for many practices, including winter wheat cover crops, filter strips, grassed waterways, and no-tillage. Wetlands were outside the scope of their work, as were cereal rye cover crops, both common practices in west-central Indiana. This work may be the first to include wetlands and cereal rye in a spatial optimization using SWAT.

#### 4.2.2.2 Estimating costs of conservation

Costs of conservation are generally economic costs incurred by the farmer for choosing to use conservation on his land. These include the costs of practice installation or initiation, annual maintenance, the opportunity cost of lost agricultural land for structural practices, and cost of foregone yield for field management practices. While costs can be calculated in several ways, many spatial optimization approaches have estimates the costs of conservation from Natural Resources Conservation Service (NRCS) estimates and practice standards (e.g. Maringanti et al., 2009; Rodriguez et al., 2011). Costs are generally considered over some practice life time, such as five, ten, or twenty years.

#### 4.2.2.3 Defining the hydrologic response unit (HRU) by field boundaries

In the SWAT model, HRUs are generally lumped areas with common land use, soil type, and slope within a subwatershed. This method of HRU definition limits the applicability of the SWAT model to optimization of conservation practices that are to be placed within farm fields. Indeed, most conservation efforts occur at the farm scale, as a result of a farmer’s and/or landowner’s decision. If optimization results spread across multiple farm fields, multiple farmers/landowners would need to agree to implement the practices in order to achieve an optimal result. In this work HRUs are instead defined by field boundaries (explained in chapter 3). The primary advantage of this approach is that conservation practices are implemented at the field scale, by a single farmer, and results can be viewed at the field scale for clarity in displaying results to farmers and landowners as well. No other studies were found to consider field boundaries in the placement of conservation practices for spatial optimization.

#### 4.2.2.4 Accurately modeling tile-drained lands

Subsurface drainage is common in the poorly drained, fairly flat farm fields that are characteristic of west-central Indiana and much of the U.S. Corn Belt, and should be included in watershed models and optimization on those lands. Tiles permit drainage waters rich in nitrate to flow rapidly beneath the ground, short-circuiting the biologically active upper soil layers, and contributing considerable loads of nitrate to surface waters (Hickey and Doran, 2004; Gentry et al., 2009). Heavily tile-drained watersheds drastically alter hydrology and nutrient export from agricultural lands.

It is critical to simulate tile drainage properly in watersheds when estimating conservation practice effectiveness. Many conservation practices will perform differently in tile-drained watersheds. Tile flows will bypass filtering through vegetated buffer strips and grassed waterways, resulting in reduced nitrate removal efficiencies. Wetlands are recommended for placement in tile-drained watersheds as one of the few practices capable of treating nitrate from tile drains. Even the performance of no-tillage and cover crops may change as tiles allow for greater infiltration and reduced surface runoff.

Recently, a physically based method for simulating tile drainage has become available in the SWAT model. While simulating tile drainage had been possible in SWAT previously, this new method uses the Hooghoudt and Kirkham tile drain equations that have been used in the DRAINMOD model (Moriasi et al., 2012). Although expected to be an improvement over the previous tile drain simulation method, little research has been conducted to evaluate the new method, and no other optimization studies were found to consider it.

### 4.2.3 Goal of the work

This work serves to extend spatial optimization with the SWAT model by including conservation practices relevant to tile-drained agricultural lands, defining HRUs by field boundaries, and simultaneously optimize the placement of many conservation practices to determine the most efficient conservation scenarios for two case study watersheds.

## 4.3 Materials and Methods

### 4.3.1 Study watersheds

Two relatively small watersheds in west-central Indiana, the Little Pine (56 $km^2$) and Little Wea Creek (45 $km^2$) watersheds, were used for this demonstration (Figure 4.1). Land use is primarily agricultural in both watersheds, with 87-92% of the land maintained in corn and soybean crops, 5% in other agricultural crops, and 3-7% is forested or low density urban. Soils in both watersheds require artificial drainage for optimal crop production; in Little Pine, 68% of soils are somewhat poorly, poorly, or very poorly drained (majority in the somewhat poorly drained category), while Little Wea has 79% poorly drained soils (majority in the poorly drained category). Both watersheds are flat or gently sloping, with an average slope of 1.2% for Little Pine and 1.9% for Little Wea. Only 2% of Little Pine’s lands and 8% of Little Wea’s exceed a 5% slope.

Tile drainage and HRU definition were both notable deviations from past SWAT studies. The SWAT model was set up using version 579, with its new tile drainage routine activated. HRUs were defined by field boundaries (chapter 3) so that the optimization would consider each field separately in placing conservation practices in the watershed. Land use and soils were pre-processed in the shape of farm fields, so no threshold for these was given in HRU definition, and a single slope class was used. In-stream water quality modeling was turned off for this modeling work.

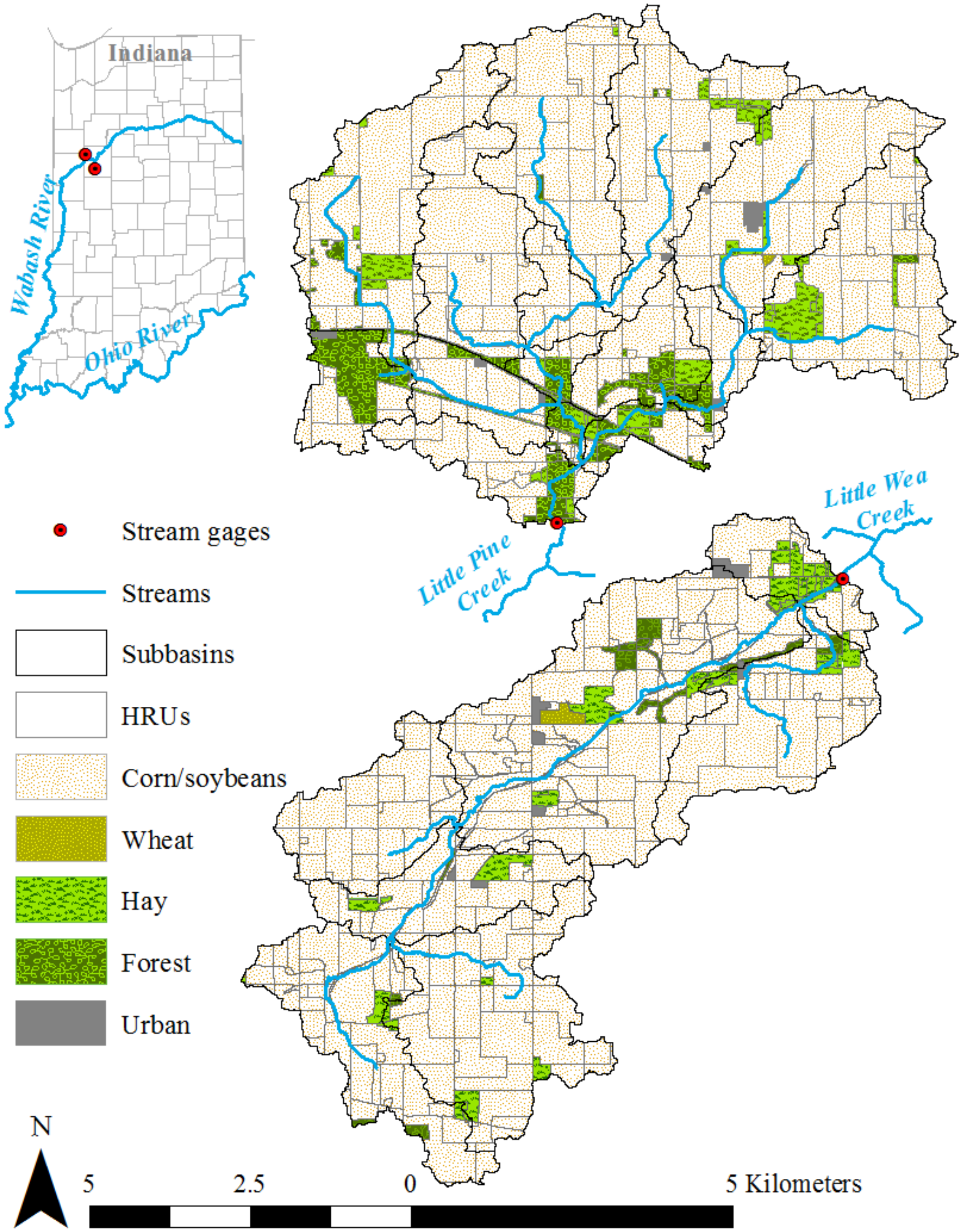

Figure 4.1 Study watersheds, Little Pine Creek watershed (top) and Little Wea Creek watershed (bottom), are located within Tippecanoe County, Indiana. Watersheds are not located as close together as shown.

Inputs to the SWAT model included a 10-meter (one-third arc second) resolution digital elevation model (National Elevation Dataset), National Hydrography Dataset high resolution streams for burning in the SWAT reach (National Hydrography Dataset), daily precipitation and minimum and maximum daily temperatures (National Climate Data Center), land use data (National Agricultural Statistics Service Cropland Data Layer, 2009), and soil data (Soil Survey Geographic (SSURGO) Database).

Model simulation began with a three-year warm-up period 2004-2006, followed by six years simulation 2007-2012. The six year time period was chosen in order to accommodate two- and three-year crop rotations, and also to cover the period for which measured water flow and quality data were available (2009-2012).

#### 4.3.1.1 Model parameter changes and crop management

Crop management varies spatially based on farm operator and land conditions, but in the absence of field-scale information on crop management assumptions must be made as to a generic crop management scheme in the study area. A standard management file for agricultural lands planted in corn and soybean was developed in conversation with local agronomy experts, and is shown in Table 4.1.

Crop yields for Tippecanoe County, Indiana from the simulation dates 2007-2012 averaged 10.1 t/ha/y (161 bu/acre) for corn and 3.3 t/ha/y (49 bu/acre) for soybeans (National Agricultural Statistics Service County Level Data; mass calculated assuming a standard density of .72 kg/L for corn and .77 kg/L for soybeans). Fertilizer applications were calculated from Extension recommendations (Vitosh et al., Bulletin E-2567) for these crop yields (160 bu/acre corn yield in a 2-year rotation with soybeans and 50 bu/acre soybean yield). Phosphorus was assumed to be applied as DAP (Di-Ammonium Phosphate, 18-46-0), MAP (Mono-Ammonium Phosphate, 11-52-0), or APP (ammonium polyphosphate, 11-37-0). Because these fertilizers have an average nitrogen to phosphorus ratio of 0.30, some nitrogen is applied in the fall during phosphorus application.

Table 4.1 Baseline management file (.mgt) used for all corn/soybean HRUs.

Crop management operations

| Crop | Date | Operation | Details |
|---|---|---|---|
| Corn | October 10 prior to plant | Phosphorus and associated nitrogen application | 112 kg/ha (of P2O5) from DAP/MAP/APP<br>18 kg/ha (of NH3) from DAP/MAP/APP |
| Corn | October 14 prior to plant | Chisel plow | 30% mixing to a depth of 150 mm |
| Corn | April 15 | Offset disk plow | 60% mixing to 100 mm depth |
| Corn | April 22 | Nitrogen application | 208 kg/ha (of NH3) from anhydrous ammonia |
| Corn | May 6 | Planted | |
| Corn | October 14 | Harvested | |
| Soybean | May 24 | No-tillage planting | 5% mixing to a depth of 25 mm |
| Soybean | October 7 | Harvested | |

Tile drainage parameters for all “poorly drained” corn and soybean HRUs (SSURGO drainage class “very poorly drained,” “poorly drained,” and “somewhat poorly drained”)

| Parameter | Explanation | Value |
|---|---|---|
| “DDRAIN” (mm) | Drain depth; depth from soil surface to tile drains | 1,000 |
| “GDRAIN” (hr) | Drain tile lag time; Time for water to travel from soil through drain to the reach | 48 |
| DEP_IMP for tile-drained (mm) | Depth to impervious soil layer | 1,200 |
| DEP_IMP for un-drained (mm) | Depth to impervious soil layer | 3,000 |
| ITDRN (flag) | Flag to use new drainage routine | 1 |
| RE_BSN (mm) | Effective drain radius | 20 |
| SDRAIN_BSN (mm) | Distance between two tiles | 20,000 |
| DRAIN_CO_BSN (mm/day) | Daily drainage coefficient | 10 |
| PC_BSN (mm/h) | Pump capacity | 0 |
| LATKSATF_BSN | Multiplication factor: ratio of lateral ksat to ksat from soils database | 1 |

The majority of nitrogen was applied in the spring at pre-plant. Total nitrogen application was calculated according to the measured corn yield (160 bu/acre after soybeans) to be 180 kg/ha of nitrogen, which is the equivalent of 208 kg/ha of NH3, and 67 kg/ha of phosphorus, which in DAP/MAP/APP form amounts to 67 kg/ha of P2O5 and 11 kg/ha of NH3. To achieve the measured soybean yield (60 bu/acre), 45 kg/ha of P2O5 is needed, but delivered in the form of DAP/MAP/APP it gives the equivalent of 7 kg/ha NH3 in addition. Phosphorus fertilizer application timing was assumed to be once every two years in the fall before corn planting, totaling 112 kg/ha of P2O5 and 18 kg/ha of NH3.

#### 4.3.1.2 SWAT model validation

In this work, the SWAT model was not calibrated for flow or water quality. Instead, measured data were used to evaluate the effectiveness of the SWAT model's estimate of streamflow and water quality. Streamflow data was obtained from the U.S. Geological Survey (USGS) for two gaging stations, Little Pine Creek near Montmorenci, IN (USGS 033356786) and Little Wea Creek at South Raub, IN (USGS 03335673). Weekly concentrations of nitrate, total phosphorus, and sediment were also gathered at the gaging stations for a three year period in 2009-2012 (Purdue, unpublished data).

Hydrology was tested using standard statistics for model fit - the coefficient of determination ($R^2$) and the Nash-Sutcliffe coefficient ($E_{NS}$). Acceptable ranges for these objective functions are $R^2$ greater than 0.6, and $E_{NS}$ greater than 0.50 (Engel et al., 2007). An annual depth of flow was used to determine how much of the flow is simulated by the model.

Nitrate, total phosphorus, and sediment concentrations were available on a near-weekly basis for the three-year period of May 2009-2012, totaling 149-153 usable samples of each type, and 1279 daily simulated estimates. Measured concentrations were converted to loads using observed daily flows, and simulated concentrations and loads were derived from SWAT's output.rch and output.hru output files. Average daily means and standard deviations were calculated at each watershed outlet, as well as monthly $R^2$ and $E_{NS}$ values.

Summary statistics were also generated for water quality on only those days with measured data (Appendix I), as well as monthly averages (Appendix J), but they did not show considerable differences from the daily statistics included here.

Two other aspects of the model were explored to determine their effect on the model validation of nutrients – in-stream water quality modeling and inclusion of existing conservation practices. While the model was run with in-stream water quality modeling turned off, it was turned on for a test to determine that it had little effect on nutrient and sediment outputs (Appendix K). In-stream water quality modeling made little difference in daily loads, possibly because of the small size of the watersheds and short length of reaches. Existing conservation practices had been determined through farmer interviews about roughly one-third of the agricultural land in each watershed (chapter 5), and these were included to test whether over-prediction of nutrients and sediments could be mitigated by known conservation practices in the watershed.

### 4.3.2 Implementing conservation practices in SWAT

Conservation practices were implemented in the SWAT model based on existing guidance (Arabi et al., 2008; Waidler et al., 2009).

#### 4.3.2.1 Continuous no-tillage (NT)

No-tillage was implemented in a given row crop (corn or soybean) HRU as both a tillage practice and a 2 point reduction of curve number (Arabi et al., 2008). Both chisel plow and disk plow before corn were removed from the management file, and tillage was changed to the SWAT default no-till, which has 5% mixing to a 25 mm depth at planting. Corn was planted on May 6.

#### 4.3.2.2 Cover crops (CC)

Cover crops were modeled as cereal rye, a recommended cover crop for this region, and a default crop in the SWAT crop database. Cereal rye was planted on October 15 after harvest of both corn and soybean, and killed on April 15 prior to planting corn or soybeans in the spring.

#### 4.3.2.3 Filter strips (FS)

Filter strips were assumed to occupy 2.5% of their HRU (crop field) area. Filter strips were installed at the start of the warm-up period for the SWAT model runs. These changes were made in the .ops file: MGT_OP = 4 for filter strip, FILTER_I = 1 to flag on filter strips, FILTER_RATIO = 40 to achieve 2.5% of field area, FILTER_CON = 0.5 assuming 50% of the HRU drains to the most concentrated 10% of the filter strip, and FILTER_CH = 0 to indicate that none of the concentrated flow is fully channelized such that it would bypass filtering effects of the filter strip.

#### 4.3.2.4 Grassed waterways (GW)

Grassed waterways were 10 m wide, with a length equal to the square root of their HRU area. Grassed waterways were installed at the start of the warm-up period. Parameters that were altered in .ops and .mgt files included MGT_OP = 7 to simulate grassed waterways in the HRU, GWATI = 1 to flag on grassed waterway simulation, and GWATW = 10 to set the average width to 10 m.

#### 4.3.2.5 Wetlands (W)

In the SWAT model, headwater wetlands are placed at the subwatershed scale, where all wetlands in a subwatershed are lumped into one wetland area, volume, and fraction of subwatershed’s flows that are intercepted. However, the spatial location of a wetland is within one or more HRUs. Unlike the other practices, which can likely be implemented in almost any cropped field, wetlands may be limited in where they can be sited throughout a watershed. For instance, wetlands should be sized according to their upland contributing areas, and a crop field must be large enough to support a wetland of that size. Topography to some extent dictates locations where wetlands can be placed. Also, wetlands should ideally intercept significant surface or subsurface flows, so that they remain inundated throughout the year, to support wetland vegetation as well as maximize nutrient removal.

The method for siting wetlands in the watersheds loosely followed that of Kalcic et al. (2012). Potential wetland outlets were placed using spatial layers of flow accumulation (created during SWAT model setup), locations of open streams (National Hydrography Dataset), HRU polygons (created during SWAT setup), land use data (National Agricultural Statistics Service), and orthophotography to further confirm what was learned from the other layers (Indiana Spatial Data Portal). Potential wetland outlets satisfied the following criteria: (1) wetlands had large contributing areas (roughly 0.2 $km^2$ or greater, which is a tenth of the criterion used by Kalcic et al. (2012)), determined by location along a major flow accumulation pathway in the subwatershed; (2) wetlands did not intercept an open waterway; (3) wetlands were located on cropland; (4) wetlands were sized at 1% of their contributing area; (5) wetland buffers constituted an additional 3% of the contributing area.

To estimate the volume of each wetland, wetlands and surrounding buffers were assumed to be bowl-shaped. Wetlands were shaped as partial spheres, with one meter depth and radius calculated from a circular surface area with area 1% of the upland contributing area. Surrounding buffers were assumed to be partial cones, with the smaller radius equivalent to that of the wetland, depth of 1.2 m, and larger radius calculated from a circle with area 4% of the upland contributing area.

Wetlands were implemented in SWAT using the .pnd files for each subwatershed where at least one potential wetland was sited. WET_FR, the fraction of a subwatershed's area that drains into wetlands within that subwatershed, was calculated as the wetland contributing area divided by the subwatershed area for each unique combination of wetlands in a subwatershed. WET_NSA, the normal surface area of wetlands in a subwatershed, was the sum of all wetland surface areas placed in a given subwatershed. WET_NVOL, the volume of a wetland filled to the normal level, was equal to the sum of placed wetland volumes in a subwatershed. When wetlands are filled to maximum volumes, the wetland surface area, WET_MXSA, and volume, WET_MXVOL, were equal to the sum of wetland and buffer surface areas and volumes, respectively.

The normal concentration of sediments in the wetland, WET_NSED, was left at its default value. Wetland hydraulic conductivity determines how much seepage takes place in the wetland. Hydraulic conductivities of all the soils in the watersheds exceeded 2.6

mm/hr, despite the presence of extensive hydric soils, so this value was used as an upper bound for wetland conductivity. A value of 2.0 mm/hr was chosen for wetland hydraulic conductivity, WET_K. Phosphorus settling rates, PSETLW, were not changed from default values of 10 m/y. Nitrogen settling rates, NSETLW, however, were altered to 39 m/y, based on data analysis from a local wetland located within the Little Pine watershed (McCahon, 2010).

#### 4.3.2.6 Habitats (H)

Wildlife habitats were modeled identically to filter strips, though they are assumed to be tall grass prairie establishments located strategically to intercept concentrated overland flows.

### 4.3.3 Objective functions: cost and water quality

Cost of conservation and associated water quality improvement were used to compare conservation practice scenarios and as objective functions for the optimization.

#### 4.3.3.1 Cost of conservation

Conservation practice costs were estimated using cost data for FY2012 Indiana Conservation Practices from the USDA Natural Resources Conservation Service (NRCS) Field Office Technical Guide for the state of Indiana (USDA, NRCS). Conservation practice costs were calculated as a sum of one-time costs, such as installation, annual costs, such as maintenance, and foregone income due to yield losses, as shown in the following equation:

$$Cost\ (\$/y) == \frac{One \cdot time\ costs}{10\ years} + Annual\ costs + Foregone\ income$$

Table 4.2 Estimation of costs using the Field Office Technical Guide itemized costs for conservation practices, displayed as one-time and annual costs over a ten year period.

| Category of costs | Time-scale of costs | No-tillage (NT) | Cover crops (CC) | Filter strips (FS) | Grassed waterways (GW) | Wetlands (W) | Habitats (H) |
|---|---|---|---|---|---|---|---|
| | | *$/ha* | *$/ha* | *$/ha* | *$/ha* | *$/ha* | *$/ha* |
| Materials | One-time | $0.00 | $0.00 | $58.27 | $293.00 | $171.59 | $191.01 |
| | Annual | $0.00 | $9.02 | $0.00 | $0.00 | $0.00 | $0.00 |
| Equipment, installation and labor | One-time | $44.52 | $0.00 | $9.63 | $1,323.32 | $979.34 | $5.83 |
| | Annual | $2.02 | $8.90 | $0.00 | $0.00 | $0.00 | $0.00 |
| Operation, maintenance and replacement | Annual | ~~$0.00~~ | ~~$0.00~~ | ~~$2.04~~ | ~~$32.33~~ | ~~$0.00~~ | ~~$0.00~~ |
| Acquisition of technical knowledge | Annual | ~~$1.21~~ | ~~$0.00~~ | ~~$0.00~~ | ~~$0.00~~ | ~~$0.00~~ | ~~$0.00~~ |
| Foregone income | Annual | Yield reduction was predicted by the SWAT model | | | | | |
| Risk | One-time | ~~$0.00~~ | ~~$0.00~~ | ~~$3.40~~ | ~~$0.00~~ | ~~$0.00~~ | ~~$9.83~~ |
| **Total** | **One-time** | **$271** | **$0** | **$415** | **$9,870** | **$7,024** | **$1,203** |
| | **Annual** | **$12** | **$109** | **$0** | **$0** | **$0** | **$0** |

Costs that are crossed out were not considered to be calculated consistently across all practices and therefore were not used in the total costs for the optimization.

Cost of foregone yield also utilized an estimate of corn ($232/tonne) and soybean ($442/tonne) grain price from Index Mundi commodity prices (http://www.indexmundi.com) averaged over the five year period 2008-2012. Average grain prices have risen rapidly since 2007, and therefore, the cost of foregone yield, while estimated from the most recent data, will greatly overestimate the cost of conservation prior to 2007. Costs from the Field Office Technical Guide and final costs used for each practice are summarized in Table 4.2. A description of the cost calculation and source of information in Tables 4.2 and 4.3 can be found in Appendix A.

#### 4.3.3.2 Water quality improvement

Three water quality indicators were considered that are particularly relevant to the intensive agricultural land use in this region, as well as the water quality goals for the Wabash River basin: nitrogen, phosphorus, and sediment. Total nitrogen (TN), total phosphorus (TP) and sediment (Sed) loads can be calculated using SWAT outputs at the HRU, subwatershed, and basin scale. Because SWAT's in-stream water quality modeling was not used, and basin-level pollutant values closely matched HRU-level outputs, a Water Quality Index was calculated at the watershed outlet.

The Water Quality Index was calculated as average, normalized water quality improvement over the baseline scenario at the watershed outlet. Water quality was calculated at the watershed outlet for TN, TP, and Sed as a normalized value by dividing by the pollutant load in the baseline simulation, which had no conservation practices, over a period of six years (2007-2012). Then the three normalized values were averaged to create the water quality index, as shown below:

$$Water\ Quality\ Index = (\frac{TN}{TN_{baseline}} + \frac{TP}{TP_{baseline}} + \frac{Sed}{Sed_{baseline}})/3$$

The index ranges from 0 to 1 (or greater, but this would mean water quality impairment). A value of 1 indicates no water quality benefit from conservation, while a value of 0 indicates complete pollutant removal in the watershed. The baseline scenario would have a Water Quality Index of 1, but other scenarios could have values of 1 if they had no net improvement of TN, TP, and Sed. In fact, many combinations of TN, TP, and Sed could lead to similar Index values.

### 4.3.4 Conservation practice scenarios

Conservation practice scenarios were used to evaluate the effectiveness of conservation practices in the watershed, as well as initialize the first generation of the optimization. Many scenarios were considered, and two sets of scenarios were chosen: one-at-a-time addition and one-at-a-time removal of conservation practices. One-at-a-time addition was chosen to rate the effectiveness of an individual conservation practice in the absence of any other conservation efforts. The best-performing single practice should dominate optimization solutions seeking for small water quality improvements at low cost, and inclusion of these scenarios in the initial population will allow the optimization to converge more quickly on this “tail” of possible solutions. One-at-a-time removal was chosen to identify the nutrient-reduction redundancy of a practice with other conservation practices. If one-at-a-time removal indicates that a given practice is responsible for significant nutrient or sediment reduction, even in the presence of all other practices, that practice will likely be present in high-cost and best water quality solutions.

Each scenario for conservation in the watersheds was run by setting all corn and soybean HRUs to one conservation practice scheme and analyzing the output at the scale of every HRU and each basin. One-at-a-time addition for each conservation practice was compared to a baseline scenario with no conservation in any HRUs. One-at-a-time removal was compared to a complete set of conservation practices in every cropped HRU. All scenarios were compared for Water Quality Index and cost over the baseline scenario.

Comparison was made using summary statistics and boxplot graphs. Cost and pollutant reductions were compared for all HRUs without considering the size of the HRUs. Because HRUs vary significantly in size, averaging small HRUs with large HRUs combines to skew the graphs and statistics towards the results of small HRUs.

### 4.3.5 Genetic algorithm optimization approach

Spatial optimization of conservation practices utilized a genetic algorithm approach called the non-dominated sorting genetic algorithm (NSGA II) (Deb et al., 2002). The genetic algorithm seeks to determine the optimal trade-off front that minimizes the two objective functions. One-at-a-time addition and removal scenarios were included in the initial population in order to hasten the model convergence on the optimal front. Each generation had 48 individual scenarios, which each had a genetic code of a set of conservation practices implemented in the watershed. All six conservation practices could be placed simultaneously in each corn or soybean HRU, except for wetlands, which were only placed in allowable HRUs as presented above. Scenarios that provided a better cost and Water Quality Index than their peers were selected to move to the next generation. Half of these were crossed with each other, and similar to parents creating offspring, a portion of their genetic code was given to the offspring. All individual scenarios then underwent mutation at low rates (0.001 chance of mutation for each HRU). Spatial optimization took place automatically through a code built in MATLAB (MATLAB, 2012), using parallel computing to reduce the time of running the SWAT model for each individual scenario. To plot final optimal curves, fifty evenly spaced bins were created from highest cost to lowest cost solutions, and individuals with the lowest Water Quality Index in each bin were selected from all generations.

## 4.4 Results and Discussion

### 4.4.1 Watershed model validation

Watershed delineation in the SWAT model resulted in fifteen subwatersheds in the Little Pine Creek watershed and seven in the Little Wea Creek watershed. Dividing HRUs by common land units resulted in 418 HRUs in Little Pine, of which 320 were corn and soybean land use, and 396 HRUs in Little Wea, of which 311 were corn and soybeans. Accuracy of these SWAT setups was evaluated using measured water balance, water quality, and crop yields.

Both watersheds had fairly good prediction of daily flow at the outlet for 2009-2012 period for which measured data were available, especially considering the model was not calibrated. Little Pine's flows had an $R^2$ of 0.76 and $E_{NS}$ of 0.69, and Little Wea had $R^2$ of 0.74 and $E_{NS}$ of 0.72. Annual flow depth was quite close for Little Pine – 0.39 m/y observed and 0.37 m/year simulated – but considerably divergent for Little Wea at 0.36 m/y observed and only 0.27 m/y simulated. Tile drainage accounted for 45% of annual flow in Little Pine and 69% of annual flow in Little Wea. Hydrographs and statistics can be found in Appendix B.

Summary statistics for measured nitrate, total phosphorus, and sediment concentration and converted loads are shown in Table 4.3, and hydrographs for nitrate, phosphorus, and sediment loading can be found in Appendix B. Model effectiveness for simulating water quality at the basin and HRU level is discussed below.

Average daily nitrate concentrations were within a reasonable range, though somewhat elevated in Little Wea and underpredicted in Little Pine. Variation was greater in the simulation than the measured samples, suggesting the pathways of nitrate transport may have greater smoothing or storage than the model predicts. Model outputs showed that nitrate made up the majority of total nitrogen in both model setups; in Little Wea, 67% of total nitrogen comes in the form of nitrate, while 81% of total nitrogen in nitrate in Little Pine. Organic nitrogen made up the remaining 33% and 19%, respectively. While most nitrogen is transported in the nitrate form, tile drainage serves as the conduit for the majority of nitrate – 60% in Little Wea, 71% in Little Pine. Therefore, simulated nitrate loads are sensitive to drainage parameters and the portion of flow traveling through tiles.

Phosphorus and sediment loading were generally reasonable, although highly erodible lands contributed to excessive sediment loading in simulation of the Little Wea watershed. Phosphorus loading was fairly well captured in the Little Pine watershed, with similar average loads and concentrations. In the Little Wea watershed, measured total phosphorus concentrations were considerably lower, and yet the model prediction was much greater than for the Little Pine watershed. Sediment loading mirrored phosphorus losses, as should be expected considering the greatest path of sediment losses in SWAT are through soil erosion in the top ten millimeters of soil. Again, Little Pine predictions appeared quite similar to measured data, while SWAT considerably over-predicted sediment losses in the Little Wea watershed.

Water quality evaluation by monthly average nitrate, TP, and sediment loads had a good fit for Little Pine, but not for Little Wea (Appendix M). Little Pine's $R^2$ values were all above 0.6 and $E_{NS}$ were above 0.5, with the exception of sediment loading. Little Wea's water quality $R^2$ values were at least 0.5, but nutrients and sediments were over-estimated to such an extent that none performed well on $E_{NS}$.

The considerable discrepancy between prediction of water quality in Little Pine and Little Wea was mainly due to higher phosphorus and sediment losses from highly erodible lands, which were considered to have no conservation in this model simulation yet are likely protected by conservation practices such as no-tillage and cover crops. Because of the skewed distribution of soil erosion on different soil types and slopes it is expected that sediment and phosphorus will show disproportionality in the landscape (Nowak et al., 2006). If these eroded soils and steeper slopes were protected by conservation practices in the model, Little Wea would have much lower phosphorus and sediment losses. The test for inclusion of known conservation practices on one-third of the watershed did improve all statistics in general. the overestimation of sediment in Little Pine was reduced by half, while in Little Wea the overestimations of phosphorus and sediment were reduced by 19% and 37%, respectively. This test suggests that at least part of the over-estimation can be explained by not including existing conservation practices in the SWAT setup.

Accurate simulation of crop yields is critical to ensure applied nutrients are being used by the plant, as well as to ensure reasonable estimates of foregone yield in the cost calculation of spatial optimization. Actual crop yields were estimated using data for Tippecanoe County, Indiana, during the simulation period 2007-2012 (National Agricultural Statistics Service). Crop yields were estimated to be 10.1 t/ha/y for corn and 3.3 t/ha/y for soybeans during the simulation period. These compare fairly well to average simulated yields of 10.8 t/ha/y (10.7-10.8 for both watersheds) for corn and 2.8 t/ha/y (for both watersheds) for soybeans.

Table 4.3 Comparison of simulated and observed water quality to assess SWAT model performance in Little Pine and Little Wea watersheds, shown with daily mean ($\mu$) and standard deviation ($\sigma$).

| | | Little Pine watershed | | Little Wea watershed | |
|---|---|---|---|---|---|
| | | Simulated *(n = 1279)* | Observed *(n = 153-155)* | Simulated *(n = 1279)* | Observed *(n = 149-153)* |
| Nitrate concentrations (*mg/L*) | $\mu$ | 4.0 | 6.6 | 7.4 | 4.5 |
| | $\sigma$ | 6.0 | 4.0 | 10 | 2.7 |
| Nitrate loading (*kg/d*) | $\mu$ | 420 | 560 | 470 | 370 |
| | $\sigma$ | 1,100 | 1,000 | 1,200 | 780 |
| Phosphorus concentrations (*mg/L*) | $\mu$ | 0.1 | 0.1 | 0.4 | 0.0 |
| | $\sigma$ | 0.1 | 0.1 | 0.6 | 0.1 |
| Phosphorus loading (*kg/d*) | $\mu$ | 13 | 13 | 48 | 10 |
| | $\sigma$ | 42 | 44 | 180 | 52 |
| Sediment concentrations (*mg/L*) | $\mu$ | 35 | 22 | 62 | 14 |
| | $\sigma$ | 57 | 33 | 120 | 39 |
| Sediment loading (*kg/d*) | $\mu$ | 6,500 | 4,200 | 9,600 | 5,100 |
| | $\sigma$ | 27,000 | 22,000 | 43,000 | 33,000 |

### 4.4.2 Conservation practice representation and effectiveness

This section outlines the representation of two conservation practices that are not frequently modeled with SWAT, wetlands and cover crops, as well as the results from one-at-a-time addition and removal scenarios.

#### 4.4.2.1 Potential wetland locations

In the Little Pine watershed, there were 22 potential wetland locations, on average 16.5 ha in normal wetland area plus surrounding buffer area, and 25 wetlands on average 5.2 ha in size Little Wea. Wetlands in Little Pine intercepted flows from 66% of the watershed, with five of its wetlands nested within other wetland drainage areas, while Little Wea's wetlands would intercept 58% of the watershed and contained only one wetland nested within another wetland's drainage area. Overall, wetlands would intercept flows from 62% of the study watersheds, and each wetland with surrounding buffer would entail an average conversion of 10.5 ha of land. Wetlands were placed more placed somewhat more strategically in the Little Wea watershed.

Wetland representation in SWAT is limited in a number of ways. First, SWAT does not provide a framework for using wetlands at a scale smaller than the subwatershed. A wetland with drainage area of one third of a subwatershed would not actually intercept that third, but rather filter one third of the water coming from all HRUs in the entire subwatershed. This limitation is inherent when using SWAT to model wetlands, unless all possible wetlands are located at subwatershed outlets. Second, the parameters for wetland nitrogen, phosphorus, and sediment removal rates are not well established, and could fluctuate a great deal from one wetland to another, leading to great changes in the wetland's ability to remove pollutants.

#### 4.4.2.2 Cover crop growth

Cover crop establishment is a critical factor in their nutrient-cycling performance, so it was important to confirm that SWAT simulated crop growth was within a reasonable range. SWAT annual outputs at the HRU level lump all crop biomass within a year into one value, so cover crop biomass could not be untied from the corn or soybean crop that followed. Therefore, cereal rye biomass was assumed to make up the difference between total crop biomass in the cover crop scenario and the baseline scenario, which is reasonable considering the simulated corn and soybean yields were essentially unaffected by the presence of a cover crop (Appendix D). Cereal rye established fairly well for most years, growing on average to a biomass of 1.7 t/ha by the time it was killed in the spring. Although no cover crop biomass data was available for these watersheds, experiments in Illinois had average annual biomass of 2.2-6.1 t/ha, which are likely a little higher than expected in the simulation because the crop was killed at least two weeks later than assumed in this work (Ruffo et al., 2004). Statistics and plots for each watershed separately can be found in Appendix C. Growth was greater on years following soybeans, achieving a biomass of 2.00 +/- 0.51 t/ha, while cereal rye growth following corn was 1.31+/- 0.32 t/ha. Such a notable difference between rye growth after corn and soybeans, as shown in Figure 4.2, is likely due to the 2-year application of phosphorus that takes place immediately prior to cover crop planting after soybeans. The rye did not grow much in the winter months, but grew rapidly in March and April, and is sensitive to the precise kill time in April.

#### 4.4.2.3 Conservation practice scenarios

Scenarios where only one (or all but one) conservation practice was applied in every corn and soybean HRU allowed for simple comparison of conservation practices as shown in Table 4.4 (4.5) and Figures 4.3-4.5. Note that cost and pollutant loading does not represent a mean value for the basins, but rather an average of all HRUs, regardless of their size. This is particularly influential for grassed waterways, which were given a set width on every HRU, causing the cost of grassed waterways to increase greatly on small HRUs. While the grassed waterway scenario appears to cost an average of $199/ha, the total cost of these grassed waterways normalized to the entire basin area reveals a much lower cost of $63/ha. Keeping in mind the fact that small HRUs are given disproportionate weight in these graphs and tables, it is possible to learn about the variability in cost and pollutant loading, as well as comparison among the scenarios.

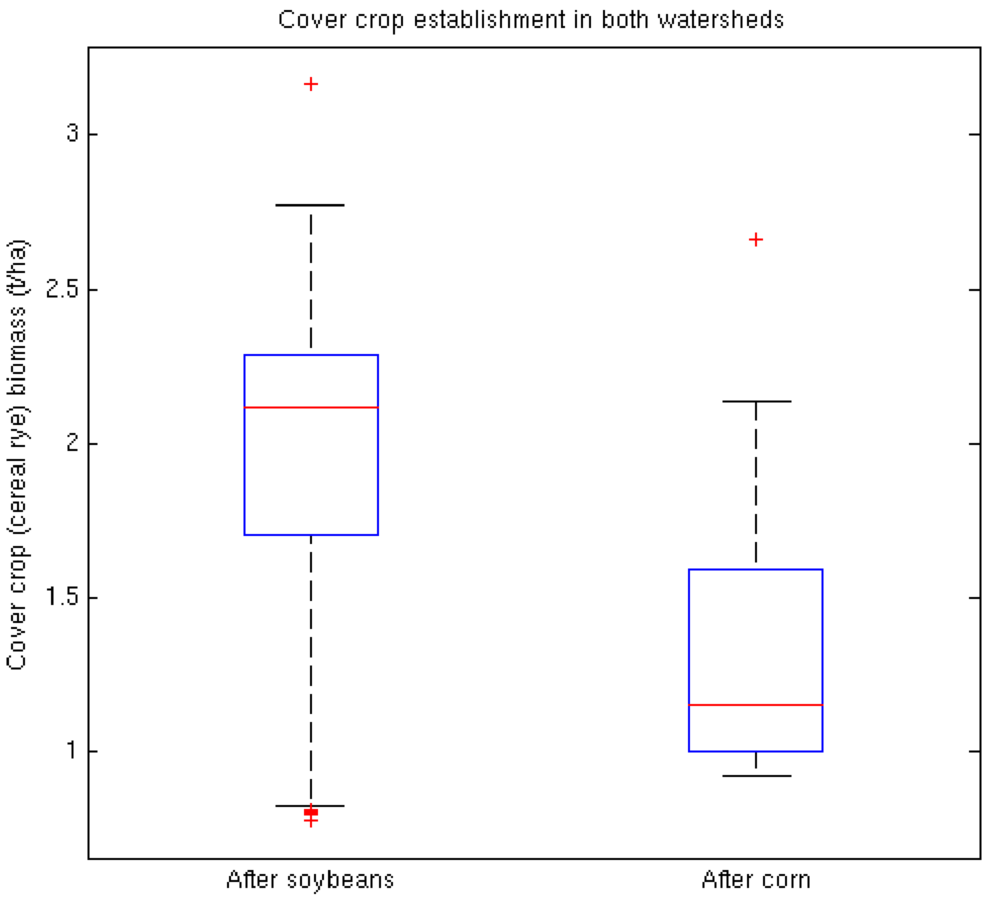

Figure 4.2 Box plot of average annual cereal rye establishment for every corn and soybean HRU in the two study watersheds.

When a single conservation practice was applied, filter strips and habitats provided the most cost effective water quality benefit in the watershed, followed by grassed waterways. The wetland scenario was in the lower cost range and somewhat effective at improving water quality. Cover crops proved to be somewhat expensive and no-tillage did little to reduce simulated pollutant export from crop fields. Therefore, in fields with the least conservation, filter strips and habitats will provide the biggest bang for the buck. Cover crops and wetlands provide less cost-effective benefits in these lands. And no-tillage, when compared with conventional chisel and disk plowing in the baseline scenario, is surprisingly ineffective in these fairly flat agricultural lands.

When all but one practice were applied to every corn and soybean HRU, the impact of removing the practice from a suite of all practices was evident, and if the resulting water quality worsens, that practice was influential in improving water quality even under high conservation conditions. Filter strips and grassed waterways are no longer influential, while cover crops and wetlands are capable of removing nutrients and especially sediments that the other practices cannot intercept. Most likely filter strips and grassed waterways intercept pollutants in a similar way, and are in effect redundant with each other, while cover crops on the field and wetlands downstream from the source are capable of intercepting a new set of pollutants. Therefore, cover crops and wetlands may be recommended in regions where more conservation is already taking place. In fact, using the current conservation practice representation in these particular case study watersheds, cover crops were essential in the suite of practices to reduce all water quality pollutants. Cover crops were the most effective practice at reducing nitrogen loading, likely because they can process nutrients in the field before nitrate passed into the tile and beyond the reach of grassed waterways, filter strips, and habitats to remediate. Wetlands, when placed most efficiently, can be highly effective as well.

Table 4.4 Cost and water quality results for the one-at-a-time addition scenarios. Means ($\mu$) and standard deviations ($\sigma$) are for the annual average of each corn and soybean HRU in both study watersheds.

| Scenario | Cost of scenario |  | TN loss |  | TP loss |  | Sed loss |  | Water Quality Index |
|---|---|---|---|---|---|---|---|---|---|
|  | *$/ha/y* |  | *kg/ha/y* |  | *kg/ha/y* |  | *t/ha/y* |  |  |
|  | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ | $\mu$ | $\sigma$ |  |
| No conservation (None) | $0 | $0 | 49.8 | 20.5 | 5.4 | 3.9 | 0.632 | 0.633 | 1.00 |
| No-tillage (NT) | $69 | $22 | 48.1 | 18.7 | 4.9 | 3.1 | 0.542 | 0.565 | 0.91 |
| Cover crops (CC | $104 | $26 | 31.7 | 12.9 | 2.9 | 2.3 | 0.300 | 0.308 | 0.55 |
| Filter strips (FS) | $48 | $2 | 33.2 | 16.7 | 1.4 | 0.9 | 0.089 | 0.110 | 0.36 |
| Grassed waterways (GW) | $199 | $315 | 32.4 | 16.4 | 1.1 | 0.9 | 0.111 | 0.143 | 0.34 |
| Wetlands (W) | $56 | *N/A** | 41.7 | *N/A** | 3.5 | *N/A** | 0.295 | *N/A** | 0.65 |
| Habitats (H) | $50 | $2 | 33.2 | 16.7 | 1.4 | 0.9 | 0.089 | 0.110 | 0.36 |

** Standard deviations could not be determined for the scenario with wetlands because HRUs with wetland outlets were considered to assume the entire cost of the wetland creation, while the water quality benefits are realized for all upstream HRUs.*

Table 4.5 Results for the one-at-a-time removal scenarios, in which all or all but one conservation practice were placed throughout corn and soybean HRUs. Means ($\mu$) are for the annual average of each corn and soybean HRU in both study watersheds.*

| Scenario | Cost of scenario | TN loss | TP loss | Sed loss | Water Quality Index |
|---|---|---|---|---|---|
| | *$/ha/y* | *kg/ha/y* | *kg/ha/y* | *t/ha/y* | |
| | $\mu$ | $\mu$ | $\mu$ | $\mu$ | |
| All conservation practices (All) | $511 | 22.5 | 0.5 | 0.020 | 0.19 |
| All except no-till (- NT) | $458 | 20.8 | 0.4 | 0.025 | 0.18 |
| All except cover crops (- CC) | $418 | 31.4 | 0.7 | 0.042 | 0.28 |
| All except filter strips (- FS) | $463 | 21.5 | 0.4 | 0.015 | 0.18 |
| All except grassed waterways (- GW) | $313 | 22.2 | 0.5 | 0.016 | 0.19 |
| All except wetlands (- W) | $455 | 24 | 0.7 | 0.044 | 0.23 |
| All except habitats (- H) | $461 | 21.5 | 0.4 | 0.015 | 0.18 |

** Standard deviations are not provided because of the way wetlands were input at the HRU level, despite being implemented at the subwatershed scale.*

Figures 4.3-4.5 also provide greater depth than the statistics in understanding the distribution of the nutrient and sediment loading from cropped HRUs. In particular, phosphorus and sediment loading has a strongly skewed distribution, where a small number of crop fields are responsible for a disproportionate share of soil erosion. These highly erodible lands would quite likely have conservation measures such as no-till, grassed waterways, and filter strips already in place. Additional descriptive statistics and plots for conservation scenarios can be found in Appendix D.

Crop yields were fairly steady throughout the scenarios, but corn yields were influenced by no-tillage and cover crops. Annual corn yields averaged 10.8 t/ha (+/- 0.5-0.6 t/ha over all HRUs), and dipped to 10.5 t/ha when no-tillage was added. Interestingly, although cover crops along did not increase corn yields, the addition of cover crops to a suite of practices counter-acted the 0.3 t/ha loss from no-tillage. Soybean yields were steady at 2.8 t/ha (+/- 0.2 t/ha over all HRUs) for all conservation scenarios.

It is important to note that many of these results are quite sensitive to cost – for instance, cover crops other than cereal rye may have greater or lesser seed costs. And many other concerns go into optimality, such as who is the decision-maker installing the practice; grassed waterways and filter strips require cooperation from those specific farmers and landowners, while cover crops may not require cooperation from a landowner, and wetlands can intercept sources far upstream.

### 4.4.3 Spatial optimization of conservation

Spatial optimization converged upon a Pareto optimal front (Deb et al., 2001) within roughly 100 generations of 48 individuals. Evenly binned optimal solutions were selected and plotted alongside the scenarios, which were present in the initial generation, in Figures 4.6 and 4.7. The optimal curve is expected to be truly near-optimal, but this cannot be proven without running optimizations using other algorithms and comparing them. Following the curve from lowest cost solutions to highest cost solutions, it is clear that water quality can be improved considerably, although the rate of water quality improvement steepens dramatically on the left tail of the optimal curve. In Little Pine, fairly low cost solutions are capable of removing up to approximately 50% of pollutants, while cost increases rapidly up to a pollutant removal of 70%. In Little Wea, low cost solutions can reduce pollutants by an average of 60%, and higher cost solutions can reduce pollutants to nearly 80% in the watershed.

Combining optimizations from Little Pine and Little Wea, maximum pollutant reduction reached approximately 70-80% when nearly all practices were used simultaneously. Far less expensive were the options available in the range of 0-50% water quality improvement. This water quality improvement threshold is expected for pollutant removal, where the first portion of pollutants can be removed readily but complete removal may be costly or impossible as the hardest to reach pollutants persist.

Initial conservation practice scenarios provide a sense of which practices are present along the optimal curves. It appears that filter strips, habitats, and grassed waterways dominate in the right hand tail of lower cost and smaller water quality improvement, while cover crops and wetlands account for much of the steeper, left tail of the curve. This inference is not proven by Figures 4.6 and 4.7, but is supported by additional inspection not presented here. It is notable that the optimal curve lies quite near to these initial scenarios, suggesting that a simple recommendation for one practice in an entire watershed may be able to achieve a near-optimal solution. If no conservation was present in these watersheds, one could simply recommend that all farms incorporate filter strips or grassed waterways, and achieve nearly a 50% improvement in water quality. Conversely, if filter strips and grassed waterways are already prevalent in these lands, one might suggest cover crops or a few targeted wetlands to achieve further water quality improvement.

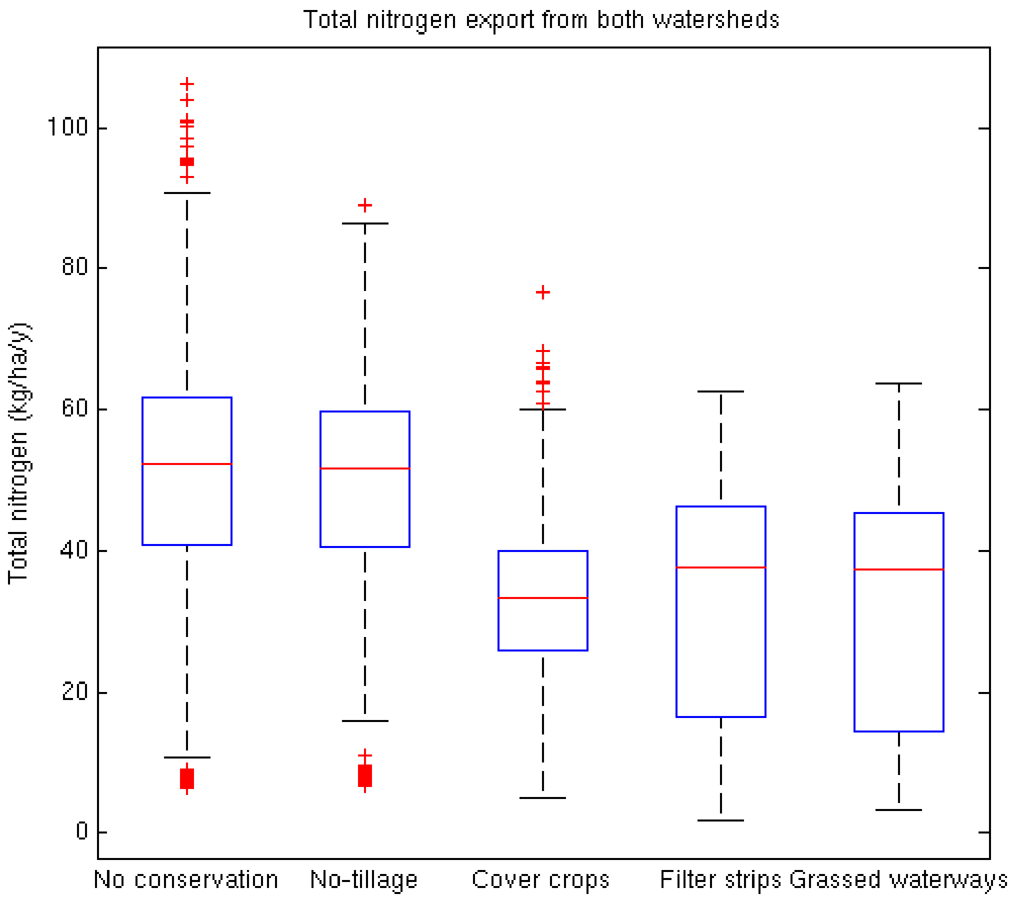

Figure 4.3 Box plot of total nitrogen export from all cropped HRUs under five one-at-a-time addition scenarios. Wetlands are not shown because they are implemented at the sub-watershed-level rather than the field scale, and habitats performed identically to filter strips.

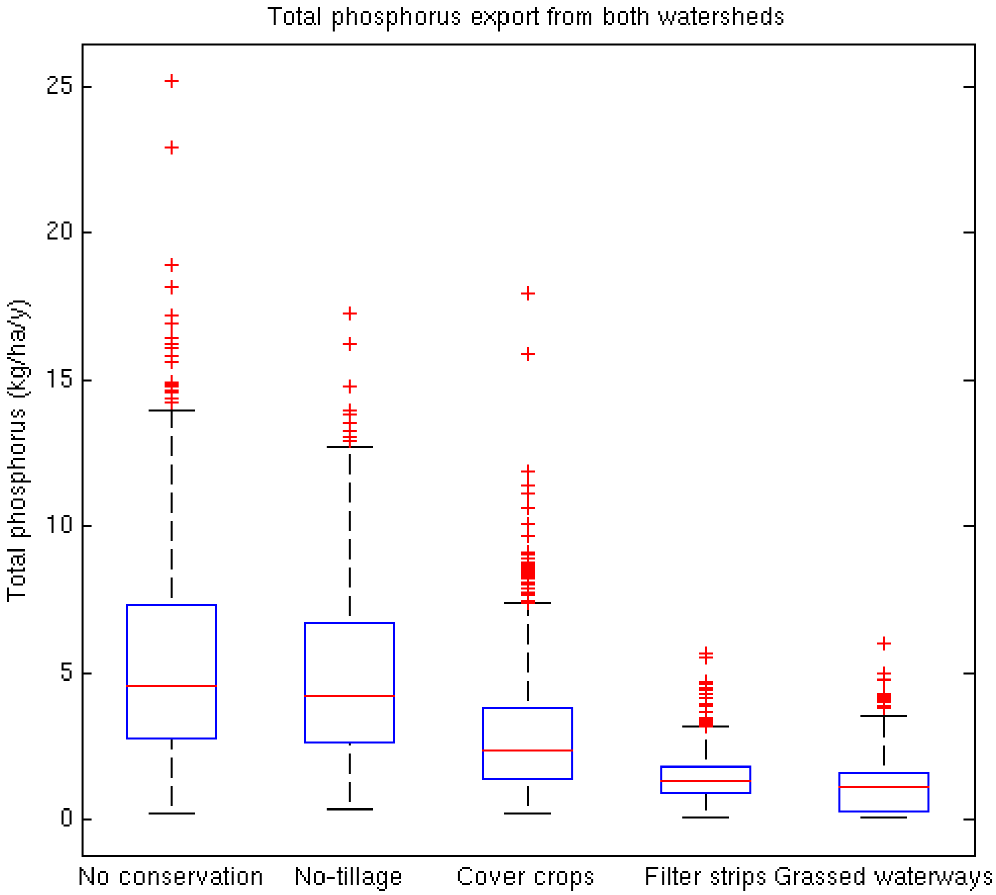

Figure 4.4 Box plot of total phosphorus export from all cropped HRUs under five one-at-a-time addition scenarios.

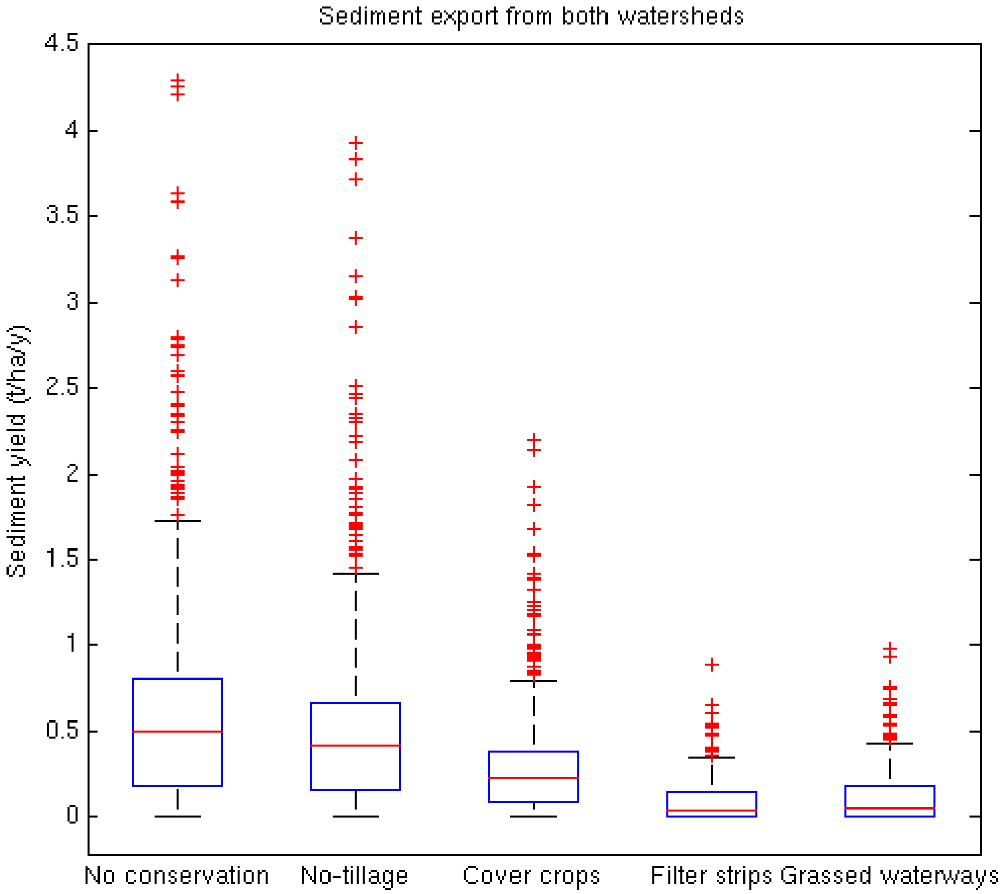

Figure 4.5 Box plot of sediment export from all cropped HRUs under five one-at-a-time addition scenarios.

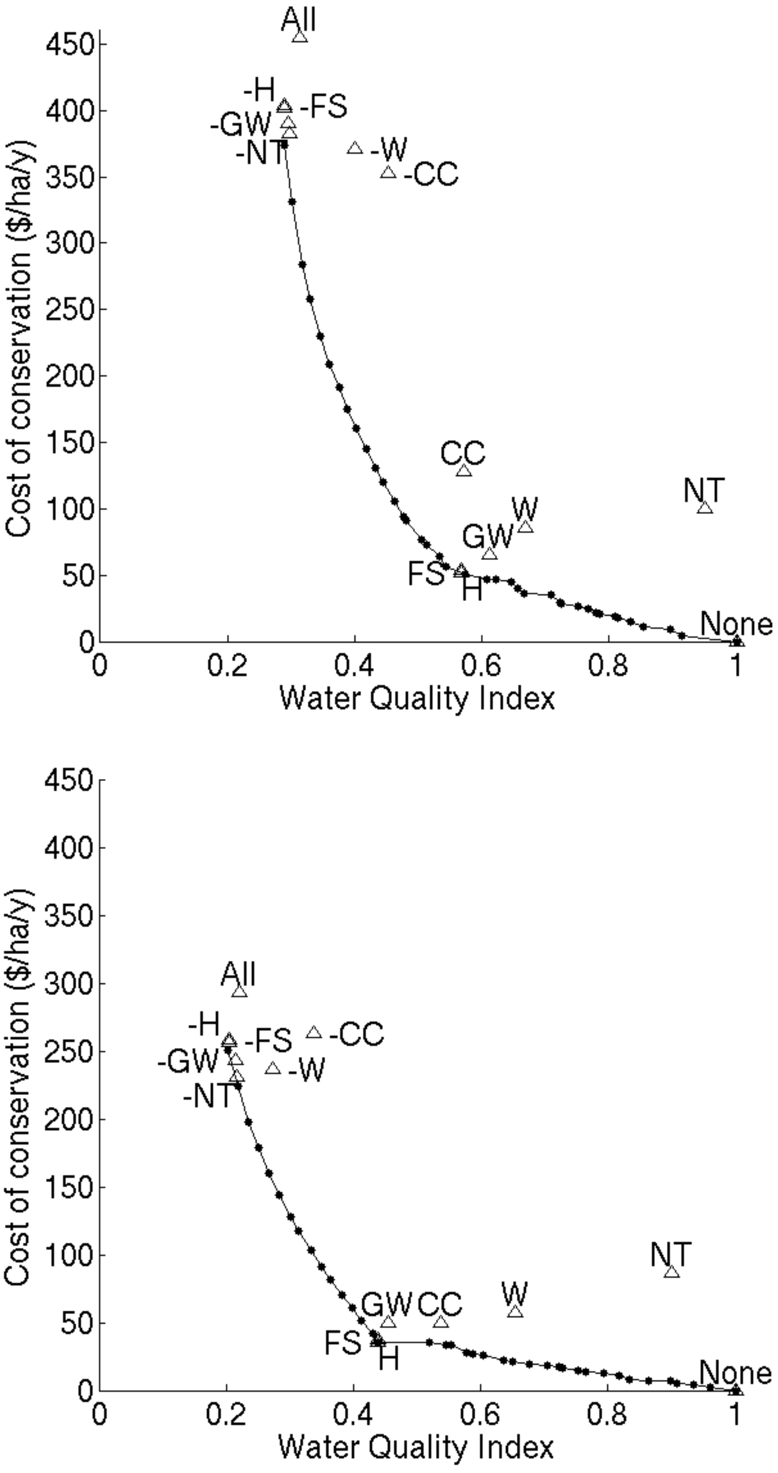

Figure 4.6 Optimization results plotted against initial conservation scenarios at the 200th generation for conservation in the Little Pine (top) and Little Wea (bottom) watersheds. See Tables 4.5 and 4.6 for meaning of symbols.

Not all watersheds would behave similarly to these, and it is relevant to look at how conservation practice effectiveness differs from one study watershed to the other. No-tillage was slightly more effective in the Little Wea watershed, which may be due to Little Wea’s slightly greater slopes. Cover crops had greater cost in Little Pine than Little Wea, which may relate to differing impacts on row crop yields. Better performance of wetlands in Little Pine than Little Wea may be an artifact of the wetland locations manually chosen. On the other hand, it may be the filter strips, grassed waterways, and wildlife habitats that shifted to provide greater effectiveness in Little Wea. Little Wea watershed was able to reach a better water quality improvement than Little Pine, and the suspected cause is elevated phosphorus and sediment loading predicted in the Little Wea watershed allowing for greater percentage improvement from conservation practices.

## 4.5 Conclusions

In this work watershed modeling is extended through representation of many conservation practices, and the spatial optimization approach is extended through definition of HRUs by field boundaries and simultaneous simulation of many conservation practices. Conservation practices were found to behave quite differently in their ability to protect surface waters from nitrogen, phosphorus, and sediment, and the placement of these practices may depend on the existing practices already in place in the watershed. Filter strips, grassed waterways, and strategically placed wildlife habitats were capable of achieving the most cost-effective reduction of all three water quality pollutants on nearly all lands. Cover crops may have come with greater cost, and were not needed to reduce erosion and phosphorus runoff, yet they provided the greatest nitrate-leaching protection in these flat, extensively tile-drained watersheds. Wetlands were sensitive to location, had reduced efficiency when nested within other wetlands' drainage areas, and may provide quite different results if nutrient and sediment removal parameters were adjusted. No-tillage was surprisingly ineffective at reducing all three of the water quality pollutants of concern, because it left an untouched soil surface with high concentrations of phosphorus vulnerable to runoff through erosive flows. No-tillage is known to have soil formation benefits and may be most effective on the few highly erodible lands.

Spatial optimization revealed an opportunity to apply lower-cost solutions to reduce nitrogen, phosphorus, and sediment loading by up to 50% at the watershed scale. If greater reductions are required, costs may increase nearly ten-fold to capture 70-80% of pollutants in the watershed. Even greater reductions may not be possible with the current set of conservation practices, particularly due to the lower bound on nitrate removal caused by excessive nitrate flows through subsurface tile drainage. While this work demonstrates that a fairly complex, computationally-intensive targeting can be achieved, there is also hope that simpler targeting efforts could be near-optimal – even the simplest initial conservation practice scenarios appeared near the Pareto optimal front, and it is not difficult to imagine simple geospatial targeting by soil type, land use, and slope could be quite effective.

Limitations of this work include the water balance, nutrient, and sediment performance of the uncalibrated SWAT model in the Little Wea Creek watershed, the unknown parameter values for many conservation practices, estimations of cost, and of course the limitations of the current SWAT model in representing conservation practices. There is always an opportunity to improve the representation of these practices through measured data and calibration of practice parameters, such as the wetland pollutant removal rates. This modeling work may also be used quite practically with policy-makers, conservation planners, and even farmers or landowners, and such an approach can be used adaptively through interactions with these stakeholders.

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# CHAPTER 5. ADAPTIVE TARGETING: ENGAGING FARMERS TO IMPROVE WATERSHED MODELING, SPATIAL OPTIMIZATION, AND ADOPTION OF AGRICULTURAL CONSERVATION PRACTICES

## 5.1 Abstract

Targeting of agricultural conservation practices to cost-effective locations has long been of interest to watershed managers, yet its implementation fails in the absence of meaningful engagement of agricultural producers who are decision-makers on the lands they farm. This work involved fourteen west-central Indiana producers and landowners in an adaptive targeting experiment. Extensive interviewing was carried out prior to targeting, which provided rich spatial information on the locations of existing conservation practices as well as producers' preferences for future conservation projects. Targeting of six of the most accepted conservation practices was performed using the Soil and Water Assessment Tool (SWAT) and a genetic algorithm spatial optimization. A total of 176 targeted results on 103 farm fields were presented to farmers in follow-up interviews with the ten producers who had targeted conservation on their lands. Primary findings indicate that producers were interested in the project, were open to hearing recommendations about their lands, and will consider implementing a significant number of the targeted practices. Producers believed that 47% of targeted results were optimal for their lands and expressed a high likelihood of adopting 35% of targeted conservation in the next five years. The adoption of these practices would cost nearly $69,000 annually over both watersheds but would result in nitrogen, phosphorus, and sediment reductions in the range of 4-11% for the watersheds. Cover crops and grassed waterways were the targeted practices that farmers accepted most readily, though wetlands and no-tillage may have had low acceptance because they were only targeted in a few cases and therefore had a small sample size. Farmers generally viewed the interview process and presentation of results quite favorably, including some who chose not to implement any

targeted conservation. Farmers were receptive to hearing about targeted conservation, and the interviews seem to have built trust with them. The preliminary interviews made the targeting process more acceptable to farmers prior to presentation of results in the follow-up interviews.

## 5.2 Introduction

Strategically placing conservation practices in the landscape, known as targeting, has long been of interest for watershed management (e.g. Hession and Shanholtz, 1988; Crumpton, 2001; Heathwaite et al., 2005; Diebel et al., 2008; Diebel et al., 2009; Tuppad et al., 2010). However, it is not always clear how to apply targeted solutions, especially when dealing with nonpoint source pollution. A variety of policy incentives have long encouraged agricultural producers to implement conservation practices (Harrington et al., 1985), but these incentives alone may not produce economically efficient solutions since they are not based on the true magnitude of pollutant reduction (Helfand and House, 1995). Generally, incentives are available to all on a “first come, first serve” basis, and enrollment is voluntary. This is not considered the most effective way to reduce pollution; nonpoint source pollution often originates in “hotspots” on a small portion of the landscape, similar to point sources, which should be targeted for maximum efficiency (Diebel et al., 2008). Similarly, the efficiency of conservation practices is site-specific and therefore locations within a watershed should be identified where a particular practice may be the most effective. This is a targeting approach, and consideration of cost or economic efficiency is called optimization, a subset of targeting. Targeting the most efficient locations for conservation may considerably raise the performance of conservation practices, thereby decreasing the cost of implementation to meet a particular water quality target.

Despite the theoretical effectiveness of targeted conservation practices, owners of high priority lands may choose to reject the suggested conservation practices as their installation cannot be enforced under any regulation (including the Clean Water Act (U.S. Congress, 1987)). Therefore, in the event that owners choose not to implement a targeting solution that solution will certainly fail to produce the promised cost-effectiveness. Furthermore, a targeting solution may fail even if certain aspects of it are implemented. For instance, if selection of each high priority crop field is dependent on other high priority lands, omitting parts of a targeted solution may not produce a cost effective result. In this case an adaptive, iterative targeting approach that involves stakeholders will likely produce greater cost effectiveness than the initial targeted solution.

Targeting approaches have focused primarily on the technical aspects of prioritizing land for conservation, and yet stakeholder engagement is an important part of an adaptive management approach. Ahnstrom et al. (2008) conclude their review on farmers and conservation by recommending that conservation programs be flexible, seeking to fulfill the aims of the program creatively, and allowing for local adaptations. Similar to findings in chapter 2, Reimer et al. (2011) suggest that successful targeting of conservation requires outreach to landholders managing the most vulnerable lands, and they caution that a one-size-fits-all approach will not succeed. Stakeholder participation in decision-making is commonly viewed positively for normative reasons such as increasing democracy or fairness, as well as for practical reasons such as contributing to wiser and more efficient solutions to complex natural resource management issues (Tuler and Webler, 1999; Lauber and Knuth, 2000; Beierle, 2002; Dietz and Stern, 2008). Since nonpoint source pollution control is in the hands of the producers and cannot be regulated externally, it is important that any plan for conservation involve producers and seek to implement their wishes. Building good relationships and trust between producers and conservation programs is more likely to lead to reduced nonpoint source pollution, particularly when dealing with targeted solutions. These solutions must take into account producers' needs and desires so that they have the highest chance of adoption in agricultural landscapes.

Bringing together the engineering solutions of targeting with the human dimensions of watershed management can lead to targeting that is practical and relevant to individual land managers. The overall goal of this work was to demonstrate an adaptive targeting approach in two small watersheds. An adaptive optimization framework is developed that engages farmers and landowners in the process of optimizing the spatial locations of conservation practices at the watershed scale. The intention of this work was to make the optimization acceptable to farmers to encourage adoption of targeting conservation in the watershed.

## 5.3 Materials and Methods

### 5.3.1 Adaptive targeting approach

An approach referred to here as “adaptive targeting” was developed that includes a multidisciplinary process of engaging farmers and running a model to develop targeted solutions. First, farmers and landowners were engaged through initial interviews about existing conservation adoption and their interest in future conservation efforts, as well as many spatial attributes of their farms. Farmer interviews provided detailed farm and farmer-specific information about as many farm fields in the study areas as possible. Eleven conservation practices were included in interviews based on their prevalence in the watersheds and likelihood of improving water quality. From these eleven practices, six were most palatable to farmers and feasible for representing well in the watershed model, and these six were used in the targeting experiment. Second, a loosely coupled watershed model and spatial optimization approach was used to determine targeted conservation recommendations. The Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) was utilized because it is capable of simulating the watershed, conservation practices, and management operations, and it is commonly used to predict the influence of land management on water quality and crop growth. An evolutionary algorithm spatial optimization approach was employed to determine the optimal placement of conservation practices in the watershed. Adaptation of the optimization used current conservation and future conservation preferences as constraints. The adaptive targeting approach was evaluated through multiple optimizations that used different levels of farmer information. Finally, follow-up interviews with farmers allowed for transfer of targeted recommendations and determination of their reactions and intentions to adopt these practices.

### 5.3.2 Application to two study watersheds

The adaptive targeting approach was applied to the Little Pine Creek and Little Wea Creek watersheds in west central Indiana, where streamflow and water quality data were available at the watershed outlets (Figure 5.1). Fairly small watersheds at 56 and 45 km$^2$ in size, respectively, Little Pine and Little Wea have approximately 90% of land in corn and soybean crops, 70-80% of cropland drained by subsurface tiles, and fairly flat topography with an average slope of 1-2%. Farms owned by Purdue University cover 13% of the Little Pine watershed.

### 5.3.3 Initial farmer interviews

#### 5.3.3.1 Interview guide

A farmer interview guide was developed to investigate farm management and farmer preferences for future conservation. First, farmers were asked to identify farm fields they owned or rented within or near the study area. Second, farmers were asked about their past use, current use, and future potential use of eleven conservation practices (Table 5.1). Farmers identified existing conservation practices on the map, then placed each practice in a preference pile: “yes,” they are interested in implementing this practice in the future; “maybe,” they may be interested in using this practice; “no,” they have no interest in using this practice; or “not applicable” if they thought that the practice was not applicable to their lands. Finally farmers were asked about their views on the benefits of conservation and their response to targeting as a theoretical concept as well as a practical approach. The interview guide was approved by the Institutional Review Board and is available in Appendix E.

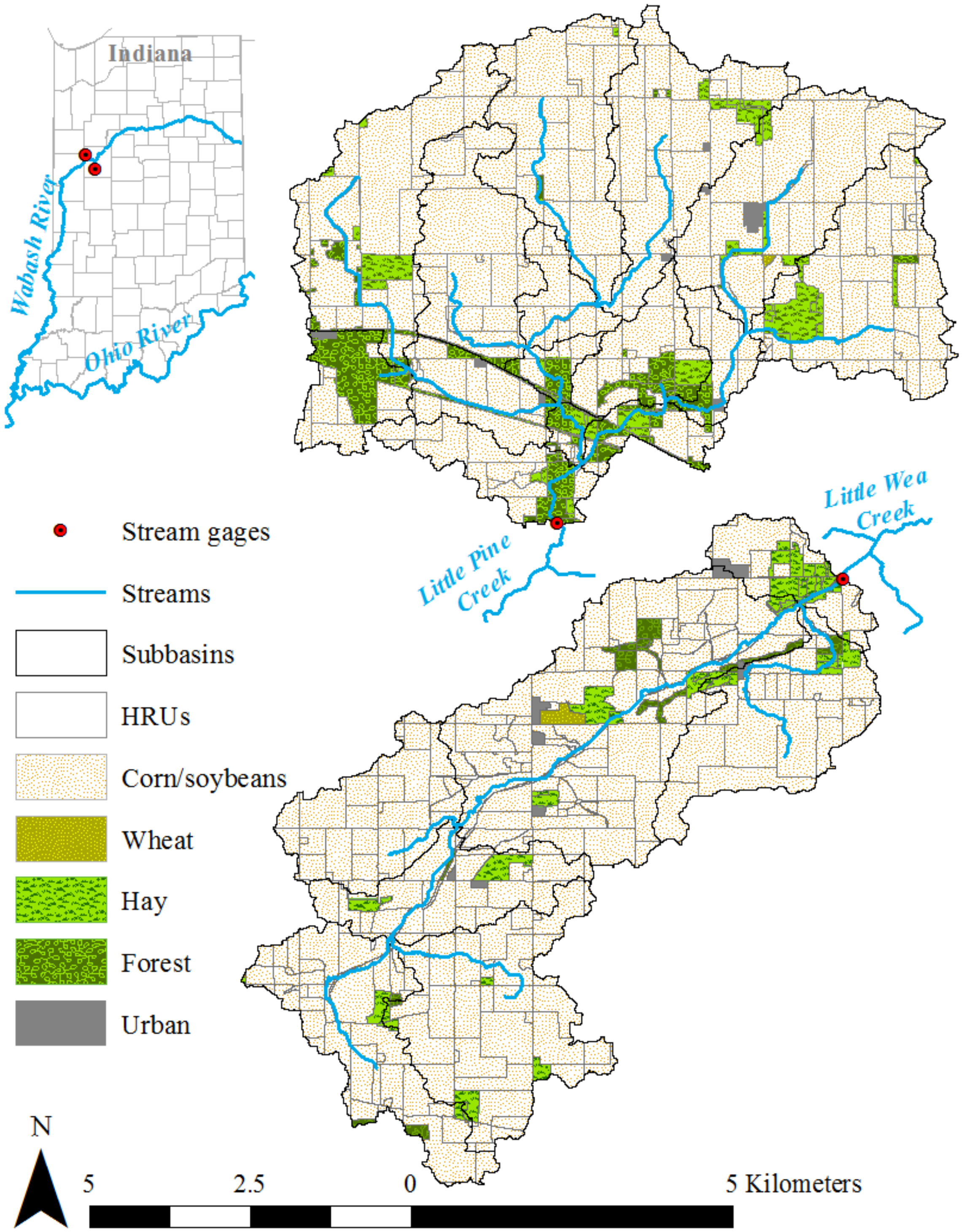

Figure 5.1 Study watersheds within Tippecanoe County, Indiana: Little Pine Creek watershed (top) and Little Wea Creek watershed (bottom). Watersheds are not located as near to each other as shown above.

Table 5.1 Conservation practices discussed in interviews

| Conservation practice (NRCS number) | Description of practice and how it was simulated in the SWAT model |
|---|---|
| None | Rotation with corn (chisel and disk plow) and soybeans (no-tillage planting). See chapter 4 for fertilizer application rates and tile drainage parameters. |
| No-tillage (329) | Using no tillage to manage crop residues on the soil surface. No-tillage planting for corn and soybeans and 2 point reduction in HRU curve number. |
| Cover crops (340) | Planting crops for seasonal cover. Planting of cereal rye October 15, following harvest of corn and soybeans. Rye was killed April 15, prior to planting corn or soybeans in the spring. |
| Filter strips (393) | Vegetated strips intended to filter contaminants from runoff. Used the SWAT filter strip routine, assuming size as 2.5% of HRU area and 50% of the HRU draining to the most concentrated 10%, with no fully channelized flow. |
| Grassed waterways (412) | A shaped strip of grass intended to prevent gully erosion from overland flow. Used the SWAT filter strip routine, assuming a 10 m width and length of the square root of the HRU area. |
| Drainage water management | Varying the depth of tile drainage outlets throughout the year using a water control structure. Not modeled due to low farmer interest and lack of current ability to model in SWAT. |
| Nutrient management (590) | Altering the amount and form of fertilizer applications to maintain high yields while minimizing the water quality impacts. Not modeled due to difficulty predicting current farmer nutrient management. |
| Waste utilization (633) | Ensuring agricultural wastes (e.g. manure) are used in a way that protects the environment. Not modeled due to difficulty predicting current farmer management |
| Restoration and management of rare or declining habitats (643) | Conserving biodiversity by providing habitat for rare and declining species. Considered “habitats” and assumed to be tall grass prairie for cost calculations and targeting recommendations. Modeled as filter strips. |
| Upland wildlife habitat management (645) | Conserving biodiversity by managing upland habitats to create connectivity of landscapes. Considered “habitats” and assumed to be tall grass prairie for cost calculations and targeting recommendations. Modeled as filter strips. |
| Two-stage ditches | Designing drainage ditches after stable natural streams, with a channel and adjacent floodplains. Not modeled due to low farmer interest and lack of ability to model in SWAT. |
| Wetland restoration or creation (657/658) | Creating a wetland to provide habitat and filter contaminants from agricultural runoff. Modeled as headwater wetlands using SWAT’s wetland routine. Sized at 4% of their contributing area, including surrounding buffer. See chapter 4 for more information on the wetland parameters and citing approach. |

#### 5.3.3.2 Farmers interviewed

Farmer and landowners were contacted by mail and by phone based on publicly available parcel information for landowners owning at least 20 ha of land in the study watersheds. All farmers reached by phone accepted the interview. In addition, two landowners who had previously farmed and were still involved in the farming operation on their lands were asked to participate in the interview, and they accepted. A total of 14 farmers and landowners were interviewed in winter of 2012, including eight farmers in Little Pine, of which two worked with the Purdue research farms, and four farmers and two landowners who were retired from farming in Little Wea. Farmer interviews provided data on land covering 34% (1900 ha) of Little Pine watershed and 32% (1440 ha) of Little Wea. Most of this land was owned by farm operators, although a small percentage of it was rented (7% of interviewed lands in the Little Pine watershed and 17% in the Little Wea watershed). Farmers operating over the majority of the study watersheds could not be determined, and is mostly likely rented by farmers who do not own at least 20 ha of land in either watershed. Most farms had primarily corn and soybean operations, though some farmers had small or large beef cattle or hog operations. All farmers were male, Caucasian, had farmed an average of 36 years, and were on average 62 years old, although some of the older interviewees were no longer actively involved in the farming operation.

### 5.3.4 Watershed modeling

The Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) was used for watershed modeling of the two study areas because of its ability to model land use and land management, including conservation practices, and its ability to implement “what if” scenarios (Arnold et al., 1998). Within the study area watersheds, SWAT delineates subwatersheds using elevation data and, optionally, hydrography. Subwatersheds are further divided into hydrologic response groups (HRUs), which are lumped regions with similar soil type, land use, and slopes. SWAT version 579 was used for this work because of its updated subsurface tile drainage routine. Details on the data layers used for this model setup can be found in chapter 4.

An important update in the use of SWAT in this approach was the definition of HRUs by a common land unit (CLU) layer, which divides land based on ownership and land use (see chapter 3). It was important to show farmers the targeting results at the field scale, rather than dispersed throughout the subwatersheds. HRU definition by common land units resulted in 418 HRUs and 320 cropped (corn and soybean) HRUs in Little Pine, and 396 HRUs and 311 cropped HRUs in Little Wea. The SWAT models were not calibrated, as the models were generally able to predict flow and nutrient loading at the outlets fairly well, and crop yields were within a reasonable range (chapter 4).

### 5.3.5 Spatial optimization of conservation practices

Identification of the optimal locations for conservation practices was performed using a genetic algorithm approach, the non-dominated sorting genetic algorithm (NSGA-II) (Deb et al., 2002). Genetic algorithms use evolutionary concepts of reproduction, mutation, and selection to improve populations or solutions over time. In this case, a "generation" of a population consists of 48 "individuals", whose "DNA" codes for a set of conservation practices in every cropped (corn and soybean) HRU. Half of all individuals were crossed to generate new "offspring", and all individuals mutated at a low rate of 0.001 chance of gaining or removing a practice per HRU. "Fitness", or effectiveness, of every individual in each generation was estimated by running the SWAT model and processing HRU-level outputs. Those individuals with greatest fitness were chosen to pass on to the next generation, while the NSGA-II algorithm attempted to maintain a good spread of solutions across the optimization front. Entirely automated, the optimization was conducted within the MATLAB environment (MATLAB) and run on a supercomputer, Carter, which is part of Purdue's Community Cluster Program. A final optimal set of individuals were selected from all generations to represent a Pareto optimal front by choosing a number of evenly spaced bins over the water quality domain and selecting the least costly individual from that bin.

Conservation practices included in the optimization were no-tillage, cereal rye cover crop, filter strips, grassed waterways, created wetlands, and restored prairie wildlife habitats. Each was implemented in the SWAT model (chapter 4), allowing every practice to be placed in any cropped HRU, with the potential for multiple practices in a given HRU. In SWAT, headwater wetlands are considered to be placed at the subwatershed-level rather than the HRU-level, and therefore wetlands were modeled at the subwatershed outlet. Possible wetland locations were located generally following a placement method based on contributing area (Kalcic et al., 2012), totaling 22 wetlands in Little Pine and 25 wetlands in Little Wea. The wetland contributing area identified as part of the placement method was divided by the subwatershed area to determine a fraction of subwatershed draining to it.

#### 5.3.5.1 Objectives: simultaneously minimize water pollution and cost of conservation

Performance of individual conservation practice scenarios, which specifies those individuals who pass on to the next generation, was quantified using two objective functions.

The first objective was to minimize conservation costs, including yield losses due to taking land out of production or changes in crop management. Cost of materials, equipment, installation, and labor for the implementation of each conservation practice over one decade were estimated from the Natural Resources Conservation Service (NRCS) Field Office Technical Guide for the state of Indiana (USDA, NRCS), which is outlined in chapter 4. Foregone yield for the six-year simulation was estimated as the SWAT model’s change in yield for each HRU by subtracting the baseline scenario in which no conservation exists in the watershed. Conservation practices that occupy no spatial area in SWAT were assumed to cause yield decreases in proportion to the calculated physical area and the average yield of that HRU. Cost of foregone yield was calculated from the five-year average grain costs from 2008-2012, which was \$232/tonne for corn grain and \$442/tonne for soybeans.

The second objective was to minimize the water quality impacts of farming, defined as a normalized average of total nitrogen, total phosphorus, and sediment reaching the watershed outlets. Each water quality indicator–total nitrogen (TN), total phosphorus (TP), and sediment (Sed)–was normalized by dividing by the baseline simulation’s pollutant load over the six-year simulation (2007-2012), and a Water Quality Index for the watershed was calculated as the average of these three indicator values. Water Quality Index value of 0 means reduction of water quality pollutants to 0, while Water Quality value of 1 means no reduction of pollutants compared to the baseline simulation.

#### 5.3.5.2 Using farmer information to develop optimization constraints

Four separate optimizations were run for each study area to determine the effect of current conservation and future preferences constraints on placement of conservation practices:

> (1) No constraints: An unconstrained optimization determined the most efficient conservation practice scenarios for the watershed
>
> (2) Current conservation: An optimization constrained to current conservation practices but not future preferences
>
> (3) Future constraints – maybe: An optimization constrained to both current conservation and future conservation constraints, using somewhat limiting future preferences by including “yes” and “maybe” categories
>
> (4) Future constraints – yes: The most limiting optimization including current conservation and most limiting future preferences by including only the “yes” category

Constraints were developed using existing conservation practices and future preference provided in farmer interviews. Existing conservation practices were digitized in ArcMAP (ESRI, 2010), and HRUs containing or adjacent to these conservation practices were given these as current conservation constraints. This means that current conservation practices cannot be removed from or added a second time to the constrained model simulations. The future constraint was implemented by tagging each field to the farmer, and only practices for which that farmer had answered “yes” or “maybe” for future preferences were permitted on his fields.

Both current and future conservation practices were implemented in the optimization code through the same structure, where any “individual” scenario of conservation for the watershed is forced to meet constraints. Constraints were applied after individuals underwent reproduction and mutation, and any violations to the constraint were corrected through addition or subtraction of that practice. Future preferences for lands for which the farmers were not interviewed were randomly assigned the preferences of another farmer interviewed in that study watershed.

### 5.3.6 Farmer follow-up interviews and stated adoption intention

Determination of optimal conservation practice recommendations to bring to farmers in follow-up interviews was not as simple as choosing one individual scenario from the final generation in the spatial optimization. Even though this scenario may have been optimal for the watershed, it is merely one possible optimal solution. Instead, all individuals in the final generation were considered to determine those practices that occurred most frequently in the final generation. This was done using a count of the number of times each conservation practice was seen in each HRU over the entire optimal front (defined at that time as the final generation in the simulation). Zero, one, or two practices were selected for each HRU that occurred at the highest frequency in the watershed. A cut-off threshold for frequency of a practice in a given HRU was chosen to be 50% of the final generation in Little Pine, and 25% of the final generation in Little Wea. These thresholds were chosen because they provided a reasonable number of recommendations to bring to farmers in follow-up interviews. For example, to determine if there is a targeted practice in HRU 1, the frequency of no-tillage, cover crops, filter strips, grassed waterways, wetlands, and habitats in HRU 1 would be counted in the optimal generation. If any practices occurred in at least 50% of the optimal generation, then the most frequently occurring practice would be selected as a first targeted choice, and if the second-most occurring practice was also above the 50% threshold it would be included as a second choice.

The SWAT model was run again with these final recommendations, and cost and water quality benefits were calculated for each HRU. In summarizing the recommendations brought to farmers, HRUs smaller than 10 ha were generally excluded for two reasons. First, the maps brought to interviews did not always display small HRUs, and in cases where they were not excluded this caused confusion. Second, such small HRUs had a higher probability of being labeled with the wrong land use (e.g. labeled cropland when in fact a sod parcel with a house) due to errors in the NASS land use data.

Once all recommendations were summarized, farmers who operated in those lands were consulted in follow-up interviews during the spring of 2013. Eleven farmers who had optimal results on their lands were contacted by phone, and ten were available for the interview. The one remaining farmer responded to the contact and intended to schedule an interview, but was unable to find the time before the busy planting season. Interview documents were created to clearly convey these optimal results to farmers (Appendix E). The interview began by reminding farmers about the study, the modeling process, the objectives of the optimization, and the conservation practices considered. Then farmers were presented with a table of optimal practice costs ($), nutrient removal (lb/acre), and sediment removal (ton/acre), along with a map identifying which farm fields were targeted for specific practices. For each targeted practice, farmers were asked (1) if they considered that practice to be optimal for that field, (2) if they see themselves implementing that practice on that field in the next five years, and (3) what reasons they had for these plans and opinions. Those practices for which farmers said "yes" they plan to implement it within five years are referred to as "adoption intention" throughout the paper. Finally, farmers were asked about their views on the adaptive targeting approach, how it felt to have their land targeted, how the interviews may influence their land management decisions, and what recommendations they had for improving the approach.

Targeted recommendations were adjusted following interviews to remove those that farmers stated were already implemented or were not on cropland, and in a few cases, were too small to find on the map. Rates of adoption intention and stated optimality of targeted recommendations were calculated as a percentage of adjusted results. Farmers' qualitative responses to the question of why they do or do not intend to adopt targeted recommendations were coded into categories.

## 5.4 Results and Discussion

### 5.4.1 Current and future conservation efforts

Current and past adoption of each conservation practice by interviewed farmers is shown in Table 5.2. The number of conservation practices present on a given farm varied from one practice to seven, with an average of 3.9 and standard deviation of 2.0. Every farm contained grassed waterways, though some likely needed rebuilding, as farmers discussed freely in the interviews. No-tillage had been attempted by all but two farmers in the sample, and four of those farmers had abandoned it for various reasons, mostly related to soil compaction. Filter strips were present on all but three farms containing open waterways. Three of the eight farmers who had used cover crops in the past had abandoned it, and yet there was some willingness to try cover crops again, as reflected by the future adoption preferences. While grassed waterways and filter strips were common among the farmers, six farmers who had adopted grassed waterways did not prefer to implement more, and three farmers who had adopted filter strips believed they had enough of these already. Both innovative conservation practices – two-stage ditches and drainage water management – were not yet in use in the study area, and generally farmers had little to no familiarity with these practices. Farmers were shown one page of information about each practice in the initial interview, which briefly defined the practice, provided a visual aid, and detailed its primarily purpose as well as the conditions where it may apply (Appendix E). Farmers expressed some interest in trying out these practices, despite having little prior knowledge of them or their effectiveness. Aside from the innovative practices, only no-tillage and cover crops elicited interest from a greater number of farmers than currently implement such practices. Wetlands were unique in their high level of “maybe” responses, perhaps revealing farmer ambivalence about incorporating these into their farms.

Current adoption of conservation practices in farmland managed by farmers who were interviewed (Table 5.3) shows that grassed waterways dominate in both watersheds, filter strips are more common in Little Pine, and no-tillage more common in Little Wea. The maximum number of conservation practices on an interviewee’s HRU was 2 for Little

Pine and 4 for Little Wea. Note that some no-tillage and cover crops may have been under-represented in Little Pine on Purdue farmland, due to the complexity of crop rotations and management discussed in interviews. Also, farmers may have neglected to mention some conservation practices, especially filter strips or habitats located adjacent to but not within farmland, as discovered in follow-up interviews. While farmers may have used many conservation practices on their farm, these practices were not dispersed uniformly across farmland. In both watersheds, nearly one-third of the farmland lacked any conservation practices..

### 5.4.2 Evaluating method through optimization comparison

Optimizations based on four levels of current conservation and future preference constraints showed similar patterns for the two study watersheds (Figure 5.2). The unconstrained optimization was able to reach a somewhat more optimal front in Little Wea than in Little Pine, as explained in chapter 4. Addition of current conservation practices shifted the optimal curves to a slightly higher cost, suggesting that current conservation is suboptimal on this scale of cost and Water Quality Index. On another scale, where one pollutant is weighted more than the others, or where other objectives are considered entirely, current conservation practices may be quite optimal, and farmers' judgment is not doubted in this area. A limitation of the Water Quality Index approach used here is that all three pollutants were reduced to one objective function, so there are many ways to achieve each Water Quality Index value by trading off nitrogen, phosphorus, and sediment reductions. If water quality goals existed for each pollutant, or each pollutant was weighted differently, a slightly more complicated Water Quality Index could have been used. While current conservation is already in place and funded by farmers or subsidies, its cost was included in this work to provide an estimate of how much all conservation in the watershed would cost, rather than merely new projects. In section 5.4.3.2 and Table 5.5, however, cost and effectiveness of targeted results brought to follow-up interviews use the current conservation scenario as its baseline.

Table 5.2 Past and current conservation practice adoption by 14 farmers, as well as future conservation interests expressed in initial interviews.

| | Past adoption | Current adoption | Future adoption preference | | | |
|---|---|---|---|---|---|---|
| | | | Yes | Maybe | No | Not applicable |
| No-tillage | 12 | 8 | 10 | 2 | 2 | 0 |
| Cover crops | 8 | 5 | 8 | 3 | 3 | 0 |
| Filter strips | 10 | 10 | 4 | 4 | 1 | 5 |
| Grassed waterway | 14 | 14 | 11 | 0 | 1 | 2 |
| Drainage water management | 0 | 0 | 2 | 3 | 7 | 2 |
| Restoration and management of rare or declining habitats | 6 | 6 | 5 | 3 | 6 | 0 |
| Upland wildlife habitat management | 7 | 7 | 4 | 3 | 7 | 0 |
| Two-stage ditch | 0 | 0 | 2 | 5 | 6 | 1 |
| Created wetland | 4 | 4 | 1 | 8 | 5 | 0 |

Table 5.3: Current adoption of conservation practices in farmlands managed by interviewed farmers for each study watershed, listed as a percent of HRUs and percent of interviewed cropland protected by the practice. Wetlands were not included, although two exist in Little Pine.

| | Little Pine interviews | | Little Wea interviews | |
|---|---|---|---|---|
| | *% of HRUs* | *% of cropland* | *% of HRUs* | *% of cropland* |
| No-tillage | 5% | 2% | 22% | 18% |
| Cover crops | 0% | 0% | 16% | 14% |
| Filter strips | 21% | 22% | 12% | 17% |
| Grassed waterway | 17% | 36% | 38% | 46% |
| Wildlife habitats | 3% | 1% | 2% | 4% |
| No practices | 43% | 33% | 36% | 27% |

Future conservation preferences were much more limiting in the Little Pine watershed than in Little Wea, especially for the most limiting “yes” future preferences. Spread of the optimal front shows that if farmers only implement targeted conservation they are most interested in, the watershed may only be capable of achieving a 50% or 70% reduction in water pollution in Little Pine and Little Wea, respectively. If no constraints are considered, Little Pine can achieve a 70% reduction and Little Wea an 80% reduction in pollution, of course at a greater cost. Overall, it may be encouraging that the optimal fronts for nearly all constraints lie within a similar range, suggesting the watershed can realistically achieve near optimal conservation if farmers adopt targeted practices that already interest them. A main reason for the similarity of these fronts is that six practices were considered, which are capable of intercepting the same pollutants, and this redundancy permits adaptation of targeting to meet each farmer’s preferences. Even a farmer who is unwilling to use four or five of the six practices may be able to achieve near optimal simulated results with the remaining practice that holds his interest.

### 5.4.3 Farmer response to targeted results

#### 5.4.3.1 Intended adoption of targeted conservation

A total of 202 targeted results on 125 farm fields were brought to ten farmers in follow-up interviews. Twelve were removed, primarily due to many small parcels modeled as cropland that were not in fact cropland caused by errors in the NASS land use data. An additional 14 targeted results were already implemented in those lands, but their presence had not been conveyed in the initial interviews. At least one of these had been implemented in the time between the initial interview and the follow-up interview, and one farmer mentioned that it would have been desirable to have checked back with farmers immediately prior to optimization to obtain the latest information. Some other practices that had not been communicated the farmer referred to as degraded filter strips or grassed waterways, and perhaps they simply had not thought they were worth mentioning. The remaining 176 adjusted targeted results on 103 farm fields were used to assess farmer response to targeted conservation (Table 5.4).

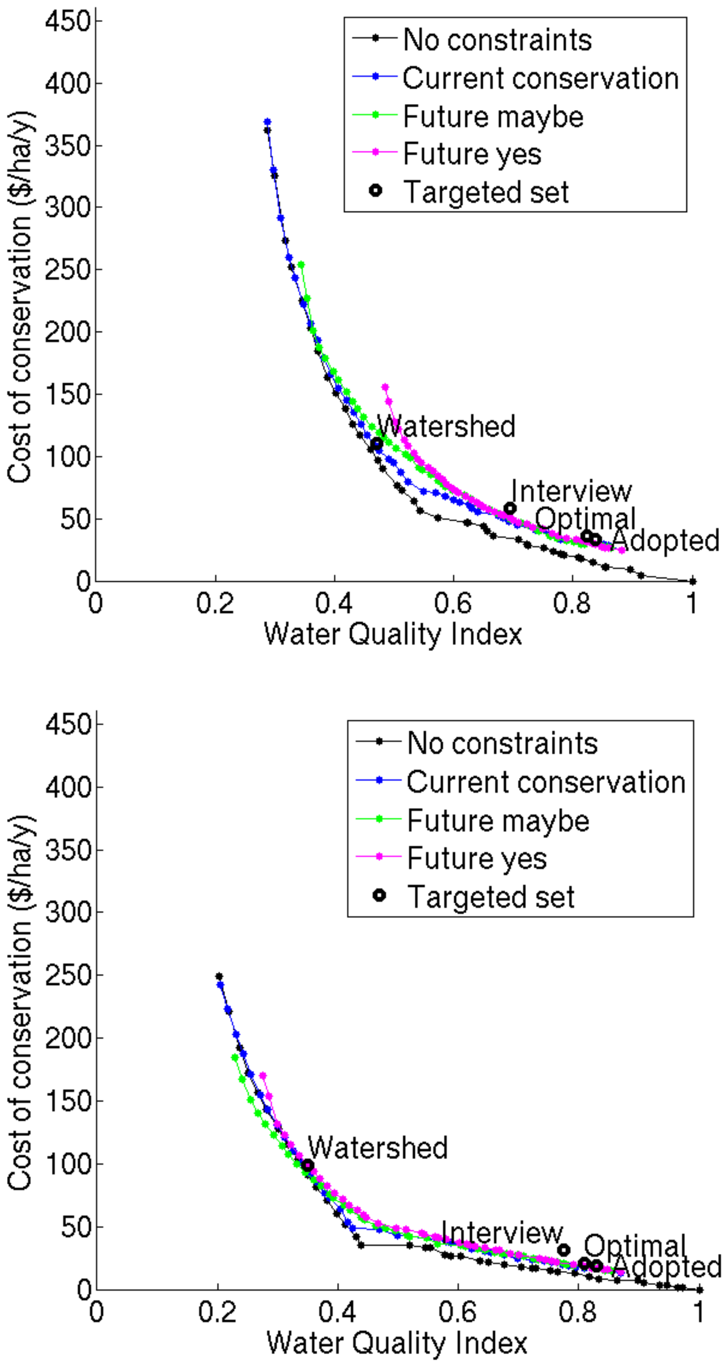

Figure 5.2 Optimal fronts developed from 300 generations for Little Pine (top) and Little Wea (bottom). Annual cost of conservation is normalized to watershed area (ha). Each line is a different adaptive optimization. "Watershed" is set of targeted recommendations for the watershed, "Interview" consists of those targeted solutions brought back to farmers in follow-up interviews, "Optimal" are those practices the farmers considered to be optimal, and "Adopted" are those farmers intend to adopt.

Most targeted conservation practices were filter strips or wildlife habitats, cover crops, and grassed waterways (Table 5.4). Only three instances of no-tillage were brought to farmers, as the model did not find no-tillage to be nearly as optimal as other practices for meeting the objectives used in this work. Only three wetlands were recommended to farmers, due in part to the small number of farmers who would consider creating wetlands on their farms and in part to the limited number of locations for placement of wetlands; study watersheds yielded only 47 possible wetland locations but 631 corn and soybean HRUs where other conservation practices could be placed. A fourth targeted wetland proposed to a farmer was found to already exist adjacent to the field it was targeted for, and the farmer remarked that the suggested wetland area was near to the size of that existing wetland, which serves as anecdotal confirmation of the wetland placement method. Cover crops were targeted in higher frequency than grassed waterways, despite being somewhat less optimal in general.

Farmers were asked not only if they would adopt each targeted conservation practice, but also if they considered that particular practice to be optimal on that land. Some farmers were not sure how to answer the question, and when they asked “optimal by what measure?” the interviewer responded by the measures used in this study: cost and water quality improvement. Some understood “optimal” to indicate practicality of use on their farm, and when they asked for clarification, the interviewer replied that “optimal” means a best practice for the land regardless of practicality to the farm, since practicality would be captured by the adoption question. Because of this difference of opinions on the meaning of optimal, these results indicate a measure of goodness of fit, but by a variety of measures. Nevertheless, rates of adoption intention and stated optimality clearly tracked with one another (Table 5.5).

Table 5.3 Process of obtaining adjusted targeted results presented to farmers in follow-up interviews.

| Conservation practice | Initial targeted results | Results removed due to errors | Results already implemented | Adjusted targeted results presented to farmers |
|---|---|---|---|---|
| No-tillage | 3 | 0 | 0 | 3 |
| Cover crops | 60 | 6 | 1 | 53 |
| Filter strips or wildlife habitats | 79 | 3 | 9 | 67 |
| Grassed waterways | 56 | 3 | 3 | 50 |
| Wetlands | 4 | 0 | 1 | 3 |
| Totals: | 202 | 12 | 14 | 176 |

Table 5.4 Adoption intention and stated optimality of recommendations presented to farmers through follow-up interviews. N/A indicates those results that were unclear.

| Conservation practice | Adjusted targeted results | Adoption intention rates: Plan to implement targeted conservation within 5 years | | | | Optimal rates: consider targeted conservation to be optimal | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Name* | | *Number of targeted results (% of adjusted results)* | | | | | | | |
| | | Yes | Maybe | No | N/A | Yes | Maybe | No | N/A |
| No-tillage | 3 | 0 (0%) | 0 (0%) | 2 (67%) | 1 (33%) | 0 (0%) | 0 (0%) | 2 (67%) | 1 (33%) |
| Cover crops | 53 | 30 (57%) | 15 (28%) | 5 (9%) | 3 (6%) | 37 (70%) | 11 (21%) | 2 (4%) | 3 (6%) |
| Filter strips or wildlife habitats | 67 | 13 (19%) | 5 (7%) | 48 (72%) | 1 (1%) | 20 (30%) | 6 (9%) | 40 (60%) | 1 (1%) |
| Grassed waterways | 50 | 19 (38%) | 5 (10%) | 25 (50%) | 1 (2%) | 25 (50%) | 5 (10%) | 20 (40%) | 0 (0%) |
| Wetlands | 3 | 0 (0%) | 0 (0%) | 3 (100%) | 0 (0%) | 0 (0%) | 0 (0%) | 3 (100%) | 0 (0%) |
| Totals: | 176 | 62 (35%) | 25 (14%) | 83 (47%) | 6 (3%) | 82 (47%) | 22 (13%) | 67 (38%) | 5 (3%) |

Farmers considered certain conservation practices more optimal than others, and they generally expressed an intention to adopt them in proportion to their optimality. A few farmers receiving targeted recommendations of no-tillage and wetlands consistently considered these practices to be non-optimal and did not intend to adopt them, yet they were recommended in so few cases that this result is not generalizable to the watershed. Cover crops had the highest assessment of optimality (70%) and the highest adoption intention (57%), which was initially surprising, since no-tillage and grassed waterways had higher farmer preferences in initial interviews. However, in the year between initial interviews and follow-up interviews, the study area had seen growing interest in and adoption of cover crops. Indeed, one farmer who had previously placed cover crops in the “no” pile for future adoption exclaimed multiple times during the follow-up interview that he had expected cover crop recommendations. His interest in cover crops was also surprising as he had a 100% non-adoption intention of the targeted practices in that interview. Following the interview, the interviewer explained that cover crops had not been placed on his lands due to his view one year prior, and agreed to send him updated results including cover crops in the optimization for his lands. Such a shift in views on cover crops is likely due to greater adoption by neighbors (which he mentioned), education about growing cover crops, and the severe drought in 2012. Grassed waterways were the second most favorable practice, at 50% optimality and 38% adoption intention, including many existing grassed waterways that required rebuilding (these existing grassed waterways were not removed as “results already implemented” because farmers agreed they needed rebuilding). Filter strips and wildlife habitats were combined in the interviews because the first interviews showed that farmers were not comfortable with the suggestion of filter strips on lands lacking open waterways, and as they were simulated the same in SWAT, it made sense to combine them to provide greater flexibility to the farmer. Farmers considered only 30% of these filter strips to be optimal, and expressed an intention to adopt only 19%.

Some farmers received many more recommendations than others. The farmer who received the fewest targeted recommendations was given just three results on three fields, the farmer who received the most was given 44. This discrepancy was due primarily to the constraint of future preference; those farmers who were unwilling to implement many practices had few options and their land was less likely to be targeted in this adaptive process. Another factor was variability of farm size. Some operations were as small as 30 ha in the study watersheds and others as large as 600 ha. Six farmers considered at least 50% of adjusted targeted results to be optimal, while the two farmers who received the fewest recommendations viewed 0% of those recommendations to be optimal. At least one farmer who adopted very few practices cited the constraints of managing a research farm as a primary reason he viewed the practices as infeasible. Farmer-specific adoption intention rates varied from 0% adoption intention, with 100% in the "no" category, to 71% adoption intention (17 of 24 targeted conservation practices). Seven farmers had greater than 10% adoption intention. Farmers were also given the option to suggest a conservation practice that was more optimal for a given farm field than the targeted recommendation. Farmers suggested cover crops would be more optimal than the recommendation on nine fields, grassed waterways would be more optimal on three fields, and filter strips on one field.

While farmers agreed to adopt 35% of targeted conservation, it is relevant to assess the cost and water quality impacts of these conservation practices, as shown in Figures 5.2 and 5.3. Targeted conservation for both study watersheds was optimal with Water Quality Index near 0.4. Those practices brought to farmers through follow-up interviews were also near optimal, though slightly sub-optimal in the Little Wea watershed, and farmer assessment of which practices were optimal resulted in a more optimal set of practices. The targeted set brought to interviews may be less optimal than the rest of the targeted results because existing conservation is known in interviewed lands, and farmers may have already implemented the most optimal conservation there, so further conservation efforts are somewhat less optimal. Because existing conservation was not identified in the two-thirds of the watersheds not covered by interviews, those lands are considered to have no conservation in place, and so the targeted set is biased towards conservation in those lands. Farmers' adoption intention mirrored targeted results they believed were optimal, and while the adopted solutions lie on the right tail of the optimal front, the practices are cost-effective as they lie on the optimal front.

Current conservation efforts were estimated to improve water quality by an average of 5% in Little Pine and 13% in Little Wea, at an annual cost of $76,000 in Little Pine $111,000 in Little Wea (Table 5.6). If all targeted results were implemented in each watershed there would be an expected additional annual cost of $382,000-$475,000, with pollutant removal of approximately 50% over the baseline scenario. In all scenarios, sediment and phosphorus are reduced more readily than nitrogen, likely due to the high nitrate loading through subsurface tile drainage that is not treated by conservation practices intended to intercept overland flow (e.g. grassed waterways, filter strips, and habitats). Selecting targeted solutions on only interviewed lands reduces the additional cost and water quality impact to $100,000-$149,000/y and 9-26%, respectively, with greater improvement seen in the Little Pine watershed. Targeted conservation that farmers considered to be optimal in their lands further reduces the efficacy of conservation in the watershed, but perhaps surprisingly the farmer's view of optimal conservation was an improvement over the entire targeted set (Figure 5.2). Those practices which farmers agreed to adopt would achieve a 4-11% average reduction of pollutants in the watersheds, with the greatest water quality improvement in Little Pine.

#### 5.4.3.2 Adoption reasoning

Adoption of conservation should depend on the type of conservation practice, as farmers will perceive practices as having different relative advantage on their farm (Pannell et al., 2006; Prokopy et al., 2008; Reimer et al., 2012). Overall, Greiner et al. (2009) found that major barriers to conservation practice adoption included insufficient time/staff, lack of incentives, loss of productivity, absence of recommended best practice standards, uncertainty about land tenure, impractical/complicated property management, and the belief that conservation practice is not necessary to improve the environment. Reimer et al. (2012) used interviews and qualitative analysis to understand farmer motivations for adoption of particular conservation practices in two Indiana watersheds similar to the ones studied here. In their work, motivations for adoption and non-adoption of grassed waterways included soil conservation, perception of need, and land tenure. Filter strip adoption and non-adoption depended on loss of productive land and lack of land ownership. Conservation tillage was adopted for soil conservation and input savings (e.g. fertilizer, labor), while barriers included yield losses and no perceived need for the practice. Cover crops were adopted to improve soil fertility and crop yields, while cost, labor, and time increases were barriers to their use in the watersheds, as was a lack of knowledge; many farmers did not fully understand the benefits of cover crops.

In this work, farmer reasons for not adopting a practice were coded into the following categories based not on previous studies but wholly on farmers' statements made in the interviews: presence/absence of soil erosion or corresponding water control issues (includes slope and water control considerations); problems associated with convenience or compatibility of the practice with the farming operation (e.g. not wanting to break up large, square fields with conservation practices); barriers related to land that is rented (e.g. a landowner who is unwilling to use conservation practices though the renter is willing); uncertainty regarding how an untested practice would work in their lands (e.g. not knowing yet if cover crops will grow sufficiently given plant date and weather conditions); presence or absence of surface drainage (e.g. belief that filter strips are unsuitable unless an open waterway needs protecting); belief that current conservation efforts are sufficient on the field; and difficulties related to the cost of conservation. The dominant categories tracked well with certain conservation practices. A total of 56 (67% of) responses for non-adoption intention were categorized out of 83 total non-adoption responses, and no clear reasoning was provided for the remaining responses. Categorized results are shown in Table 5.7.

Table 5.5 Net cost and water quality improvement of targeted conservation and intended adoption over the baseline simulation (with existing conservation practices).

| | Cost | Water quality improvement* | Total nitrogen removal | Total phosphorus removal | Sediment removal |
|---|---|---|---|---|---|
| *Baseline scenarios* | *($/y)* | *(Pollutant removal compared with no conservation simulation)* | | | |
| **Little Pine Baseline:** Existing conservation from Little Pine interviews | $110,946 | 5% | 2% | 5% | 8% |
| **Little Wea Baseline:** Existing conservation from Little Wea interviews | $76,060 | 13% | 6% | 15% | 18% |
| *Little Pine targeting* | *($/y over baseline)* | *(Pollutant removal as % of Little Pine baseline with existing conservation)* | | | |
| **Watershed:** Targeted conservation in Little Pine | $382,240 | 48% | 24% | 51% | 69% |
| **Interview:** Adjusted targeted results for follow-up interviews | $148,702 | 26% | 10% | 24% | 42% |
| **Optimal:** Targeted conservation considered optimal (Yes) by farmers | $51,402 | 13% | 6% | 14% | 18% |
| **Adopted:** Targeted conservation farmers intend to adopt (Yes) | $37,280 | 11% | 5% | 12% | 16% |
| *Little Wea targeting* | *($/y over baseline)* | *(Pollutant removal as % of Little Wea baseline with existing conservation)* | | | |
| **Watershed:** Targeted conservation in Little Wea | $475,232 | 52% | 29% | 59% | 68% |
| **Interview:** Adjusted targeted results for follow-up interviews | $100,357 | 9% | 5% | 11% | 13% |
| **Optimal:** Targeted conservation considered optimal (Yes) by farmers | $42,410 | 6% | 3% | 7% | 8% |
| **Adopted:** Targeted conservation farmers intend to adopt (Yes) | $31,613 | 4% | 2% | 5% | 5% |

$* \ Water\ quality\ improvement = 100\% \times (1 - Water\ quality\ index)$

Table 5.6 Reasons and justifications given for choosing to adopt (“Yes” or “Maybe”) or not to adopt (“No”) targeted conservation practices.

| Reasoning or justification | | No-tillage | Cover crops | Filter strips / wildlife habitats | Grassed waterways | Wetlands | Total |
|---|---|---|---|---|---|---|---|
| | | *Count of times reason was given for choosing to adopt or not adopt a targeted practice* | | | | | *Sums all practices* |
| Presence of soil erosion | Adoption | 0 | 2 | 1 | 4 | 0 | 7 |
| Absence of soil erosion | No adoption | 0 | 1 | 4 | 12 | 0 | 17 |
| Convenience | Adoption | 0 | 1 | 1 | 1 | 0 | 3 |
| | No adoption | 0 | 2 | 6 | 2 | 0 | 10 |
| Land is rented | Adoption | 0 | 1 | 0 | 0 | 0 | 1 |
| | No adoption | 0 | 0 | 5 | 3 | 1 | 9 |
| Uncertainty of performance | No adoption | 0 | 1 | 0 | 0 | 0 | 1 |
| Presence of open ditches | Adoption | 0 | 1 | 0 | 0 | 0 | 1 |
| Absence of open ditches | Adoption | 0 | 0 | 0 | 1 | 0 | 1 |
| | No adoption | 0 | 0 | 9 | 0 | 0 | 9 |
| Current conservation is sufficient | No adoption | 0 | 0 | 10 | 2 | 1 | 13 |
| Cost is a barrier | No adoption | 0 | 0 | 1 | 0 | 0 | 1 |
| Requires rebuilding | Adoption | 0 | 0 | 1 | 8 | 0 | 9 |
| Already in plans | Adoption | 0 | 8 | 2 | 4 | 0 | 14 |

Similar to Reimer et al. (2012), absence of soil erosion was the leading reason for not implementing conservation, especially with regards to grassed waterways and filter strips, while presence of erosion was a major driver for choosing to adopt these practices. Grassed waterways were primarily seen as solutions to soil erosion problems. Lack of convenience, issues related to farming rented lands, absence of open ditches, and a belief that current conservation was sufficient, were frequently given as reasons for not adopting conservation, especially filter strips. In particular, many farmers firmly believed that filter strips did not belong on a farm that lacked open ditches, even though wildlife habitats were combined with filter strips in most interviews. Filter strips and habitats were also seen as the most inconvenient of the practices, breaking up fields or requiring management changes. One farmer did not intend to adopt many filter strips because he knew his landlord would not permit it, and he preferred to use cover crops in this situation because they would not take land out of production. Relatively few reasons were given for adoption or non-adoption of no-tillage and cover crops, while two of the three recommended wetlands were not adopted due to lack of land ownership or belief that they are not needed.

Surprisingly, cost was given as a barrier to implementing targeted conservation only once, despite being mentioned at many other times in the interviews. This aligns with other works finding that farmers may stress the economics of conservation more in early interviews than later ones, where they begin to articulate other reasoning (Ahnstrom et al., 2008). Reasoning involving rental land, however, may indirectly imply financial issues. For instance, farmers may be less willing to invest in long-term conservation on rental land if their contract lacks a long-term commitment. Perhaps even more relevant in these interviews was the problem of reaching landowner agreement on implementing conservation that affects the farm’s bottom line, especially through conversion of productive cropland to filter strips and grassed waterways.

### 5.4.4 Discussion of adaptive targeting approach

#### 5.4.4.1 Farmer response to the entire approach

Nine of the ten farmers in follow-up interviews agreed that conservation practices coming from model results were applicable to their lands. Emphasis was again placed on the reasons categorized in Table 5.7, such as already planning a number of the targeted practices, identifying practices needing repair, and preventing topsoil erosion. The one farmer who did not find the targeted conservation applicable to his lands was one of only two who did not intend to adopt any of the practices. He had conveyed a limited set of future interests in the first interview, and consequently only three targeted results had been brought to him in the follow-up interview.

When asked about their expectations for the project and how well those expectations had been met, farmers communicated that they had understood that their information would be applied to a modeling study, and most of them–including those who had no interest in adopting the solutions–stated that the study had met or exceeded their expectations. Many suggested that the information provided to them was practical, useful, and would be helpful for them in making farm decisions. At least two farmers expressed surprise by the targeted conservation practices, either the types of practices (e.g. not seeing no-tillage among targeting results) or their locations (e.g. they expected to see targeting of ditch banks rather than uplands). When asked how the targeted suggestions might impact their farm management decisions, eight farmers shared that the results would be influential, either because they aligned with—and provided justification for—their current plans, or because they provided the farmers with new information and ideas to think about.

Finally, when asked how it felt to be given recommendations about which conservation practices may be most optimal on their lands, many farmers emphasized their open-mindedness and willingness to receive recommendations, and a couple specifically appreciated having “another pair of eyes” to look into conservation on their lands. One contrasted the approach with regulations – he likes to be presented with “options, not requirements,” and another said “I don’t feel compelled to do it,” but affirmed his interest in the study. Some spoke in detail of the specific targeted results, while others took a more global view – the study is a “reminder to think about conservation. Conservation takes more management, and it’s not easy to implement. It takes planning, dedication, and continual learning.”

#### 5.4.4.2 Farmer recommendations for the approach

Participants were asked if there was anything else they would have liked to see from the interviewer in the follow-up interview, and asked what recommendations they would have if another adaptive targeting study was conducted. Recommendations for additional information in the follow-up interview, when offered, were quite specific and different for each interviewee: presenting filter strips and wildlife habitats separately in results; presenting cost and nutrient loads on a per acre basis for enhanced comprehension; providing more information on how costs were calculated; and providing estimates of wind erosion on soils. One expressed surprise that increased subsurface tile drainage was not recommended. At the conclusion of many interviews the interviewer agreed to email the farmer some additional follow-up information, usually any updated results coming from running the optimization longer or including additional current conservation practices. Recommendations for the study and interview approach differed for each farmer as well, including: ensuring that the latest data is used; re-interviewing farmers immediately before running the final model optimization to be certain to include all of the latest conservation practices; including more conservation options such as bioreactors, drop boxes, and minimum tillage; and presenting farmers with more information on how they may save nitrogen by using cover crops. Five farmers had no recommendations for improving the approach, and one affirmed the approach as “clear, straightforward, easy to understand, and objective.” Overall, the recommendations do not converge on one or two main themes, but refer to the plethora of decisions that were made in the modeling and displaying of targeted results. If there were readily apparent issues in the approach, one would hope they would have been mentioned by at least two of the participants. If the targeting had been performed in the absence of initial interviews, there would have clearly been more poorly-made decisions about model set-up, current conservation practices, targeting options, and the display of results. Involving farmers in the early stages of the project and being willing to correspond with them even after follow-up interviews were crucial to providing farmers with useful information. Farmer satisfaction of the adaptive targeting approach clearly relates to the level of involvement and adaptation of the research to the participants' needs.

#### 5.4.4.3 Limitations of the approach

It is worth asking whether the value of this adaptive targeting approach justified the time spent engaging farmers and performing optimization. The entire process—from designing farmer interviews through conducting follow-up interviews—lasted approximately fifteen month, and required one researcher's full attention through much of that period. However, much of that time was spent on activities that could be abbreviated or removed from the process in future projects, including: (1) developing an appropriate interview guide, (2) transcribing interviews verbatim, and (3) carefully studying interviews to evaluate the approach and pull out themes related to farmer perceptions of targeting. If the approach developed here was replicated in other watersheds, the most time intensive activities are likely to be performing initial farmer interviews (~2 hours per interview), setting up the SWAT model and spatial optimization (days to weeks), running the optimization, preferably through parallel computing (days to weeks of computer time), choosing a final set of targeted results (days), and conducting follow-up interviews (~1 hour per interview).

One of the greatest difficulties in the approach was identifying and contacting farmers who operated over the entire study area, yet this information would be available to USDA. Targeting the most vulnerable lands requires reaching all or most farmers in the watershed, and this study missed many operators, especially those renting land in the watershed. Ideally, teams leading future targeting efforts would have access to farmer contact information and trusted networks through which to establish communication with farmers, such as the Soil and Water Conservation Districts.

## 5.5 Conclusions

Adaptive targeting through spatial optimization and farmer interviews can help scientists and agencies learn from farmers, display complex results in an appropriate manner, and utilize computer models to target multiple conservation practices on farm fields. Detailed spatial understanding of existing conservation practices was gained through interviews with fourteen farmers covering one-third of lands in two study watersheds. Farmers already use many conservation practices, though up to one-third of agricultural lands may lack any form of conservation. Grassed waterways were the only practice present on all farms. Existing conservation efforts were estimated to cost between \$76,000 and \$111,000 per year in each watershed, and model simulations estimated these practices improve average water quality by 5%-13%, with particular effectiveness in reducing sediment and phosphorus loading to surface waters. Model simulations predicted fairly low nitrogen removal rates by conservation practices, likely because of the extensive subsurface tile drainage that permits export of high nitrate loads directly to surface waterways, short-circuiting the filtering process of grassed waterways, filter strips, and wildlife habitats.

Watershed modeling and spatial optimization were conducted to promote incorporation of farmer data and make the results more understandable to farmers by defining HRUs according to farm field boundaries. Optimal fronts were summarized by one set of targeted results through analyzing the frequency of conservation practices in each HRU across the optimal front. Farm fields owned or rented by interviewees in this targeted set consisted of 202 targeted results on 125 farm fields, which was pared down to 176 adjusted targeted results on 103 farm fields, all of which were brought to ten farmers in follow-up interviews. Optimality of targeting results were confirmed through follow-up interviews in a number of ways: (1) farmers generally viewed results as optimal for their lands; (2) in choosing to adopt targeted solutions, many farmers shared that they already planned to implement that practice in that field; (3) a number of targeted solutions were found to already exist in the watershed, though this had not been communicated in the first interview. Farmers intended to adopt 35% of targeted practices within the next five years. Cover crops, which had increased in popularity between the two sets of farmer interviews, had the highest level of adoption intention with 30 farm fields and a 57% adoption intention rate. If farmers adopt the practices they anticipate implementing, it entail an estimated annual cost of nearly $69,000 over both watersheds, and produce water quality improvements in the range of 4-11% nitrogen, phosphorus, and sediment load reduction. Soil erosion played a crucial role in convincing farmers to adopt—or not to adopt—conservation practices; many farmers who chose to adopt targeted recommendations were motivated by the desire to prevent soil erosion, while some who chose not to adopt targeted conservation did so because they did not think the recommended practices would affect erosion. Grassed waterways were seen as particularly useful in addressing erosion issues. Farmers used a variety of reasons to justify non-adoption of conservation practices, particularly filter strips, including convenience, land tenure, the absence of open waterways on their land, and their perceptions that current conservation efforts were sufficient.

Interviews were a critical part of this approach. Farmers were generally quite pleased with the interview process and presentation results, including some who chose not to implement any targeted conservation. Farmers were receptive to hearing about targeted conservation, and the interviews may have served to build trust as well as make targeting more practical prior to presenting results in the follow-up interviews. Yet if this adaptive targeting approach were scaled up to larger watersheds, it may not be feasible to interview every farmer. In scaling up this approach, alternative methods for learning about existing conservation practice could be developed such as Grady et al. (2013), and surveys could be used to obtain information on future conservation preferences. Interviews still may be required to build trust and encourage farmer consideration of targeted results, however. From this work it can be expected that some farmers will choose not to adopt any targeted practices, and may have little interest in future conservation. But these farmers were nonetheless willing to conduct interviews, and they generally viewed the interviews positively, so it is possible that the interview process was beneficial in turning their thoughts toward conservation and preparing them to consider farm management changes.

Overall, this work in engaging fourteen farmers demonstrates a promising approach for targeting conservation in agricultural lands. Though this work was limited to two small watersheds, and farmers for two-thirds of the land could not be determined due to issues relating to contact information and land rental, those who were contacted almost unanimously agreed to participate. Initial interviews provided extensive spatial information, which was used to improve the watershed model, and farmer preferences, which was used to adapt the model constraints in order to place on a given farmer's land only those practices acceptable to that farmer. Spatial optimization results showed that even when farmer preferences are considered, near-optimal targeting scenarios could be achieved in the watershed. Farmer response in follow-up interviews was quite positive, and farmers plan to adopt a considerable portion of targeted results.

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# CHAPTER 6. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FUTURE RESEARCH

This interdisciplinary set of four studies analyzed farmer and landowner perceptions of targeting and conservation practices and demonstrated an innovative, adaptive approach to targeting through farmer interviews, watershed modeling, and spatial optimization of conservation practices. Overall, studies support a flexible targeting approach that involves farmers and landowners to build trust, improve modeling, and adapt to their needs and interests.

In the first study, an exploratory qualitative analysis of transcribed interviews provided a base on which to better understand farmer perceptions of targeting. Although farmers held clearly differing views on conservation programming, stewardship, and disproportionality of farmland vulnerability, they showed unanimous support for the concept of targeting. All farmers agreed to participate in the targeting experiment and were amenable to receiving feedback on their land management practices. Several opinions expressed highlight difficulties of practically implementing targeting in these lands, including many farmers holding views of government and conservation programming distrust, garnering farmer support for the objectives of targeting efforts, and the importance of farmer input and on-site field inspection before final conservation decisions are made. Findings confirmed the value of involving farmers at the onset of targeting.

A second study assessed the creation of a simple tool for using farm field boundaries to define hydrologic response units (HRUs), the smallest spatial unit in the Soil and Water Assessment Tool (SWAT), which was the watershed model used for this work. This is necessary to incorporate field- and farmer-specific interview data into the watershed model and optimization approach that follow. Little Pine Creek watershed was used to demonstrate the new HRU definition approach and compare it to the standard HRU definition approach where similar soils, slopes, and land uses are lumped within subwatersheds. Both uncalibrated models performed similarly, with good simulation of hydrology and fair prediction of nutrients and sediments at the watershed scale. Simulations using the one-field to one-HRU mapping appear quite reasonable and suitable for many purposes, especially integrating human dimensions and watershed modeling.

The third study demonstrated and extended a targeting method through watershed modeling and spatial optimization of conservation practices in both study watersheds. Six conservation practices were represented in the SWAT model and provided as options for corn and soybean HRUs in the spatial optimization: no-tillage, cereal rye cover crops, filter strips, grassed waterways, created wetlands, and restored prairie habitats. Grassed waterways, filter strips, and strategically placed prairie habitats were generally most optimal on lands with little existing conservation, while cover crops and wetlands were capable of capturing additional nutrients and sediments from lands with existing conservation. At an annual cost of $250-350/ha, total nitrogen could be reduced 50-60% at the watershed scale, total phosphorus 90-95%, and sediments by at least 95%. Somewhat smaller but considerable water quality improvements can be made for less than $50/ha/y.

The final study was a culmination of all three preceding works that demonstrated and evaluated the adaptive targeting approach. A targeting experiment was conducted in both study watersheds using watershed modeling and spatial optimization, along with knowledge of farmer current conservation practices. Farmer preferences for future conservation were used as constraints to the optimization so that targeted recommendations would be more likely adopted by farmers. Follow-up interviews provided an opportunity to transfer knowledge of field-specific recommendations to ten farmers, obtain stated adoption rates, and receive feedback on the adaptive targeting approach. Overall, farmers stated likely adoption of 35% of targeted conservation, favoring adoption of cover crops and grassed waterways. All farmers, including those with little or no stated adoption, were receptive to hearing recommendations and generally viewed the process quite favorably. Farmer engagement clearly improved the targeting approach, practicality of recommendations, and served to build trust that will likely lead to greater adoption of targeted conservation at the watershed scale.

A primary limitation of this work is the small sample size of farmers who were interviewed and participated in the targeting experiment. While interviews provided a rich dataset for learning the practices and views of these few farmers, greater efforts at larger scales will be needed to achieve water quality improvements in lakes, rivers, and coastal regions. Scaling up the methodology would necessitate significant changes to the approach, including considerations about time taken interviewing, as well as the computational ramifications of defining HRUs at the field scale. Another consideration in application of this methodology is designing an interdisciplinary team suitable for stakeholder engagement, watershed modeling, and spatial optimization. The approach may be scaled up most effectively if a targeting tool other than watershed modeling and optimization were chosen, and findings here indicate that a simpler tool designed well could be quite effective.

Many avenues of future work could improve the adaptive targeting approach. Alternative styles of stakeholder engagement could be tested, including focus groups and surveys. Representation of conservation practices in SWAT could be improved through sensitivity analysis, collection of measured data, and further testing. For instance, few studies have considered SWAT's wetland routine, and there are no recommendations as to the nitrogen, phosphorus, and sediment removal rates to use in SWAT to simulate created wetlands. Inclusion of more or different conservation practices in the approach is another possibility – for instance, more minimum tillage operations or different varieties of cover crops could have improved the realistic scenarios created in this work, though they were not used in an effort to keep the optimization approach simple enough to converge in a reasonable computational time. The optimization approach could be tweaked to study the impact of mutation rates and crossover rates, for instance, on convergence time. Optimization approaches other than NSGA-II could be used as well, and may have faster convergence or more optimal fronts.  Another direction for future work could be to study the difference the adaptive approach makes compared to other targeting approaches in paired watersheds. Longer-term studies that follow up on farmers to help design targeted conservation practices and learn actual adoption rates can further assess the targeting method.

# APPENDICES

# Appendix A Estimating conservation practice costs

Conservation practice costs were estimated using NRCS data for installation and maintenance of conservation practices, as well as an estimate of foregone income through loss yields.

## A.1 Conservation practice scenarios

The conservation practices I am estimating costs for are shown below, along with a brief definition of how they would be "implemented" in the "what-if" model scenarios:

No-tillage – continuous no-tillage for both corn and soybeans in a 2-year corn/beans rotation

Cover crops – cereal rye planted after both corn and soybeans in a 2-year corn/beans rotation

Filter strips – removing corn/soybean land from production along streams/ditches

Grassed waterways – removing corn/soybean land from production for grassed waterways

Wetlands – removing corn/soybean land from production to create "large" created wetlands for the purpose of nutrient (nitrate) removal (wetland area would be ~1% of its drainage area)

Wildlife habitats – removing corn/soybean land from production to restore prairie grasses (tall grass prairie)

## A.2 General equation for calculating costs

A suitable framework for calculating costs consistently for each conservation practice was determined based on intuition, knowledge of farming practices, and analysis for the FOTG costs for Indiana Conservation Practices for 2012. I developed simple equations to calculate cost of each conservation practice. Cost estimation would include both annual costs and one-time costs, and I am considering the costs of the practice over a 10-year span. The general equation for each conservation practice is as follows:

$$Total\ annual\ cost = \frac{Onetime\ costs}{10\ years} + Annual\ costs + Foregone\ income$$

In this equation, $Total\ annual\ cost$ is the total cost for that practice per year in the 10-year span, $Onetime\ costs$ are initial start-up costs (e.g. no-tillage equipment upgrades), $Annual\ costs$ occur annually (e.g. seeding a cover crop), and $Foregone\ income$ is the yield loss due to yield reduction (e.g. no-tillage) or taking land out of production (e.g. filter strip).

### A.3 NRCS Field Office Technical Guide (FOTG) for Indiana

In order to estimate costs of each conservation practice, I had to determine appropriate datasets. I found that NRCS has already completed this cost estimation, and so in this next section I show these NRCS costs for the specific conservation practice scenarios above.

Data were primarily obtained from the following sources. All costs except foregone income were determined from: NRCS Field Office Technical Guide (FOTG), State of Indiana, Costs, FY2012, Indiana Conservation Practices. Foregone income from either reduced yields or taking land out of production came from: Commodity prices: Index Mundi (http://www.indexmundi.com/commodities/?commodity=soybeans).

### A.1 Synthesis of FOTG costs

Below I have detailed the cost data from the FOTG, but you may find it helpful to reference the spreadsheet Kalcic_ConservationCosts_01092013.xlsx, which contains the raw data from the FOTG, as well as the cost justification alongside the costs, rather than as footnotes.

Below: Estimation of costs using FOTG itemized costs for conservation practices. The information from the FOTG was synthesized for each practice, and costs are displayed as one-time and annual costs. The raw data used to calculate these costs can be found in the footnotes below, or in the attached spreadsheet.

| Category of costs | Time-scale of costs | No-tillage *$/acre* | Cover crops *$/acre* | Filter strips *$/acre* | Grassed waterways *$/acre* | Wetlands *$/acre* | Habitats *$/acre* |
|---|---|---|---|---|---|---|---|
| Materials | One-time | $0.00 | $0.00 | $144.17[3a] | $724.29[4a] | $424.00[5a] | $472.46[6a] |
| | Annual | $0.00 | $22.27[2a] | $0.00 | $0.00 | $0.00 | $0.00 |
| Equipment, Installation and Labor | One-time | $109.60[1a] | $0.00 | $23.79[3b] | $3,269.87[4b] | $2,418.67[5b] | $14.35[6b] |
| | Annual | $5.00[1b] | $22.02[2b] | $0.00 | $0.00 | $0.00 | $0.00 |
| Operation, maintenance and replacement | Annual | $0.00 | $0.00 | $5.04[3c] | $79.88[4c] | $0.00 | $0.00 |
| Acquisition of technical knowledge | Annual | $3.00[1c] | $0.00 | $0.00 | $0.00 | $0.00 | $0.00 |
| Foregone income | Annual | SWAT[1d] | SWAT[2c] | SWAT[3d] | SWAT[4d] | SWAT[5c] | SWAT[6c] |
| Risk | One-time | $0.00 | $0.00 | $8.40[3e] | $0.00 | $0.00 | $24.34[6d] |
| Total one-time costs ($/acre) | One-time | $109.60 | $0.00 | $176.36 | $3,994.15 | $2,842.67 | $511.15 |
| Total annual costs ($/acre/year) | Annual | $8.00 | $44.29 | $5.04 | $79.88 | $0.00 | $0.00 |
| Total cost over 10 years ($/acre) | 10-year | $189.60 | $442.88 | $226.75 | $4,792.98 | $2,842.67 | $511.15 |

## No-tillage

[1a] Purchasing and upgrading field equipment: upgrades to combine chaff spreader, $4000; no-till fertilizer injection equipment, $5400; planter attachments, $12000; floatation tires, $6000. All equipment assumed to have a 5-year life. All farms assumed to have 500 acres upon which this equipment is used, so the totals are divided by 500.

[1b] Annual cost comes from labor: management for pests, upgrade and maintain equipment modifications.

[1c] Attend Purdue short course and conduct on farm research plots for $1500, divided by 500 acres of assumed farm size.

[1d] Foregone income comes from yield reduction, which is calculated using the SWAT model simulations. SWAT simulations determine amount of yield reduction (tons), which are converted into monetary values using average price of corn and soybean yields. In the case of no-till, yield reduction in a farm field is the yield in that field in the current simulation minus the yield in that farm field in the baseline simulation. If there is a gain in yield, the practice receives an equivalent credit.

**Cover crops**

[2a] 28 lb/acre/year cereal rye at 0.3525 $/lb plus 12.395 $/acre herbicide Glyphosate to kill the cover crop in the spring. An additional cost of 12.32 $/acre/year for a mixed crop with 4 lbs/acre tillage radishes at 3.08 $/lb was not considered since SWAT is incapable of simulating a mixed crop.

[2b] A seeding operation costing 16.116 $/acre/year, as well as a chemical application of 5.907 $/acre/year. Includes labor costs.

[2c] Foregone income comes from yield reduction, which is calculated using the SWAT simulations. SWAT simulations determine amount of yield reduction (tons), which are converted into monetary values using average price of corn and soybean yields. In the case of cover crops, yield reduction in a given farm field is the yield in that farm field in the current simulation minus the yield in that farm field in the baseline simulation. If there is a gain in yield, the practice receives an equivalent credit.

**Filter strips**

[3a] Planting and fertilizing material costs: Cool season grass mix, \$19.74/acre; Cool season legumes, \$10.92/acre; Phosphorus, 43 lbs, at \$0.72/lb; Potassium, 83 lbs, at \$0.45/lb, lime, 2 tons, at \$17.50/ton; herbicide, burn down, at \$10.20/acre.

[3b] Planting and fertilizing installation costs: broadcast fertilizers, \$4.72/acre; lime application, \$4.72/acre; no-till planting, \$14.35/acre.

[3c] Estimated as 3% of materials, equipment, and labor (note: some inconsistencies in EQIP cost spreadsheet between OM&R vs. technical knowledge, but I believe this is the appropriate resolution of it.)

[3d] Foregone income comes from foregone yields on land taken out of production, calculated using the Soil and Water Assessment Tool simulation of yield in the farm field with the practice vs. yield without the practice.

[3e] According to the eFOTG for this practice, Risk = ((sum of Mat, Equip, Mobil) X 50% owner cost) X 10% chance of occurrence). I'm not sure what the 10% chance of occurrence means.

**Grassed waterways**

[4a] Planting and fertilizing material costs: Fertilizer, 500 lbs, \$0.28 lb/acre; cool season grasses, \$73.09/acre; lime, 2 ton, \$17.50/acre; rip rap, installed, 6.6 cubic yards, \$57.00/cubic yard; riser, 6" assembly, 1, \$100.

[4b] Planting, tilling, fertilizing, and earthwork: broadcast fertilizer, \$4.72/acre; lime application, \$4.72/acre; disking, 2 passes per acre, \$10.54/pass; no-till planting, \$14.35/acre; earthwork 60' wide x 726' long, 1075 cubic yards, \$3/cubic yard.

[4c] Estimated as 2% of materials, equipment, and labor.

[4d] Foregone income comes from foregone yields on land taken out of production, calculated using the Soil and Water Assessment Tool simulation of yield in the farm field with the practice vs. yield without the practice.

**Wetlands**

[5a] Tile replacement: 200 feet of 10", $880.00. Outlets for new tile: 2 x 10' sections of PVC @ $196 each. Divide by 3 to convert from 3 acre wetland to 1 acre wetland.

[5b] Excavation: 1 foot excavated over 0.9 acre = 1452 cy @ $2.86/cy. Seeding: 2 acres of seeding at $313 (not all is seeded). Structure for water control: 1 15" WCS with appurtances = $1220 Installation = $400. Levee fill: 500 cy of fill at outlet area @ $2.86/cy (somehow this gets to $858).

[5c] Foregone income comes from foregone yields on land taken out of production, calculated using the Soil and Water Assessment Tool simulation of yield in the farm field with the practice vs. yield without the practice.

**Habitats**

[6a] Tall grass prairie mix ($462.26/acre); herbicide, burn down ($10.20/acre).

[6b] No-till planting ($14.35/acre)

[6c] Foregone income comes from foregone yields on land taken out of production, calculated using the Soil and Water Assessment Tool simulation of yield in the farm field with the practice vs. yield without the practice.

[6d] Estimated as 5% of materials and equipment/installation/labor (this was not explicit in the FOTG, but I deduced it easily).

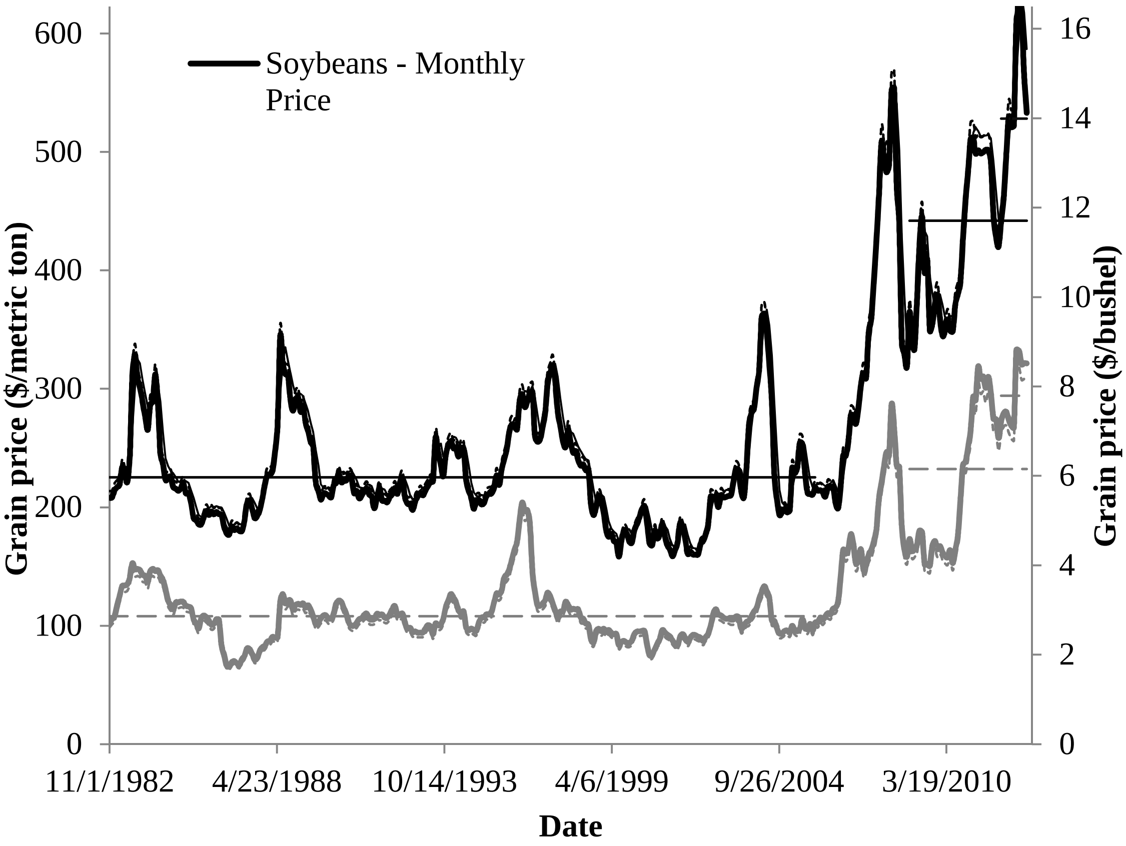
## Cost of foregone yield

The cost of yield losses to the farmer were calculated from the Index Mundi Commodity prices: http://www.indexmundi.com/commodities/?commodity=soybeans http://www.indexmundi.com/commodities/?commodity=corn

I looked at historic commodity prices of both corn and soybeans from the past 30 years. In Figure A.1 I have plotted these historic prices, as well as some average values that are candidates for use as benchmark prices in the optimization.

Which average value should we use for corn/soybean prices? Notice how grain prices were relatively stable for the first 25 years of data, then rose rapidly over the past 6 years. It is unclear which average value would be the most suitable for the optimization – the relatively steady values of 1982-2005, or the more recent but perhaps more volatile high values of 2008-2012? If we have entered a new regime in prices, which is quite possible given competition for grain increasing for biofuel production, then it would be more suitable to use the recent higher averages. But if the grain market is simply fluctuating and will eventually reach levels more similar to historic ones (1982-2005), then we should use a historic average.

For cost of yield loss to farmers, I plan to use the past 5 year average from 2008-2012 – though I realize these years have been fraught with drought, high grain prices, and may not be the most representative. **These values are $232/ton ($5.90/bushel) for corn, and $442/ton ($12/03/bushel) for soybeans.**



Above: Historic grain commodity prices, from 1982-2012, for corn and soybeans. Source: Index Mundi (http://www.indexmundi.com/commodities/?commodity=soybeans, and http://www.indexmundi.com/commodities/?commodity=corn). Grain prices are plotted on dual axes, showing price per metric ton, as well as price per bushel of grain. Thin horizontal black lines represent average soybean prices for 1982-2005 ($225/ton, $6.13/bushel), 2008-2012 ($442/ton, $12.03/bushel), and 2011-2012 ($528/ton, $14.38/bushel). Horizontal grey dashed lines represent average corn prices for 1982-2005 ($108/ton, $2.75/bushel), 2008-2012 ($232/ton, $5.90/bushel), and 2011-2012 ($294/ton, $7.47/bushel).

# Appendix B SWAT model performance

## Flow:

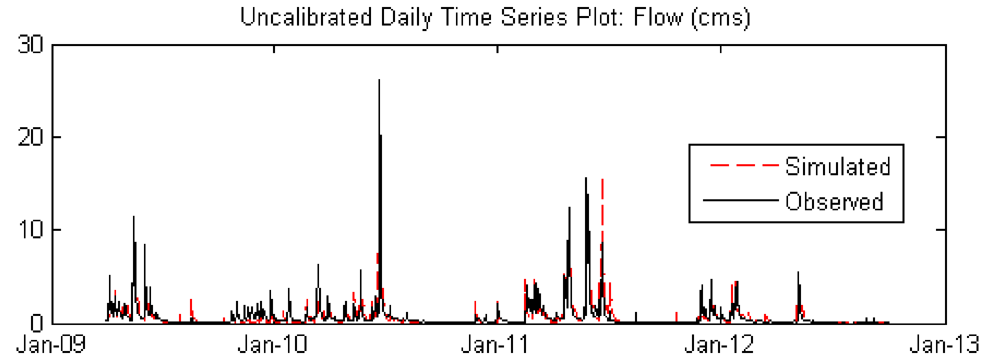
| | | Little Wea | Little Pine |
|---|---|---|---|
| R2 daily | | 0.74 | 0.77 |
| NS daily | | 0.72 | 0.76 |
| R2 monthly | | 0.8803 | 0.88 |
| NS monthly | | 0.7965 | 0.80 |
| Simulated flow | m/y | 0.27 | 0.37 |
| Observed flow | m/y | 0.36 | 0.39 |

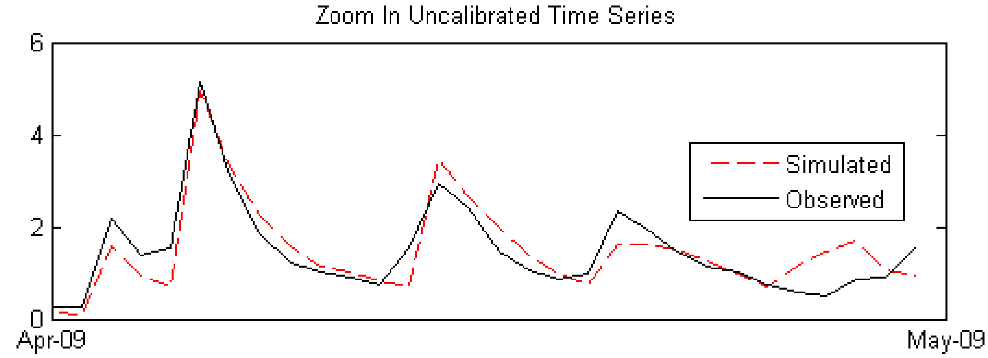
| | | Little Wea | | Little Pine | |
|---|---|---|---|---|---|
| | | mean | std | mean | std |
| Tile flow | m/y | 0.18 | 0.44 | 0.17 | 0.39 |
| Precipitation | mm/day | 2.88 | 7.29 | 2.89 | 8.11 |
| Nitrate in surface flows | kg/day | 30.30 | 98.27 | 37.86 | 96.31 |
| Nitrate from tiles | kg/day | 517.75 | 1421.20 | 381.74 | 1024.60 |
| Total nitrate | kg/day | 576.04 | 1503.60 | 434.62 | 1085.70 |
| Organic nitrogen | kg/day | 287.43 | 1095.40 | 100.73 | 344.23 |
| Total nitrogen | kg/day | 863.47 | 2203.10 | 535.35 | 1306.20 |
| Total phosphorus | kg/day | 36.89 | 150.38 | 6.37 | 32.82 |
| Sediment | t/day | 10.78 | 55.08 | 4.10 | 22.91 |

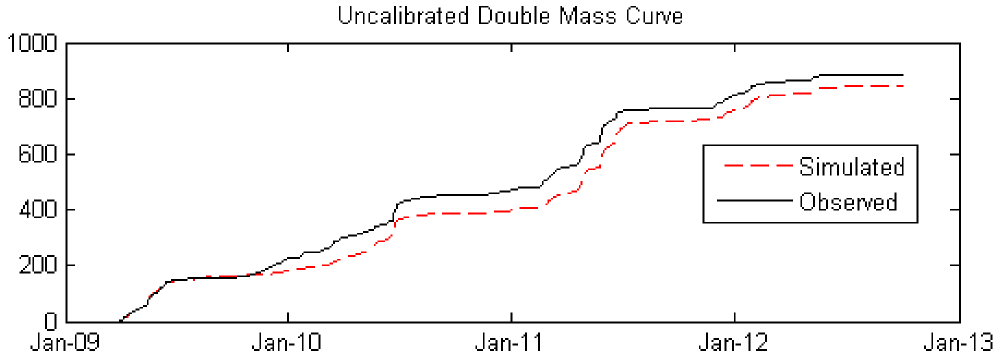
Water quality:

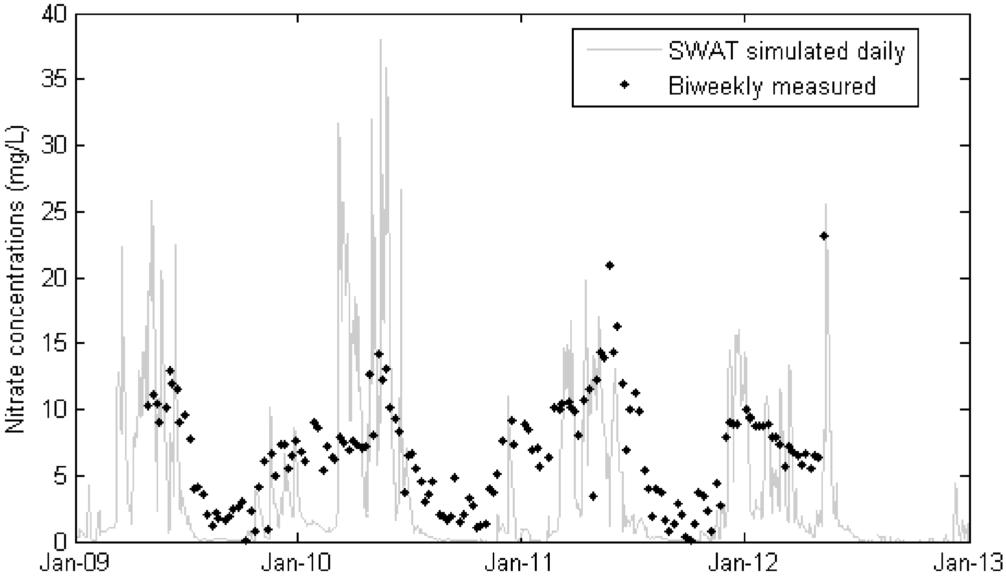
| | | Little Wea | | Little Pine | |
|---|---|---|---|---|---|
| | | Simulated | Observed | Simulated | Observed |
| Total NO3 in mg/L | mean | 7.42 | 4.49 | 4.10 | 6.64 |
| | std | 9.99 | 2.74 | 6.07 | 4.01 |
| | min | 0.00 | 0.02 | 0.00 | 0.03 |
| | max | 86.03 | 14.17 | 38.00 | 23.20 |
| Total NO3 in kg/d | mean | 470.96 | 371.66 | 444.03 | 563.43 |
| | std | 1204.50 | 778.60 | 1086.10 | 994.84 |
| | min | 0.00 | 0.25 | 0.00 | 0.01 |
| | max | 12500.00 | 6736.30 | 9765.00 | 6356.80 |
| TP in mg/L | mean | 0.40 | 0.05 | 0.14 | 0.14 |
| | std | 0.57 | 0.11 | 0.17 | 0.13 |
| | min | 0.00 | -0.05 | 0.00 | 0.00 |
| | max | 3.01 | 0.73 | 0.83 | 0.89 |
| TP in kg/d | mean | 48.01 | 10.40 | 20.53 | 12.52 |
| | std | 182.33 | 52.30 | 68.29 | 43.58 |
| | min | 182.33 | -5.90 | 0.00 | 0.00 |
| | max | 3000.80 | 475.45 | 946.10 | 369.02 |
| Sed in mg/L | mean | 62.19 | 14.15 | 30.12 | 21.52 |
| | std | 118.69 | 38.73 | 49.15 | 33.13 |
| | min | 0.00 | 0.00 | 0.00 | 1.20 |
| | max | 852.32 | 786900.00 | 341.86 | 261.00 |
| Sed in kg/d | mean | 9630.10 | 5097.30 | 5448.10 | 4242.70 |
| | std | 43902.00 | 33020.00 | 22929.00 | 21689.00 |
| | min | 0.00 | 0.00 | 0.00 | 1.08 |
| | max | 786900.00 | 360840.00 | 352600.00 | 215300.00 |

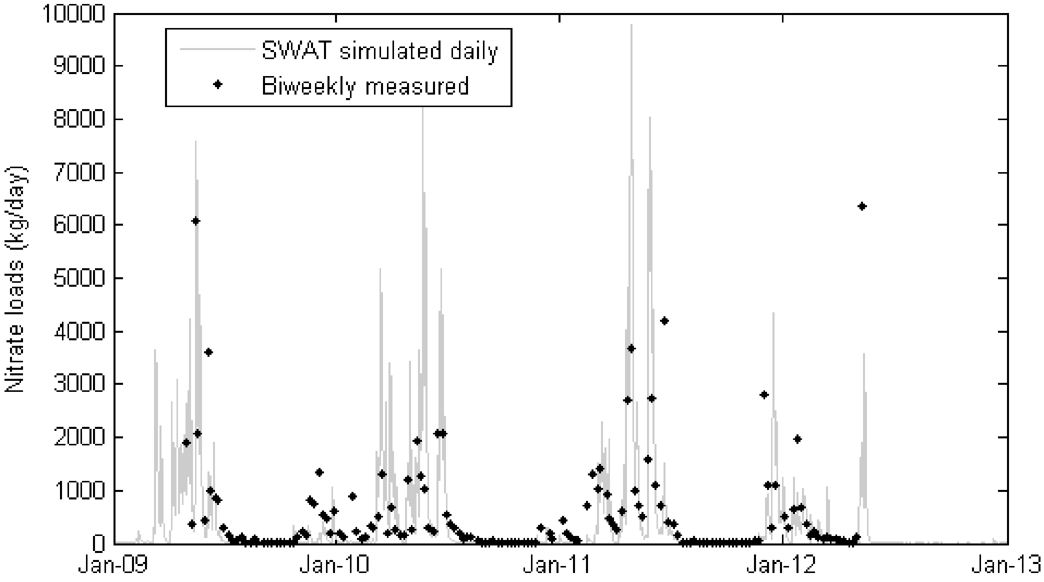
Little Pine Creek watershed

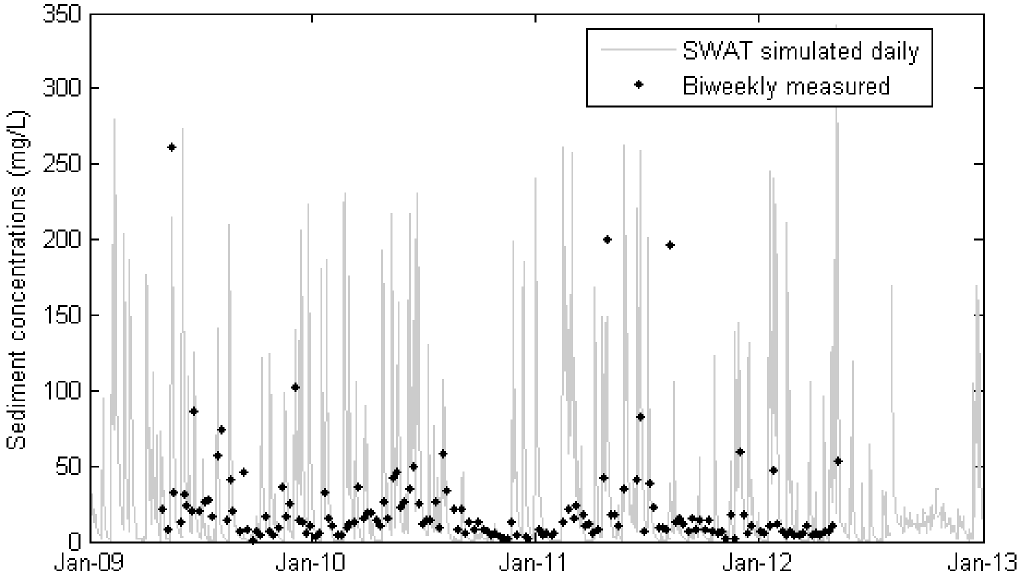


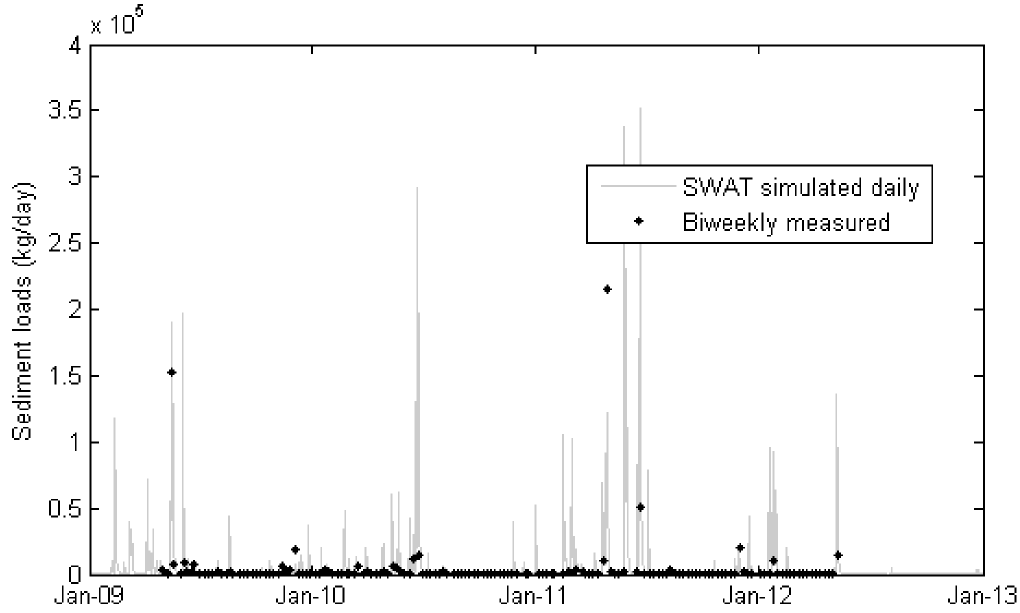


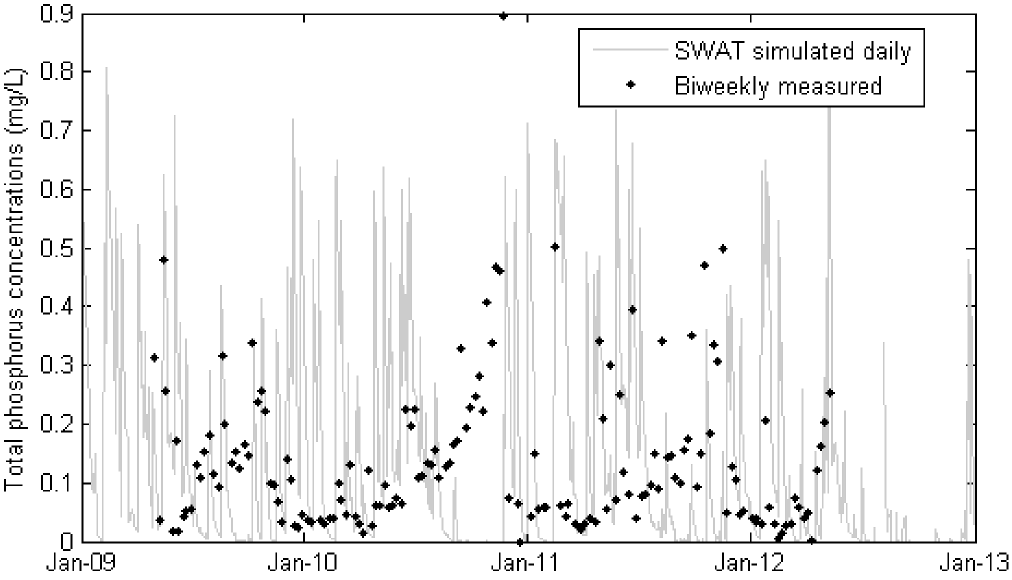


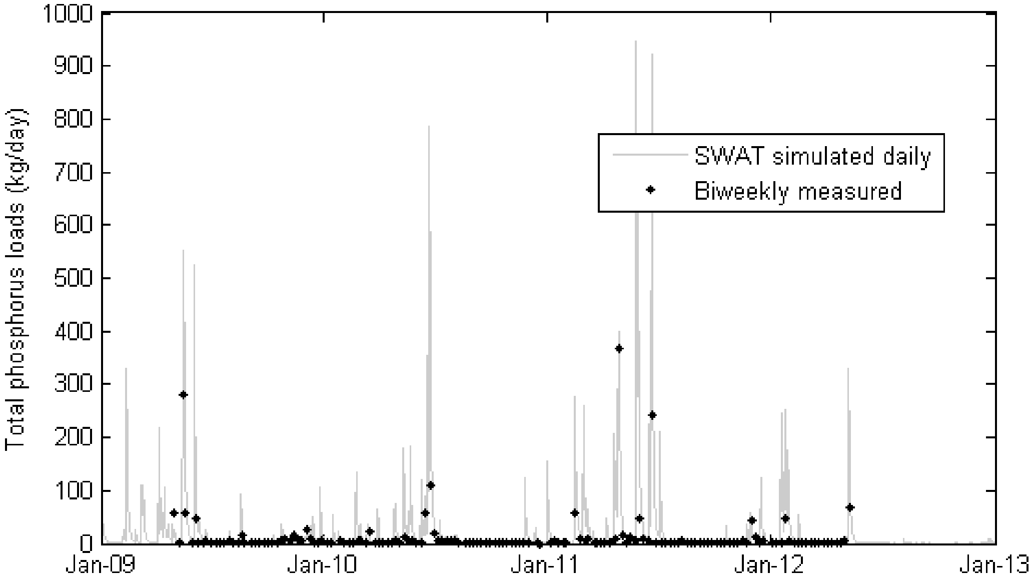

SWAT simulated daily
Biweekly measured
Nitrate concentrations (mg/L)
0
5
10
15
20
25
30
35
40
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13


SWAT simulated daily
Biweekly measured
Nitrate loads (kg/day)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13

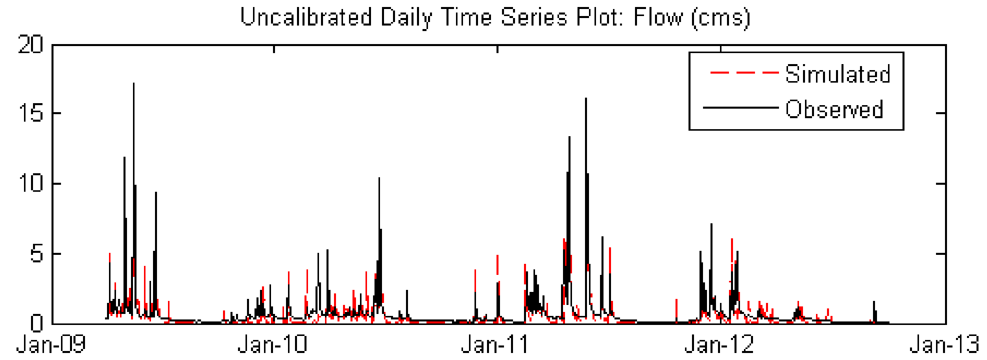

Sediment concentrations (mg/L)
350
300
250
200
150
100
50
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
SWAT simulated daily
Biweekly measured

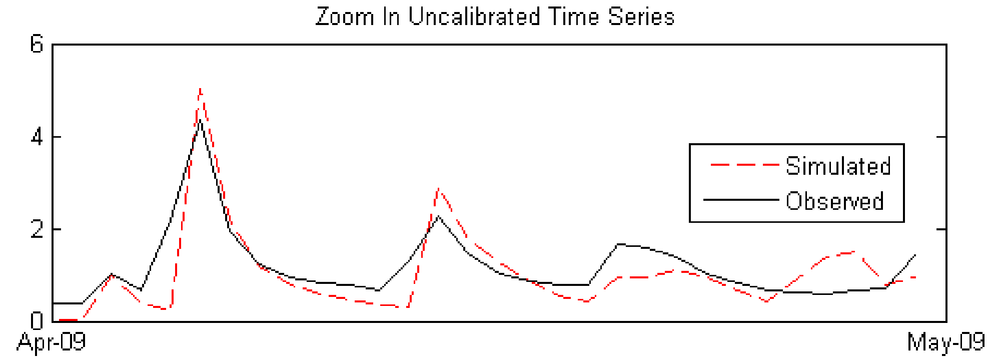

x $10^5$
Sediment loads (kg/day)
4
3.5
3
2.5
2
1.5
1
0.5
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
SWAT simulated daily
Biweekly measured

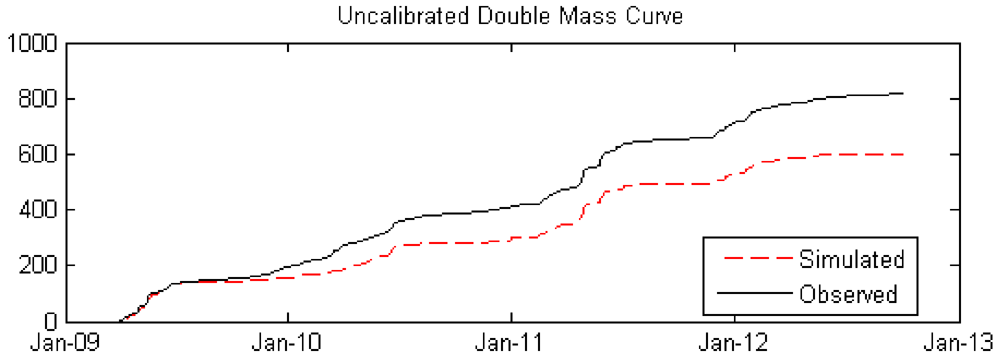

Total phosphorus concentrations (mg/L)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
SWAT simulated daily
Biweekly measured

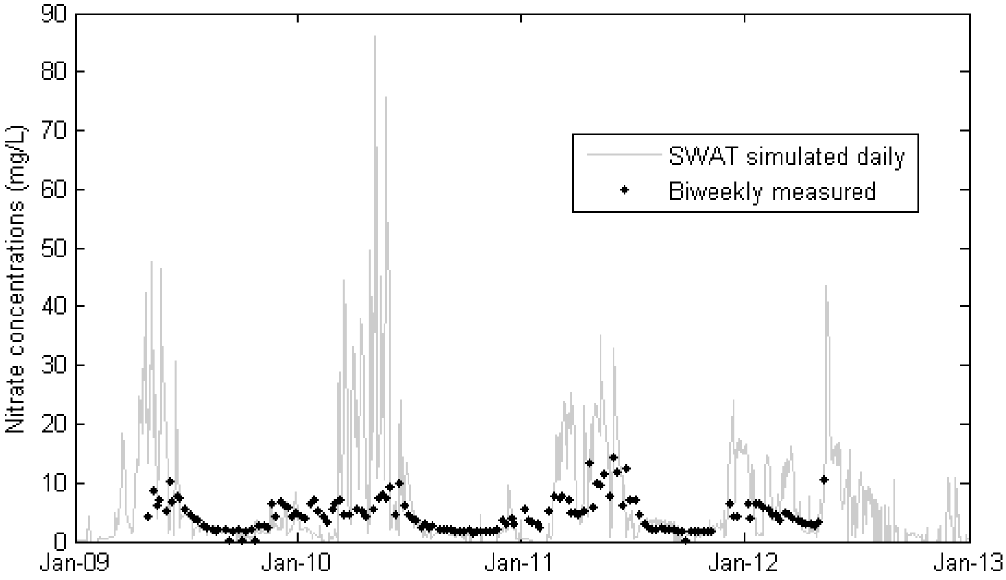

Total phosphorus loads (kg/day)
1000
900
800
700
600
500
400
300
200
100
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
SWAT simulated daily
Biweekly measured

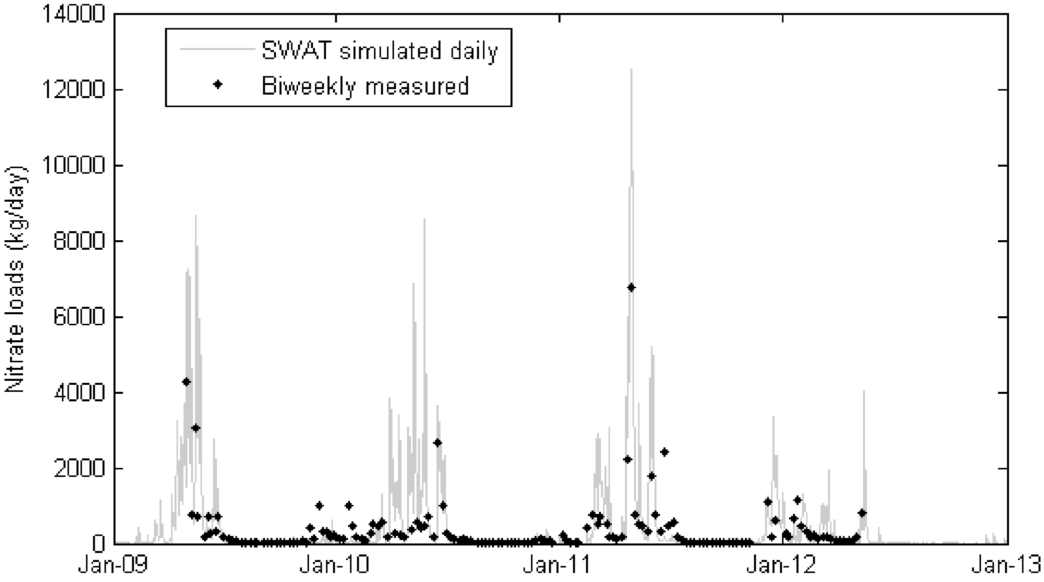
## Little Wea Creek watershed

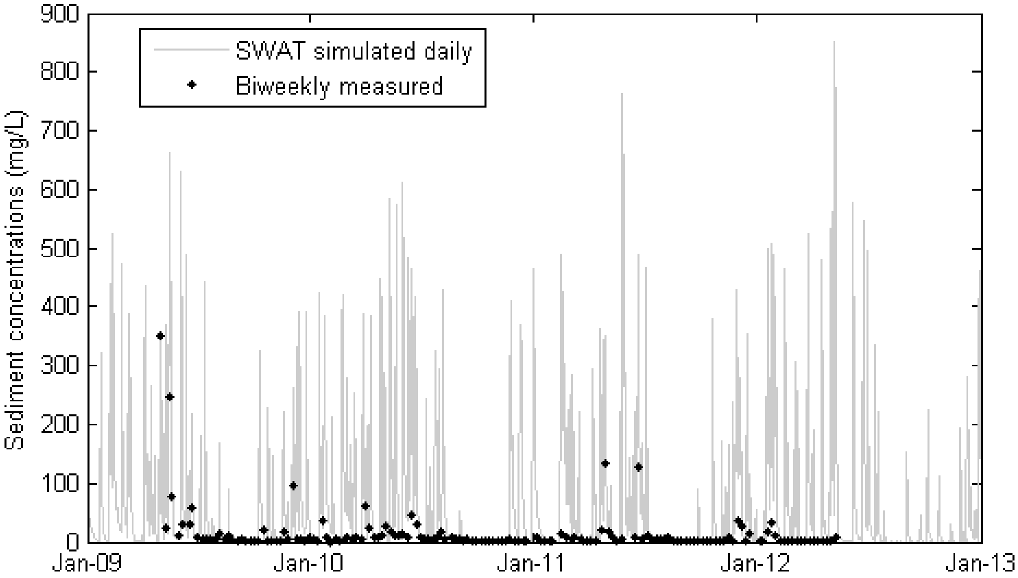

Uncalibrated Daily Time Series Plot: Flow (cms)

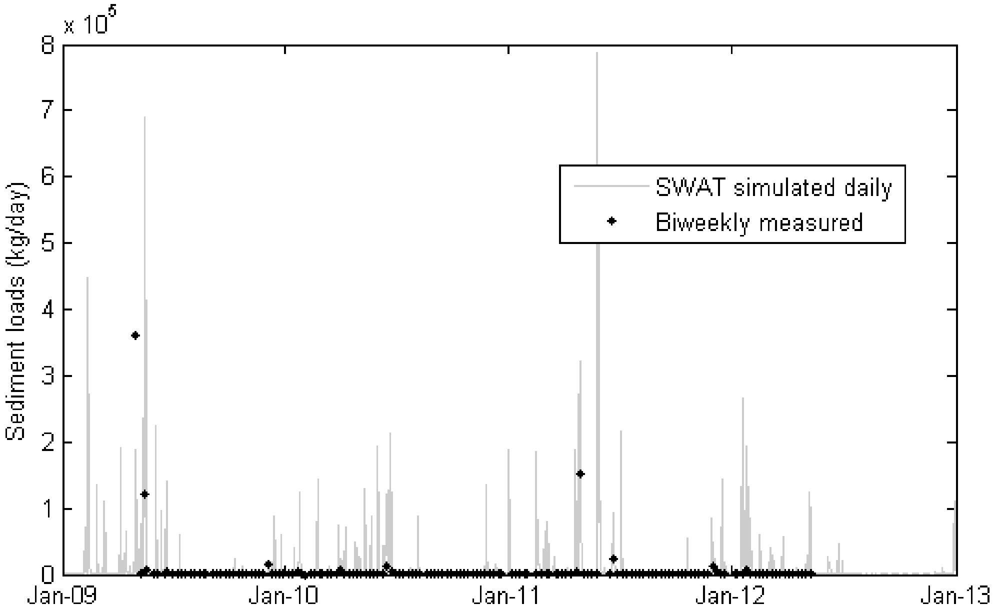

Zoom In Uncalibrated Time Series

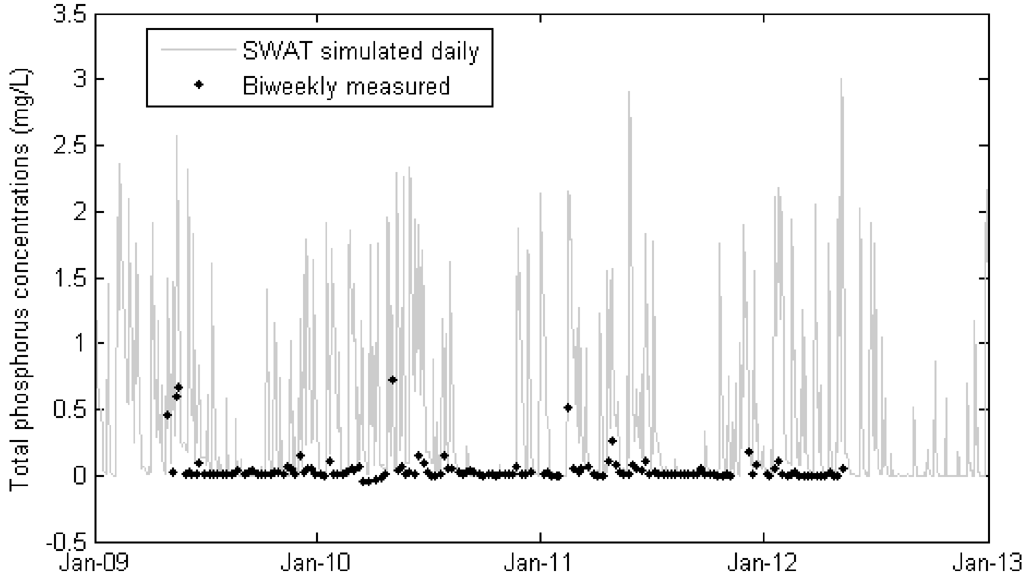

Uncalibrated Double Mass Curve

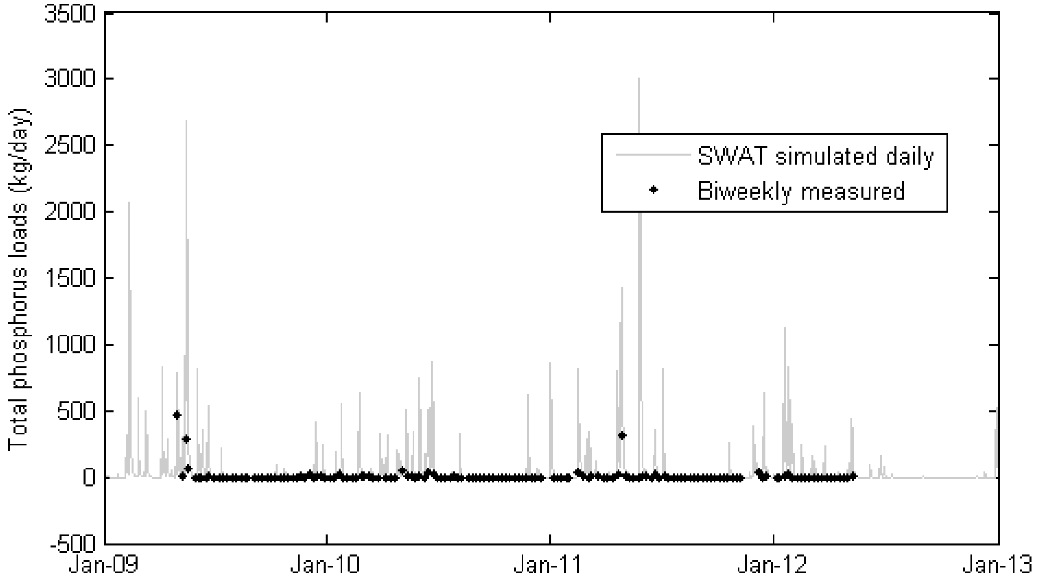

Nitrate concentrations (mg/L)
0
10
20
30
40
50
60
70
80
90
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
SWAT simulated daily
Biweekly measured


Nitrate loads (kg/day)
0
2000
4000
6000
8000
10000
12000
14000
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
SWAT simulated daily
Biweekly measured


900
800
700
600
500
400
300
200
100
0
Sediment concentrations (mg/L)
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
SWAT simulated daily
Biweekly measured


x $10^5$
8
7
6
5
4
3
2
1
0
Sediment loads (kg/day)
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
SWAT simulated daily
Biweekly measured


SWAT simulated daily
Biweekly measured
Total phosphorus concentrations (mg/L)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13

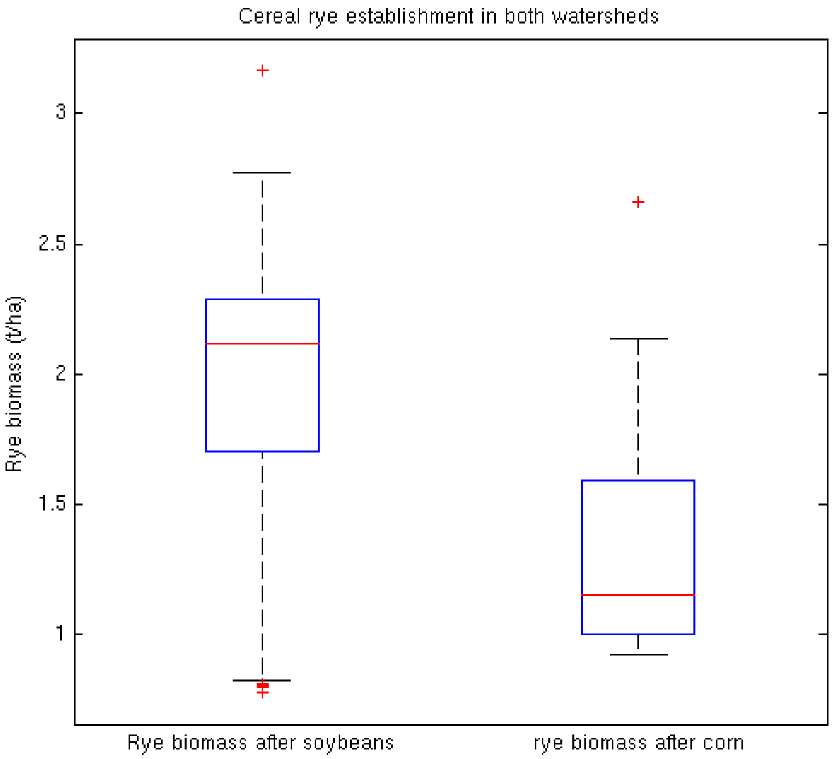

SWAT simulated daily
Biweekly measured
Total phosphorus loads (kg/day)
3500
3000
2500
2000
1500
1000
500
0
-500
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13

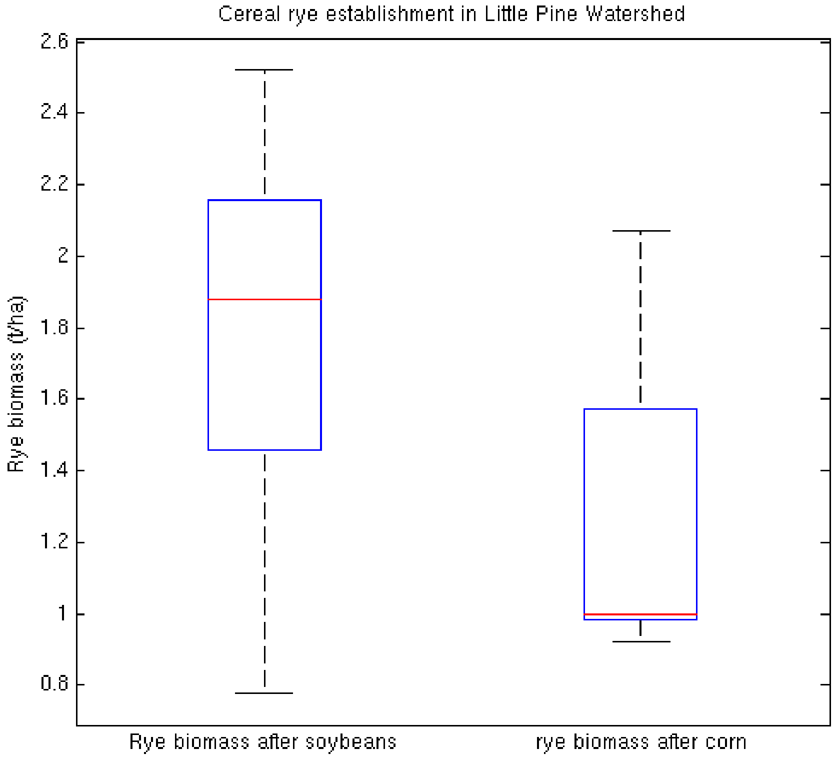
# Appendix C Cover crop establishment in SWAT model setups

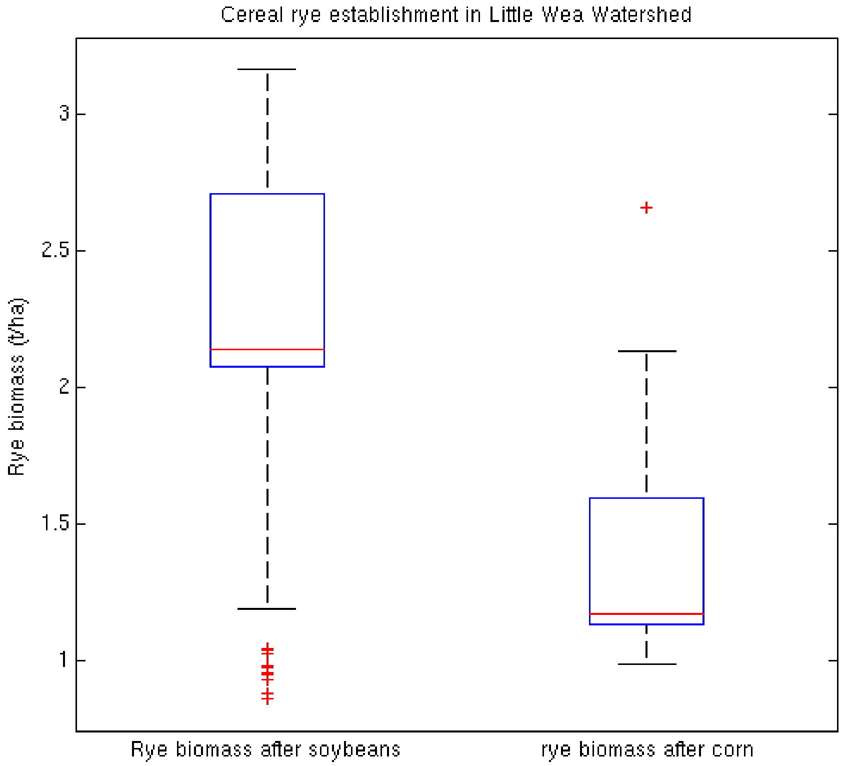
Below: Annual average cereal rye growth in t/ha for every corn/soybean HRU.

| | | Both watersheds | Little Pine | Little Wea |
|---|---|---|---|---|
| after soybeans | mean | 2.00 | 1.81 | 2.20 |
| | stdev | 0.51 | 0.47 | 0.48 |
| after corn | mean | 1.31 | 1.25 | 1.37 |
| | stdev | 0.3217 | 0.3423 | 0.2879 |

Below: plots of cereal rye growth in each watershed.




Cereal rye establishment in Little Pine Watershed
Rye biomass (t/ha)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
Rye biomass after soybeans
rye biomass after corn


Cereal rye establishment in Little Wea Watershed
Rye biomass (t/ha)
3
2.5
2
1.5
1
Rye biomass after soybeans
rye biomass after corn

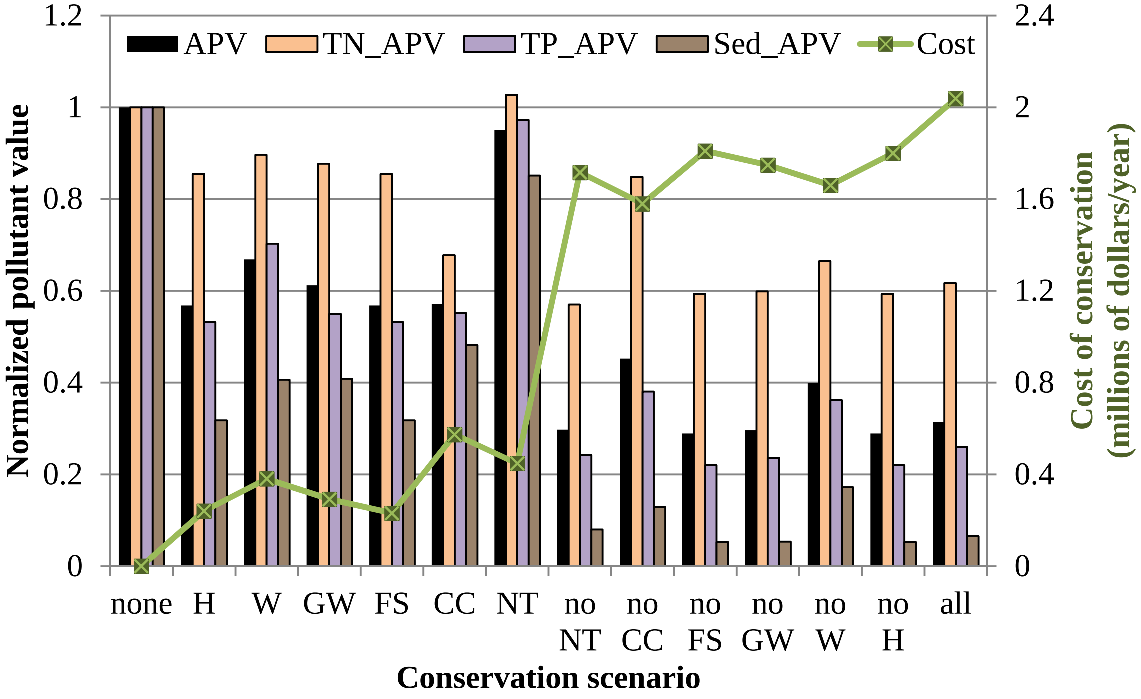
# Appendix D Conservation practice scenarios

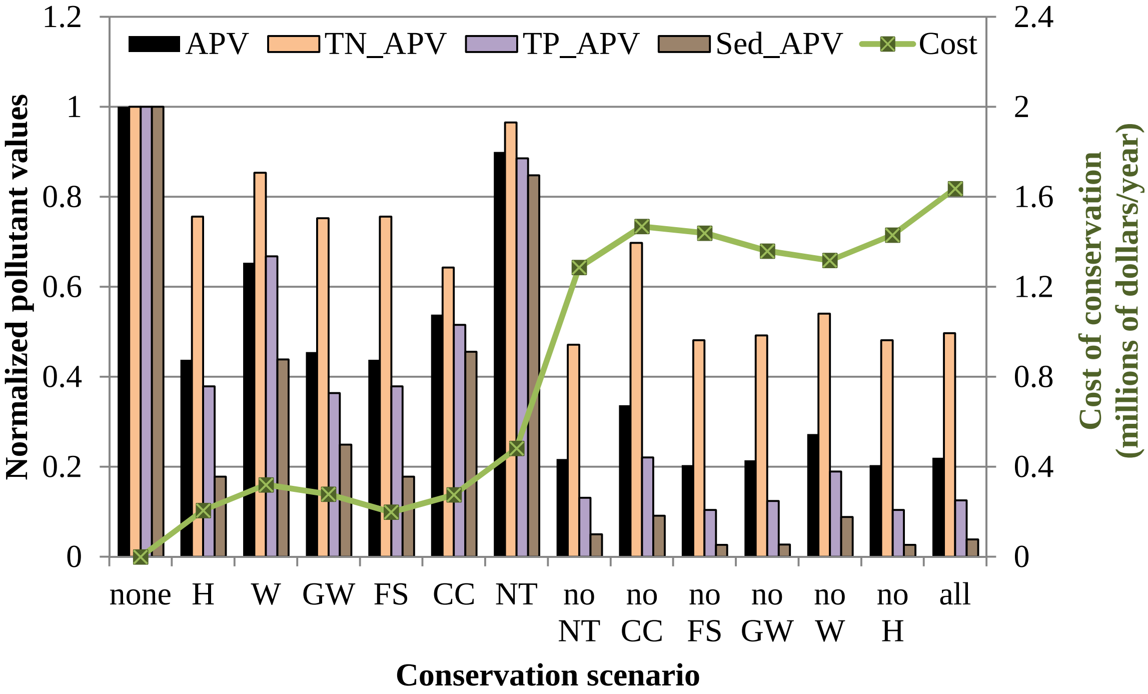
## One-at-a-time addition

| Scenario | Water-shed | Cost of scenario $/ha/y | | Total nitrogen kg/ha/y | | Total phosphorus | | Sediment yield | | Corn yield t/ha/y | | Soybean yield | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *μ* | *σ* | *μ* | *σ* | *μ* | *σ* | *μ* | *σ* | *μ* | *σ* | *μ* | *σ* |
| No conservation (NONE) | Little Pine | $0 | $0 | 41.0 | 20.9 | 3.7 | 2.9 | 547.0 | 502.8 | 10.7 | 0.6 | 2.8 | 0.1 |
| | Little Wea | $0 | $0 | 58.9 | 15.5 | 7.2 | 4.0 | 719.7 | 733.4 | 10.8 | 0.5 | 2.8 | 0.3 |
| | Both | $0 | $0 | 49.8 | 20.5 | 5.4 | 3.9 | 632.1 | 632.6 | 10.8 | 0.5 | 2.8 | 0.2 |
| No-tillage (NT) | Little Pine | $65 | $23 | 41.3 | 20.7 | 3.5 | 2.5 | 469.5 | 448.3 | 10.5 | 0.6 | 2.8 | 0.1 |
| | Little Wea | $74 | $21 | 55.1 | 13.2 | 6.2 | 3.1 | 616.7 | 656.8 | 10.5 | 0.5 | 2.8 | 0.3 |
| | Both | $69 | $22 | 48.1 | 18.7 | 4.9 | 3.1 | 542.0 | 565.2 | 10.5 | 0.6 | 2.8 | 0.2 |
| Cover crops (CC) | Little Pine | $114 | $28 | 26.8 | 13.4 | 2.0 | 1.7 | 268.6 | 255.3 | 10.7 | 0.7 | 2.8 | 0.1 |
| | Little Wea | $94 | $18 | 36.8 | 10.2 | 3.8 | 2.5 | 331.8 | 351.4 | 11.0 | 0.4 | 2.8 | 0.3 |
| | Both | $104 | $26 | 31.7 | 12.9 | 2.9 | 2.3 | 299.7 | 307.8 | 10.8 | 0.6 | 2.8 | 0.2 |
| Filter strips (FS) | Little Pine | $48 | $2 | 30.0 | 17.7 | 1.2 | 0.7 | 96.7 | 112.9 | 10.7 | 0.6 | 2.8 | 0.1 |
| | Little Wea | $48 | $3 | 36.4 | 15.0 | 1.7 | 0.9 | 80.9 | 106.9 | 10.8 | 0.5 | 2.8 | 0.3 |
| | Both | $48 | $2 | 33.2 | 16.7 | 1.4 | 0.9 | 88.9 | 110.2 | 10.8 | 0.5 | 2.8 | 0.2 |
| Grassed waterways (GW) | Little Pine | $211 | $340 | 30.1 | 16.9 | 1.0 | 0.7 | 113.3 | 137.3 | 10.7 | 0.6 | 2.8 | 0.1 |
| | Little Wea | $187 | $286 | 34.8 | 15.5 | 1.2 | 1.0 | 108.2 | 147.8 | 10.8 | 0.5 | 2.8 | 0.3 |
| | Both | $199 | $315 | 32.4 | 16.4 | 1.1 | 0.9 | 110.8 | 142.5 | 10.8 | 0.5 | 2.8 | 0.2 |
| Wetlands (W) | Little Pine | $46 | x | 36.0 | x | 2.6 | x | 280.1 | x | 10.7 | 0.6 | 2.8 | 0.1 |
| | Little Wea | $66 | x | 47.5 | x | 4.5 | x | 310.3 | x | 10.8 | 0.5 | 2.8 | 0.3 |
| | Both | $56 | x | 41.7 | x | 3.5 | x | 295.0 | x | 10.8 | 0.5 | 2.8 | 0.2 |
| Habitats (H) | Little Pine | $50 | $2 | 30.0 | 17.7 | 1.2 | 0.7 | 96.7 | 112.9 | 10.7 | 0.6 | 2.8 | 0.1 |
| | Little Wea | $50 | $3 | 36.4 | 15.0 | 1.7 | 0.9 | 80.9 | 106.9 | 10.8 | 0.5 | 2.8 | 0.3 |
| | Both | $50 | $2 | 33.2 | 16.7 | 1.4 | 0.9 | 88.9 | 110.2 | 10.8 | 0.5 | 2.8 | 0.2 |

## One-at-a-time removal

| Scenario | Water-shed | Cost of scenario $/ha/y |  | Total nitrogen kg/ha/y |  | Total phosphorus |  | Sediment yield |  | Corn yield t/ha/y |  | Soybean yield |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | μ | σ | μ | σ | μ | σ | μ | σ | μ | σ | μ | σ |
| All conservation practices (ALL) | Little Pine | $518 | x | 21.5 | x | 0.5 | x | 23.0 | x | 10.6 | 0.7 | 2.8 | 0.1 |
|  | Little Wea | $503 | x | 23.5 | x | 0.4 | x | 16.6 | x | 10.8 | 0.4 | 2.8 | 0.3 |
|  | Both | $511 | x | 22.5 | x | 0.5 | x | 19.9 | x | 10.7 | 0.6 | 2.8 | 0.2 |
| All except no-till (no NT) | Little Pine | $468 | x | 19.7 | x | 0.4 | x | 28.2 | x | 10.7 | 0.7 | 2.8 | 0.1 |
|  | Little Wea | $447 | x | 22.0 | x | 0.4 | x | 21.3 | x | 11.0 | 0.4 | 2.8 | 0.3 |
|  | Both | $458 | x | 20.8 | x | 0.4 | x | 24.8 | x | 10.8 | 0.6 | 2.8 | 0.2 |
| All except cover crops (no CC) | Little Pine | $417 | x | 29.9 | x | 0.7 | x | 45.2 | x | 10.5 | 0.6 | 2.8 | 0.1 |
|  | Little Wea | $420 | x | 32.9 | x | 0.7 | x | 39.2 | x | 10.5 | 0.5 | 2.8 | 0.3 |
|  | Both | $418 | x | 31.4 | x | 0.7 | x | 42.3 | x | 10.5 | 0.6 | 2.8 | 0.2 |
| All except filter strips | Little Pine | $471 | x | 20.4 | x | 0.4 | x | 19.4 | x | 10.6 | 0.7 | 2.8 | 0.1 |
|  | Little Wea | $455 | x | 22.5 | x | 0.3 | x | 11.2 | x | 10.8 | 0.4 | 2.8 | 0.3 |
|  | Both | $463 | x | 21.5 | x | 0.4 | x | 15.4 | x | 10.7 | 0.6 | 2.8 | 0.2 |
| All except grassed | Little Pine | $308 | x | 21.0 | x | 0.5 | x | 19.8 | x | 10.6 | 0.7 | 2.8 | 0.1 |
|  | Little Wea | $317 | x | 23.5 | x | 0.5 | x | 11.6 | x | 10.8 | 0.4 | 2.8 | 0.3 |
|  | Both | $313 | x | 22.2 | x | 0.5 | x | 15.8 | x | 10.7 | 0.6 | 2.8 | 0.2 |
| All except wetlands (no | Little Pine | $472 | $338 | 22.7 | 12.4 | 0.7 | 0.4 | 48.7 | 58.8 | 10.6 | 0.7 | 2.8 | 0.1 |
|  | Little Wea | $437 | $286 | 25.3 | 11.0 | 0.7 | 0.5 | 39.0 | 55.7 | 10.8 | 0.4 | 2.8 | 0.3 |
|  | Both | $455 | $314 | 24.0 | 11.8 | 0.7 | 0.4 | 43.9 | 57.5 | 10.7 | 0.6 | 2.8 | 0.2 |
| All except habitats (no | Little Pine | $469 | x | 20.4 | x | 0.4 | x | 19.4 | x | 10.6 | 0.7 | 2.8 | 0.1 |
|  | Little Wea | $453 | x | 22.5 | x | 0.3 | x | 11.2 | x | 10.8 | 0.4 | 2.8 | 0.3 |
|  | Both | $461 | x | 21.5 | x | 0.4 | x | 15.4 | x | 10.7 | 0.6 | 2.8 | 0.2 |





Above: Scenarios for conservation in the Little Pine (top) and Little Wea (bottom) study watersheds.

# Appendix E Farmer interview script

## Farmer Interview Information Sheet

Adaptive targeting: Engaging stakeholders to improve watershed modeling and in-field implementation of agricultural conservation practices

Dr. Jane Frankenberger and Margaret Kalcic

Purdue University, Department of Agricultural and Biological Engineering

Purpose of Research: The interviews are being conducted to collect land management practice data from agricultural producers to inform a watershed-scale model that will be used to identify locations for conservation that are cost-effective and efficient. Social information will also be collected to tailor conservation practices to producer preferences in order to improve relevance of targeted solutions and hopefully increase adoption rates.

Specific Procedures: You will be asked to participate in individual interviews that will be audio recorded. The student will use an interview guide to work through the interview. During the interview, you will be asked questions relating to your farming practices, conservation practices, and your views on targeting conservation to the most cost-effective and efficient locations.

Duration of Participation: The study will be conducted from December 2011 to summer of 2012. Interviews will average one hour and you will be asked to participate in only one or two interviews.

Risks: Risks are no more than one would encounter in everyday life. If you are uncomfortable with any of the techniques used or questions asked, you may choose not to participate.

Benefits: There will be no direct benefits to individual participants.

Compensation: No compensation will be provided for participating in these interviews.

Confidentiality: All opinions you share, and information related to your management practices, will be purely confidential and accessible only to the research team. Information related to the spatial locations of structures and practices (e.g. conservation practices) may be shared with conservation staff. Transcriptions of the interviews will be confidential and stored indefinitely. Raw interview data will be confidential and destroyed at the conclusion of the study, approximately May 2013. Individual names of interviewees will not be included in the reporting of findings; instead a generic identity such as "Interviewee 1" will be used to replace names or other identifying information that could be used to associate specific responses with individual participants.

Voluntary Nature of Participation: Participation is voluntary - you do not have to participate in this research project. If you agree to participate you can withdraw your participation at any time without penalty.

Contact Information: Contact information was provided to the farmer, but has been removed for this appendix.

Informed Consent: I have had the opportunity to read this information sheet and have the research study explained. I have had the opportunity to ask questions about the research project and my questions have been answered. I am prepared to participate in the research project described above.

## Introduction

Before we start the interview, I want to go over an information sheet with you. This sheet explains my study, that it is ethically sound, and will protect all persons involved. Note that if at any point in our conversation you are uncomfortable with the information you shared or have been asked to share, you can simply let me know and we'll move on.

I will be taking notes during our interview, but I may not be able to catch everything on paper. Would you mind if I tape record our conversation today?

## Farm information

I would like to get some basic information about you and your farm.

1. Approximately what year did you start farming in this region? ____________

2. What year were you born? ____________

3. I would like to know what type of farm you have.

    a. What are the primary crops that you grow?
    ___________________________

    b. Do you have livestock on your farm? If so, what livestock do you have?
        i. Dairy cattle
        ii. Beef cattle
        iii. Hogs
        iv. Poultry
        v. Sheep
        vi. Goats
        vii. Other

4. I have here a number of maps of my study area, and I believe you farm some land in this area. Will you point out to me the locations where you grow crops? If you don't mind, please mark the fields you own and farm or rent and farm in highlighter, and mark "O" in fields you won and "R" in fields you rent. You will be marking up these small maps throughout our interview today.

## Conservation practices

Now I want to ask you some questions about conservation practices. We will go through conservation practices one at a time, looking at each one carefully.

5. Before we do this, do you have any streams or ditches on your property? If so, do they match up with this streams data layer on the map?

6. Do you have any tile drains on your property? For each field, please write “ND” for no drains, “RD” for randomly patterned drains, and “PD for patterned tiles. Also estimate drain spacing if it is known.

**Continuous no-till, strip till, or mulch till (Residue and tillage management (329))**

7. Would you please describe your current tillage practices for corn and bean crops?

8. Have you ever used continuous no-till on your farm? If yes:
   a. Are you currently using this practice? If not, why did you stop using this practice?

   b. What crops do you no-till –beans, corn, or others?

   c. Can you show me where on the map you are currently using no-till? Mark with ‘NT’.

   d. Why did you implement no-till?

   e. Are you receiving, or did you receive in the past, any incentives for this practice? If so, which ones?

9. What benefits do you think continuous no-till/strip-till/mulch-till provides?

10. Do you think this practice could be applicable to the land you farm? If yes:
    a. Would you consider using continuous no-till on your farm, if given an incentive to do so?

    b. Why or why not? Please place the fact sheet in one of three piles: yes, no, and maybe.

    c. If not applicable, would you be interested in the practice under different circumstances? What would those be?

### Cover crops (340)

11. Have you ever grown cover crops on your farm? If yes:

    a. Are you currently using this practice? If not, why did you stop using this practice?

    b. Can you show me where on the map you are currently using this practice? Mark with ‘CC’.

    c. What cover crop variety do you use?

    d. Why did you grow cover crops?

    e. Are you receiving, or did you receive in the past, any incentives for this practice? If so, which ones?

12. What benefits do you think cover crops provide?

13. Do you think this practice could be applicable to the land you farm? If yes:

    a. Would you consider installing this practice on your farm, if given an incentive to do so?

    b. Why or why not? Please place the fact sheet in one of three piles: yes, no, and maybe.

    c. If not applicable, would you be interested in the practice under different circumstances? What would those be?

### Filter strip (393)

14. Have you ever implemented filter strips on your farm? If yes:

    a. Are you currently using this practice? If not, why did you stop using this practice?

   b. Can you show me where on the map you are currently using this practice? Mark with ‘FS’.

   c. Why did you implement filter strips?

   d. Are you receiving, or did you receive in the past, any incentives for this practice? If so, which ones?

15. What benefits do you think filter strips provide?

16. Do you think this practice could be applicable to the land you farm? If yes:

   a. Would you consider installing this practice on your farm, if given an incentive to do so?

   b. Why or why not? Please place the fact sheet in one of three piles: yes, no, and maybe.

   c. If not applicable, would you be interested in the practice under different circumstances? What would those be?

### Grassed waterway (412)

17. Have you ever implemented grassed waterways on your farm? If yes:

   a. Are you currently using this practice? If not, why did you stop using this practice?

   b. Can you show me where on the map you are currently using this practice? Mark with ‘GW’.

   c. Why did you implement this practice?

   d. Are you receiving, or did you receive in the past, any incentives for this practice? If so, which ones?

18. What benefits do you think this practice provide?

19. Do you think this practice could be applicable to the land you farm? If yes:

    a. Would you consider installing this practice on your farm, if given an incentive to do so?

    b. Why or why not? Please place the fact sheet in one of three piles: yes, no, and maybe.

    c. If not applicable, would you be interested in the practice under different circumstances? What would those be?

### Drainage water management (554)

20. Have you ever implemented drainage water management on your farm? If yes:

    a. Are you currently using this practice? If not, why did you stop using this practice?

    b. Can you show me where on the map you are currently using this practice? Mark with 'DWM'.

    c. Why did you implement this practice?

    d. Are you receiving, or did you receive in the past, any incentives for this practice? If so, which ones?

21. What benefits do you think this practice provide?

22. Do you think this practice could be applicable to the land you farm? If yes:

    a. Would you consider installing this practice on your farm, if given an incentive to do so?

    b. Why or why not? Please place the fact sheet in one of three piles: yes, no, and maybe.

    c. If not applicable, would you be interested in the practice under different circumstances? What would those be?

## Nutrient management (590)

23. Can you please describe your nutrient management strategies?

    a. Can you tell me at what rates and timings your fertilizers and/or manure is applied?

    b. How do you decide your application rates? What's the basis for the decision?

    c. How do you apply Phosphorus? Do you apply it below the soil? If broadcast, is it incorporated?

24. Have you ever received funding for nutrient management on your farm? Or have you worked with a certified technical service provider (TSP) to develop a comprehensive nutrient management plan (CNMP)? (TSPs can be crop advisors, chemical reps, seed salesman, etc.) If yes to either question:

    a. Are you currently using this practice? If not, why did you stop using this practice?

    b. Can you show me where on the map you are currently using this practice? Mark with 'NM'.

    c. What specifically have you done for this practice?

    d. Why did you implement this practice?

25. What benefits do you think this practice provide?

26. Do you think this practice could be applicable to the land you farm? If yes:

    a. Would you consider working with a certified technical service provider to develop a comprehensive nutrient management plan on your farm, if given an incentive to do so?

    b. Why or why not? Please place the fact sheet in one of three piles: yes, no, and maybe.

    c. If not applicable, would you be interested in the practice under different circumstances? What would those be?

## Waste utilization (633)

27. Do you apply manure on your farm?

28. Do you have animals on your farm? If yes:

    a. Do you apply their manure as fertilizer? Where?

    b. When do you apply this manure?

    c. Approximately how many animals do you have?

    d. Approximately how much manure do they produce?

    e. How do you decide your manure application rates? What’s the basis for the decision?

    f. Do you think that you could apply less fertilizer overall if you spread out your manure applications to a wider area?

    g. In what other fields would you be interested in applying the manure?

29. Have you ever received funding to use waste utilization on your farm? If yes:

    a. Are you currently using this practice? If not, why did you stop using this practice?

    a. Can you show me where on the map you are currently using this practice? Mark with ‘WU’.

    b. Why did you implement this practice?

30. What benefits do you think this practice provide?

31. Do you think this practice could be applicable to the land you farm? If yes:

   a. Would you consider installing this practice on your farm, if given an incentive to do so?

   b. Why or why not?  Please place the fact sheet in one of three piles: yes, no, and maybe.

   c. If not applicable, would you be interested in the practice under different circumstances?  What would those be?

**Restoration and management of rare or declining habitats (643)**

32. Have you ever implemented this practice on your farm?  Or do you grow any prairie grasses on your farm?  If yes:

    a. Are you currently using this practice?  If not, why did you stop using this practice?

    b. Can you show me where on the map you are currently using this practice?  Mark with ‘Restore’.

    c. What habitats have you restored/managed?

    d. Why did you implement this practice?

    e. Are you receiving, or did you receive in the past, any incentives for this practice?  If so, which ones?

33. What benefits do you think this practice provide?

34. Do you think this practice could be applicable to the land you farm?  If yes:

    a. Would you consider installing this practice on your farm, if given an incentive to do so?

    b. Why or why not?  Please place the fact sheet in one of three piles: yes, no, and maybe.

c. If not applicable, would you be interested in the practice under different circumstances? What would those be?

### Upland wildlife habitat management (645)

35. Have you ever implemented this practice on your farm? If yes:

    a. Are you currently using this practice? If not, why did you stop using this practice?

    b. Can you show me where on the map you are currently using this practice? Mark with ‘Upland’.

    c. What specific habitats have you managed on your farm? What species? (trees, grasses?)

    d. Why did you implement this practice?

    e. Are you receiving, or did you receive in the past, any incentives for this practice? If so, which ones?

36. What benefits do you think this practice provide?

37. Do you think this practice could be applicable to the land you farm? If yes:

    a. Would you consider installing this practice on your farm, if given an incentive to do so?

    b. Why or why not? Please place the fact sheet in one of three piles: yes, no, and maybe.

    c. If not applicable, would you be interested in the practice under different circumstances? What would those be?

### Two-stage drainage ditches (option of 654)

38. Have you ever implemented two-stage ditches on your farm? If yes:

a. Are you currently using this practice? If not, why did you stop using this practice?

b. Can you show me where on the map you are currently using this practice? Mark with ‘2-stage’.

c. Why did you implement this practice?

d. Are you receiving, or did you receive in the past, any incentives for this practice? If so, which ones?

39. What benefits do you think this practice provide?

40. Do you think this practice could be applicable to the land you farm? If yes:

a. Would you consider installing this practice on your farm, if given an incentive to do so?

b. Why or why not? Please place the fact sheet in one of three piles: yes, no, and maybe.

c. If not applicable, would you be interested in the practice under different circumstances? What would those be?

### Wetlands (Wetland restoration/creation (657/658))

41. Have you ever created or restored a wetland on your farm? If yes:

a. Are you currently using this practice? If not, why did you stop using this practice?

b. Can you show me where on the map you are currently using this practice? Mark with ‘Wetland’.

c. Why did you implement this practice?

   d. Are you receiving, or did you receive in the past, any incentives for this practice? If so, which ones?

42. What benefits do you think this practice provide?

43. Past research has indicated that wetlands can be applicable to a variety of farmland in this area.

    a. Would you consider installing a wetland on your farm, if given an incentive to do so?

    b. Why or why not? Please place the fact sheet in one of three piles: yes, no, and maybe.

    c. If not applicable, would you be interested in the practice under different circumstances? What would those be?

### Summary of conservation practices

44. Let's look back through the piles you made. Would you move anything around? Why?

45. Have you used other conservation practices, which we did not cover? If so, which ones? What benefits do these provide?

46. Are there any other reasons you would choose to or not to install conservation practices? What might cause you to decide you want to implement more conservation practices on your farm?

    a. *May probe further into incentives:* What kinds of incentives are appealing to you? What kinds of incentives do not appeal to you?

47. Are you familiar with the term "ecosystem services?"

    a. How would you describe ecosystem services?

48. Do you think some farmers contribute more to water quality problems than others? Why or why not?

49. How do you think farmers should take responsibility for water quality preservation?

### Response to targeting

50. Do you think conservation practices should be targeted to locations where they are most effective?

    a. Should conservation practices be prioritized in locations where they do the most good for water quality at the least cost? Why do you think this?

51. Do you think conservation funding should be higher for land that is most vulnerable to soil and water quality problems? Why or why not?

52. In my research, I am using a landscape-scale model to find optimal locations for conservation practices in this area. Do you think computer models can effectively identify good locations for conservation practices? What would increase your trust in these models?

53. After I use the computer model to find optimal locations for conservation, I will approach those landowners to show them what I've found. How would you feel if you were told that you had the opportunity to be compensated for adopting an optimal conservation practice on your farm?

    a. How would you likely respond?

54. We have nearly concluded the interview. Do you have any questions for me?

55. If I find that your land may be optimal for a conservation practice that you expressed an interest in during this study, would you like me to contact you for a second interview?

## Conservation Practice Cards

Conservation practice cards were used within the interview discussions about eleven conservation practices.

Sources of information, text, and images used in creation of these descriptive conservation practice guides included:

Conservation Choices brochure, USDA Natural Resources Conservation Service, available online at: http://www.ia.nrcs.usda.gov/news/brochures/choices.html

National Conservation Practice Standards, as well as standards specific to Indiana

USDA NRCS Photo Gallery

**Continuous no-till, strip till, or mulch till…** leaving last year's crop residue on the soil surface by reduced tillage.

## Definition

Managing the amount, orientation and distribution of crop and other plant residue on the soil surface year round while limiting soil-disturbing activities to those necessary to place nutrients, condition residue and plant crops.

## Purposes

- Reduce sheet and rill erosion.
- Reduce wind erosion.
- Improve soil organic matter content.
- Reduce $CO_2$ losses from the soil.
- Reduce soil particulate emissions.
- Increase plant-available moisture.
- Provide food and escape cover for wildlife.

## Conditions where this practice applies

This practice applies to all cropland and other land where crops are planted.

Includes tillage and planting methods: No till, zero till, slot plant, row till, zone till, strip till, or direct seed. Approved implements are: no-till and strip-till planters; certain drills and air seeders; strip-type fertilizer and manure injectors and applicators; in-row chisels; and similar implements that only disturb strips and slots.

Includes: tillage methods commonly referred to as mulch tillage or chiseling, subsoiling and disking. Also included is use of a "modified no-till" system that leaves as much as 85% of the initial residue on the soil surface. A "vertical tillage system" may use an in-line low disturbance ripper to fluff surface residue and break any soil surface crust prior to planting.

**Cover crop…**a close-growing crop that temporarily protects the soil when crop residues are not adequate.

## Definition

Crops including grasses, legumes, and forbs for seasonal cover and other conservation purposes.

## Purposes

- Reduce erosion from wind and water.
- Increase soil organic matter content.
- Capture and recycle or redistribute nutrients in the soil profile.
- Promote biological nitrogen fixation and reduce energy use.
- Increase biodiversity.
- Suppress Weeds.
- Manage soil moisture.
- Minimize and reduce soil compaction.

## Conditions where this practice applies

All lands requiring vegetative cover for natural resource protection and or improvement.

**Filter strip…** a strip of grass, trees, or shrubs that filters runoff and removes contaminants before they reach water bodies or water sources such as wells.

### Definition

A strip or area of herbaceous vegetation that removes contaminants from overland flow.

### Purposes

- Reduce suspended solids and associated contaminants in runoff.
- Reduce dissolved contaminant loadings in runoff.
- Reduce suspended solids and associated contaminants in irrigation tailwater.
- Manage soil moisture.
- Minimize and reduce soil compaction.

### Conditions where this practice applies

Filter strips are established where environmentally-sensitive areas need to be protected from sediment, other suspended solids and dissolved contaminants in runoff.

**Grassed waterway…**shaping and establishing grass in a natural drainageway to prevent gullies from forming.

## Definition

A shaped or graded channel that is established with suitable vegetation to carry surface water at a non-erosive velocity to a stable outlet.

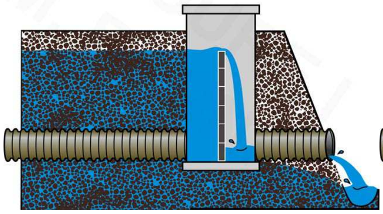
## Purposes

- Convey runoff from terraces, diversions, or other water concentrations without causing erosion or flooding.
- Reduce gully erosion.
- Protect/improve water quality.

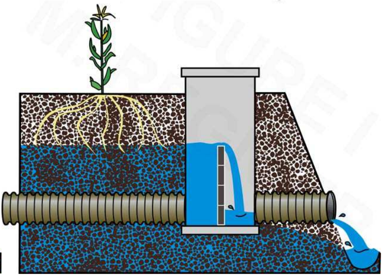
## Conditions where this practice applies

In areas where added water conveyance capacity and vegetative protection are needed to control erosion resulting from concentrated runoff.

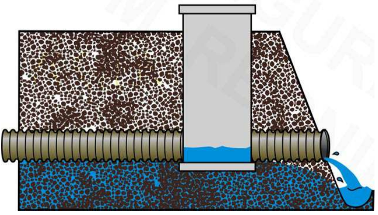
**Drainage water management…** using a water control structure to vary the depth of drainage outlets throughout the year.



The outlet is raised after harvest to reduce nitrate delivery.



The outlet is lowered a few weeks before planting and harvest to allow the field to drain fully.



The outlet is raised after planting to potentially store water for crops.

## Definition

Drainage water management is the practice of using a water control structure in a main, submain, or lateral drain to vary the depth of the drainage outlet. The water table must rise above the outlet depth for drainage to occur, as illustrated above.

## Purposes

- Reduce nutrient loading from drainage systems into downstream receiving waters.
- Possibly raise crop yields.

## Conditions where this practice applies

This practice is applicable to agricultural lands with subsurface agricultural tile drainage systems that are adapted to allow management of drainage discharges.

This practice may be most applicable to fairly flat crop fields with patterned tile drains.

**Nutrient management…** applying the correct amount and form of plant nutrients for optimum yield and minimum impact on water quality.

## Definition

Managing the amount, source, placement, form and timing of the application of plant nutrients and soil amendments.

## Purposes

- Budget and supply nutrients for plant production.
- Properly utilize manure or organic by-products as a plant nutrient source.
- Minimize agricultural nonpoint source pollution of surface and ground water resources.
- Protect air quality by reducing nitrogen emissions (ammonia and $NO_x$ compounds) and the formation of atmospheric particulates.
- Maintain or improve the physical, chemical and biological condition of soil.

## Conditions where this practice applies

This practice applies to all lands where plant nutrients and soil amendments are applied.

**Waste utilization…**using agricultural wastes such as manure and wastewater or other organic residues in a way that protects the environment.

## Definition

Using agricultural wastes such as manure and wastewater or other organic residues in a way that protects the environment.

## Purposes

- Protect water quality.
- Protect air quality.
- Provide fertility for crop, forage, fiber, production and forest products.
- Improve or maintain soil quality.
- Provide feedstock for livestock.
- Provide a source of energy.

## Conditions where this practice applies

This practice applies where agricultural wastes— including animal manure and contaminated water from livestock and poultry operations, solids and wastewater from municipal treatment plants, and agricultural processing residues— are generated and/or utilized.

## Details

- Create an operation and maintenance plan based on conservation practice standard.
- Test nutrient content of wastes and soil.
- Apply wastes using Nutrient Management.
- Follow guidelines each purpose.

**Restoration and management of rare or declining habitats…** providing habitat for rare and declining species.

## Definition

Restoring and managing rare and declining habitats and their associated wildlife species to conserve biodiversity.

## Purposes

- Restore land or aquatic habitats degraded by human activity.
- Provide habitat for rare and declining wildlife species by restoring and conserving native plant communities.
- Increase native plant community diversity.
- Manage unique or declining native habitats.

## Conditions where this practice applies

Sites that previously or currently support the rare or declining habitat targeted for restoration or management. This standard applies to the establishment/restoration of following habitat types:

- Tall Grass Prairie Establishment
- Low Stature Prairie Establishment
- Sedge Meadow Establishment
- Fen Restoration
- Savanna Establishment
- Open Oak Woodland
- Restoration of Existing Degraded Habitats

**Upland wildlife habitat management…** providing and managing upland habitats and connectivity within the landscape for wildlife.


### Definition

Provide and manage upland habitats and connectivity within the landscape for wildlife.

### Purposes

- Enable movement, shelter, cover, and food to sustain wild animals that inhabit uplands during a portion of their life cycle.

### Conditions where this practice applies

- Land where the decision maker has identified an objective for conserving a wild animal species, guild, suite or ecosystem.
- Land within the range of targeted wildlife species and capable of supporting the desired habitat.

### Details

- Habitat should be native plant species whenever possible.
- No disruption of cover (e.g. mowing) during primary nesting period (April 1 – August 1).
- Prevent excessive soil loss.
- Species such as Bobwhite Quail, Pheasant, Rabbit, and grassland songbirds.
- Prevent harvesting or grazing by domestic livestock,
- Species such as grasses, legumes, forbs, trees, and shrubs.
- Control any plant species that jeopardizes the practice.

**Two-stage drainage ditches…** ditches designed after stable natural streams.

### Definition

Designing ditches after stable natural streams with appropriately sized inset channels and vegetated floodplains. More self-sustaining than traditional drainage ditches with greater water quality benefits.

### Purposes

- Protect water quality.
- Protect stream ecosystems.
- Minimize ditch maintenance required.

### Conditions where this practice applies

- Channelized drainage ditches are present in sufficient length.
- Drainage ditch may be somewhat widened.
- Drainage ditch has characteristics that allow a stable two-stage ditch to be created.

**Wetlands…** marsh-type area with saturated soils and water-loving plants. Wetlands provide wildlife habitat and serve as natural filters for agricultural runoff.

## Definition

The return of a wetland and its functions to a close approximation of its original condition as it existed prior to disturbance on a former or degraded wetland site.

## Purposes

- Restore conditions conducive to hydric soil maintenance.
- Restore wetland hydrology.
- Restore native hydrophytic vegetation.
- Restore original fish and wildlife habitats.
- Protect water quality.

## Conditions where this practice applies

This practice applies only to natural wetland sites with hydric soils which have been subject to the degradation of hydrology, vegetation, or soils.

This practice is applicable only where the natural hydrologic conditions can be approximated by actions such as modifying drainage, restoring stream/floodplain connectivity, removing diversions, dikes, and levees, and/or by using a natural or artificial water source to provide conditions similar to the original, natural conditions.

# Appendix F Farmer follow-up interviews

## Introduction

Before we start the interview, I want to review this information sheet with you. This sheet explains my study, that it is ethically sound, and will protect all persons involved. Note that if at any point in our conversation you are uncomfortable with the information you shared or have been asked to share, you can simply let me know and we'll move on.

I will be taking notes during our interview, but I may not be able to catch everything on paper. Would you mind if I tape record our conversation today?

## Presentation of results for each field

This next section is the bulk of the follow-up interview. Here I am going to present to you the results I learned from my modeling work, which are based on the details you provided in the last interview about farm management, conservation practices that are already on your farm, and your future plans for conservation projects.

First, this sheet shows you the conservation practices that I ended up using in the optimization, based on interest in the farmer interviews, as well as scope of the project. Using my model, I hypothetically placed these practices on farm fields and saw the outcome in cost of conservation and water quality benefit. I only placed practices on your fields that you stated were in the "yes" and "maybe" piles for future interest in our last interview.

I have here a map of a number of your farm fields, which were within the upper Little Pine Creek watershed that served as the study site for this work. The study site is highlighted with a purple border. Each orange shape is a field that you rent or own, and the green shapes are current conservation practices you shared with me in the last interview. Each field is numbered, and this sheet of paper shows the results on a field-by-field basis.

The results of my model were used to identify the top two choices for future conservation practices you might choose to implement on each of the fields. The criteria for choosing these top two practices are first, the conservation practices should minimize nutrient and sediment runoff coming from the farm fields, and second, the cost of conservation should be kept as low as possible. On this sheet of paper you can see the top two choices for future conservation for each field, along with the estimated cost of implementing this project, and the percent of total nitrogen, phosphorus, and sediment runoff that these practices reduce from your farming operation.

Note that the cost here is an estimate of total cost, regardless of any incentive you may receive from the government. If you are interested in implementing these practices, you may qualify for incentives that would dramatically reduce the cost to you as the farmer.

1. Let’s talk about each one of these fields and the results for each field, one at a time.
    a. Do you think the top two conservation practices are likely to be optimal for your field?
    b. Do you see yourself implementing this practice on this field in the next five years? Why or why not?
    c. If not, is there any other practice that you are not currently using that you think might be better suited to these fields?
2. Now that we have gone through every field, do you expect that you will pursue any of these conservation practices in the next five years?

*Take notes for each field below, including reasons why or why not:*

| **Field number** | **Field size** | **Choice** | **Conservation Practice** | **a. Practice likely to be optimal** | **b. Implement within 5 years** | **c. Any other practice better suited** |
|---|---|---|---|---|---|---|
| X | 39 | #1 | Wildlife habitat | | | |
| X | 76 | #1 | Cover crops | | | |
| X | 24 | #1 | Grassed waterway | | | |
| X | 24 | #2 | Cover crops | | | |
| X | 24 | both | | | | |

## Response to being targeted

These last few questions are intended to better understand your opinion on this interview process.

3. Do you feel that the conservation practices coming from model results are applicable to your lands?

    a. Why do you think this?

4. Do you think conservation practices should be targeted to locations where they are the most effective?

    a. Why do you think this?

5. Do you think computer models can effectively identify good locations for conservation practices?

6. Thinking back to the first interview we had together one year ago, how did you think your information would be used in this study?

    a. How well were your expectations met by this second interview?

7. How did it feel for you to be given recommendations about which conservation practices may be most optimal on your lands?

    a. Why did you feel this way?

8. How do you feel these interviews may impact your land management decisions, if at all?

9. Is there anything that I did not bring to the interview that you would like to see from me?

10. Do you have any recommendations for me, how I could improve this work, or the interview approach?

The final set of questions is intended to clarify some points that we discussed in the last interview, and mostly relate to the current management of your farm. I realized when I was modeling the watershed that there are some pieces of information that I was missing.

## Farm information

Last interview I did not specifically ask about the size of your farming operation.

56. Approximately how large is your farming operation? How many acres do you farm? _______________

I want to ask you a few more questions about your general approach to fertilizer applications.

11. Do you generally apply phosphorus every other year, in the fall, after soybeans are harvested?
    a. If not, what is the general timing of your phosphorus application?

12. In the last 5 years, roughly how often were you able to get your phosphorus applied in November or early December when the weather was fairly dry?

    a. In the years that you weren’t able to apply phosphorus in November or early December, when did you get it applied? (Understand the conditions that they waited for; i.e., was it frozen?)

13. If you have used variable rate technology, is the nitrogen applied variable rate, or just the phosphorus?

    a. If the nitrogen is applied variable rate, how do you determine the rate at a given location?

*The text below was provided to the farmer during an explanation of which conservation practices were used in the model.*

## Conservation practice specifications

The conservation practices I ended up using in the optimization are shown below, with a few pertinent details about each one. These are the assumptions I made in the modeling, and they can serve as guidelines as to how a given practice could be implemented. While I did not draft up preliminary designs for each practice, I hope that this leaves you with enough information to understand how the optimal practices may be designed on your farm fields.

**No-tillage –** Continuous no-tillage of corn and soybeans. No-tillage is used both years in a 2-year rotation.

**Cover crops –** Cereal rye planted after harvest (October 15) and killed before spring tillage/planting (April 15).

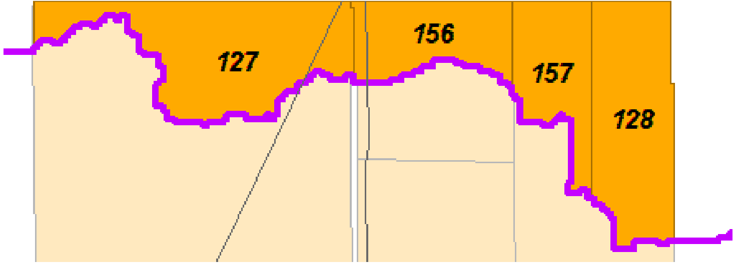
**Filter strips –** Filter strip area is 2.5% of field area, located alongside ditch/waterway, or where surface runoff accumulates.

**Wildlife habitats –** Tall prairie grass establishment, assumed to be 2.5% of field area, located along ditch/waterway or where surface runoff accumulates.

**Grassed waterways –** Average width of 33 feet, located where surface flows accumulate.

**Wetlands –** Sized as 4% of their upland contributing areas. This includes both wetland area (normally ponded) and surrounding buffer area.

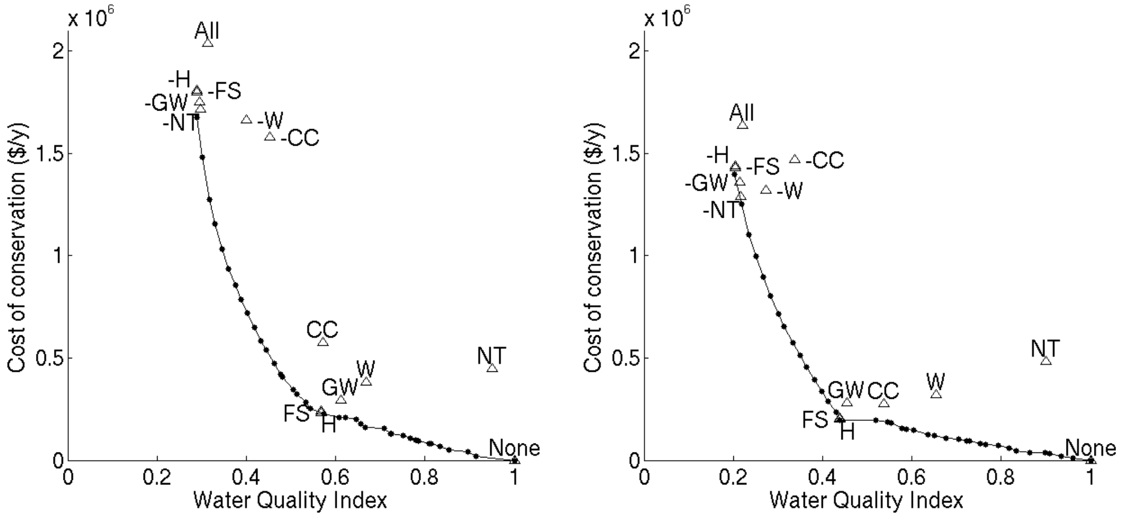
*The sample map below was provided to the farmer including the number of each farm field, the study area boundary, existing open waterways, and existing conservation practices learned from the first interview.*



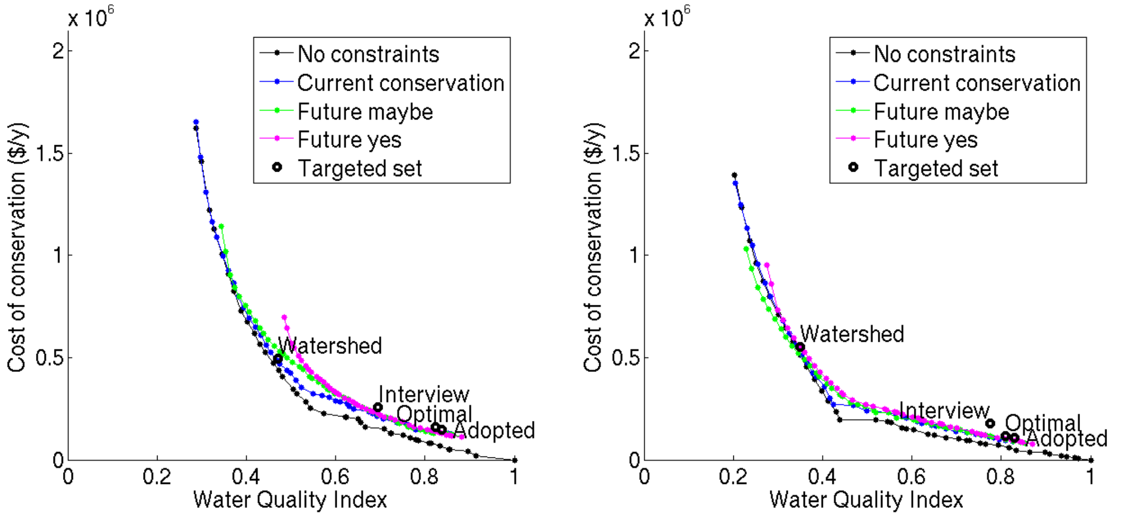
*The sample table below was provided to the farmer as results they could see in pollutant load reductions and cost if they adopted each optimal conservation practice.*

| Field number | Field size | Choice | Conservation Practice | Practice Area | Total Nitrogen | Total Phosphorus | Sediment | Approximate Cost |
|---|---|---|---|---|---|---|---|---|
| *No.* | *Acres* | *Priority* | *Name* | *Acres* | *Load in lbs/year of nutrients prevented from reaching stream* | | *Tons/year sediment retained* | *$* |
| X | 39 | #1 | Wildlife habitat | 1.0 | 96 | 21 | 2 | $738 |
| X | 76 | #1 | Cover crops | 75.7 | 432 | 18 | 2 | $3,147 |
| X | 24 | #1 | Grassed waterway | 0.8 | 131 | 30 | 2 | $866 |
| X | 24 | #2 | Cover crops | 23.7 | 199 | 21 | 1 | $972 |
| X | 24 | both | | 24.5 | 261 | 35 | 3 | $1,841 |

# Appendix G Additional targeting figures and tables



Optimization results plotted against initial conservation scenarios at the 200th generation for conservation in the Little Pine watershed (left) and Little Wea watershed (right).



Optimal fronts from 300 generations for the Little Pine (left) and Little Wea (right) showing each step in the adaptive optimization. Annual conservation costs are not normalized to watershed area.

Net cost and water quality improvement of targeted and adopted conservation.

| | Cost for watershed | Cost per ha of watershed | Average pollutant removal | Total nitrogen export | Total phosphorus export | Sediment export |
|---|---|---|---|---|---|---|
| | *$/y* | *$/ha/y* | *% over no conservation* | *Annual pollutant export in kg per ha of watershed* | | |
| *No conservation scenarios* | | | | | | |
| **Little Pine:** No conservation practices | $0 | $0 | 0% | 40.08 | 2.66 | 556.26 |
| **Little Wea:** No conservation practices | $0 | $0 | 0% | 42.47 | 3.99 | 650.03 |
| *Existing conservation* | | | | | | |
| **Little Pine:** Existing conservation from Little Pine interviews | $110,946 | $24.75 | 5% | 39.47 | 2.54 | 509.15 |
| **Little Wea:** Existing conservation from Little Wea interviews | $76,060 | $13.62 | 13% | 39.77 | 3.39 | 535.12 |
| *Little Pine targeting* | | | | | | |
| **Watershed:** Targeted conservation in Little Pine | $493,186 | $110 | 53% | 29.92 | 1.18 | 123.21 |
| **Interview:** Adjusted targeted results for follow-up interviews | $259,648 | $58 | 30% | 35.29 | 1.89 | 274.23 |
| **Optimal:** Targeted conservation considered optimal (Yes) by farmers | $162,348 | $36 | 18% | 36.95 | 2.17 | 408.94 |
| **Adopted:** Targeted conservation adopted (Yes) | $148,226 | $33 | 16% | 37.29 | 2.21 | 418.72 |
| *Little Wea targeting* | | | | | | |
| **Watershed:** Targeted conservation in Little Wea | $551,292 | $99 | 65% | 27.45 | 1.05 | 92.95 |
| **Interview:** Adjusted targeted results for follow-up interviews | $176,417 | $32 | 23% | 37.52 | 2.96 | 453.53 |
| **Optimal:** Targeted conservation considered optimal (Yes) by farmers | $118,470 | $21 | 19% | 38.50 | 3.12 | 481.55 |
| **Adopted:** Targeted conservation adopted (Yes) | $107,672 | $19 | 17% | 38.83 | 3.20 | 502.26 |

## Appendix H Additional comparison for SWAT setup by Common Land Units

Additional graphs and statistics for Little Pine and Little Wea watersheds, comparing the SWAT setup by usual HRUs to the SWAT setup using common land units (CLUs) to define HRUs.

### Tables

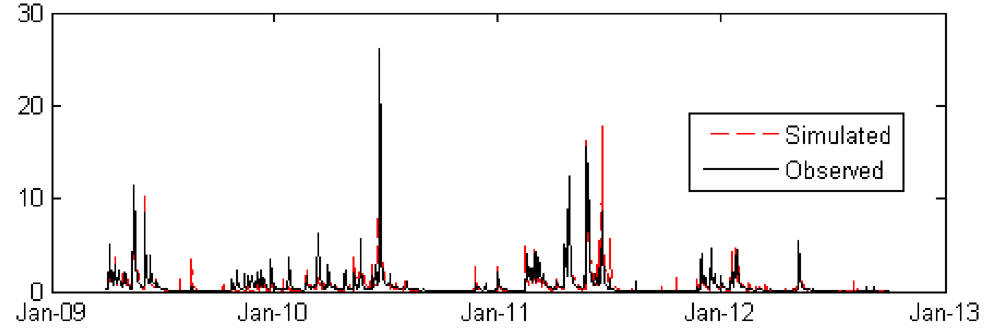
| Variable | Statistic | HRUs by usual method | HRUs by common land units | Observed values (2009-2012) |
|---|---|---|---|---|
| Flow at watershed outlet | | | | |
| Goodness-of-fit | R2 daily | 0.76 | 0.76 | |
| | NS daily | 0.76 | 0.76 | |
| | R2 monthly | 0.85 | 0.86 | |
| | NS monthly | 0.83 | 0.84 | |
| Total flow depth in m/y | | 0.36 | 0.37 | 0.39 |
| Tile flow in m/y | mean | 0.12 | 0.14 | |
| | std | 0.28 | 0.35 | |
| Precipitation in mm/day | mean | 2.89 | 2.89 | |
| | std | 8.11 | 8.11 | |
| Nutrient balance from output.std | | | | |
| Nitrate in surface flows in kg/day | mean | 52.57 | 38.86 | |
| | std | 158.26 | 97.14 | |
| Nitrate from tiles in kg/day | mean | 311.97 | 358.60 | |
| | std | 811.42 | 999.63 | |
| Total nitrate in kg/day | mean | 374.01 | 410.82 | |
| | std | 879.83 | 1059.00 | |
| Organic nitrogen in kg/day | mean | 121.99 | 112.52 | |
| | std | 425.22 | 378.72 | |
| Total nitrogen in kg/day | mean | 496.01 | 523.34 | |
| | std | 1158.50 | 1306.60 | |
| Total phosphorus in kg/day | mean | 15.76 | 3.01 | |
| | std | 69.60 | 19.34 | |

| | | | | |
|---|---|---|---|---|
| Sediment in t/day | mean | 5.20 | 5.41 | |
| | std | 26.60 | 28.63 | |
| Nutrient balance from output.rch | | | | |
| Total NO3 in mg/L | mean | 4.53 | 3.94 | 6.64 |
| | std | 6.53 | 5.99 | 4.01 |
| | min | 0.00 | 0.00 | 0.03 |
| | max | 42.19 | 37.89 | 23.20 |
| Total NO3 in kg/d | mean | 390.55 | 420.98 | 563.43 |
| | std | 884.52 | 1061.30 | 994.84 |
| | min | 0.00 | 0.00 | 0.01 |
| | max | 8531.00 | 10390.00 | 6356.80 |
| TP in mg/L | mean | 0.21 | 0.09 | 0.14 |
| | std | 0.23 | 0.11 | 0.13 |
| | min | 0.00 | 0.00 | 0.00 |
| | max | 1.44 | 0.51 | 0.89 |
| TP in kg/d | mean | 29.13 | 12.95 | 12.52 |
| | std | 102.09 | 42.11 | 43.58 |
| | min | 0.00 | 0.00 | 0.00 |
| | max | 1589.30 | 605.80 | 369.02 |
| Sed in mg/L | mean | 42.72 | 35.32 | 21.52 |
| | std | 56.27 | 56.90 | 33.13 |
| | min | 0.00 | 0.00 | 1.20 |
| | max | 432.70 | 494.09 | 261.00 |
| Sed in kg/d | mean | 6707.90 | 6490.70 | 4242.70 |
| | std | 25801.00 | 26949.00 | 21689.00 |
| | min | 0.00 | 0.00 | 1.08 |
| | max | 403100.00 | 425700.00 | 215300.00 |
| Crop yields (measured data is County-level data from 2007 - 2012) | | | | |
| Corn yield in t/ha/y | 10-year annual mean | 10.60 | 11.15 | 10.10 |
| Soybean yield in t/ha/y | 10-year annual mean | 2.46 | 2.68 | 3.30 |
| Percent of soils in watershed | | | | |
| Somewhat poorly drained | | 41% | 41% | |
| Poorly drained | | 21% | 24% | |
| Very poorly drained | | 4% | 3% | |

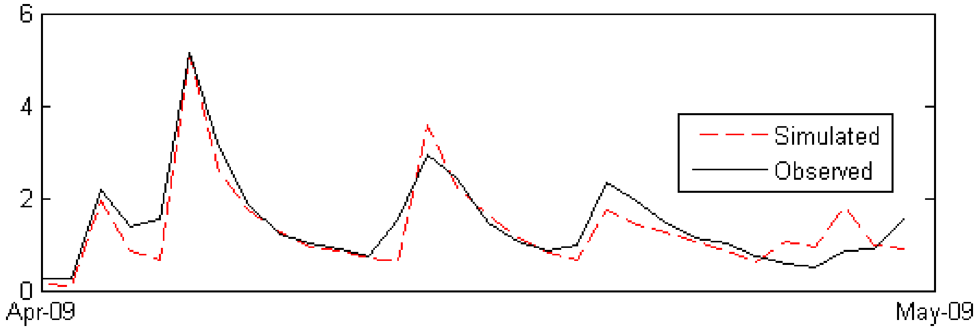
| | | |
|---|---|---|
| Total poorly drained | 67% | 68% |
| Tile-drained (% of watershed area) | 53% | 59% |
| Tile-drained (% of cropland area) | 67% | 68% |
| Percent of land use in watershed | | |
| Corn | 47% | 51% |
| Soybean | 33% | 37% |
| Hay | 6% | 5% |
| Grass | 10% | 2% |
| Forest | 4% | 5% |
| Other | 1% | 0% |

## Little Pine plots for usual HRU method

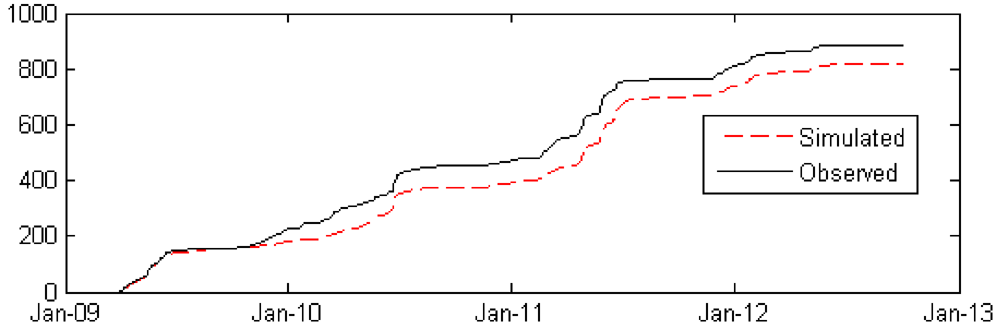
Uncalibrated Daily Time Series Plot: Flow (cms)

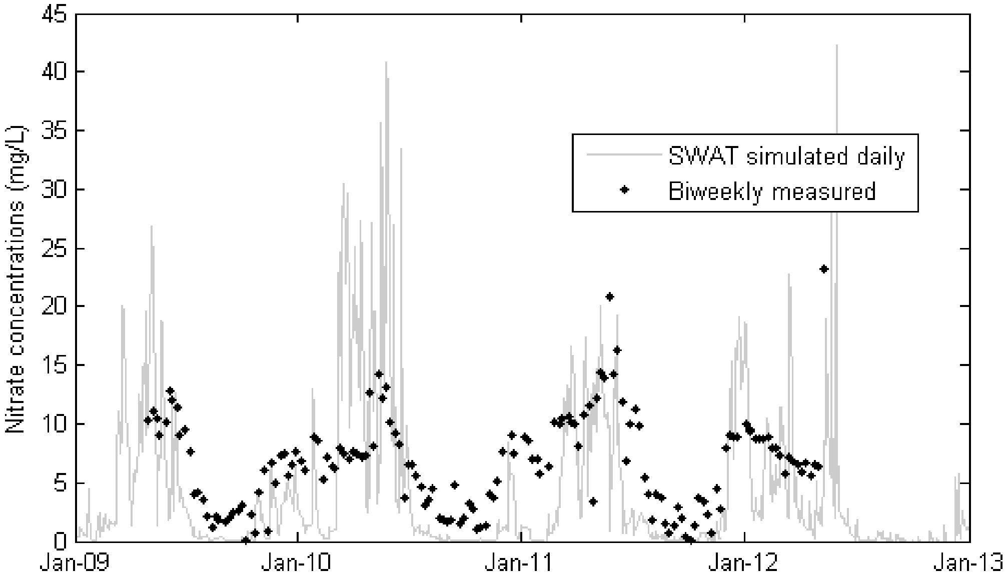


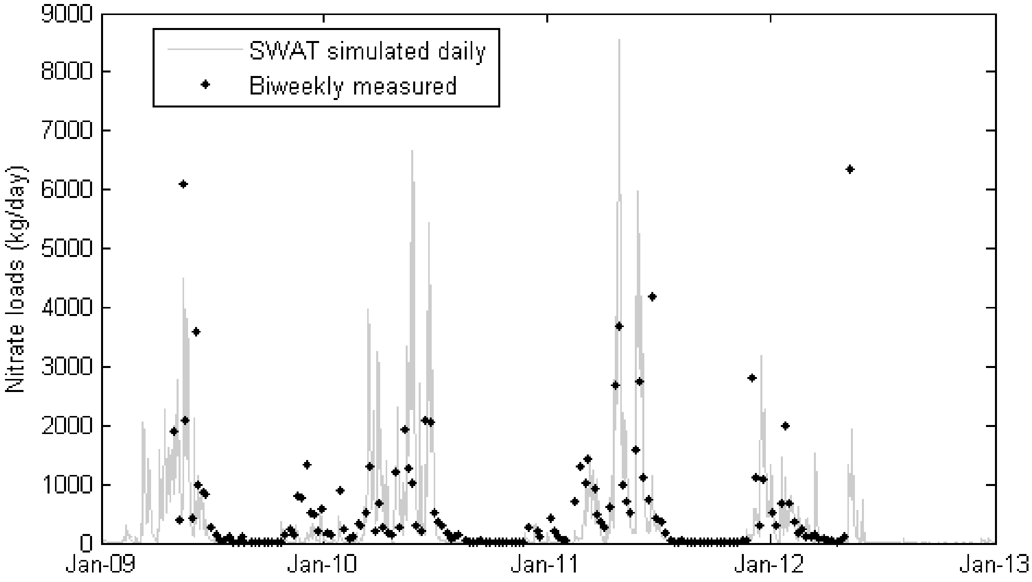
Zoom In Uncalibrated Time Series

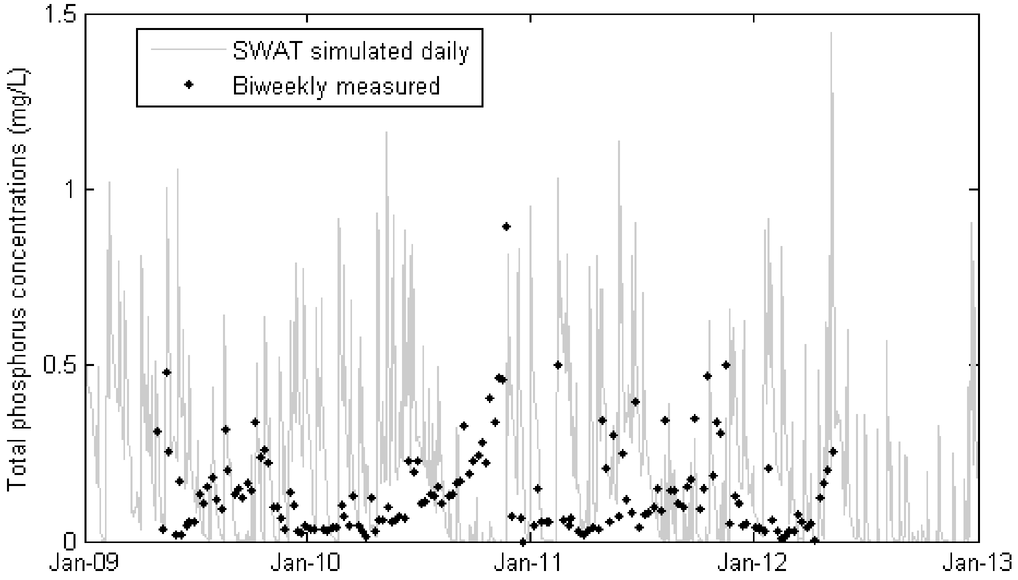


Uncalibrated Double Mass Curve

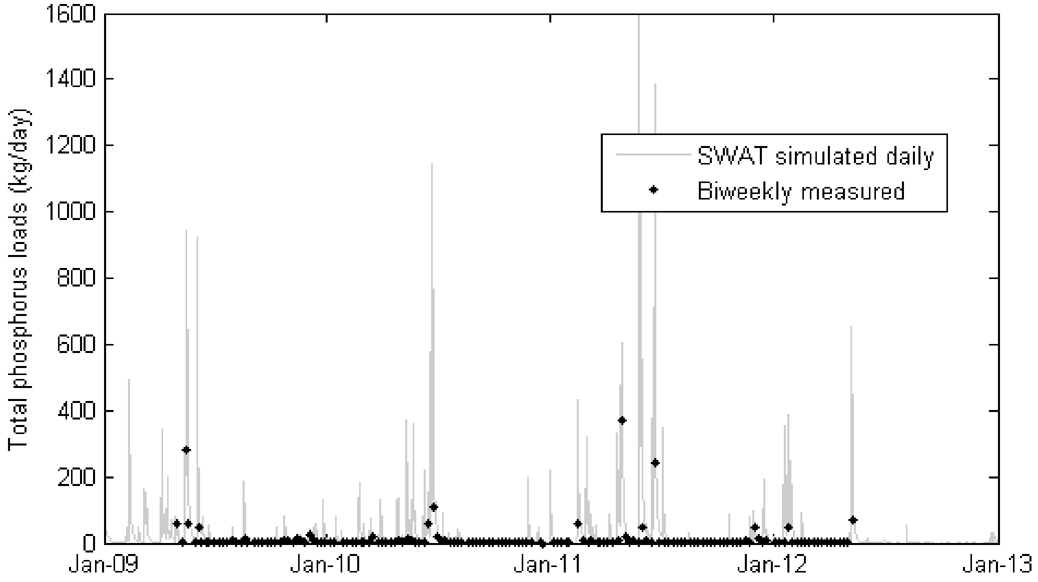



Nitrate concentrations (mg/L)
0
5
10
15
20
25
30
35
40
45
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
SWAT simulated daily
Biweekly measured

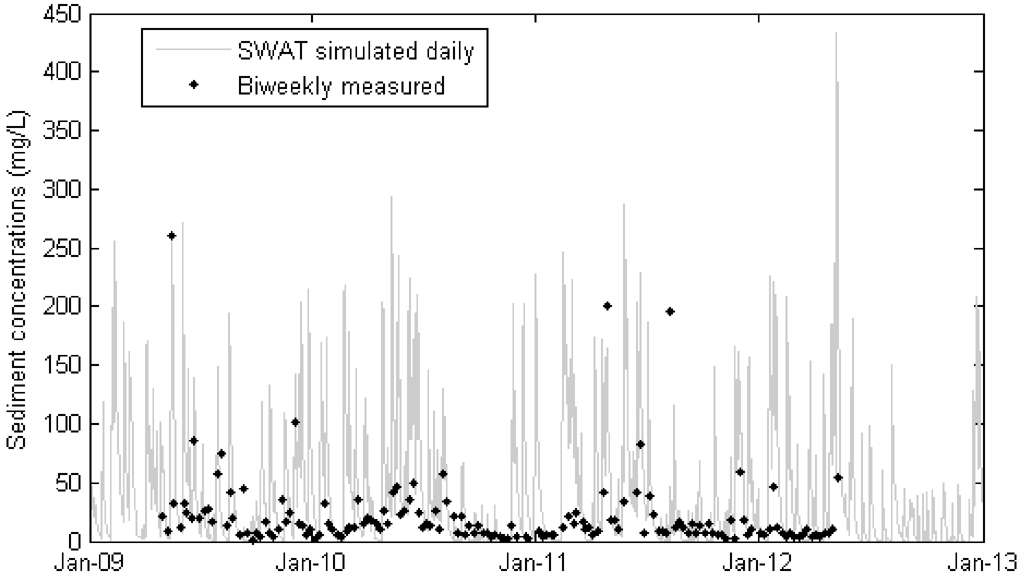

Nitrate loads (kg/day)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
SWAT simulated daily
Biweekly measured

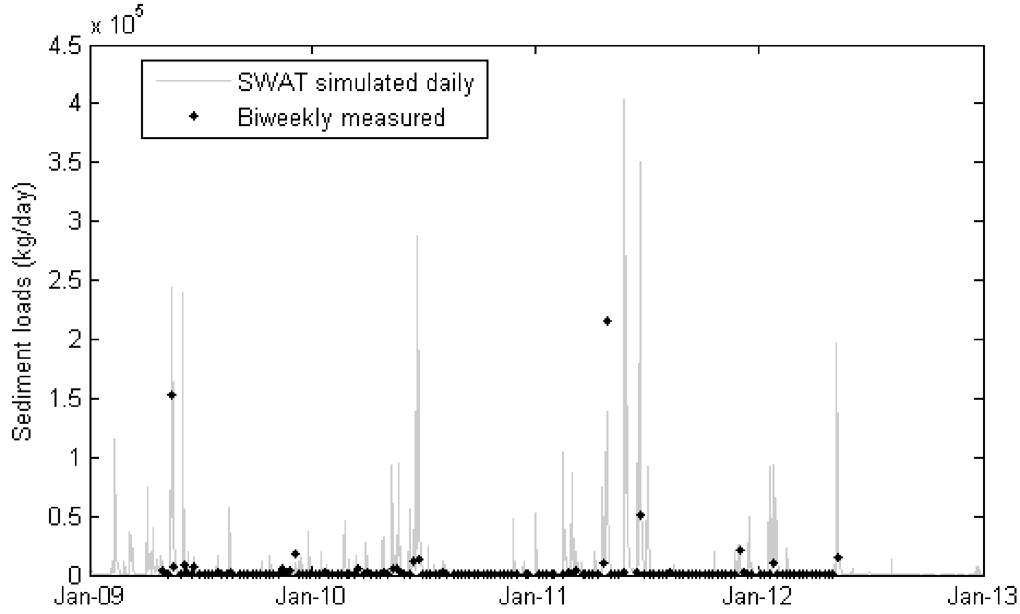


SWAT simulated daily
Biweekly measured
Total phosphorus concentrations (mg/L)
1.5
1
0.5
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13

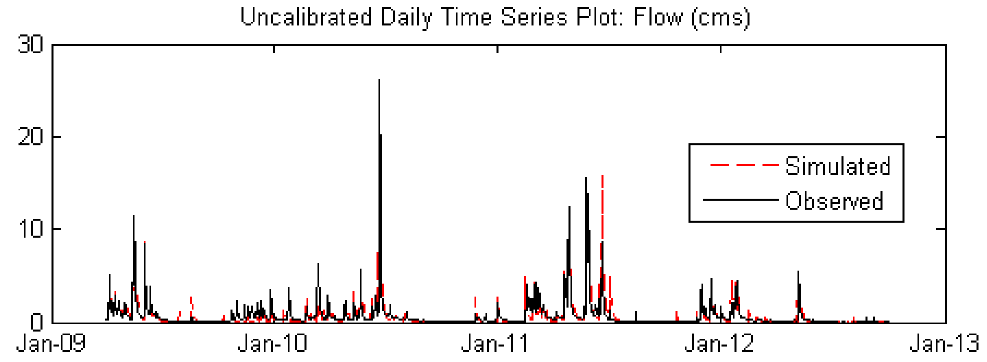


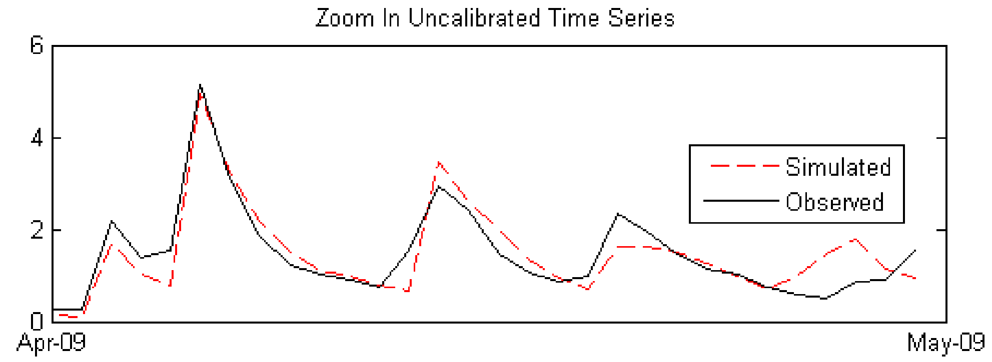
SWAT simulated daily
Biweekly measured
Total phosphorus loads (kg/day)
1600
1400
1200
1000
800
600
400
200
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13

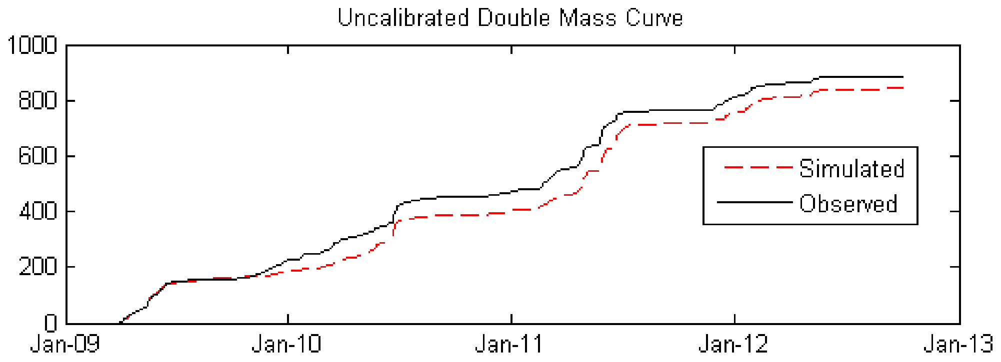

SWAT simulated daily
Biweekly measured
Sediment concentrations (mg/L)
450
400
350
300
250
200
150
100
50
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13

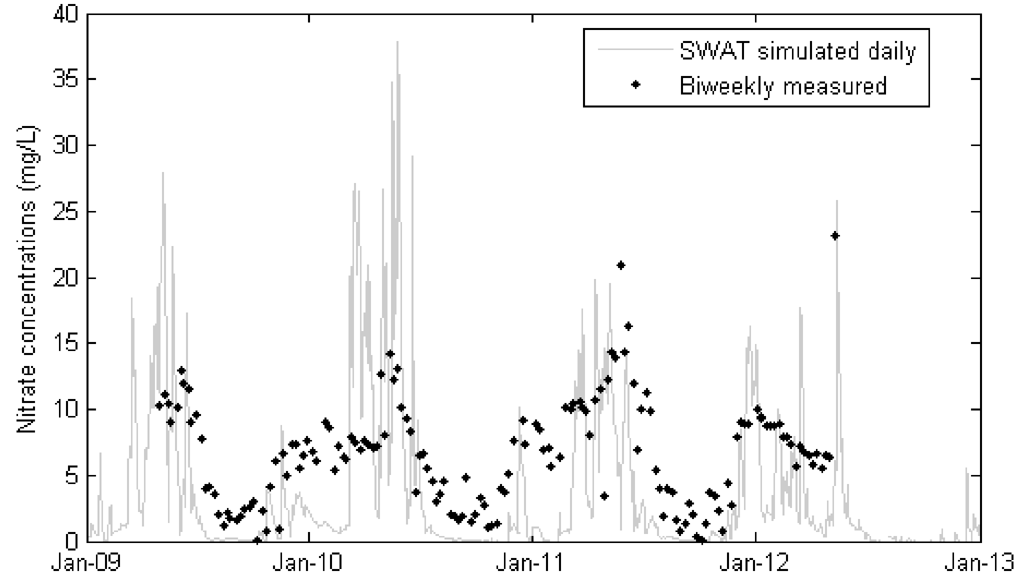

x 10^5
SWAT simulated daily
Biweekly measured
Sediment loads (kg/day)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13

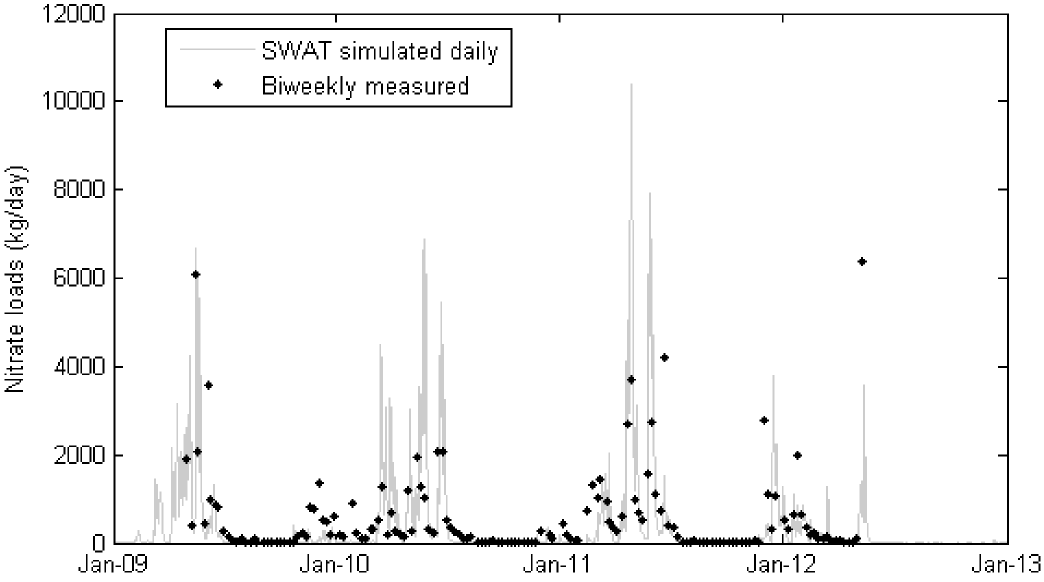
# Little Pine plots for HRU by field boundary method

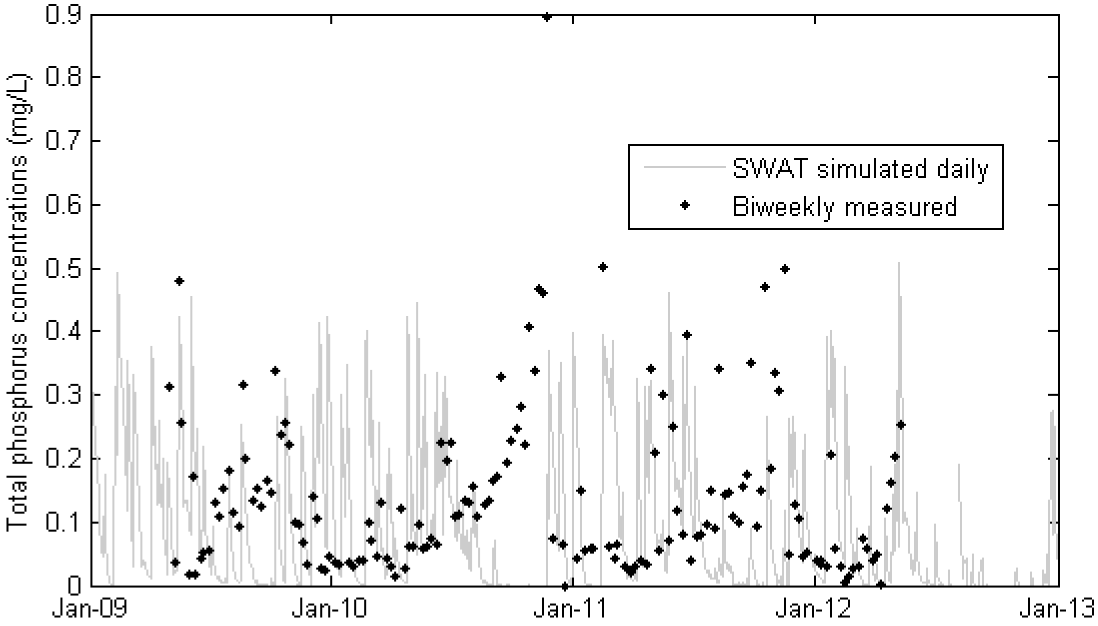


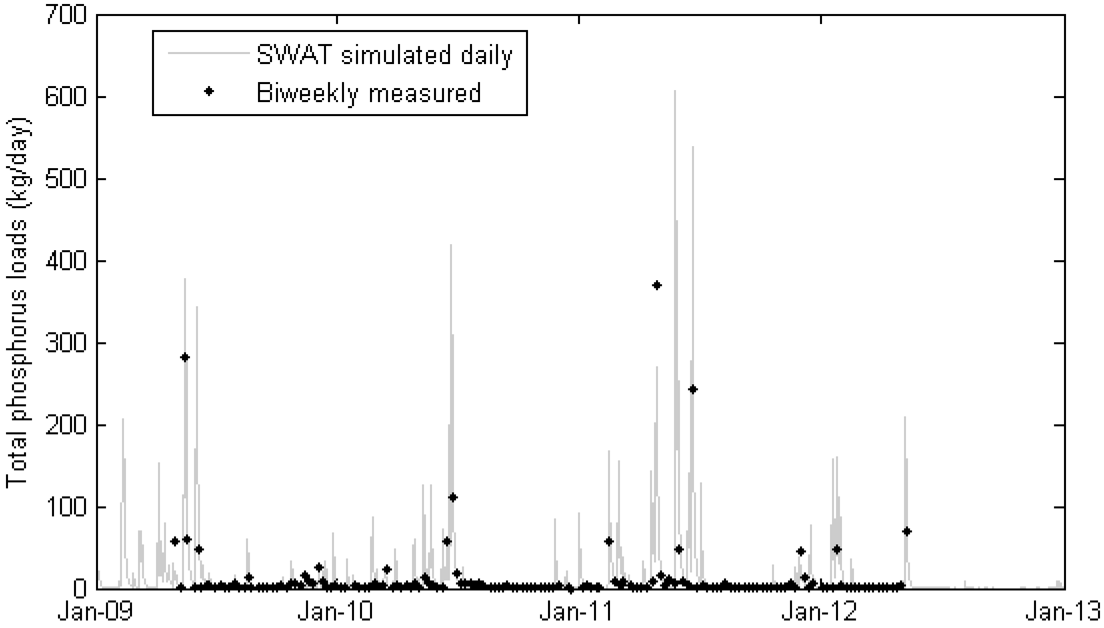


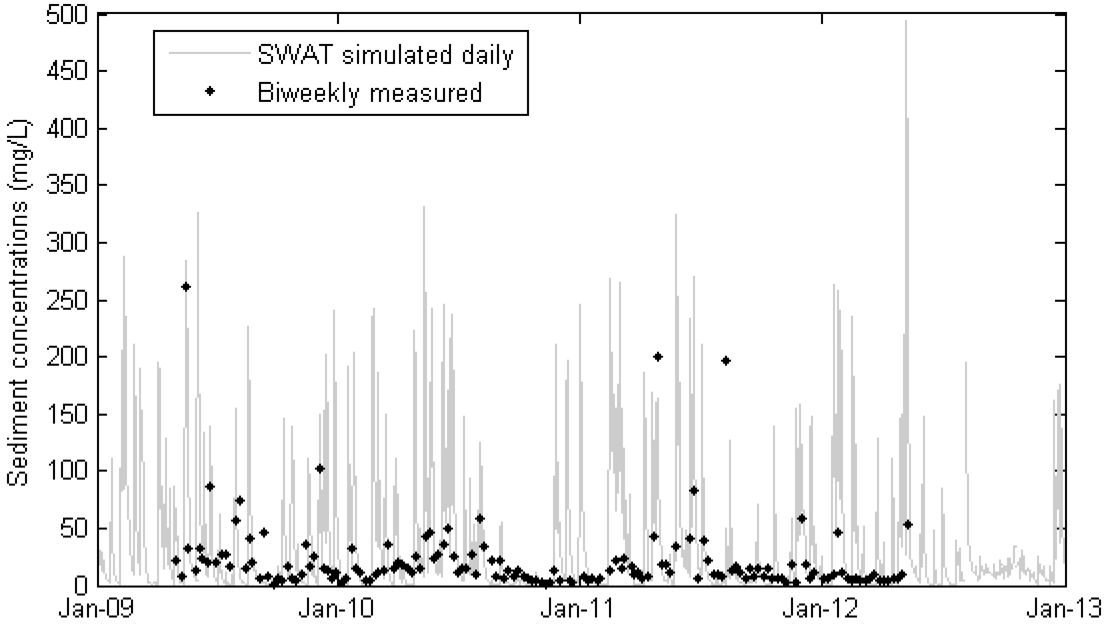


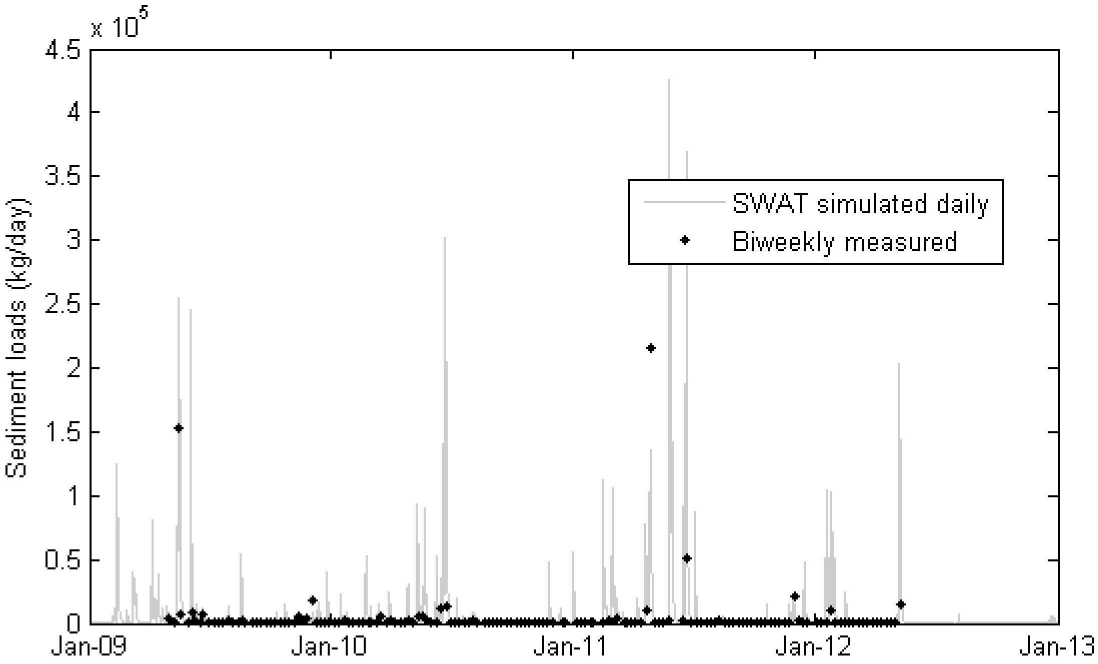

SWAT simulated daily
Biweekly measured
Nitrate concentrations (mg/L)
0
5
10
15
20
25
30
35
40
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13


SWAT simulated daily
Biweekly measured
Nitrate loads (kg/day)
0
2000
4000
6000
8000
10000
12000
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13


Total phosphorus concentrations (mg/L)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
SWAT simulated daily
Biweekly measured


Total phosphorus loads (kg/day)
700
600
500
400
300
200
100
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
SWAT simulated daily
Biweekly measured


Sediment concentrations (mg/L)
500
450
400
350
300
250
200
150
100
50
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
SWAT simulated daily
Biweekly measured


x 10^5
Sediment loads (kg/day)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
SWAT simulated daily
Biweekly measured

# Appendix I Comparing simulated and observed water quality data for only days with observed data

## Purpose

To see if water quality comparison (especially phosphorus and sediment in Little Wea) improves when comparing the simulated and observed data distributions (summary statistics) on only those days with observed data.

## Method

I updated and re-ran the matlab script that calculates summary statistics from output.std at the watershed outlet for a daily timescale, considering only simulated data from days with observed data. Table shown on next page.

## Result

In general, the subset data was fairly similar to the entire range in mean, standard deviation, minimum, and maximum. However, mean phosphorus and sediment loading generally worsened (was higher in subset than entire sample), while the maximum was more reasonable (lower than the entire sample). I noted these in red (worse) and green (better) highlighting in the table.

I don't think the subset clearly performed "better" than the entire sample. I will continue looking at the other suggestions made during the defense to compare water quality.

| Summary statistics for water quality data | | Little Wea | | | Little Pine | | |
|---|---|---|---|---|---|---|---|
| | | Simulated all days | Simulated subset | Observed | Simulated all days | Simulated subset | Observed |
| Total NO3 in mg/L | mean | 7.4 | 7.2 | 4.5 | 4.1 | 3.8 | 6.6 |
| | std | 10.0 | 10.4 | 2.7 | 6.1 | 5.5 | 4.0 |
| | min | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | max | 86.0 | 75.6 | 14.2 | 38.0 | 26.6 | 23.2 |
| Total NO3 in kg/d | mean | 471 | 559 | 372 | 444 | 410 | 563 |
| | std | 1,205 | 1,550 | 779 | 1,086 | 1,083 | 995 |
| | min | 0 | 0 | 0 | 0 | 0 | 0 |
| | max | 12,500 | 12,500 | 6,736 | 9,765 | 10,390 | 6,357 |
| TP in mg/L | mean | 0.4 | 0.4 | 0.0 | 0.1 | 0.1 | 0.1 |
| | std | 0.6 | 0.6 | 0.1 | 0.2 | 0.1 | 0.1 |
| | min | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | max | 3.0 | 2.8 | 0.7 | 0.8 | 0.4 | 0.9 |
| TP in kg/d | mean | 48 | 63 | 10 | 21 | 15 | 13 |
| | std | 182 | 220 | 52 | 68 | 40 | 44 |
| | min | 0 | 0 | -6 | 0 | 0 | 0 |
| | max | 3,001 | 1,841 | 475 | 946 | 269 | 369 |
| Sed in mg/L | mean | 62 | 71 | 14 | 30 | 37 | 22 |
| | std | 119 | 135 | 39 | 49 | 56 | 33 |
| | min | 0 | 0 | 0 | 0 | 0 | 1 |
| | max | 852 | 701 | 352 | 342 | 325 | 261 |
| Sed in kg/d | mean | 9,630 | 13,096 | 5,097 | 5,448 | 6,895 | 4,243 |
| | std | 43,902 | 52,711 | 33,020 | 22,929 | 22,219 | 21,689 |
| | min | 0 | 0 | 0 | 0 | 0 | 1 |
| | max | 786,900 | 472,800 | 360,840 | 352,600 | 154,100 | 215,300 |

# Appendix J Comparing simulated and observed water quality data by monthly loads

## Purpose

To see if water quality comparison (especially phosphorus and sediment in Little Wea) improves when comparing the simulated and observed data distributions (summary statistics) at the monthly time scale.

## Method

I updated and re-ran the matlab script that calculates summary statistics from output.std at the watershed outlet for a monthly timescale. Daily concentrations were averaged to monthly concentrations, while daily flow rates were averaged to monthly flow rates. Then monthly concentration and flow were used to calculate monthly loads.

## Results

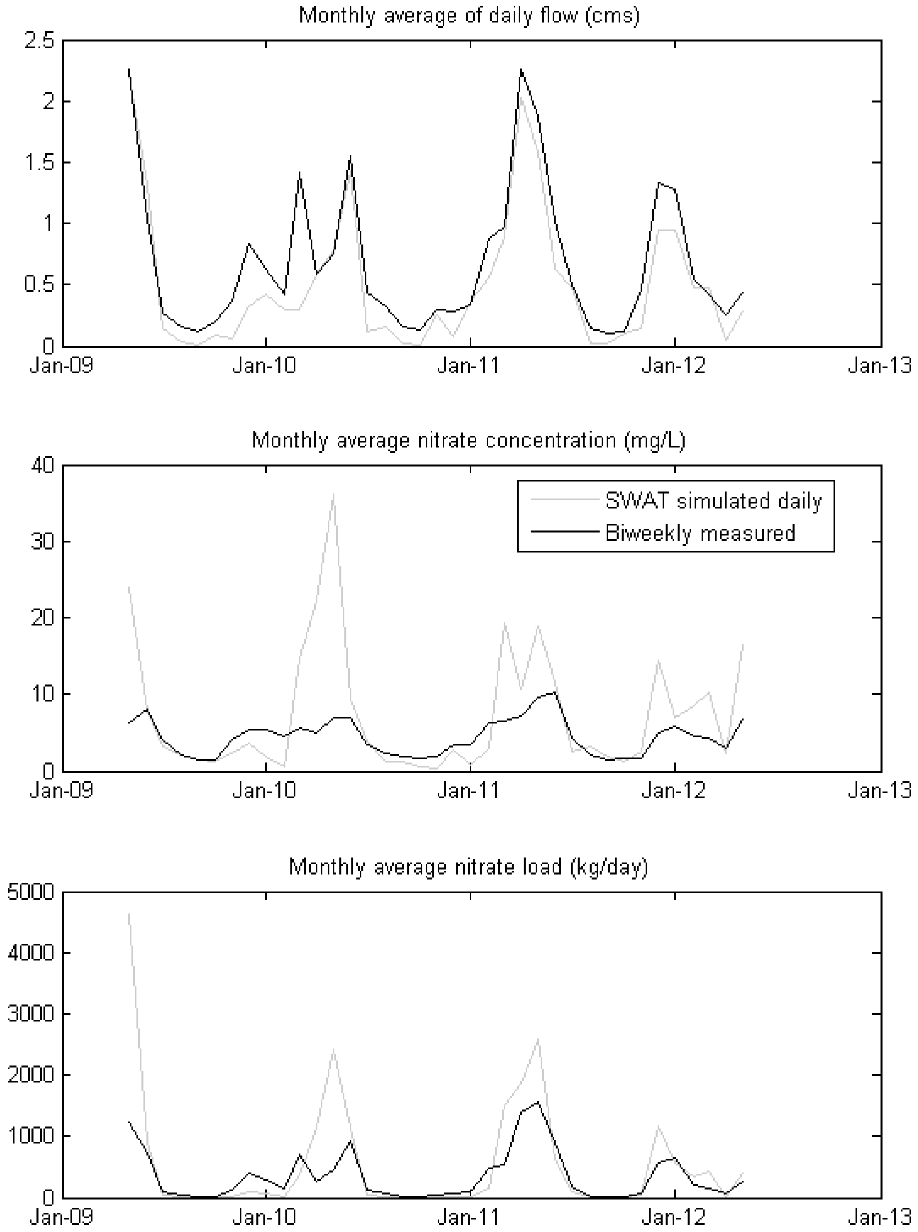
Results are shown in the table and figures below. The monthly approach shifted average loading significantly. Little Wea water quality is still not well predicted by the SWAT model, while Little Pine predictions are fairly close to measured data. You can see the seasonal variability clearly in the graphs. I am a little concerned about taking measured concentrations from four days in a month and predicting monthly loads, because these concentrations may not be representative of the entire month. I explored this a little in the last set of plots for each watershed, titled “Additional plots to show how weekly observed measurements (blue) relate to their monthly average.” Nitrate concentrations were fairly constant in a given month, so their average is probably representative of the month (provided no major storm even was missed). Sediment and phosphorus, however, varied widely in the daily time scale so the monthly average may not be representative. In conclusion, I’m not sure whether including monthly averages improves the model evaluation enough over the daily comparison to include in my papers, and I’d be happy to hear from the committee if they have any preference.

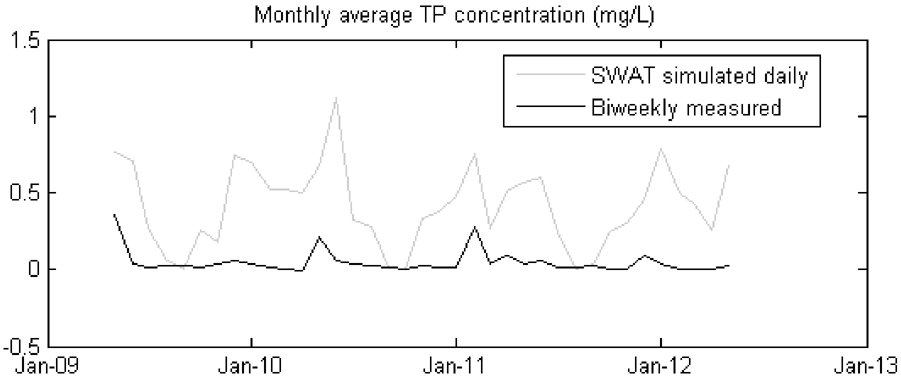
| | | Little Wea | | Little Pine | |
|---|---|---|---|---|---|
| | | Simulated monthly | Observed monthly | Simulated monthly | Observed monthly |
| Total NO3 in mg/L | mean | 7.4 | 4.5 | 4.2 | 6.8 |
| | std | 8.3 | 2.4 | 4.9 | 3.6 |
| | min | 0.4 | 1.4 | 0.0 | 1.6 |
| | max | 36.2 | 10.3 | 18.4 | 15.3 |
| Total NO3 in kg/d | mean | 561.9 | 351.5 | 450.4 | 588.4 |
| | std | 974.6 | 411.9 | 711.0 | 733.9 |
| | min | 0.3 | 13.1 | 0.0 | 4.1 |
| | max | 4,623.0 | 1,566.2 | 2,536.0 | 3,330.3 |
| TP in mg/L | mean | 0.4 | 0.0 | 0.1 | 0.1 |
| | std | 0.3 | 0.1 | 0.1 | 0.1 |
| | min | 0.0 | 0.0 | 0.0 | 0.0 |
| | max | 1.1 | 0.4 | 0.2 | 0.5 |
| TP in kg/d | mean | 26.4 | 4.8 | 8.5 | 8.1 |
| | std | 37.0 | 12.0 | 11.9 | 10.4 |
| | min | 0.0 | -0.6 | 0.0 | 0.5 |
| | max | 147.4 | 68.7 | 47.5 | 35.0 |
| Sed in mg/L | mean | 64.6 | 13.8 | 36.9 | 21.2 |
| | std | 43.3 | 24.3 | 23.1 | 16.0 |
| | min | 0.0 | 1.4 | 2.4 | 3.3 |
| | max | 182.8 | 142.0 | 87.6 | 67.2 |
| Sed in kg/d | mean | 4,189.1 | 1,618.8 | 3,305.3 | 1,901.6 |
| | std | 6,044.1 | 4,656.1 | 4,737.4 | 3,013.1 |
| | min | 0.0 | 14.9 | 3.3 | 20.0 |
| | max | 22,617.0 | 27,642.0 | 19,996.0 | 13,157.0 |

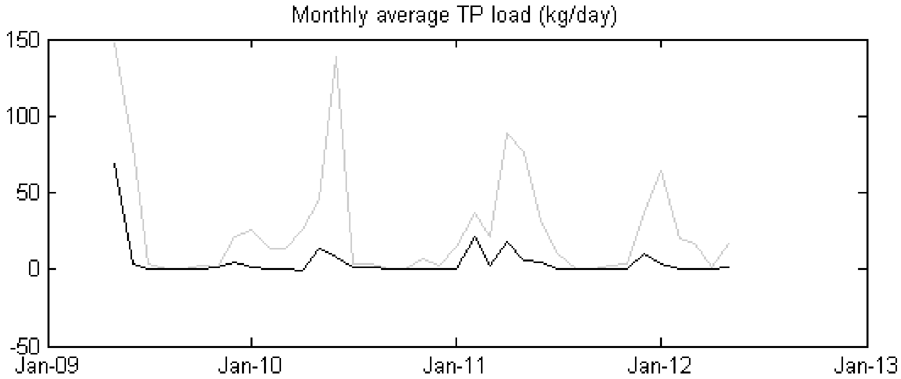
We see a sizable shift between the original values for both simulated and observed when we take a monthly average of all days rather than daily average. For instance, phosphorus and sediment loading are lower for both simulated and observed in the monthly approach.

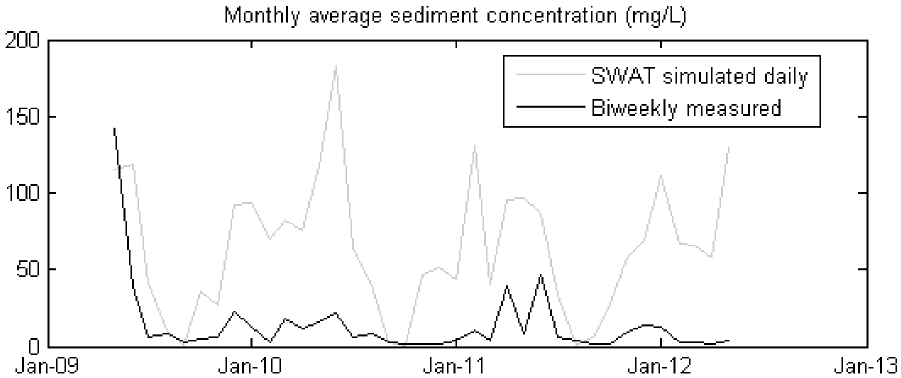
In general, Little Pine water quality appears to be predicted fairly well, and Little Wea pollutants are consistently over-estimated, especially phosphorus and sediment. Figures show this over-estimation clearly.

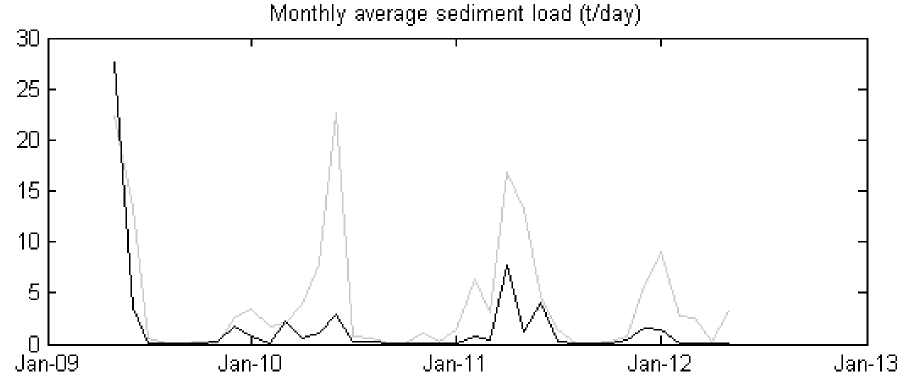
Little Wea plots



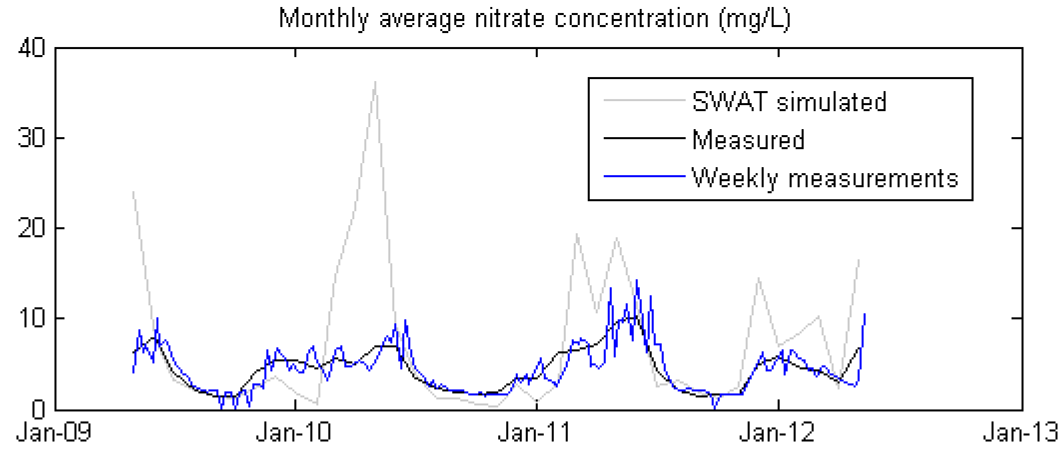

Monthly average TP concentration (mg/L)

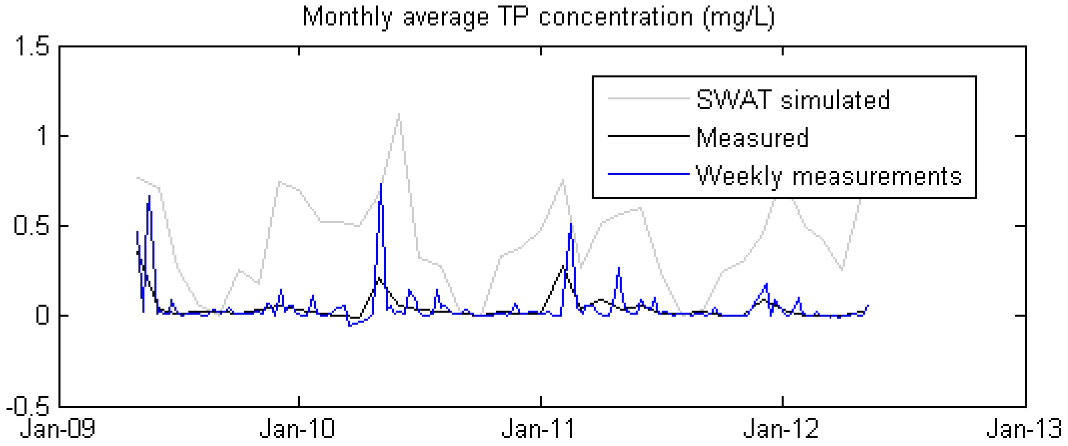

Monthly average TP load (kg/day)

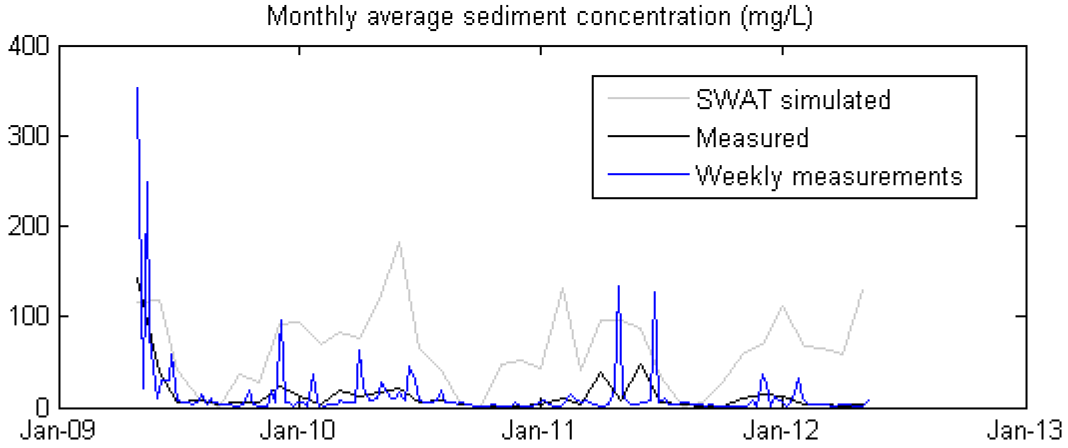

Monthly average sediment concentration (mg/L)


Monthly average sediment load (t/day)

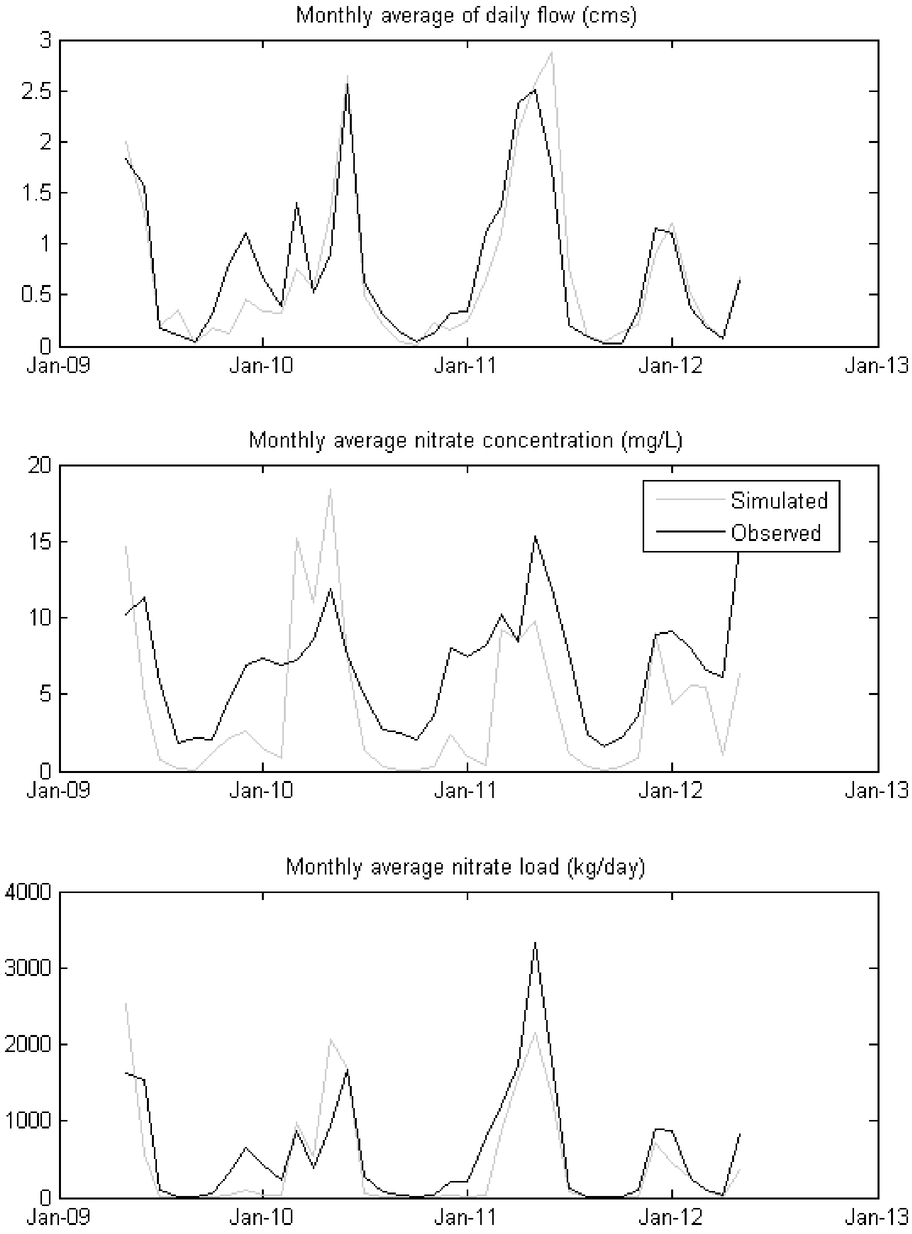
Additional plots to show weekly observed measurements along with monthly averages.

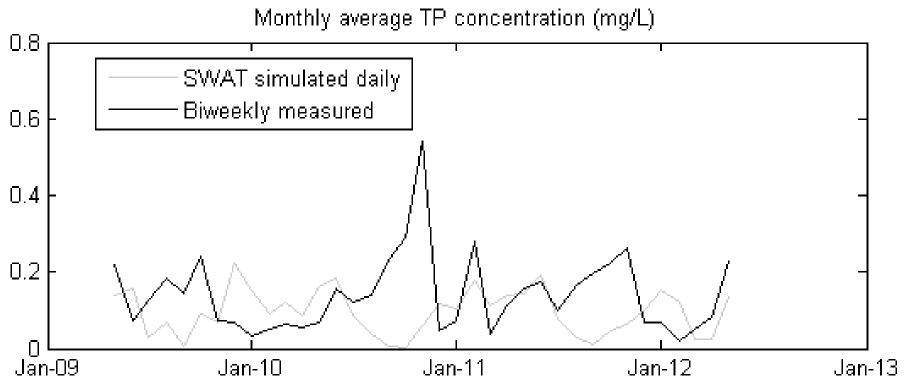


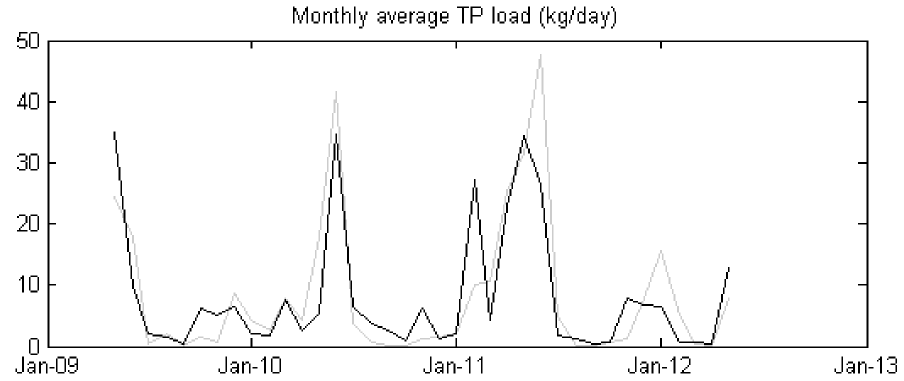


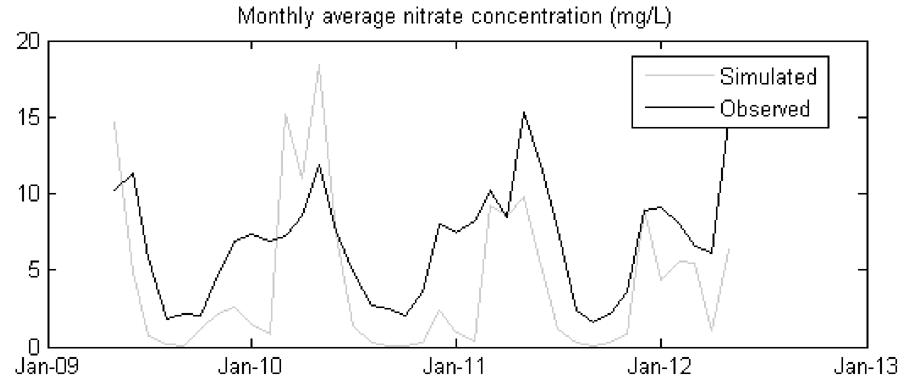


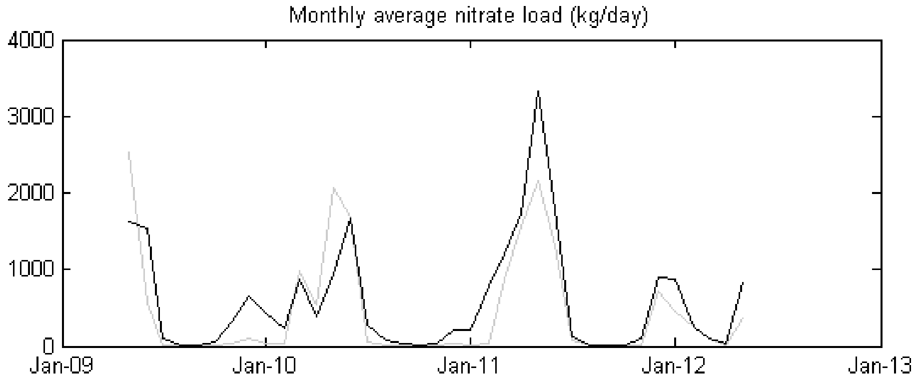
Little Pine plots



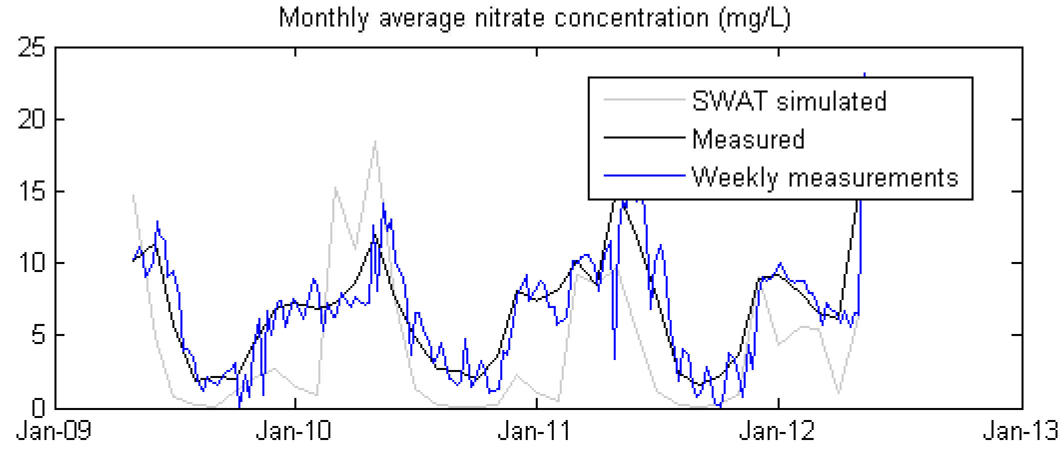

Monthly average TP concentration (mg/L)
SWAT simulated daily
Biweekly measured
0.8
0.6
0.4
0.2
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13

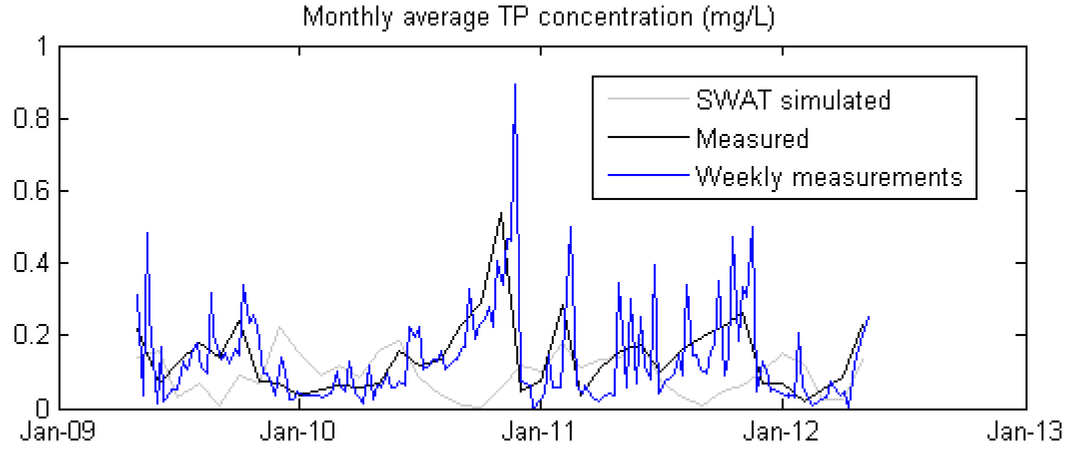

Monthly average TP load (kg/day)
50
40
30
20
10
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13

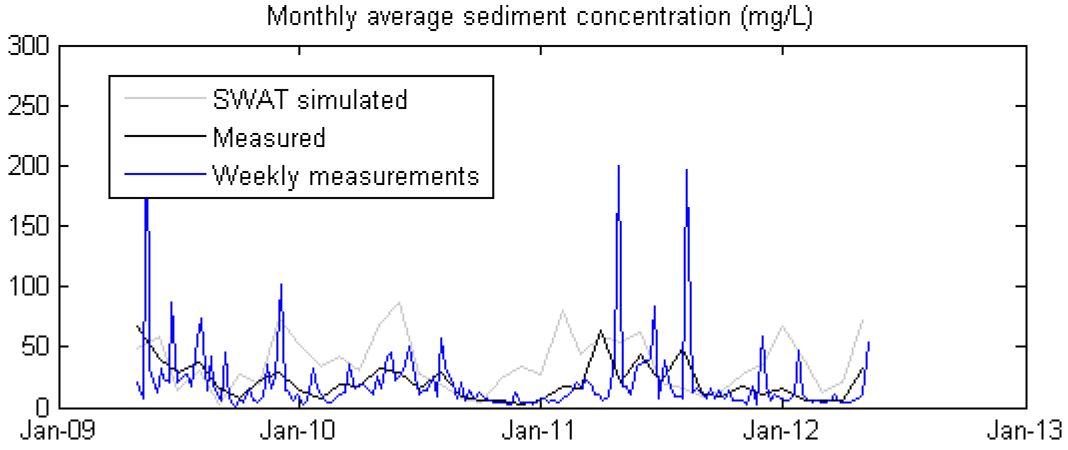

Monthly average nitrate concentration (mg/L)
Simulated
Observed
20
15
10
5
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13


Monthly average nitrate load (kg/day)
4000
3000
2000
1000
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13

Additional plots to show weekly observed measurements along with monthly averages.


Monthly average nitrate concentration (mg/L)


Monthly average TP concentration (mg/L)


Monthly average sediment concentration (mg/L)

# Appendix K Comparing simulated and observed water quality data using in-stream water quality modeling (IWQ=1)

## Purpose

To see if water quality comparison (especially phosphorus and sediment in Little Wea) improves when in-stream water quality routine is turned on (IWQ = 1 in basins.bsn)

## Method

I flagged on the in-stream water quality routine (IWQ = 1) in the basins.bsn file for each SWAT setup. Then I re-ran the matlab script that calculates summary statistics from output.std at the watershed outlet for daily and monthly timescales.

## Results

In-stream nutrient processing made almost no difference at all in the daily and monthly nitrate, TP, and sediment loads reaching the watershed outlet. You can see this from the table, which shows the original WQ statistics alongside the ones obtained using in-stream processes. You can also compare the graphs here to Appendix J to see that the monthly loads and concentrations are nearly identical.

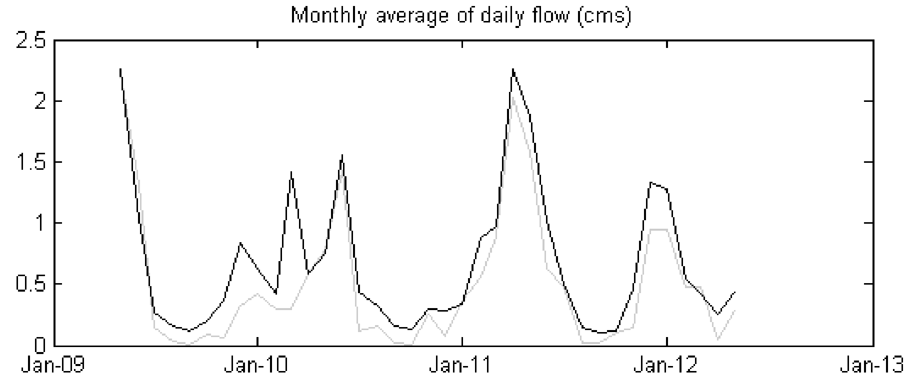
In conclusion, in-stream processes made very little impact on nitrate, TP, and sediment loads in the two watersheds. This confirms that the decision not to include in-stream processes in the SWAT setups did not make a difference in the main findings from this study.

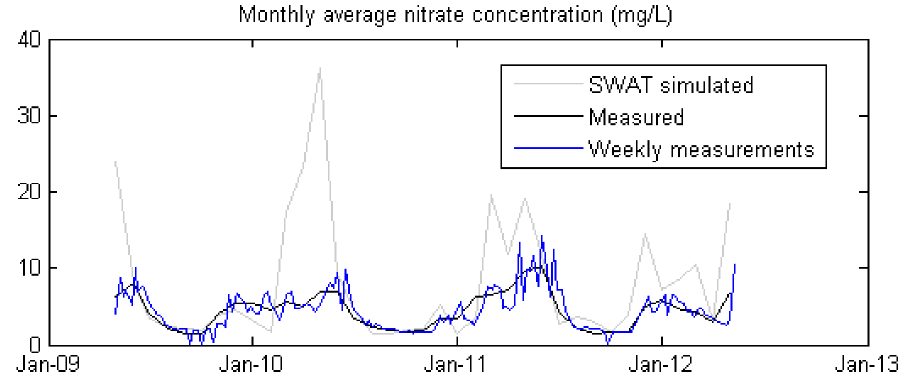
| | | Little Wea | | | Little Pine | | |
|---|---|---|---|---|---|---|---|
| | | In-stream simulated daily | Original simulated daily | Observed daily | In-stream simulated daily | Original simulated daily | Observed daily |
| Total NO3 in mg/L | mean | 8.4 | 7.4 | 4.5 | 4.4 | 4.1 | 6.6 |
| | std | 9.9 | 10.0 | 2.7 | 5.8 | 6.1 | 4.0 |
| | min | 0.3 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 |
| | max | 86.0 | 86.0 | 14.2 | 37.9 | 38.0 | 23.2 |
| Total NO3 in kg/d | mean | 473.2 | 471.0 | 371.7 | 424.0 | 444.0 | 563.4 |
| | std | 1,203.7 | 1,204.5 | 778.6 | 1,060.2 | 1,086.1 | 994.8 |
| | min | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 |
| | max | 12,500.0 | 12,500.0 | 6,736.3 | 10,390.0 | 9,765.0 | 6,356.8 |
| TP in mg/L | mean | 0.4 | 0.4 | 0.0 | 0.1 | 0.1 | 0.1 |
| | std | 0.6 | 0.6 | 0.1 | 0.1 | 0.2 | 0.1 |
| | min | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | max | 3.0 | 3.0 | 0.7 | 0.5 | 0.8 | 0.9 |
| TP in kg/d | mean | 47.8 | 48.0 | 10.4 | 13.0 | 20.5 | 12.5 |
| | std | 181.3 | 182.3 | 52.3 | 41.9 | 68.3 | 43.6 |
| | min | 0.0 | 0.0 | -5.9 | 0.0 | 0.0 | 0.0 |
| | max | 2,981.6 | 3,000.8 | 475.4 | 603.4 | 946.1 | 369.0 |
| Sed in mg/L | mean | 62.2 | 62.2 | 14.2 | 35.3 | 30.1 | 21.5 |
| | std | 118.7 | 118.7 | 38.7 | 56.9 | 49.2 | 33.1 |
| | min | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 |
| | max | 852.3 | 852.3 | 352.0 | 494.1 | 341.9 | 261.0 |
| Sed in kg/d | mean | 9,630.1 | 9,630.1 | 5,097.3 | 6,490.7 | 5,448.1 | 4,242.7 |
| | std | 43,902.0 | 43,902.0 | 33,020.0 | 26,949.0 | 22,929.0 | 21,689.0 |
| | min | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 |
| | max | 786,900.0 | 786,900.0 | 360,840.0 | 425,700.0 | 352,600.0 | 215,300.0 |

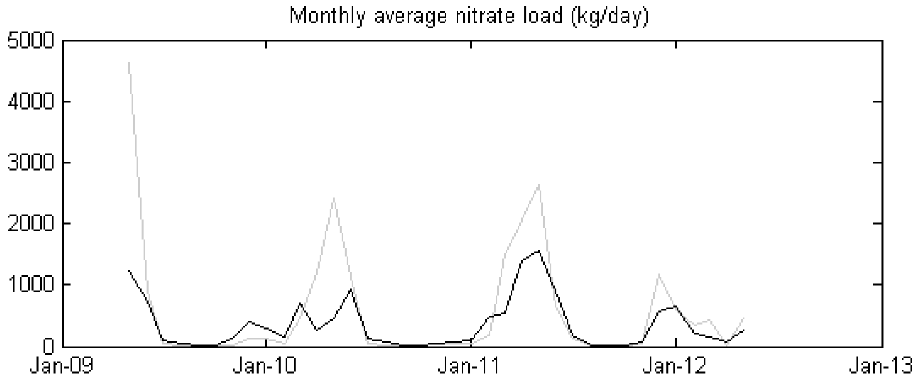
Differences between original SWAT model and model with in-stream processing shown in purple. The in-stream processing barely impacted Little Wea, though phosphorus in Little Pine was reduced (and closer to measured) when considering in-stream processing, while sediment was increased somewhat (farther from measured). Overall the impacts were fairly low.

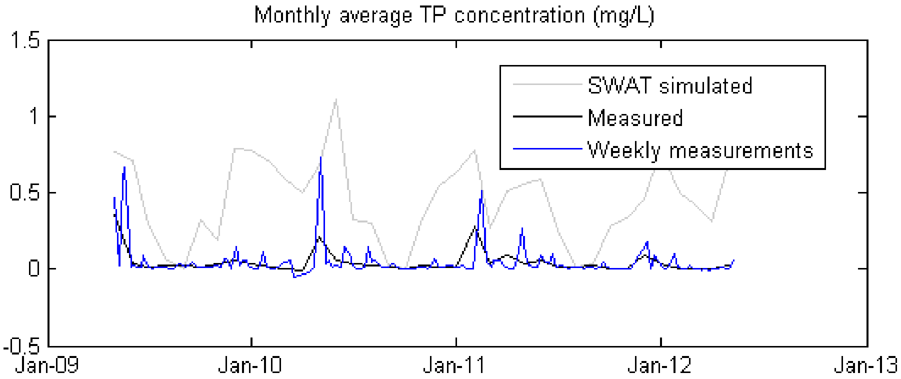
The sediment concentrations and loads were identical for Little Wea, which seems odd. I double-checked that these are correct, and they are.

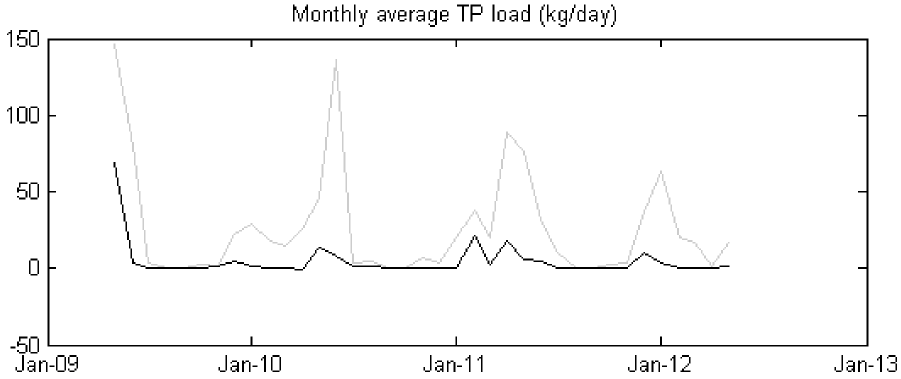
# Little Wea plots

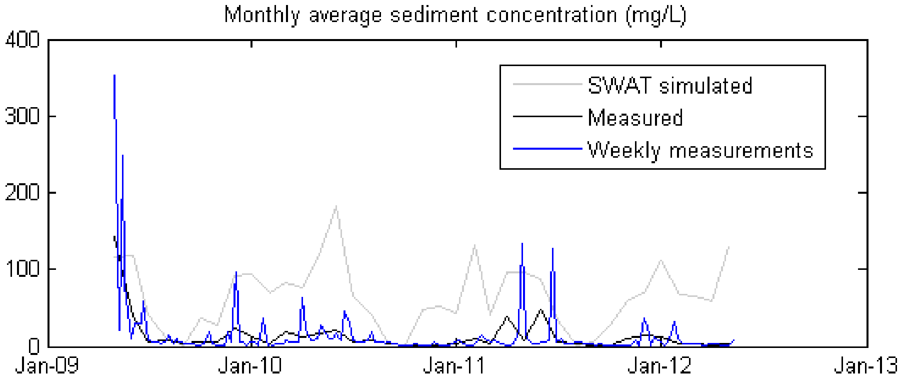


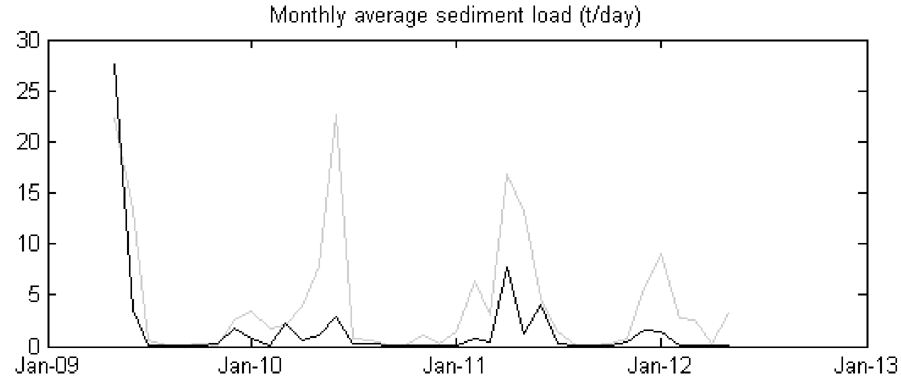




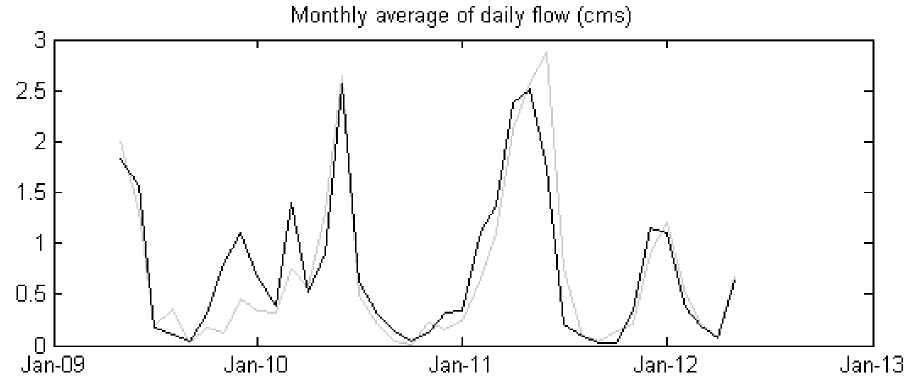

Monthly average TP concentration (mg/L)


Monthly average TP load (kg/day)

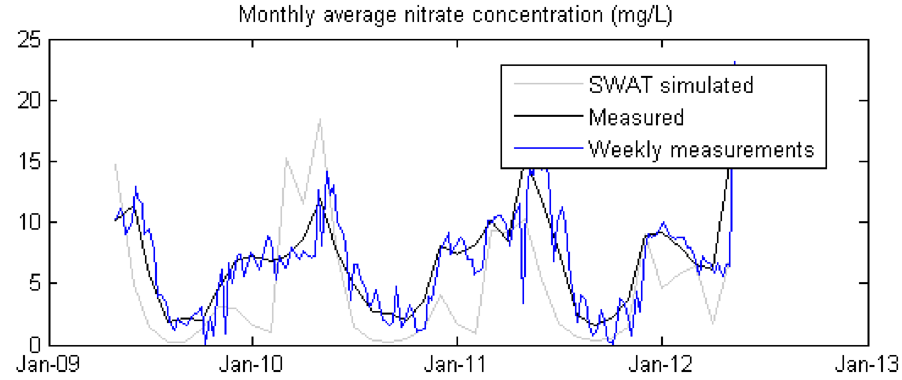

Monthly average sediment concentration (mg/L)


Monthly average sediment load (t/day)

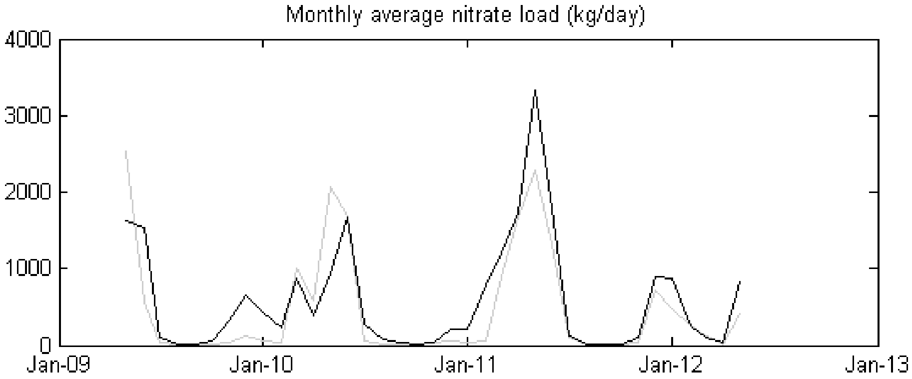
# Little Pine plots



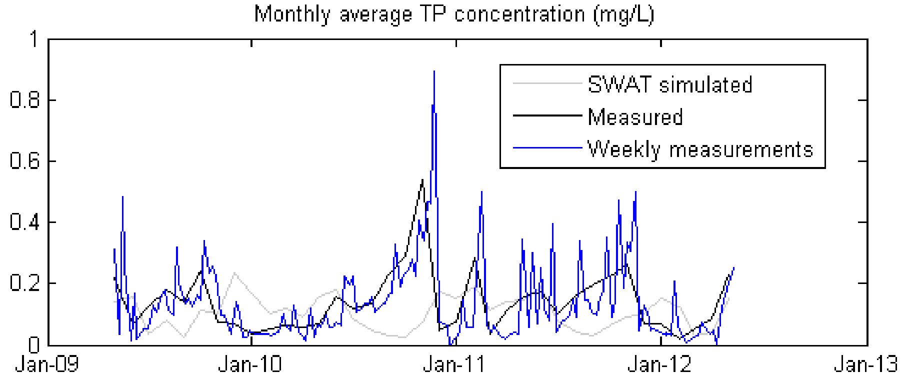
Monthly average of daily flow (cms)

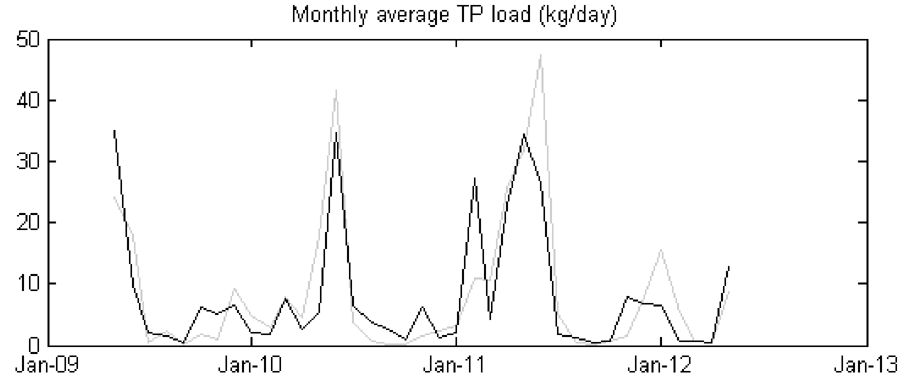


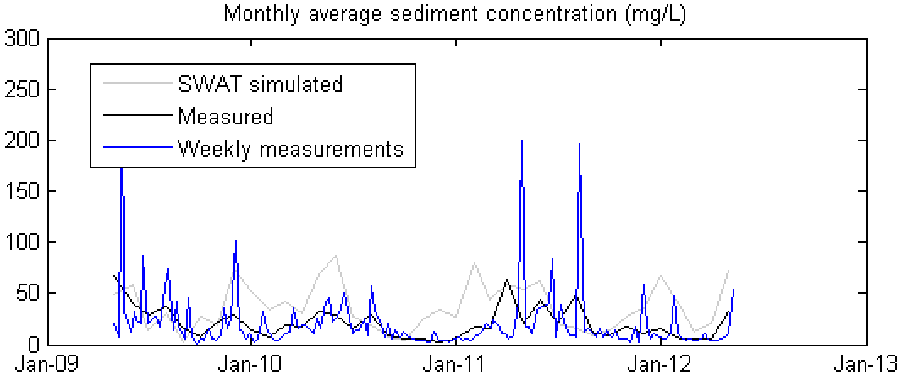
Monthly average nitrate concentration (mg/L)

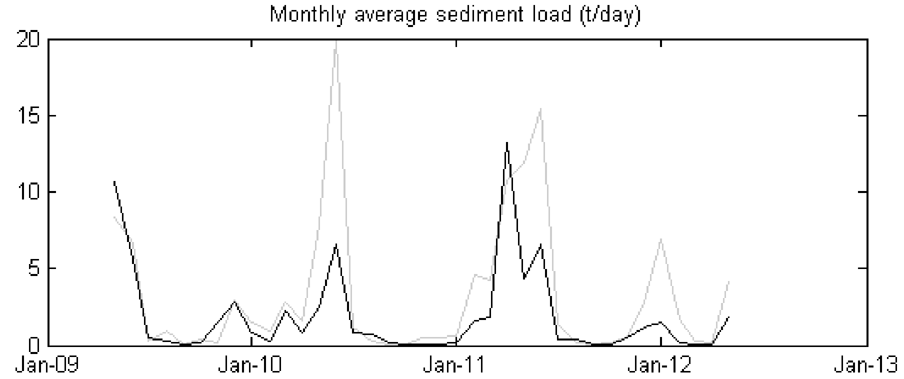


Monthly average nitrate load (kg/day)


Monthly average TP concentration (mg/L)
SWAT simulated
Measured
Weekly measurements
1
0.8
0.6
0.4
0.2
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13


Monthly average TP load (kg/day)
50
40
30
20
10
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13


Monthly average sediment concentration (mg/L)
SWAT simulated
Measured
Weekly measurements
300
250
200
150
100
50
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13


Monthly average sediment load (t/day)
20
15
10
5
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13

# Appendix L Comparing simulated and observed water quality data when considering high flow events vs. baseflow

## Purpose

To see if water quality comparison (especially phosphorus and sediment in Little Wea) improves when differentiating days when streamflow is dominated by storm water vs. baselow.

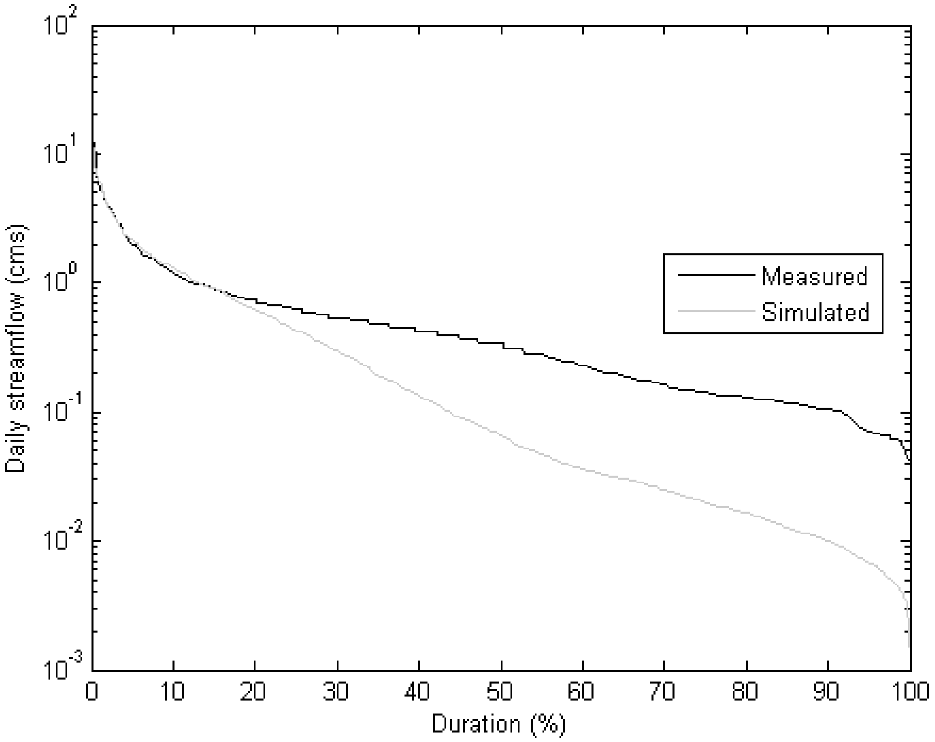
## Method

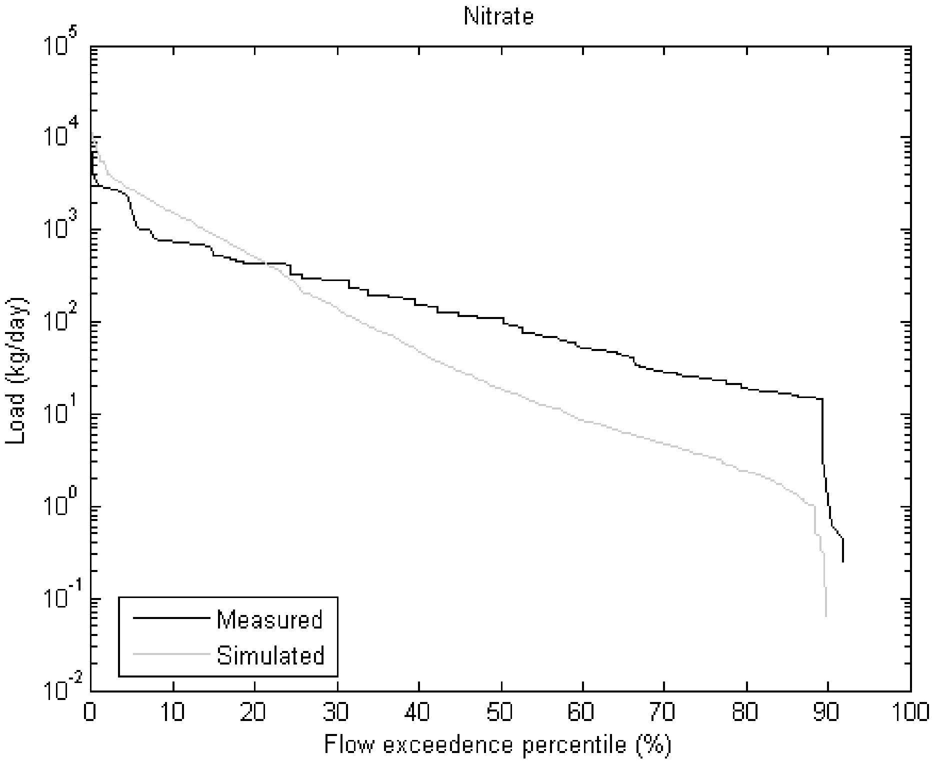
I created flow and load duration curves for each watershed, comparing measured and simulated data. The flow duration curves are from daily flow data. The load duration curves used daily simulated data and weekly measured data. An important adjustment, however, was making sure to calculate exceedance probability of measured data using the daily dataset. If I only used the subset of dates with sampling to create the load duration curve, then I am biasing the distribution to only the days when samples were taken, which we already discussed could be a problem in comparing measured to simulated data. Therefore, this approach allows me to essentially remove this bias from the data. It also shows where the model predictions are the most problematic.

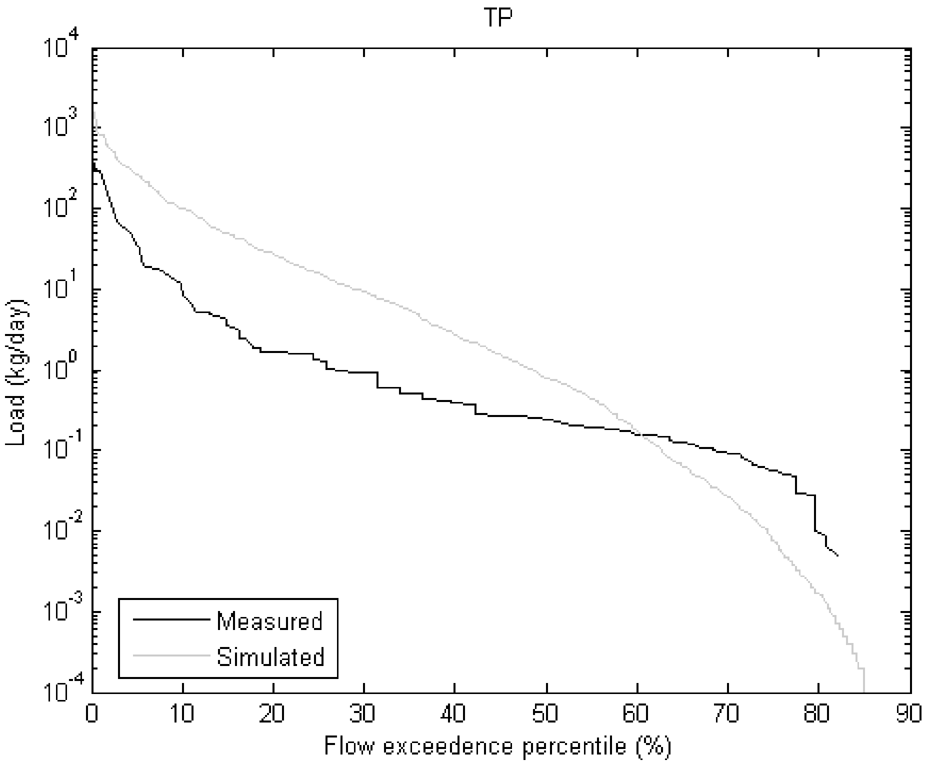
## Results

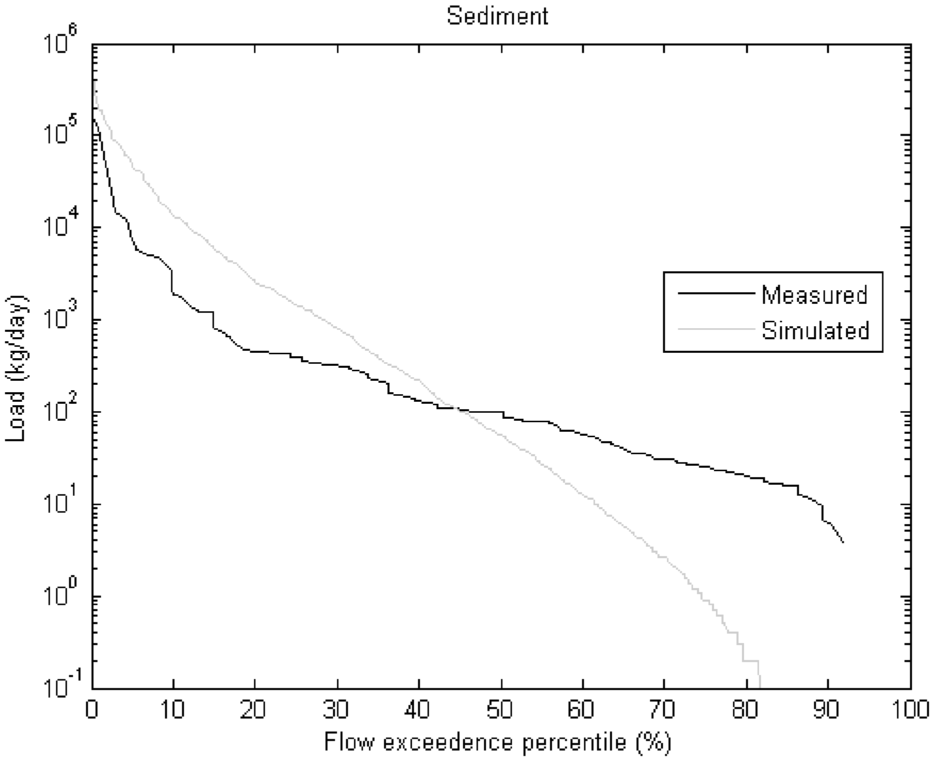
Flow duration curves show that the Little Pine model predicts flows well across all high and low flow events. Little Wea, however, had good prediction only during high flow events. Baseflow and medium flows were clearly under-estimated. Load duration curves for nitrate, TP, and sediment showed a fairly good match for Little Pine, although some lower flows had under-predicted nitrate. Little Wea had over-predicted WQ indicators in the high flows and under-predicted in the low flows. I'm not exactly sure what the take-home message of this is. I think this shows that there is an issue with Little Wea water quality regardless of the river stage, and that removing bias based on storm flow vs. baseflow does not solve the problem.

## Little Wea plots

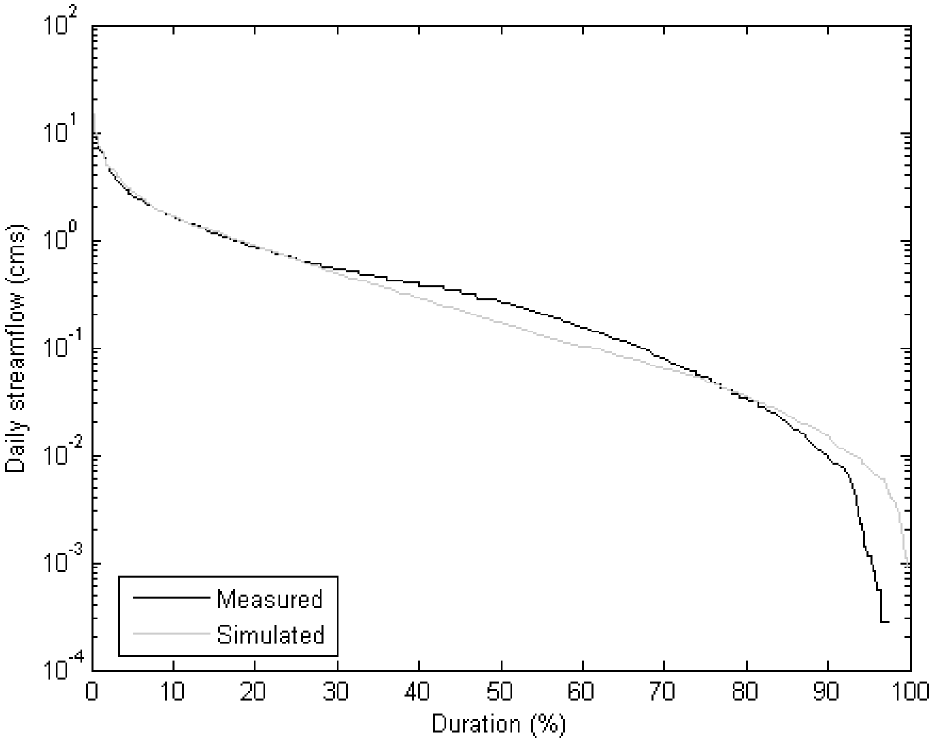


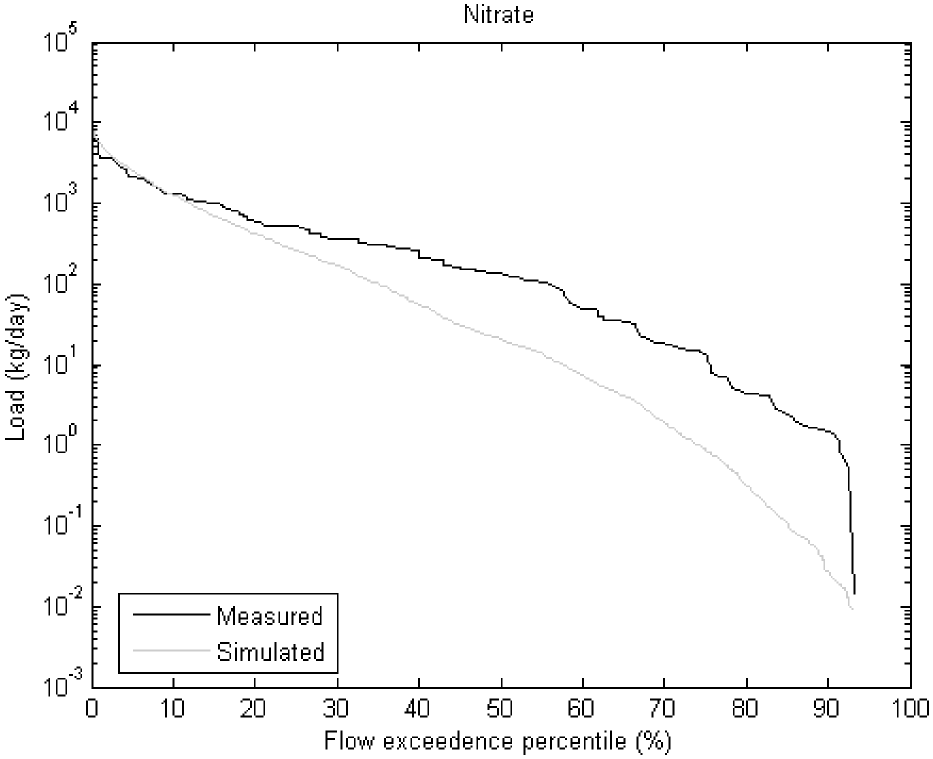


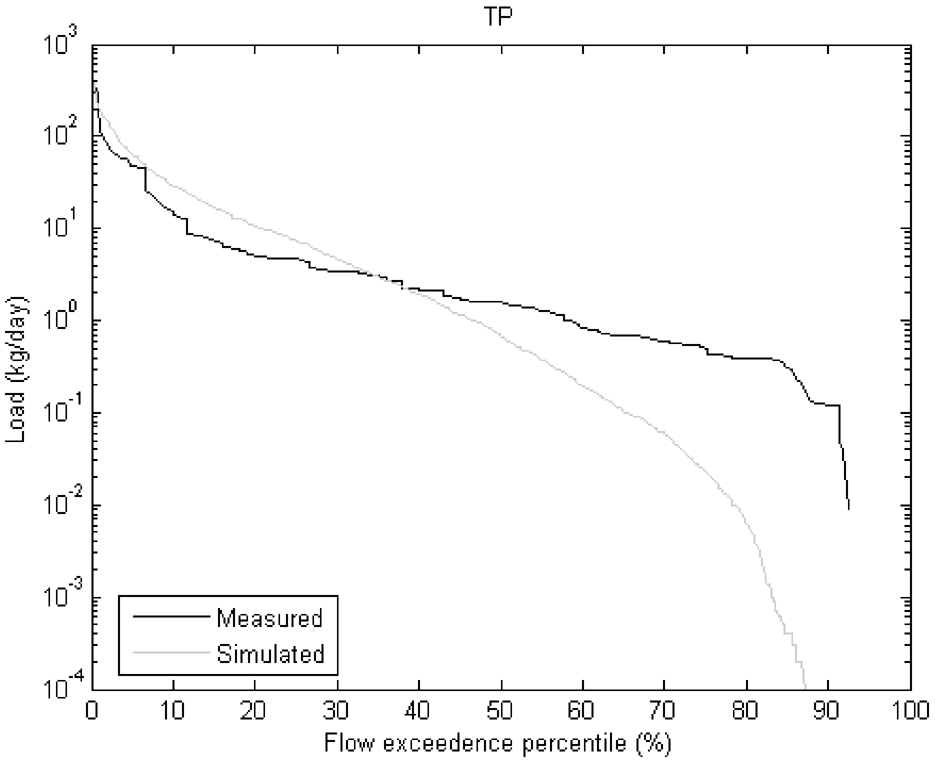

TP
$10^4$
$10^3$
$10^2$
$10^1$
$10^0$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
Load (kg/day)
Measured
Simulated
0
10
20
30
40
50
60
70
80
90
Flow exceedence percentile (%)

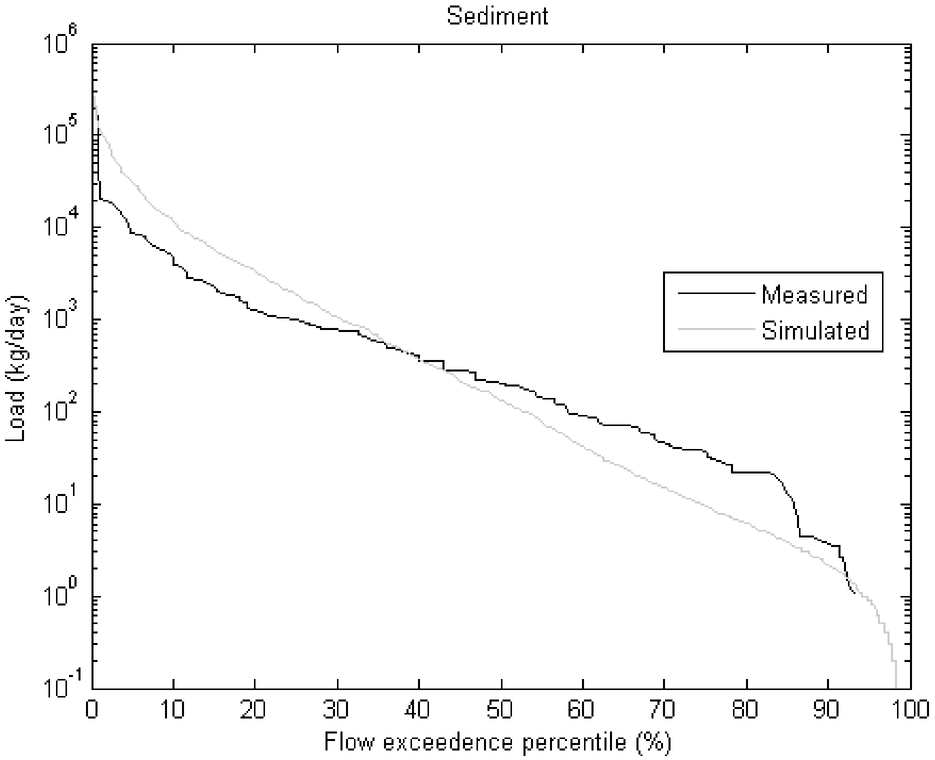

Sediment
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
$10^1$
$10^0$
$10^{-1}$
Load (kg/day)
Measured
Simulated
0
10
20
30
40
50
60
70
80
90
100
Flow exceedence percentile (%)

Little Pine plots






TP
Load (kg/day)
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
0
10
20
30
40
50
60
70
80
90
100
Flow exceedence percentile (%)
Measured
Simulated


Sediment
Load (kg/day)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
0
10
20
30
40
50
60
70
80
90
100
Flow exceedence percentile (%)
Measured
Simulated

# Appendix M Comparing simulated and observed water quality data when conservation practices (CPs) are included

## Purpose

To see if water quality comparison (especially phosphorus and sediment in Little Wea) improves when conservation practices are applied in the watershed.

## Method

I added current CPs into the SWAT models for Little Pine and Little Wea and re-ran statistics and graphs to evaluate the models' ability to predict water quality. I also calculated R2 and NS for the monthly water quality loads, using the same approach as before (taking the average monthly concentration from weekly samples and daily flows and calculating monthly loads). Current CPs were only known for farmland that was included in interviews, which covered 33% of the watersheds. The other 77% of the land was assumed to have no conservation practice.

## Results

Main results are highlighted in green and red in the tables below. More detailed information is available on the graphs that follow. Including current CPs improved (lowered) Little Wea phosphorus and sediment loading. Little Wea monthly nitrate, TP, and sediment loading has reasonably R2 but poor Nash Sutcliffe statistics. Little Pine has good R2 for monthly nitrate, TP, and sediment loading, and good NS for nitrate and TP, though poor for sediment. Including current CPs improved Little Pine sediment loading.

The overall results show that introducing current conservation practices improves model performance, especially for sediment, which had been over-estimated. Model performance for the Little Wea model remains problematic, but these results show that it would likely improve if all current CPs in the watershed were known and included.

Little Wea statistics

| | | With CPs simulated daily | Original simulated daily | Observed daily | With CPs simulated monthly | Original simulated monthly | Observed monthly |
|---|---|---|---|---|---|---|---|
| Total NO3 in mg/L | mean | 7.4 | 7.4 | 4.5 | 7.4 | 7.5 | 4.5 |
| | std | 9.9 | 10.0 | 2.7 | 8.2 | 8.4 | 2.4 |
| | min | 0.0 | 0.0 | 0.0 | 0.4 | 0.4 | 1.4 |
| | max | 85.1 | 86.3 | 14.2 | 35.5 | 36.2 | 10.3 |
| Total NO3 in kg/d | mean | 465.0 | 472.0 | 371.7 | 556.7 | 563.3 | 351.5 |
| | std | 1,185.0 | 1,202.0 | 778.6 | 961.0 | 973.2 | 411.9 |
| | min | 0.0 | 0.0 | 0.3 | 0.3 | 0.3 | 13.1 |
| | max | 12,190.0 | 12,370.0 | 6,736.3 | 4,552.9 | 4,597.7 | 1,566.2 |
| TP in mg/L | mean | 0.4 | 0.4 | 0.0 | 0.4 | 0.4 | 0.0 |
| | std | 0.5 | 0.6 | 0.1 | 0.2 | 0.3 | 0.1 |
| | min | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | max | 2.4 | 3.0 | 0.7 | 1.0 | 1.1 | 0.4 |
| TP in kg/d | mean | 40.8 | 47.9 | 10.4 | 23.8 | 26.4 | 4.8 |
| | std | 148.5 | 182.3 | 52.3 | 33.9 | 37.0 | 12.0 |
| | min | 0.0 | 0.0 | -5.9 | 0.0 | 0.0 | -0.6 |
| | max | 2,356.1 | 3,001.8 | 475.4 | 138.0 | 147.3 | 68.7 |
| Sed in mg/L | mean | 52.7 | 62.2 | 14.2 | 55.0 | 64.6 | 13.8 |
| | std | 95.9 | 118.7 | 38.7 | 37.8 | 43.3 | 24.3 |
| | min | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.4 |
| | max | 662.5 | 851.6 | 352.0 | 152.6 | 182.8 | 142.0 |
| Sed in kg/d | mean | 7,960.0 | 9,620.0 | 5,100.0 | 3,613.0 | 4,183.0 | 1,619.0 |
| | std | 35,220.0 | 43,890.0 | 33,020.0 | 5,286.0 | 6,045.0 | 4,656.0 |
| | min | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 15.0 |
| | max | 612,700.0 | 787,000.0 | 360,840.0 | 19,905.0 | 22,613.0 | 27,642.0 |

Including current CPs improved TP and sediment loading in Little Wea somewhat. If Current CPs were known for the other ~70% of the watershed we could expect to see more reasonable TP and sediment loading.

| Flow statistics | | With current CPs | No CPs |
|---|---|---|---|
| R2 daily | | 0.7 | 0.7 |
| NS daily | | 0.7 | 0.7 |
| R2 monthly | | 0.9 | 0.9 |
| NS monthly | | 0.8 | 0.8 |
| Simulated flow | m/y | 0.3 | 0.3 |
| Observed flow | m/y | 0.4 | 0.4 |

| WQ statistics | With current CPs | No CPs |
|---|---|---|
| Nitrate (monthly average kg/day) | | |
| R2 monthly | 0.6 | 0.6 |
| NS monthly | -2.1 | -2.2 |
| TP (monthly average kg/day) | | |
| R2 monthly | 0.5 | 0.5 |
| NS monthly | -6.5 | -8.5 |
| Sed (monthly average kg/day) | | |
| R2 monthly | 0.5 | 0.5 |
| NS monthly | 0.1 | -0.2 |

R2 values for nitrate, TP, and sediment were fairly reasonable (we look for > 0.6). NS values were unreasonable for all three, showing that peaks are not well matched.

| Other statistics | | With current CPs | | No CPs | |
|---|---|---|---|---|---|
| | | mean | std | mean | std |
| tile flow | m/y | 0.2 | 0.4 | 0.2 | 0.4 |
| precip | mm/day | 2.9 | 7.3 | 2.9 | 7.3 |
| NO3 in surface flows | kg/day | 28.5 | 91.6 | 30.3 | 98.3 |
| NO3 from tiles | kg/day | 512.6 | 1,397.7 | 517.7 | 1,421.2 |
| Total NO3 | kg/day | 569.1 | 1,477.3 | 576.0 | 1,503.6 |
| Organic N | kg/day | 242.9 | 882.4 | 287.4 | 1,095.4 |
| TN | kg/day | 812.0 | 2,043.1 | 863.5 | 2,203.1 |
| TP | kg/day | 31.3 | 123.2 | 36.9 | 150.4 |
| Sed | t/day | 8.7 | 44.5 | 10.8 | 55.1 |

Little Pine statistics

| | | With CPs simulated daily | Original simulated daily | Observed daily | With CPs simulated monthly | Original simulated monthly | Observed monthly |
|---|---|---|---|---|---|---|---|
| Total NO3 in mg/L | mean | 4.0 | 4.0 | 6.6 | 4.2 | 4.2 | 6.8 |
| | std | 6.1 | 6.0 | 4.0 | 4.9 | 4.9 | 3.6 |
| | min | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.6 |
| | max | 38.1 | 37.7 | 23.2 | 18.2 | 18.3 | 15.3 |
| Total NO3 in kg/d | mean | 418.0 | 421.0 | 563.4 | 440.1 | 451.0 | 588.4 |
| | std | 1,058.0 | 1,059.0 | 994.8 | 689.7 | 709.4 | 733.9 |
| | min | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4.1 |
| | max | 10,260.0 | 10,330.0 | 6,356.8 | 2,450.5 | 2,512.9 | 3,330.3 |
| TP in mg/L | mean | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| | std | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| | min | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | max | 0.4 | 0.5 | 0.9 | 0.2 | 0.2 | 0.5 |
| TP in kg/d | mean | 11.6 | 12.9 | 12.5 | 7.9 | 8.4 | 8.1 |
| | std | 36.2 | 42.0 | 43.6 | 11.5 | 11.8 | 10.4 |
| | min | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 |
| | max | 504.2 | 604.0 | 369.0 | 48.7 | 47.4 | 35.0 |
| Sed in mg/L | mean | 30.7 | 35.3 | 21.5 | 31.9 | 36.9 | 21.2 |
| | std | 46.1 | 56.9 | 33.1 | 19.6 | 23.0 | 16.0 |
| | min | 0.0 | 0.0 | 1.2 | 2.5 | 2.4 | 3.3 |
| | max | 363.9 | 493.2 | 261.0 | 73.4 | 87.6 | 67.2 |
| Sed in kg/d | mean | 5,260.0 | 6,480.0 | 4,242.7 | 2,788.0 | 3,300.0 | 1,902.0 |
| | std | 20,900.0 | 26,940.0 | 21,689.0 | 4,011.0 | 4,735.0 | 3,013.0 |
| | min | 0.0 | 0.0 | 1.1 | 3.0 | 3.0 | 20.0 |
| | max | 325,200.0 | 425,600.0 | 215,300.0 | 16,322.0 | 19,978.0 | 13,157.0 |

Sediment loading improved when current CPs were included in the Little Pine model.

| Flow statistics | | With current CPs | No CPs |
|---|---|---|---|
| R2 daily | | 0.8 | 0.8 |
| NS daily | | 0.8 | 0.8 |
| R2 monthly | | 0.9 | 0.9 |
| NS monthly | | 0.8 | 0.8 |
| Simulated flow | m/y | 0.4 | 0.4 |
| Observed flow | m/y | 0.4 | 0.4 |

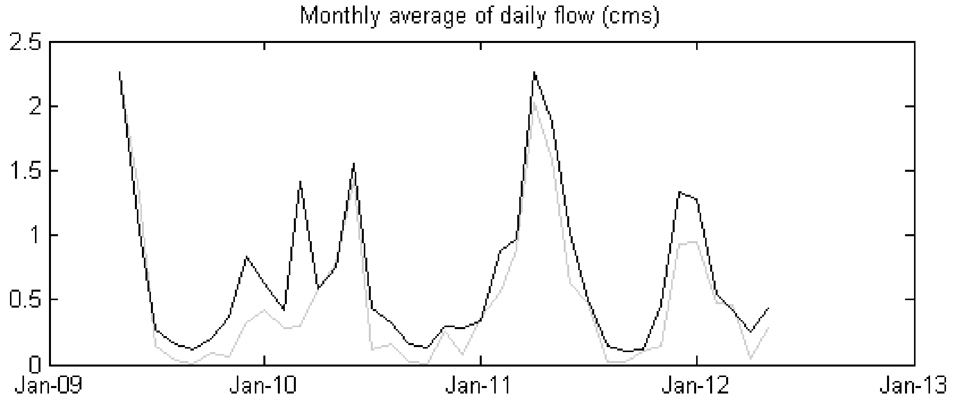
| WQ statistics | With current CPs | No CPs |
|---|---|---|
| Nitrate (monthly average kg/day) | | |
| R2 monthly | 0.7 | 0.7 |
| NS monthly | 0.7 | 0.7 |
| TP (monthly average kg/day) | | |
| R2 monthly | 0.7 | 0.7 |
| NS monthly | 0.6 | 0.6 |
| Sed (monthly average kg/day) | | |
| R2 monthly | 0.6 | 0.6 |
| NS monthly | 0.2 | -0.3 |

R2 values for nitrate, TP, and sediment, and NS for nitrate and TP were good for Little Pine. NS for sediment was not acceptable, though inclusion of current CPs improved it considerably. Perhaps including current CPs for the other ~70% of the watershed would further improve sediment loading.

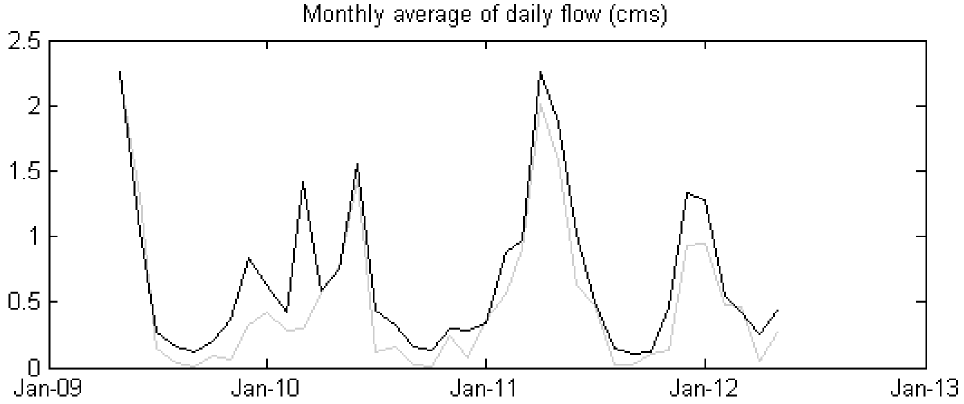
| Other statistics | | With current CPs | | No CPs | |
|---|---|---|---|---|---|
| | | mean | std | mean | std |
| tile flow | m/y | 0.1 | 0.4 | 0.1 | 0.4 |
| precip | mm/day | 2.9 | 8.1 | 2.9 | 8.1 |
| NO3 in surface flows | kg/day | 34.4 | 85.0 | 38.2 | 96.3 |
| NO3 from tiles | kg/day | 360.9 | 1,001.6 | 359.7 | 998.7 |
| Total NO3 | kg/day | 408.2 | 1,056.4 | 411.3 | 1,057.6 |
| Organic N | kg/day | 98.5 | 314.9 | 112.3 | 378.3 |
| TN | kg/day | 506.7 | 1,264.3 | 523.6 | 1,303.9 |
| TP | kg/day | 2.3 | 16.4 | 3.0 | 19.3 |
| Sed | t/day | 3.9 | 21.5 | 5.4 | 28.6 |

Little Wea plots

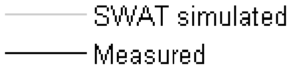
Monthly flow rate



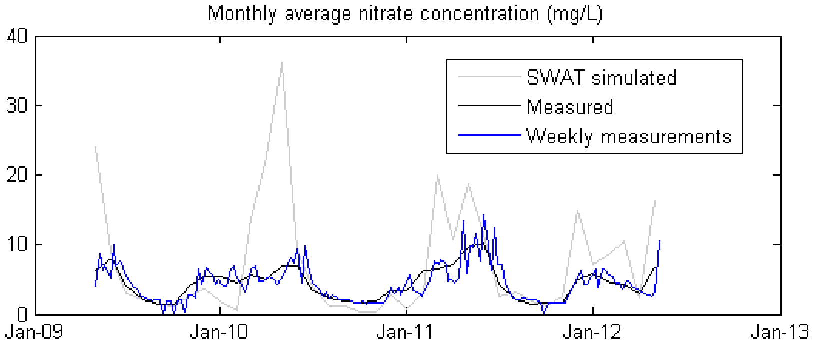
No CPs

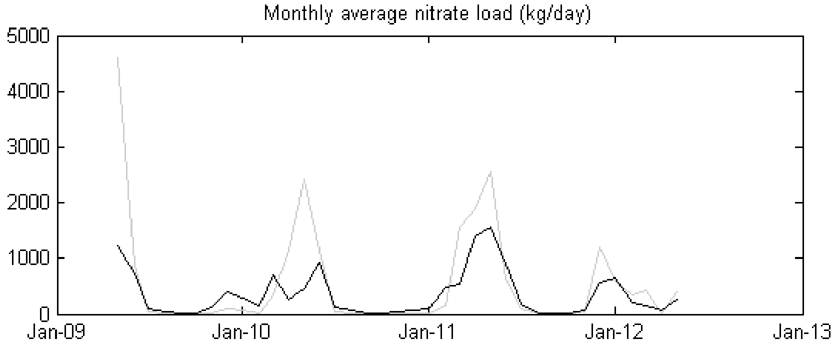


Current CPs

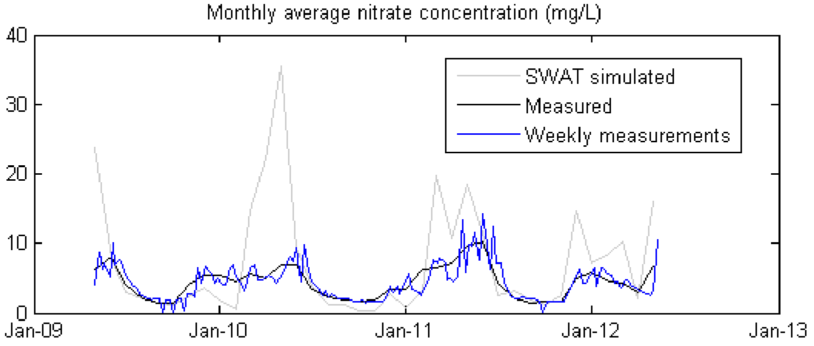


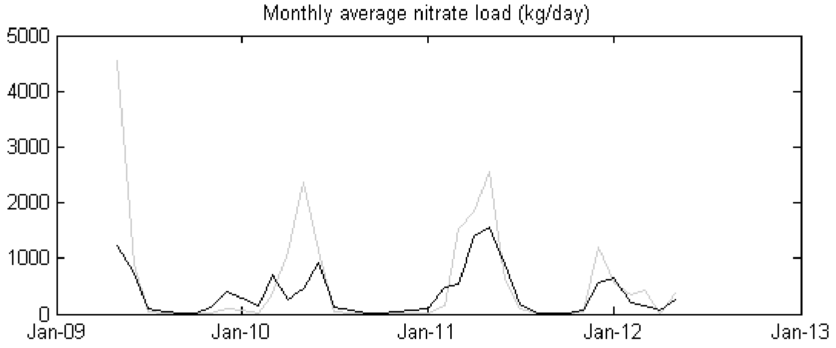
Monthly average nitrate





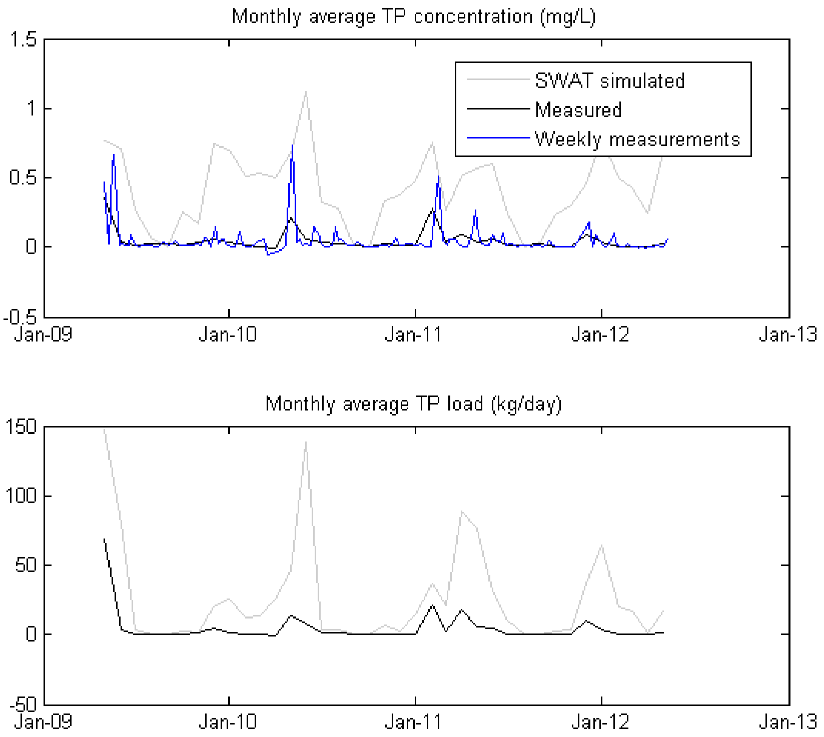
No CPs



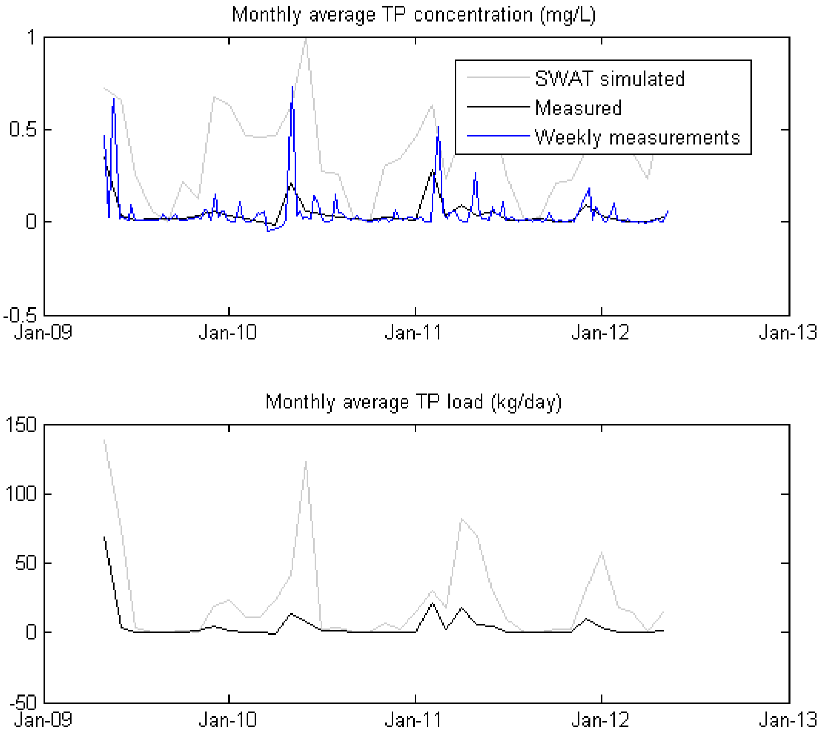


Current CPs

Monthly average TP

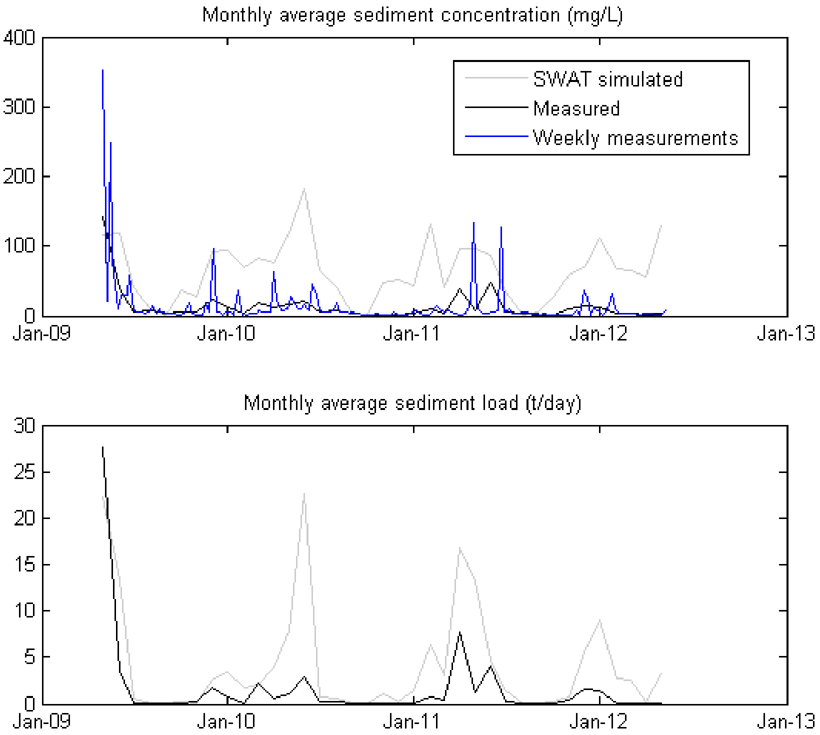


No CPs

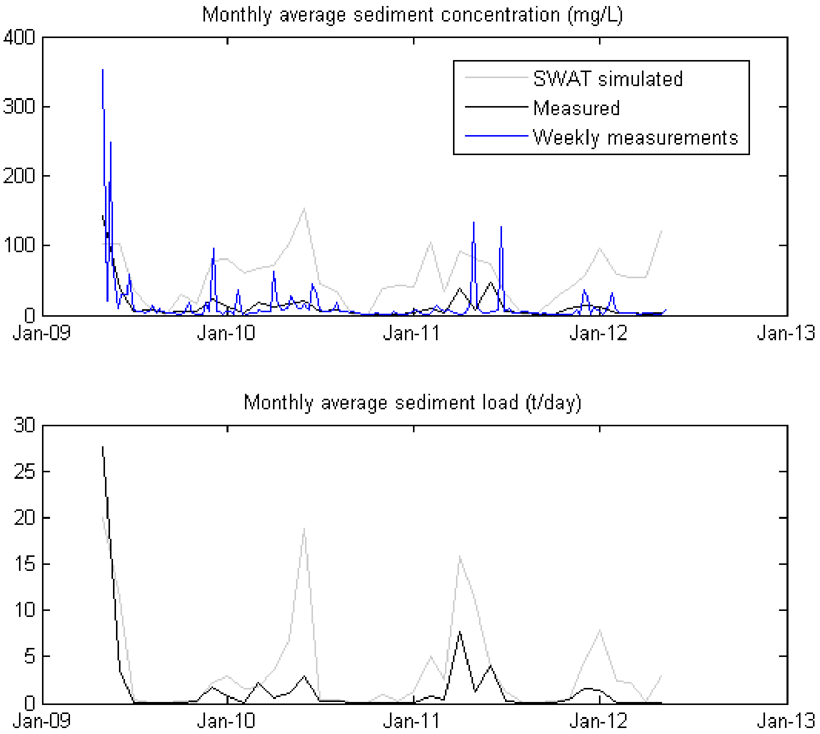


Current CPs

Monthly average sediment

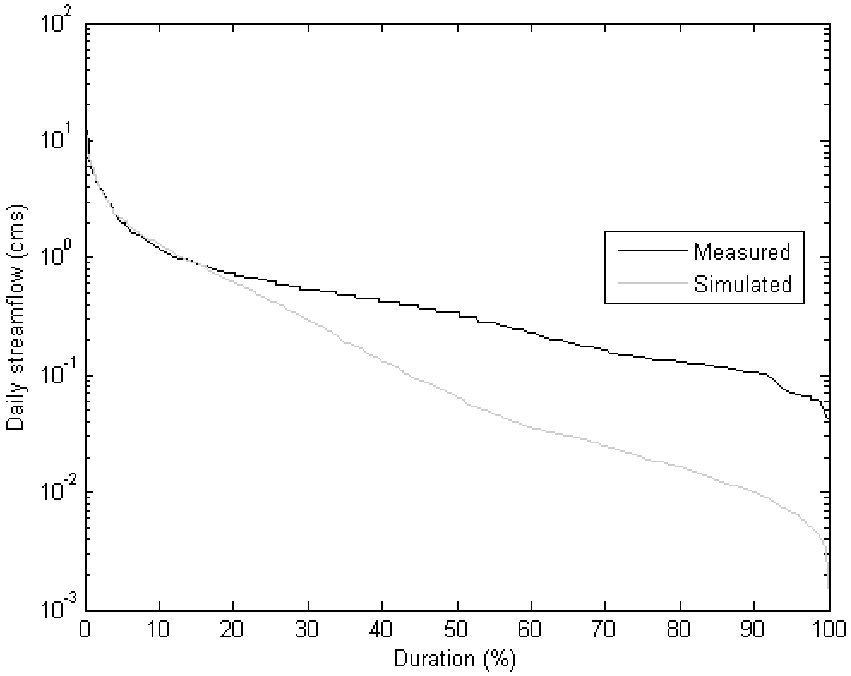


No CPs

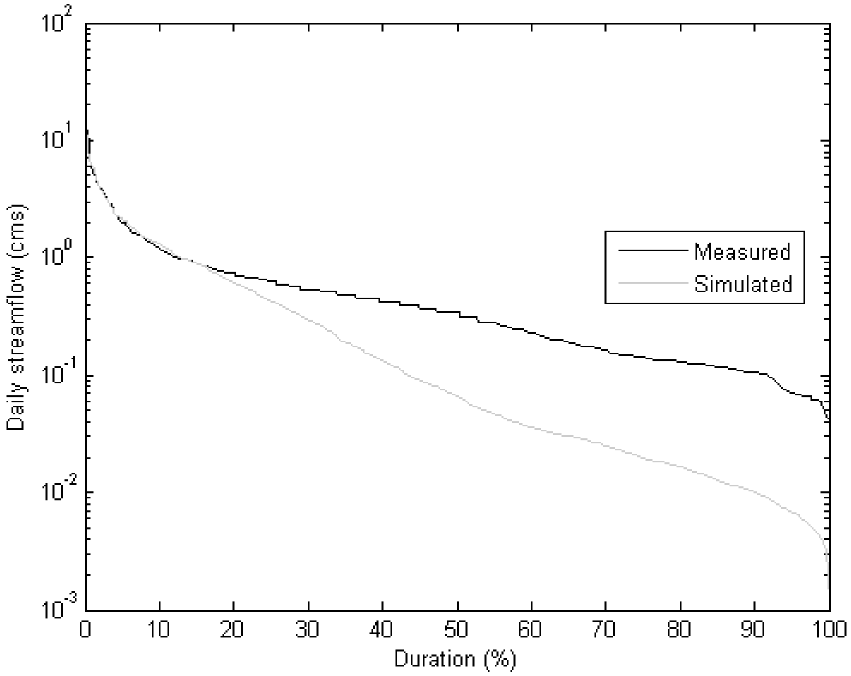


Current CPs

Flow duration curves

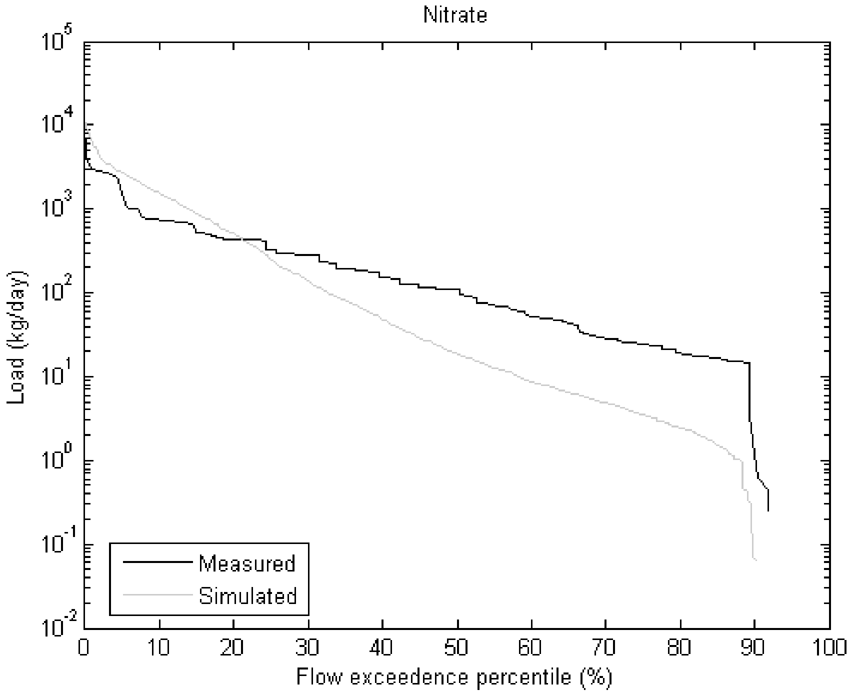


No CPs

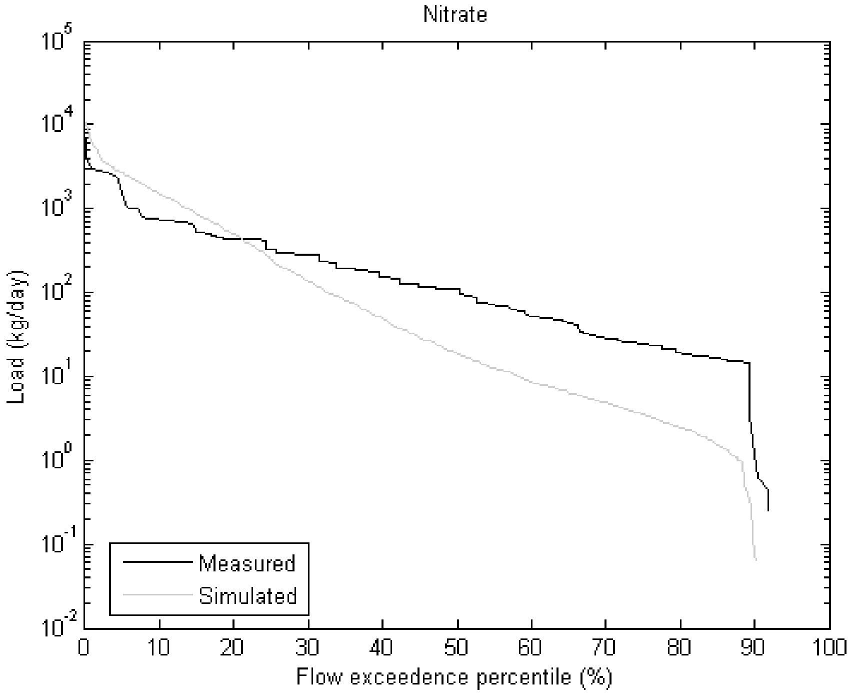


Current CPs

Nitrate load duration curves

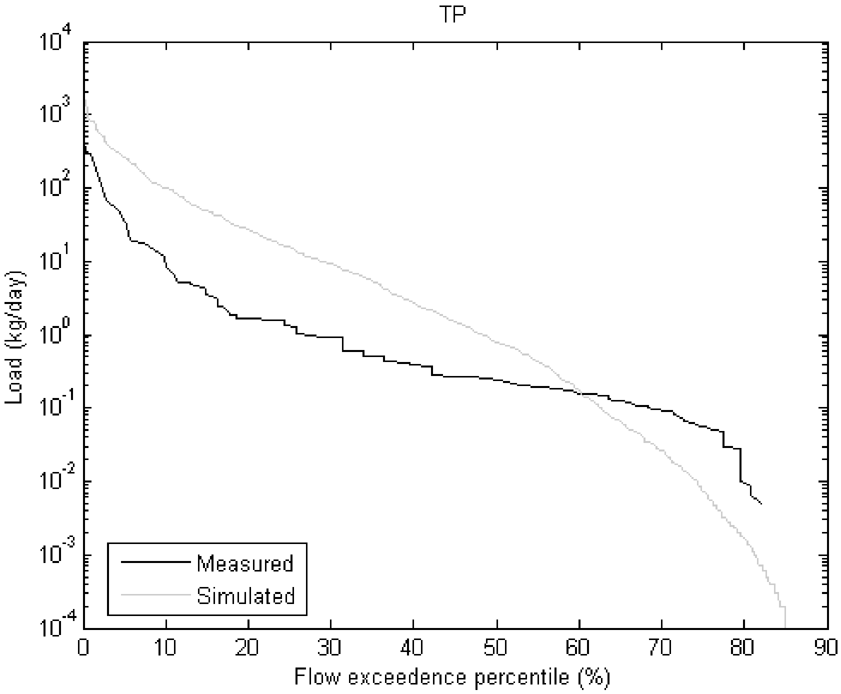


No CPs

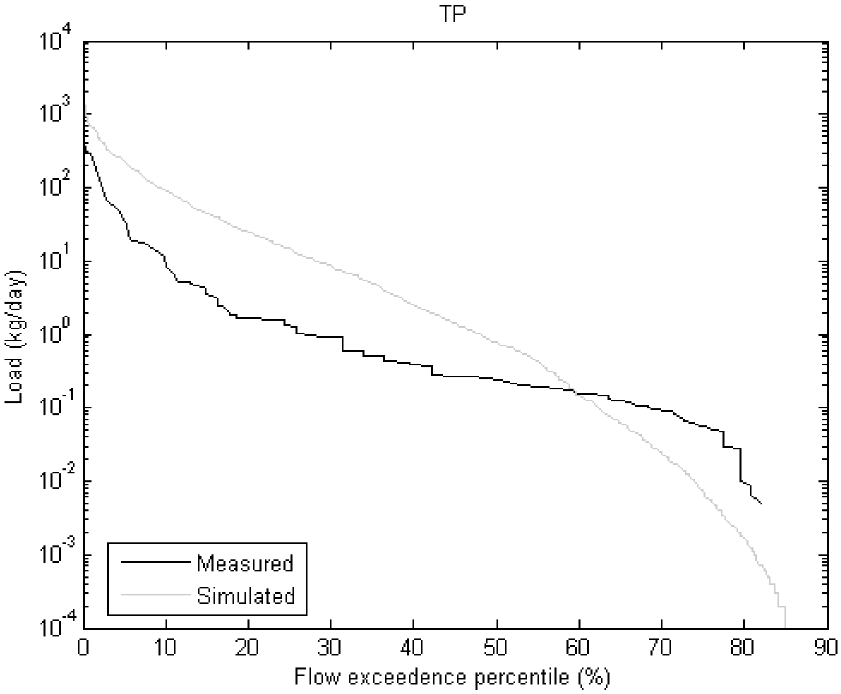


Current CPs

TP load duration curves

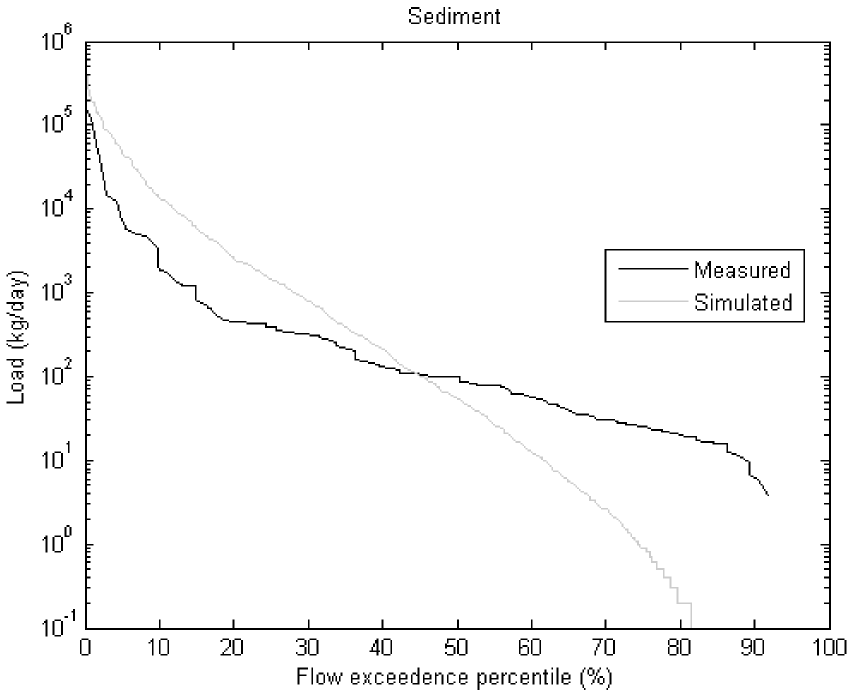


No CPs

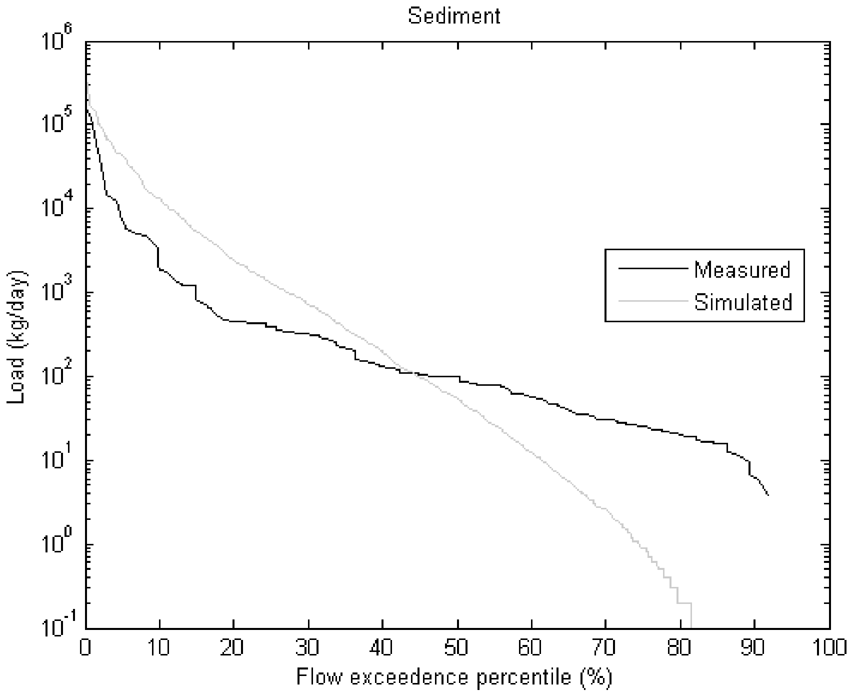


Current CPs

Sediment load duration curves



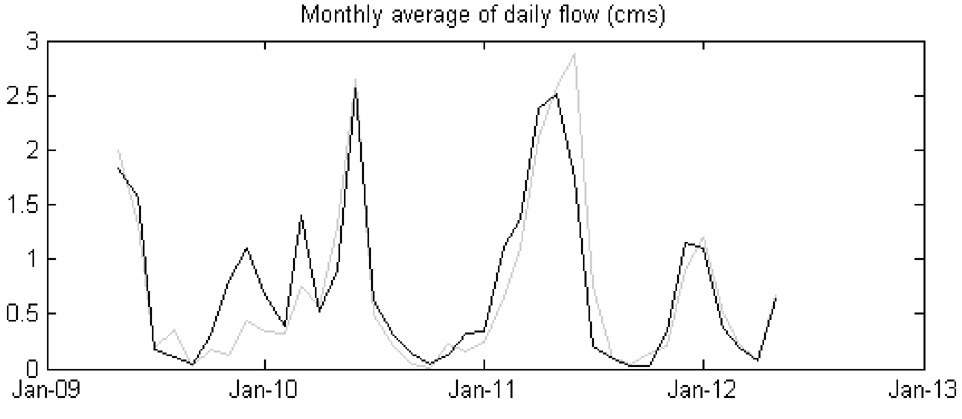
No CPs



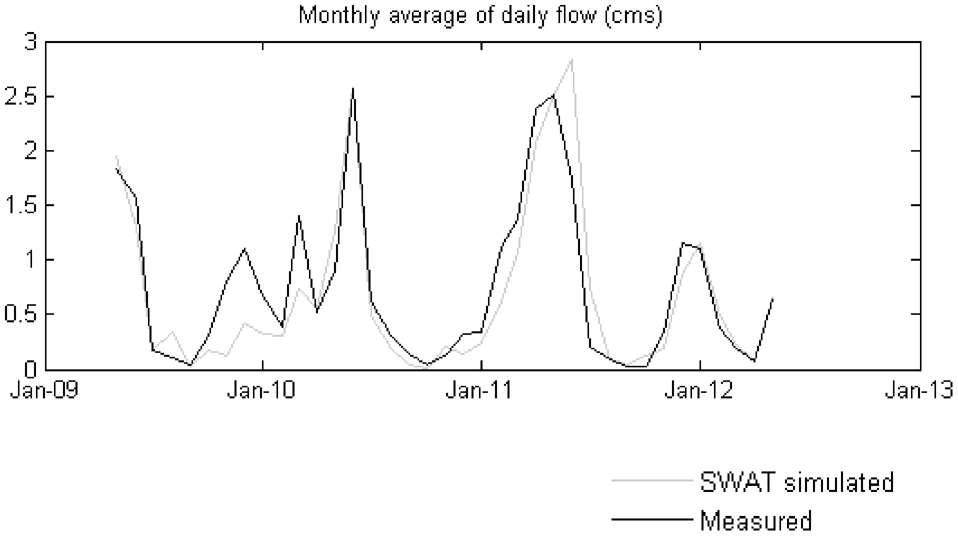
Current CPs

## Little Pine plots

### Monthly flow rate

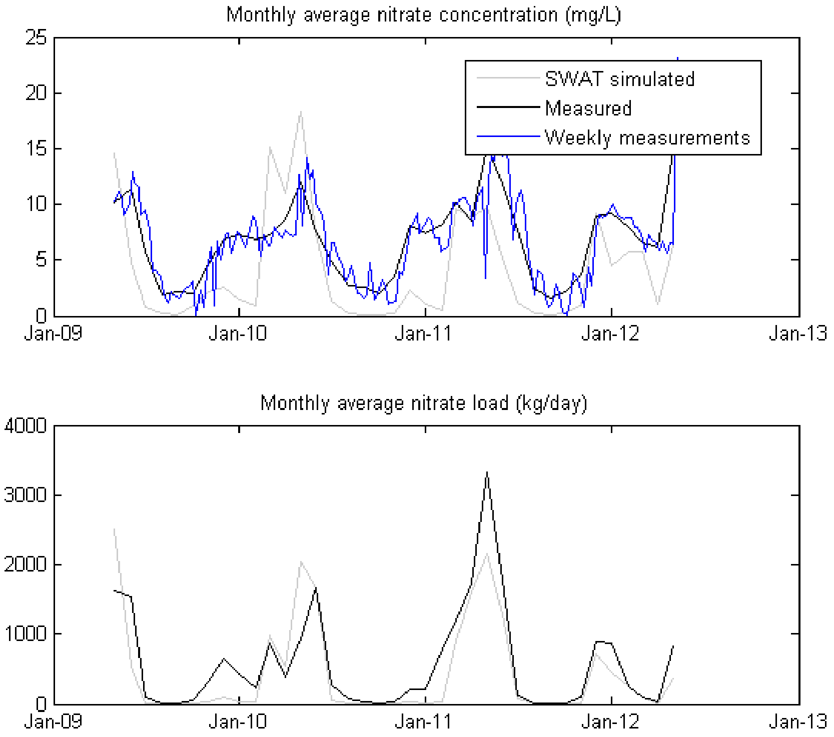


No CPs

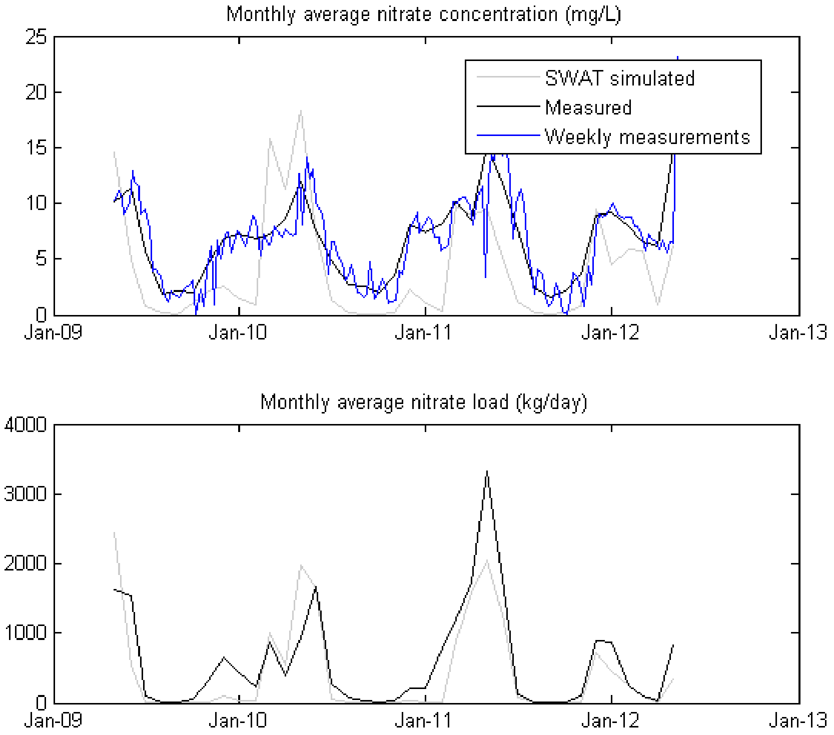


Current CPs

Monthly average nitrate

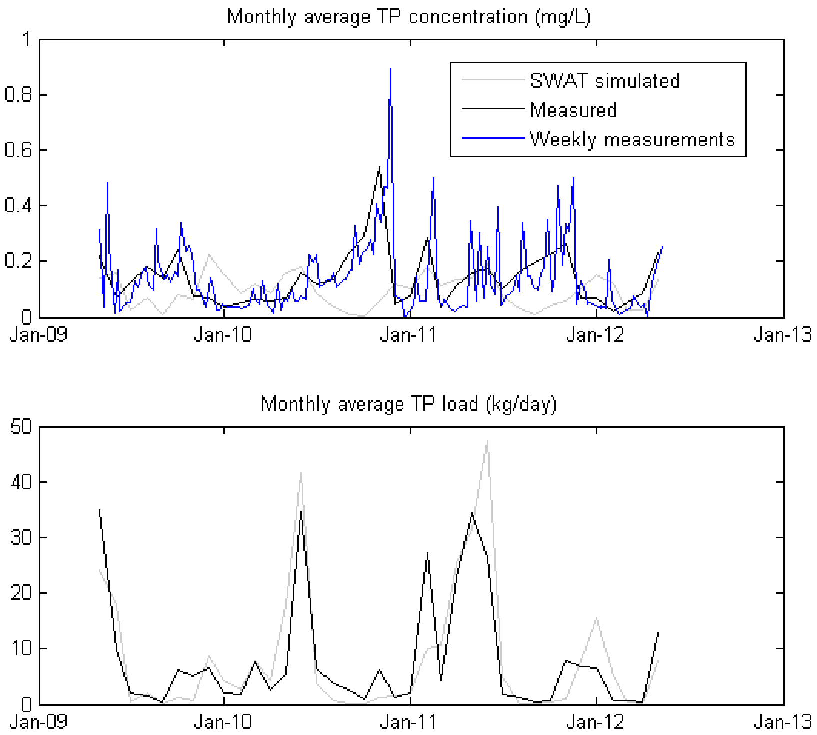


No CPs

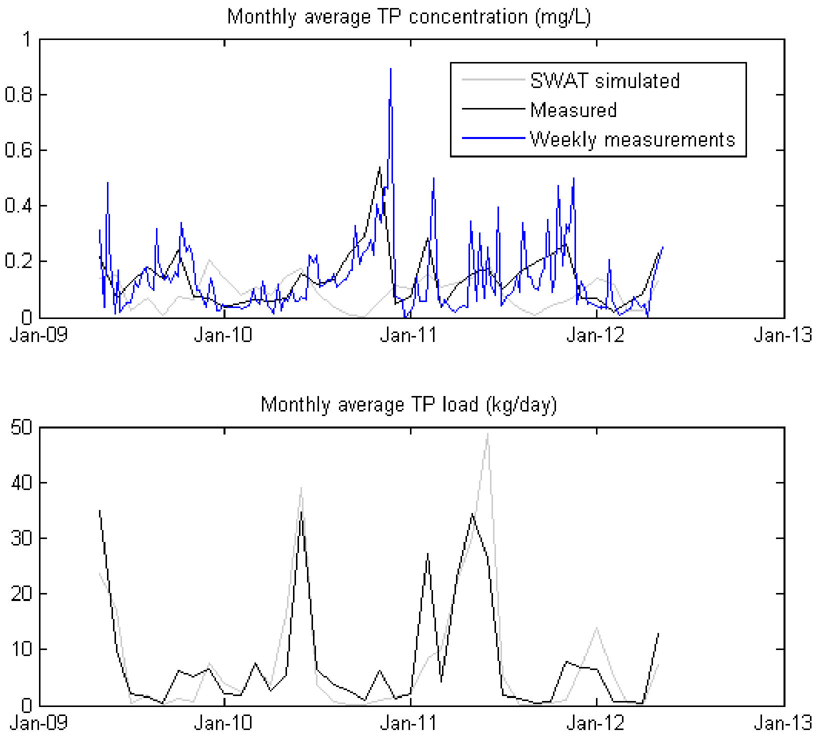


Current CPs

Monthly average TP

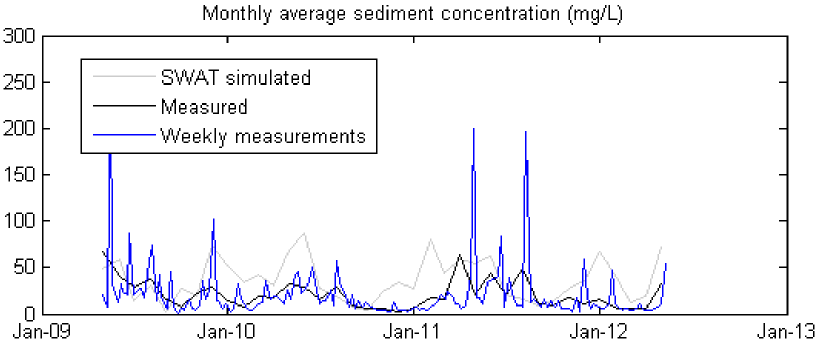


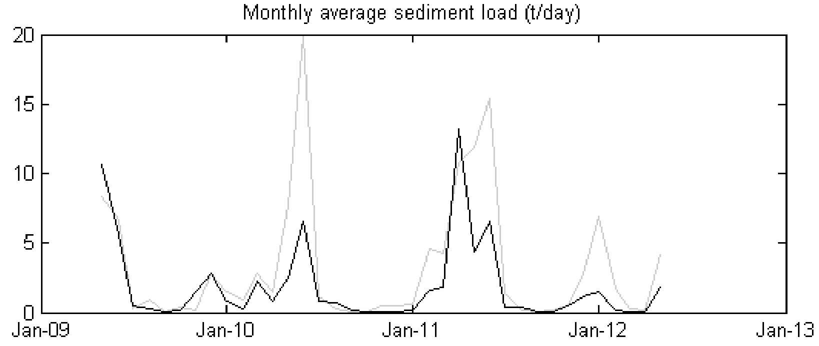
No CPs



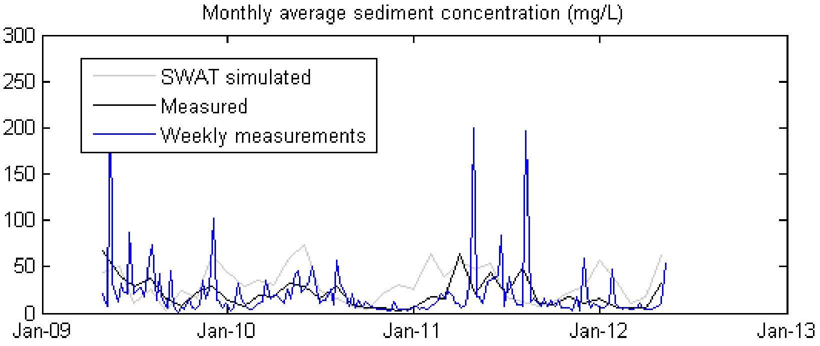
Current CPs

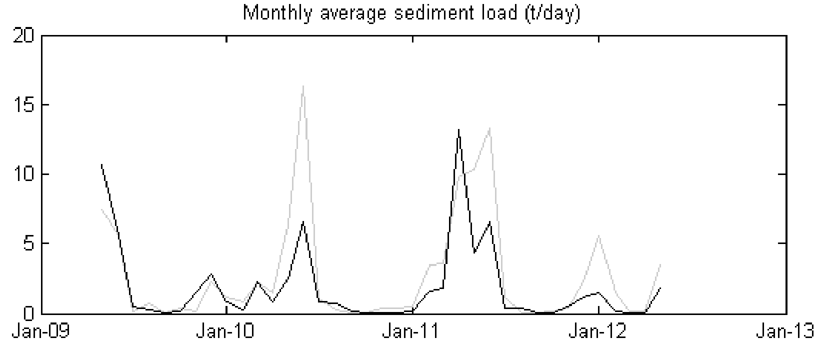
Monthly average sediment





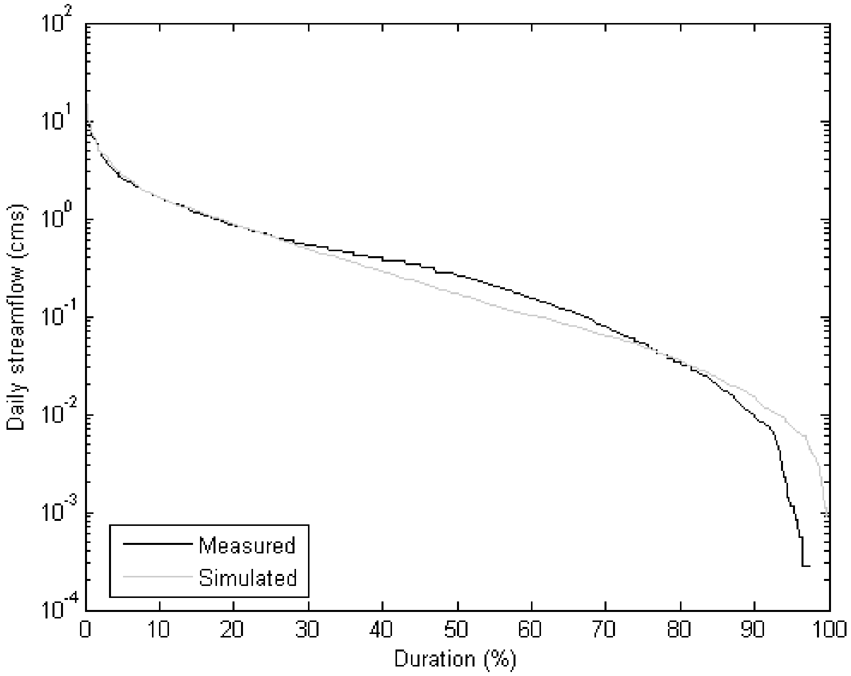
No CPs



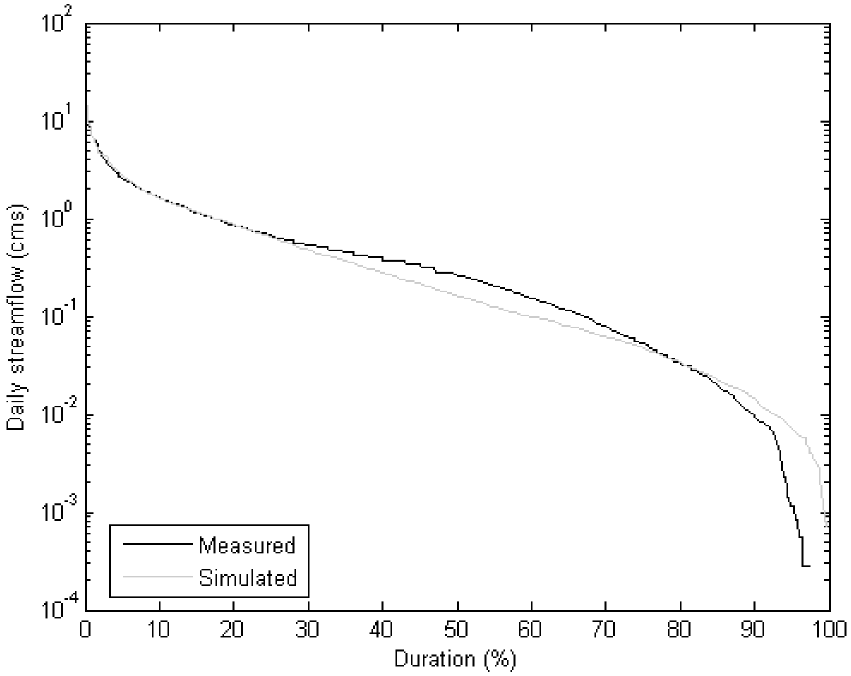


Current CPs

Flow duration curves

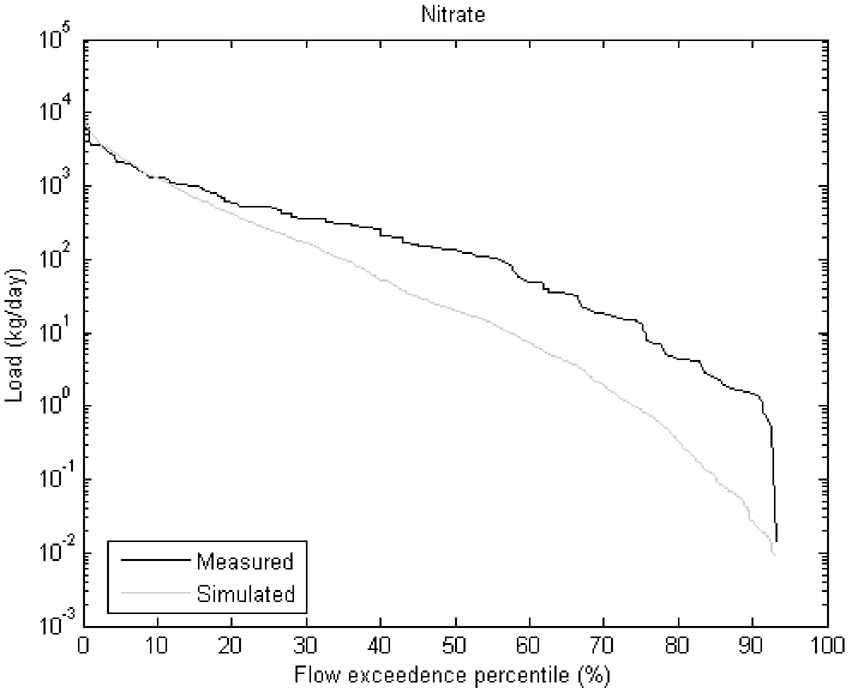


No CPs

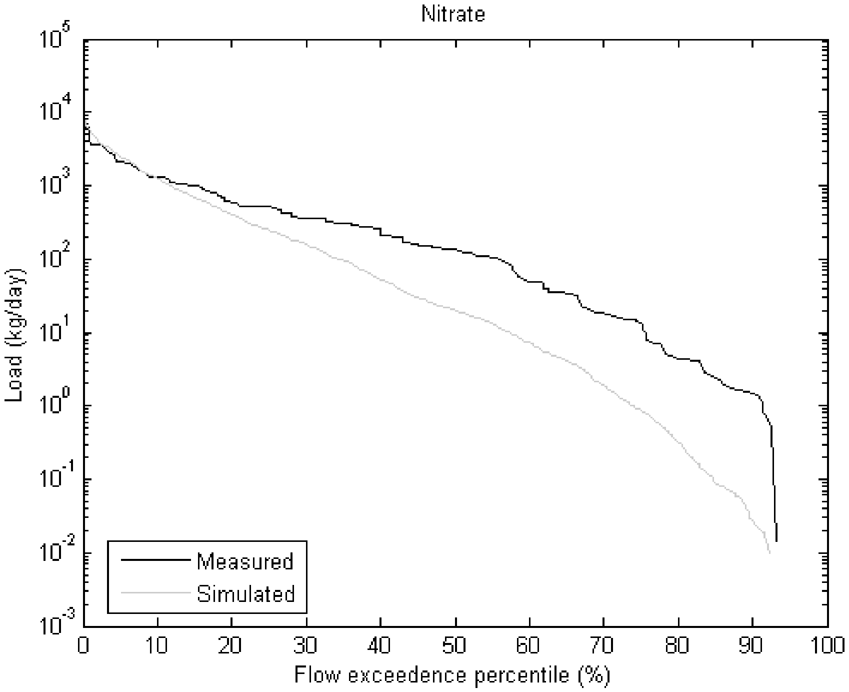


Current CPs

Nitrate load duration curves

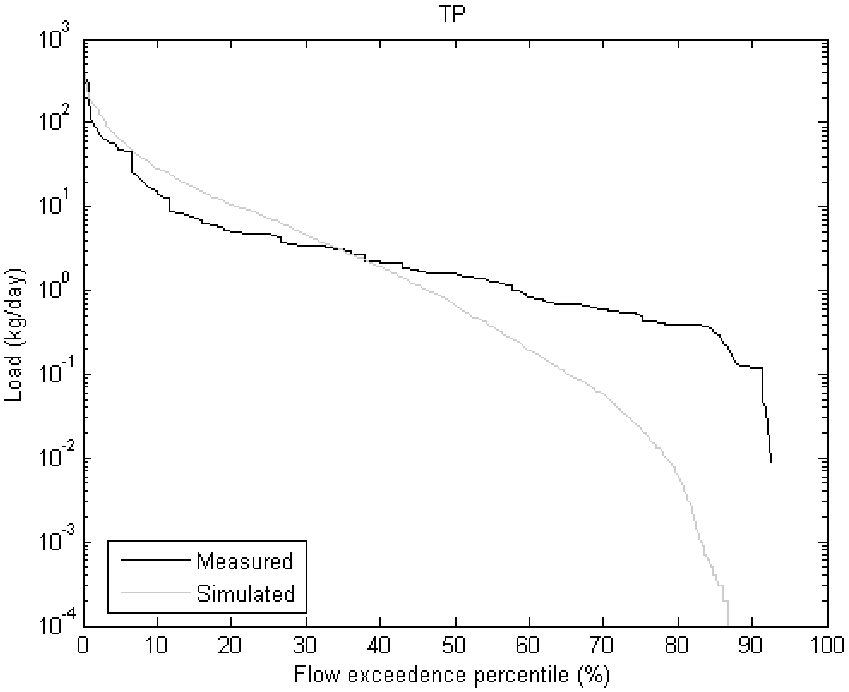


No CPs

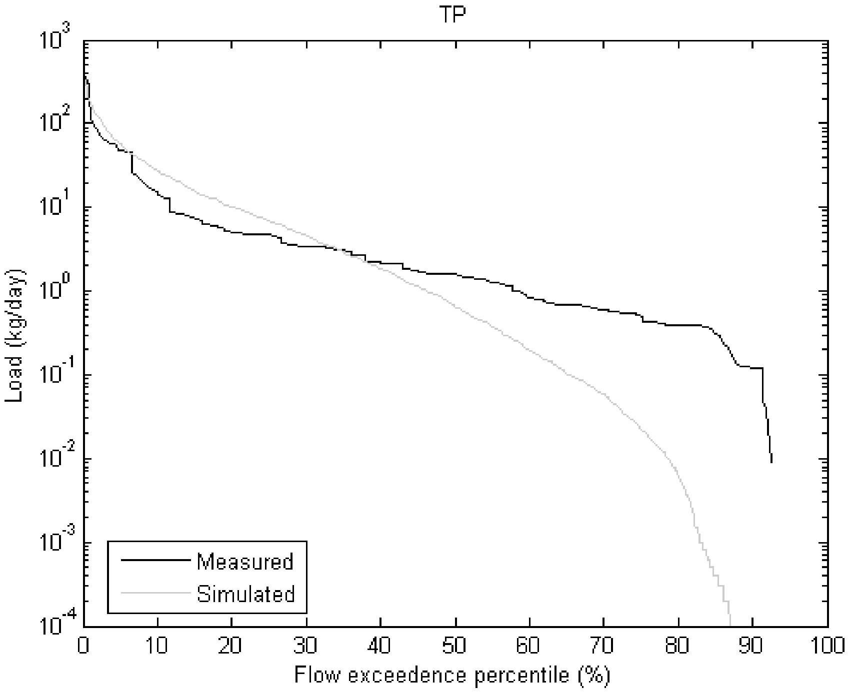


Current CPs

TP load duration curves

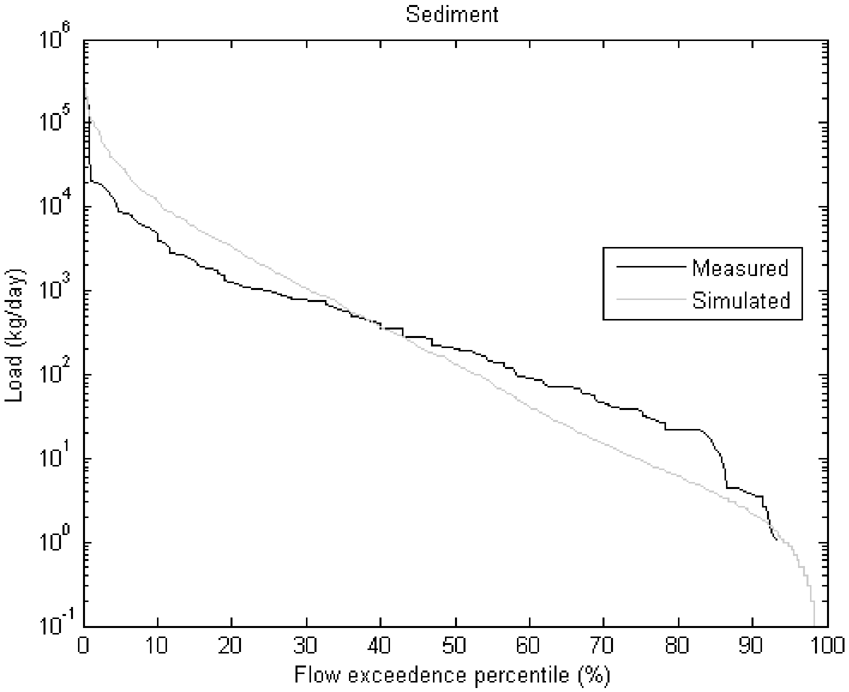


No CPs

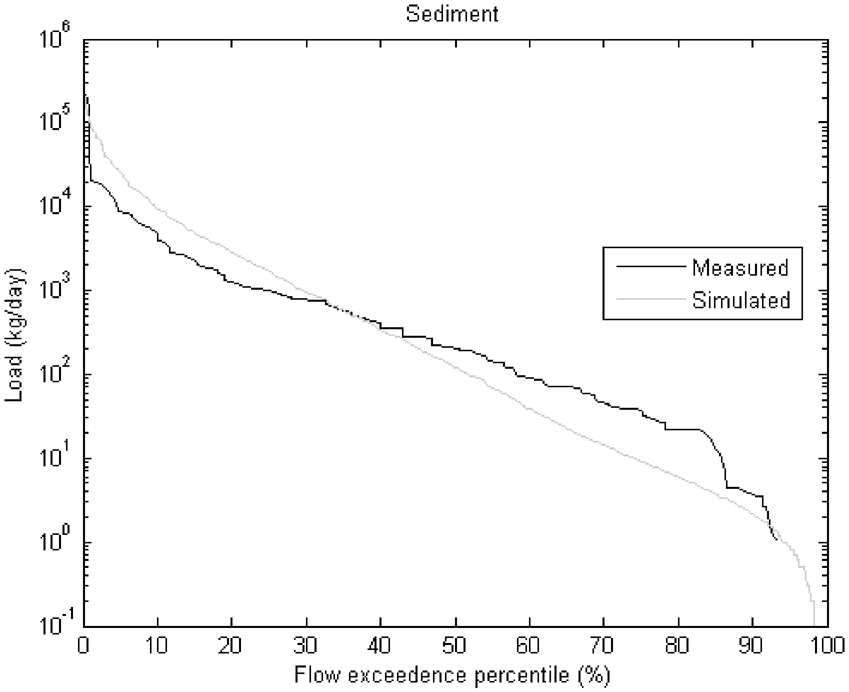


Current CPs

Sediment load duration curves



No CPs



Current CPs

# VITA

# VITA

Margaret was born and raised in the woods and hills of western Massachusetts. In 2008 she graduated from Franklin W. Olin College of Engineering with a degree in General Engineering and a concentration in Bioengineering. She was proud to be a member of Olin College’s third graduating class. In 2008 she began graduate studies at Purdue University in the new Ecological Sciences and Engineering Interdisciplinary Graduate Program and home department Agricultural and Biological Engineering. Her master’s work focused on targeting the placement of constructed wetlands in tile drained Indiana watersheds for the purpose of nitrate removal from agricultural drainage waters. She completed her Master’s of Science in Engineering in 2010 and continued with doctoral studies. Her dissertation research is an interdisciplinary project bringing together the engineering aspects and the human dimensions of watershed management. She conducted a targeting experiment involving farmer interviews, watershed modeling using the Soil and Water Assessment Tool (SWAT), as well as spatial optimization of conservation practices. She will complete her Doctor of Philosophy in 2013, and soon after begin postdoctoral research at the University of Michigan.

# PUBLICATION

# PUBLICATION

Kalcic, M., Chaubey, I., Frankenberger, J., and E. Kladivko. 2012. A Geospatial Approach to Targeting Constructed Wetlands for Nitrate Removal in Agricultural Watersheds. Applied Engineering in Agriculture, 28(3): 347-357.