INCREASING THE ENVIRONMENTAL SERVICES OF WORKING AGRICULTURAL LANDS THROUGH BEST MANAGEMENT PRACTICES

A DISSERTATION
SUBMITTED TO THE FACULTY OF
UNIVERSITY OF MINNESOTA
BY

ANN MARIE O’NEILL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

DEAN A. CURRENT AND MICHAEL A. KILGORE

SEPTEMBER 2015

Acknowledgements

I would like to thank my co-advisors, Dean Current and Mike Kilgore, as well as committee members Dennis Becker and Mae Davenport, for sharing their expertise, helpful comments, and encouragement in finishing this dissertation and degree. I would especially like to express my deep thanks to Dean Current for his guidance and time throughout my graduate experience as my functional primary advisor.

This research would not have been possible without many supportive partners. I am grateful to the focus group participants for their candid comments and enlightening stories. Special thanks to the coordinators at each site who helped with focus group logistics and recruiting participants. Thanks also to assistant moderators Charlene Brooks, Dean Current, and Amanda Sames. I am indebted to Steve Taff for formative and thought provoking conversations that steered the general direction of this research. Thanks also to Richard Krueger, Joe Magner, and Mae Davenport for helpful guidance and input in the development of the focus group research. Thank you to Bill Lazarus, Linda Meschke, Roger Ruan, and Paul Chen for helpful suggestions on the biofuels model and comments to strengthen this portion of the research.

This research was funded in part by grants from the U.S. Department of Agriculture, U.S. Department of Energy, Minnesota Pollution Control Agency, and the U.S. Environmental Protection Agency. Support was also provided by the University of Minnesota Department of Forest Resources and the 2015 University of Minnesota Dissertation Writing Retreat.

I am humbled by and grateful for the dedicated support of my family. Thank you to my husband David for his love and very practical support in encouraging me to pursue this incredible opportunity. Thanks for taking up the slack at home when I was (yet again) working. Thank you for deferring other dreams to make time for this one to happen. Timothy and Matthew, thank you for hanging in there when Mommy needed to get just one more thing done for work. Baby #3, you have become a real motivator to get this degree completed! I can’t wait to see who each of you become as the years pass. Thank you Mom for your time caring for Timothy and Matthew, cleaning up our kitchen to keep the house running, and the million other servant-hearted things you do with such joy. Thank you Dad for your encouragement in word and deed to do hard things, and that I will indeed be fine no matter the circumstances. Your Appalachian Trail through hike could not be a better example to us all. We all know this degree has been a team effort! Finally, I am grateful to God for this opportunity that I never could have imagined years ago. I am blessed beyond anything I deserve.

Abstract

Conservation managers working to reduce agricultural nonpoint source (NPS) pollution through best management practice (BMP) implementation must work in light of competing objectives and multiple constraints. These include the limitations of current decision frameworks, budgets, and socially acceptable practices. All three studies in this dissertation sought to investigate one primary, over-arching question: What strategies should conservation decision makers consider to increase environmental services through BMP implementation on working agricultural lands? The first study addresses this question from a social science perspective, by using focus group methodology to describe and analyze the decision making process of conservation managers working to implement BMPs on agricultural lands in Minnesota. The study develops a descriptive decision framework of local conservation managers, which may be useful to enable evidence-based conservation efforts to overcome the knowledge-implementation gap. A second study addresses this question from physical science and economics perspectives, by comparing rankings of BMP physical effectiveness (% of total phosphorus removed) to BMP cost-effectiveness ($/lb. of total phosphorus removed). Empirical BMP effectiveness studies from five Midwestern states and cost data from Minnesota BMP installations were used. Study results demonstrate the importance of including cost data, along with pollution reduction data, in agricultural BMP decision processes. This research summarizes the wide range of cost-effectiveness values for BMP implementation, both within and between agricultural BMPs, and offers suggestions to use limited conservation resources more efficiently. The third study addresses this question from a techno-economic and policy perspective, by developing a model to estimate the economic feasibility and environmental implications of various scenarios of microwave assisted pyrolysis (MAP) units to process cellulosic biofuels from perennial feedstock BMPs in southern Minnesota. The study finds that the expected economies of scale gained by the mobility of small-scale pyrolysis units are not sufficient to overcome the increased labor costs, but that stationary small-scale distributed pyrolysis units show some economic promise, particularly if environmental benefits are considered. This research is of primary interest to state and perhaps federal-level policy makers working to design efficient and effective programs to implement BMPs to improve water quality and increase the provision of environmental services on working agricultural lands.

Table of Contents

List of Tables

Chapter 1

Chapter 2

Chapter 3

Chapter 4

List of Figures

Chapter 2

Chapter 3

Chapter 4

Chapter 1: Introduction

Organization of the Dissertation

My research seeks to investigate one primary, over-arching question: What strategies might conservation decision makers consider to increase environmental services through BMP implementation on working agricultural lands? This first introductory chapter is followed by three major research chapters (chapters two through four) and one concluding chapter (chapter five).

Chapter two addresses this question from a social science perspective by using focus group methodology to describe and analyze the decision making process of conservation managers working to implement BMPs on agricultural lands. Chapter three addresses the primary question from physical science and economics perspectives by using empirical data to estimate BMP physical effectiveness and cost-effectiveness, and comparing rankings of these two attributes. Chapter four addresses the primary research question from techno-economic and policy perspectives by analyzing the financial and economic benefits of three pyrolysis scenarios using perennial grasses from agricultural BMPs. Chapter five summarizes and integrates the research described in the previous four chapters and suggests recommendations for policy makers, highlights contributions of this dissertation to the literature, and provides ideas future research. Research findings may be helpful for decision makers working to design efficient and effective programs to implement BMPs to improve water quality and increase the provision of environmental services on working agricultural lands.

Background

The Case for Agricultural Best Management Practice Implementation

Agricultural production has been highly successful in increasing both total yields and per acre yields in recent decades (Fuglie and Wang 2012). The increase in agricultural productivity has provided profound benefits for global food security, even in the midst of increasing human population and per-capita consumption. However, these benefits have been accompanied by environmental costs externalized to society. One externality that continues to present problems for natural resource managers is non-point source (NPS) water pollution from modern agricultural production. Non-point source water pollution from agricultural sources in the upper-midwest United States, contributing to problems ranging from human health concerns to the hypoxic dead zone in the Gulf of Mexico (Rabalais et al. 2002; USEPA 2005).

Prior research has indicated that agriculture has a very significant role to play in this water quality decline. According to the EPA, "agricultural nonpoint source pollution was the leading source of water quality impacts on surveyed rivers and lakes, the second largest source of impairments to wetlands, and a major contributor to contamination of surveyed estuaries and groundwater" (USEPA 2014). A study focusing on the causes of the Gulf of Mexico hypoxic zone found that agriculture was the largest contributor to both nitrogen (N) and phosphorus (P) loading. This study also found that 90% of the total pollution to the Gulf, about 21 million tons of N per year, is from nonpoint sources (Goolsby et al. 1999). The causes of this agricultural NPS pollution are varied. These can include plowing too often or at the wrong time; improper, excessive, or poorly timed pesticide, irrigation water, or fertilizer application; inappropriate ground cover; farming close to open water bodies; and increased artificial drainage with decreased natural drainage through wetlands (USEPA 2014; USGS 2007). These practices can lead to excessive nutrient runoff of nitrogen and phosphorous, sedimentation of waterways, and pesticides harming non-targeted species.

The EPA has declared that excessive nitrogen and phosphorous in waterways is one of "America's most widespread, costly, and challenging environmental problems" (USEPA 2012a). Although present and necessary in all natural ecosystems, N and P become problematic when natural background levels are exceeded. Both can lead to excessive algal growth, which in turn decreases the oxygen content of water bodies and can be detrimental to other aquatic life. Excessive nutrients can also harm humans directly, both via contaminated drinking water and recreational areas, such as swimming. The biophysical connection between nitrate in drinking water supplies and human health endpoints is well established (USEPA 2009). Nitrate levels beyond the 45 mg/L threshold set by the USEPA have been linked to increased risk of infant methemoglobinemia, or blue-baby syndrome, which reduces oxygen transport to the bloodstream (Bryan and van Grinsven 2013; USEPA 2012b).

Risks associated with recreational swimming in areas with degraded water quality have also been studied. Swimming in water with harmful algal blooms (HABs) has been linked to illnesses including nausea, skin irritation, gastroenteritis and heart failure (Weirich and Miller 2014). Aquatic snails, whose populations increase with eutrophication of water, can transmit parasitic diseases to swimmers, resulting in increased incidences of swimmers' itch (Valdivinos and Balboa 2008; Yescott 1989). Multiple prospective studies have found a relationship between enterococcal, staphylococci, fecal coliforms, and fecal streptococci populations in swimming water and diseases including swimmers' itch, gastrointestinal illnesses, eye and skin diseases, and "total illnesses" (Seyfried et al. 1985; Wade et al. 2006).

Excessive nutrient levels in water bodies can have detrimental impacts beyond human health. Low oxygen levels in water can reduce fish populations, decrease aquatic biodiversity, reduce property values, harm commercial and recreational fishing and shellfish harvesting, and reduce tourism (Anderson et al. 2012; Dodds et al. 2008; Poor et al. 2001; Ribaudo et al. 1999). Because of these numerous costs to human health and wellbeing, federal, state and local governments spend billions of dollars annually to prevent and treat waterways contaminated with excessive nutrients (USEPA 2012a).

Excess sediment can also be a problem in agricultural watersheds. Sediment can increase turbidity in streams and rivers. Sediment can inhibit growth of natural vegetation, clog fish gills, decrease primary productivity, and decrease desirable habitat for crevice-occupying organisms (Cruse et al. 2012; MARC n.d.). Since sediment can carry particulate phosphorous, high sediment loading can be accompanied by significant P loading (Panuska and Karthikeyan 2010). These effects of increased sediment lead to decreases in aquatic biodiversity and degrade the overall health of an ecosystem. Excess sediment can degrade drinking water by causing odor and taste problems (Gray 2008). Pollutants in sediment can bioaccumulate resulting in cancerous tumors in fish and fish consumption warnings for humans (Lyman et al. 1987; USEPA 2015). Flooding potential can increase if sediment fills storm drains and catch basins (MARC n.d.). Dredging of drainage basins may need to occur to prevent the basins from filling up with sediment. Water depth can be reduced causing problems for navigation or recreation, again possibly requiring dredging (USEPA 2015). Although natural erosion does contribute 30% of all sediment in waterways today, human-induced land use changes (such as agriculture) account for the remaining 70%. Ribaudo (1989a) estimated that water quality damages from sediment pollution costs the U.S. $8.8 billion annually ($17.2 billion in 2015 dollars).

Modern agricultural production and associated land use changes have also altered the hydrology of agricultural watersheds (Blann et al. 2009; Brooks et al. 2003; Tilman 1999). Soil tillage and compaction, artificial tile drainage systems, stream straightening, wetland alteration and loss and other practices have both increased water quantity flowing across the landscape and reduced the natural storage capacities to hold or slow the flow of water (Cruse et al. 2012; Blann et al. 2009). These related issues of excessive water quantity and reduced water storage have also had a series of detrimental effects. They increase rates of sedimentation and nutrients reaching open bodies of water. Decreased storage reduces the ability of natural wetland and riparian systems to treat the water before reaching streams, rivers, and lakes. Flooding risks are increased, along with infrastructure costs to prevent and respond to flooding (Cruse et al. 2012).

To address these water quality issues, the Clean Water Act (33 U.S.C. §§ 1288, 1329) was signed into law in 1972 requiring that all waters in the United States be assessed for various impairments. These include bacteria, chemicals, nutrients, turbidity and mercury (Ribaudo et al. 1999). If a water body does not meet predetermined standards it is added to the “Impaired Waters List”, also known as the 303[d] list. If a water body is on the 303[d] list, a Total Maximum Daily Load (TMDL) threshold must be set in order to reduce pollutant loads to levels deemed acceptable in the Clean Water Act (MPCA 2015a). Of the 72% of Minnesota water bodies that have been assessed for impairments, 40% are impaired for one or more pollutants, accounting for 4,114 total known impairments in 2014 (MPCA 2015a; MPCA 2015b). As of 2014, the four leading causes of impairments in Minnesota’s water bodies are: 1) mercury in fish tissue (39%); 2) nutrient loading (14%); 3) fecal coliform (13%); and turbidity (9%) (MPCA 2015a). Today, most of these listings are attributable to non-point source (NPS) pollution (USEPA 2012c). Although decades have passed since the Clean Water Act was enacted, many areas in the Mississippi River Basin still face large challenges (Sprague et al. 2011; Turner et al. 2008).

To reduce the agricultural contribution to NPS pollution, conservation managers have employed a wide variety of best management practices (BMPSs). The United

States Department of Agriculture (USDA) defines BMPs to include “soil and water conservation practices, other management techniques, and social actions that are developed for a particular region as effective and practical tools for environmental protection” (Sharpley et al. 2006). The Minnesota Department of Agriculture (MDA) defines BMPs as “practicable voluntary practices that are capable of preventing and minimizing degradation of ground water and surface water, considering economic factors, availability, technical feasibility, implementability, effectiveness, and environmental effects” (MDA 2012). Agricultural BMPs can be classified in a number of different ways. Four BMP classification systems include: 1) Issue/pollutant(s) addressed; 2) BMP location (on field, edge of field, off field, in a stream); 3) BMP mechanism (avoiding, controlling or trapping); or 4) BMP type (vegetative, structural, or management). Table 1.1 lists some common agricultural BMPs and their respective classification. Implementation of these BMPs has become the primary method encouraged by the EPA to address the consequences of agricultural nonpoint source pollution (USEPA 2003).

Literature Review

Introduction

It is widely accepted that water quality and other environmental concerns stemming from modern agricultural production are significant and should be addressed. Implementation of agricultural BMPs is generally seen as the most promising solution to address the problem. This research accepts these two statements on premise. However, this leaves state and federal level conservation decision makers with a large set of theoretical options and potential strategies to pursue. Which BMPs should be implemented and where? How should that decision be made? What specifically should be minimized (or maximized) and how should success or failure be measured? Should decision makers pursue more funding for current BMP implementation strategies, or maintain current funding levels and focus on more optimal BMP placement? What should be the role of local conservation managers working with landowners to implement BMPs? What new technologies or financial models might help make funding for conservation more sustainable? In other words, what strategies might conservation decision makers consider to increase environmental services through BMP implementation on working agricultural lands? This is the overarching question addressed by this research. Although there are myriad potential frameworks, angles, and disciplines from which to address this question, this research focuses on three: social science management, physical science, and economics, with the goal of synthesizing and communicating research results that are relevant for decision makers in the policy arena. The following sections discuss relevant literature in these disciplines and identify gaps in the literature that are addressed by this research.

The Agricultural BMP Implementation Decision Process of Local Conservation Managers

Significant research has been conducted to analyze the human decision making processes. Broadly speaking, the study of how choices are made between alternatives has been labeled as "decision theory". The interdisciplinary nature of this topic lends itself to inquiry in many fields including mathematics, sociology, economics and others. Mathematical or statistical approaches to decision theory emphasize the quantitative and rational aspects of decision making in order to maximize utility. On the other hand, the social science fields of psychology and behavioral economics have focused on describing the limitations of the theoretical super-rational person that is assumed in classical microeconomic theory. Herbert Simon was an early pioneer in this field, describing a model of an "administrative man" with bounded rationality over the "economic man" with perfect rationality (Simon 1957).

Although many theories or frameworks have been proposed from these various disciplines to describe how people make decisions, this research focused on decision theory as described by Bell et al. (1988). They describe how decision theory can be divided into three types: 1) Normative decision theory analyzes what decision makers *ought* to choose in a perfectly ideal and rational world with complete information; 2) Descriptive decision theory describes how and why imperfect actors (i.e., humans) *actually* make decisions. 3) Prescriptive decision theory analyzes how people can improve the decision making process.

Decision theory in the published literature related to conservation managers implementing agricultural BMPs, such as county-level Soil and Water Conservation District (SWCD) or Natural Resources Conservation Service (NRCS) professionals, generally focuses on either the normative or prescriptive decision theories described by Bell et al. (1988). Recent efforts to employ evidence-based conservation are what Bell et al. (1988) might call "normatively motivated" decision theory. Evidence-based conservationists believe that conservation decisions "should be based on effectiveness as demonstrated by scientific experiment or systematic review of evidence" (Pullin et al. 2004; Sutherland et al. 2004). Methods to promote this normative decision theory include dissemination of information and the promotion of decision support systems or tools to make efficient conservation decisions. Three (of many) examples of conservation decision support systems to promote this evidence-based decision process include: 1) targeting critical source areas with SWAT (Soil and Water Assessment Tool) (e.g. Ghebremichael et al. 2013); 2) the Nutrient Tracking Tool, which estimates nutrient runoff in various management scenarios (e.g. Saleh 2011); and 3) PLOAD, a GIS-based model to estimate nonpoint source pollution loads in watersheds (e.g. Syed and Jodoin 2006). A brief summary of 36 decision support tools to aid in decisions related to water quality improvements in the Midwest can be found in Appendix A.

Prescriptive decision theory as described by Bell et al. (1988) can be found in environmental conservation literature in the form of various decision frameworks. The idea of an adaptive management framework combines "research and action…the integration of design, management, and monitoring to systematically test assumptions in order to adapt and learn” or also known as learning from your mistakes (Lee 1993; Salafsky et al. 2001; Salafsky et al. 2002). Other prescriptive decision-making frameworks proposed for conservation managers include structured-decision making based on thresholds (Martin et al. 2009), methodological frameworks such as the NRCS Nine-Step Conservation Planning Process (USDA NRCS 2014a), or an ecosystem-services framework (Turner and Daily 2008).

Of the three types of decision theory described by Bell et al. (1988), descriptive decision theory is by far the least common in the environmental conservation literature. Descriptive decision theory research that has been conducted relating to agricultural BMPs focuses mainly on landowners. Studying the descriptive decision process of landowners is an important objective because agricultural BMP implementation relies considerably on landowner willingness to participate in conservation efforts. Research on landowners confirms the idea proposed by Herbert Simon (1957) and subsequent research in the fields of psychology and behavioral economics (e.g. Kahneman 2011) that a simplistic picture of landowners as hyper-rational or driven solely by economic profits is not accurate. Rather, landowners experience many drivers and constraints in their decision making process related to BMP implementation (Davenport and Olson 2012; Kabii and Horwitz 2006). Landowner conservation decisions have been shown to be motivated or influenced by a wide range of factors including information sources, aesthetic considerations, finances, environmental awareness, level of education, personal values, social factors, parcel size, and recreational activities (Brook et al. 2003; Prokopy et al. 2008).

Although the literature does describe the decision process of landowners in the BMP implementation process, much less is known about the decision process of conservation managers related to BMP implementation. This is a notable gap in the literature given the influence that conservation managers can have in the landowner conservation decision process in certain contexts (Brook et al. 2003; Kueper et al. 2012; Wright and Shindler 2001). Additionally, the lack of discussion in the literature describing the decision process of local conservation managers is important to address because local conservation managers are entrusted with public funds to implement BMPs on working agricultural lands. The USDA spent about $6 billion/year in both 2012 and 2013 on its major conservation programs, including the Environmental Quality Incentives Program (EQIP), Conservation Stewardship Program (CSP), the Conservation Reserve Program (CRP), and others (USDA ERS 2014). Conservation managers at the state and county level play an important role in deploying these federal resources at the local level. In spite of both the influence of conservation managers in the BMP implementation decision process and the considerable budgets they manage, a review of the literature found no studies that describe the current decision making process of conservation managers working to improve water quality on agricultural lands in the United States.

Physical Effectiveness Measures of Agricultural Best Management Practices

Agricultural BMP implementation strategies to increase environmental services are multi-dimensional and interdisciplinary. One important and relatively thoroughly studied dimension that decision makers need to consider is the physical science research conducted on BMP effectiveness. Significant research has been conducted on the effectiveness of various agricultural BMPs to improve water quality. For purposes of this research, BMP physical effectiveness is defined as “the percentage by which [pollutant] loss is reduced” by the installation of a BMP (Gitau et al. 2005; Merriman et al. 2009). Physical effectiveness estimates require pre-BMP installation and post-BMP installation measurements of pollutant loss from a given area, either as a concentration or total loading volume or mass. Multiple BMPs are often implemented and often necessary to meet pollution reduction goals. However, the methodology used in this research requires that only one BMP be installed in a given system, or else the results are confounded and not attributable to a specific BMP.

One major distinction between BMP effectiveness studies are those that are based on observed data, and those that are based on modeled data. This research presented here in chapters 3 and 4 focuses nearly exclusively on the former, using observed BMP effectiveness studies. Observed data studies, sometimes constructed as paired watershed studies (e.g. Udawatta et al. 2002; Bishop et al. 2005), require instruments in fields or waterways measuring the physical, on-the-ground changes attributable to BMP implementation. Best Management Practice studies based on modeled data use computer models to estimate the effects of BMP implementation on water quality. Modeled studies on BMP effectiveness will usually calibrate the models with observed data, but results are essentially based on mathematical representations of physical realities. Examples of these water quality models include Integrated Valuation of Environmental Services and Tradeoffs (InVEST), Agricultural Policy Environmental eXtentder (APEX), and the Soil and Water Assessment Tool (SWAT). Descriptions of these models, and many other decision support tools related to water quality, can be found in Appendix A. Both modeled and observed estimates of BMP effectiveness are of course important research objectives with their own strengths and weaknesses.

To date there have been a number of efforts to categorize and summarize agricultural BMP effectiveness studies to improve water quality, an important source of data for the research in chapters 3 and 4. Due to the extensive nature of agricultural BMP effectiveness studies, most review papers limit their scope to a particular pollutant, a particular BMP, and/or a particular geographic region. Some of these are relatively simple summaries of the related literature, while others attempt a full meta-analysis of BMP effectiveness literature. All observed-data studies were considered for inclusion in this review as they provide important information used in the subsequent research. Water quality BMP papers that did not include effectiveness estimates, only providing general information about BMPs, were not included in this literature review.

One key publication to summarize agricultural BMP effectiveness is a 2005 paper that summarizes 33 published papers related to phosphorous control BMPs from across the United States (Gitau et al. 2005). From this summary they developed a database and tool for users to search the data based on desired inputs, such as soil type and geographic location. Although the tool developed from this literature review was designed for use in rural New York watersheds, the authors believe the tool is applicable to the entire U.S. A similar tool was developed for N, P, and sediment BMPs with data from across the south-central and southeastern United States. This tool was designed primarily for use in Arkansas but, according to the authors, the underlying database could be modified for other geographic areas (Merriman et al. 2009).

In 2012 Emmons and Oliver, Inc. developed “The Agricultural BMP Handbook for TMDLs in Minnesota” (Miller et al. 2012). This handbook defines various BMPs, estimates the effectiveness of each BMP, and estimates the cost for design, installation and maintenance. The handbook also contains a table reviewing the agricultural BMP literature for many pollutants and many BMPs at various geographic scales. Information from this handbook is being used to construct a database for users to search BMP effectiveness literature.

At least two efforts have been made to summarize the relative effectiveness of different agricultural BMPs (Brach et al. 1989; Brown et al. n.d.). In the Brown et al. review, each pollutant/BMP combination is given a ranking of: 1) medium to high effectiveness; 2) low to medium effectiveness; 3) no control to low effectiveness; or 4) may increase or decrease impact. Although the authors acknowledge that BMP effectiveness varies with physical site characteristics, these are attempts to offer broad information on which BMPs are more or less effective for specific pollutants. No effort is made to specify site characteristics that would lead to more to less effective BMP outcomes. Although the first study is from the Minnesota Pollution Control Agency and the second is from Ohio State University Extension, the data in each of the tables is similar, such that the latter may have been based on the former, but updated with new research and more relevant BMPs for the geographic area. Other studies specifically avoid summary tables of BMP effectiveness due to their highly context specific nature (Miller et al. 2012).

Some agricultural BMP effectiveness review papers limit their scope to one specific pollutant of concerns. For example, many papers have reviewed the effectiveness of BMPs on phosphorous reduction. Some examples include Sharpley et al. 2009; Dinnes 2004; Carpenter et al. 1998; Gitau et al. 2005; and Devlin et al. 2003. Review papers for BMPs relating to nitrogen include Dinnes et al. 2002; Russelle et al. 2001; Huggins et al. 1997; Carpenter et al. 1998; Merriman et al. 2009; and Kaspar et al. 2008. Review papers focusing on sediment control include Waters 1995; and Zhang et al. 2008.

Many agricultural BMP effectiveness studies focus on the effectiveness of a specific agricultural BMP or practice. A limited number of studies that are relevant to this research are listed in Table 1.2. Based on a review conducted by Emmons and Oliver Research and the MDA, it is estimated that there are approximately 75 published studies measuring the effectiveness of various agricultural BMPs in improving water quality in the upper Midwest. The empirical studies reviewed here are some of the primary data sources for BMP physical effectiveness estimates required for chapters 3 and 4 of this research.

The Economics of Agricultural Best Management Practices

Costs of Agricultural Best Management Practices

Research in chapters 3 and 4 requires the estimation of many costs related to BMP installation and maintenance, but as a literature review on BMP cost estimate methodologies indicates, this is not a straightforward task. Costs to install and maintain a BMP are sensitive to many factors, including but not limited to the location, type, scale, access to capital, life expectancy, maintenance of a BMP. The many sources of variation can make it difficult to estimate costs prior to implementation (Parker et al. 1994; Walker 1994; Wossink and Osmond 2002). In spite of known difficulties, efforts have been made to estimate agricultural BMP costs prior to implementation.

Many conservation managers are guided by recommended Natural Resource Conservation Service Environmental Quality Incentives Program (EQIP) rates when estimating costs of agricultural BMPs. The EQIP program is the largest financial assistance program for working agricultural lands. It is a voluntary program, providing farmers with “financial and technical assistance to plan and implement soil and water conservation practices” (Stubbs 2010). EQIP participants receive a portion of the cost of BMP installation and, in exchange, sign a contract agreeing to maintain a specific conservation practice for a pre-determined period of time. EQIP contracts are limited to paying for a maximum of 75% of costs related to planning, design, materials, equipment, installation, labor, management, maintenance and training. Rates are higher for historically disadvantaged or beginning farmers. Up to 100% of any forgone income due to the conservation practices can be reimbursed (Stubbs 2010). Typically EQIP payment rates are established at the state or regional level. For example, in Minnesota in 2011, contour farming with an EQIP contract was reimbursed at $10/acre (no payment cap), a critical area planting of native grasses was $163/acre (no payment cap), and no-till was reimbursed at $23/acre (with a payment cap of $9,000). Details on these BMPs and others can be found in the 2011 Minnesota EQIP Conservation Practice Schedule (MNRCS 2011).

The USDA's Economic Research Service (ERS) has compiled EQIP data from across the United States and put it in user-friendly Excel data tables. The ERS divides the United States into nine "Farm Resource Regions" (USDA ERS 2007). Minnesota falls into three of these regions: Heartland (southern and western MN), the Northern Great Plains (northwestern MN), and the Northern Crescent (central and northern MN). The data provided by the ERS distinguishes between EQIP reimbursement rates, and total project costs for the landowner before EQIP payments. They provide total project costs for the 33 most common agricultural BMPs, along with the mean, standard error, median, and number of data entries for each practice. For example, cover crops in the Heartland region between 2001 and 2003 cost an average of $12.64/acre ± $0.70/acre ($16.71/acre ± $0.93/acre in 2015 dollars). This average was based on 143 observations with a median cost of $10.67/acre ($14.10/acre in 2015 dollars). In addition, the ERS considered the effects of scale on the cost of these 33 conservation practices, providing average costs for projects above the median project cost and average costs for projects below the median cost. This data allows an estimate of scaling effects on total costs for a given practice (USDA ERS 2007).

The EQIP data sets described above contain large numbers of BMPs in their cost estimates, an important factor for chapter 3 in comparing BMP costs between BMPs. However, BMP costs are also found in published, peer-reviewed papers. These detailed cost estimates for specific BMPs were more helpful for chapter 4 in attempts to estimate costs of operating the pyrolysis units, but were also helpful to cross-check the EQIP cost and BMP life span estimates. Liu et al. (2011) analyzed the costs of riparian buffers strips in six Kentucky counties to promote water quality trading programs. This study estimated that buffer establishment and maintenance costs were $32.79/acre, based on an expected 10 year life (Bonham et al. 2006). The USEPA published a technical and reference guide summarizing some of the agricultural BMP cost literature (Dressing 2003). For example, nutrient management plans in Wisconsin cost $5-$8/acre in 1998, not including landowner savings from reduced fertilizer use, and fencing was estimated to cost $367/kilometer ($591/mile) (Dressing 2003). Smolen and Humenik (1989) reported estimated capital costs for the installation of diversions ($1.97-$5.51/ft), terraces ($3.32-$14.79/ft), permanent vegetative cover ($69-$270/acre), conservation tillage ($9.50-$63-35/acre) and other practices. Camacho (1992) estimated annualized cost estimates for BMPs from Chesapeake Bay installations, including operation, maintenance, planning, and assistance costs. This study estimated median annual costs for nutrient management plans ($4.21/ac/yr), terraces ($150.33/ac/yr), cover crops ($17.52/ac/yr), conservation tillage ($30.31/ac/year) and eight other BMPs (all costs converted to 2015 dollars). In addition to the BMP cost research summarized here, many other publications citing BMP cost data are used and cited throughout chapters 3 and 4. The wide range of BMP cost data identified in the literature was narrowed by focusing on BMP cost data from agricultural regions of Minnesota. In cases where Minnesota BMP cost data was not found, cost estimates were identified from other sources as necessary and are detailed in each study.

Due to the various life expectancies of differing agricultural BMPs, costs in published and peer-reviewed literature are often annualized to facilitate comparison between BMPs with different life expectancies (Camacho 1992; Gitau et al. 2004; Heatwole et al. 1987; Yuan et al. 2002). For example, contour buffer strips have a lifetime of 10+ years, while nutrient management plans last one year (NRCS 2014b; Gitau et al. 2004). Christianson et al. (2013) and Burdick et al. (1982) calculate BMP equivalent annualized costs (EACs) by multiplying the total present value cost of a BMP by a capital recovery factor (CRF) (Equation 1.1). Annualizing BMP costs was done throughout chapters 3 and 4 of this research, and specific methods used are described in context and more depth in these chapters.

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{1.1}$$

Where:

n = estimated life of BMP, or planning horizon (years)

i = Annual real discount rate (%)

Cost-Effectiveness of Agricultural Best Management Practices

Conservation managers have limited time, knowledge, and funds to address the problem of NPS pollution. One important goal in their work is to effectively target scarce conservation dollars in cost-effective ways, so that they can minimize per-unit pollution reduction costs. Chapters 3 (a cost-effectiveness analysis) and 4 (a techno-economic analysis) both seek to discover and describe cost-effective strategies for conservation managers to consider. In this research, a cost-effective BMP is defined as the BMP with the lowest per unit costs of pollutant reduction. In comparing scenarios with different BMP installations, the most cost-effective or financially efficient BMP may or may not have the lowest upfront or capital costs. Additionally, the most cost-effective option also may or may not be the scenario that reduces pollution by the greatest total amount. For example, a Florida study found that the most cost-effective placement of BMPs can provide 90% of the pollution-reduction benefits (compared to the maximum reduction BMP scenario) at just a quarter of the cost (Heatwole et al. 1987).

To estimate the cost-effectiveness of a BMP in chapter 3, two data points are required for each BMP installation: 1) the physical effectiveness (e.g. lbs./acre/year) of a given BMP in reducing pollution; and 2) the cost to install and maintain a BMP. This section reviews the published literature that attempts to estimate the cost-effectiveness of agricultural BMPs to reduce non point source water pollution.

A 2002 study examined the cost-effectiveness of eight different BMPs in three different physiographic regions of North Carolina (Wossink and Osmond 2002). They accounted for costs and benefits from the perspective of the landowner, including revenue from various cost-share programs (15-year, 30-year, or permanent easements), lower production costs (such as with fertilizer management), land opportunity costs, and BMP installation, maintenance, and labor costs. Physical effectiveness benefits of the BMPs (only N-reduction was considered) were based on research done by a local river basin committee and considered equal for all three physiographic regions. No further information is given on the research done by this local river basin committee, such as how they estimated BMP physical effectiveness. Key findings include the sensitivity of BMP cost-effectiveness to both location (due to differences in soil and land rent) and duration of the Conservation Reserve Enhancement Project (CREP) contract. They also found that buffer strips, in most scenarios, are not financially efficient. The authors found a nitrogen reduction rate of 65% for grass buffers, but note that CREP cost-share payments for grass buffers may not be justified by the total amount of N reduction (Wossink and Osmond 2002).

A study in a Delaware County, New York watershed estimated BMP cost-effectiveness based partially on studies using empirical data. This research attempted to optimize BMP placements to reduce dissolved P loading in the most cost-effective manner (Gitau et al. 2004). This study used an optimization algorithm, Soil and Water Assessment Tool (SWAT), and a BMP literature survey tool (discussed in the BMP physical effectiveness section) to estimate the effectiveness of various BMP configurations ranging from farm-scale up to watershed scale. The most cost-effective scenario reduced 0.6 kg dissolved P per dollar spent per year, including a minimum pollution reduction target of 60% below baseline levels. The authors note that this approach for estimating cost-effectiveness is applicable to scenarios where two things are known or can be estimated: 1) baseline pollutant loadings; and 2) field study data for BMP effectiveness (Gitau et al. 2004).

One study based in the Texas high plains used APEX to estimate conservation practice effectiveness in reduced sedimentation (Willis 2008). Costs were measured as a sum of forgone crop yields and BMP installation and maintenance costs. A study based in the Mississippi River delta used a similar approach, but modeling was done with Annual Agricultural Non-Point Source Pollution Model (AnnAGNPS) (Yuan et al. 2002). This study considered four agricultural BMPs and three tillage systems and found that the most cost-effective BMPs for the 12ha site studied included cover crops with various types of edge-of-field and grade-control pipes. They found the marginal cost for sediment reduction from agricultural BMPs to be approximately $7.3/ton.

One strategy that has gained momentum in recent years with the advancement of GIS technology is to "target" lands for conservation that are contributing a disproportionate amount of non-point source pollution. The thought is that focusing efforts on these areas should lead to the most cost-effective solutions. However, research has shown that targeting may not be the most cost-effective option because it does not explicitly consider costs, and may unnecessarily limit conservation efforts to a few lands while also possibly eliminating near-optimal conservation options that may be more socially acceptable (Veith et al. 2004; Arabi et al. 2006; Ribaudo 1989b). Research by Veith et al. (2004) recommends using optimization algorithms (Veith et al. 2003; Gitau et al. 2004; Arabi et al. 2006) as a more accurate way to determine a cost-effective BMP configuration on the landscape. They found that the targeting strategy reduced sediment loading at a cost of $42/kg/ha/yr, while the optimization strategy reduced sediment loading at a cost of $36/kg/ha/yr. Although this optimization strategy identified a relatively cost-effective configuration of BMPs on the landscape, its results are very site-specific and significant training is required to adapt the model to other locations.

In reviewing these studies, it is clear that many methodologies have been used to estimate the cost-effectiveness of BMPs, or a proxy variable assumed to represent BMP cost-effectiveness. These studies are primarily based on modeled data while relatively few studies use empirical data for BMP cost-effectiveness estimates, and no studies in the last twenty years were found that use empirical data for baseline pollution estimates in estimating BMP cost-effectiveness. The few studies that do use empirical data generally focus on either BMP physical effectiveness or BMP cost-effectiveness, not both. Given the wide range of methodologies, there are understandably wide ranges in BMP cost-effectiveness estimates. Each study also has unique (or unstated) assumptions in BMP cost-effectiveness estimates, making it difficult or impossible to compare BMP cost-effectiveness estimates between agricultural BMPs.

Gaps in the Literature Addressed by this Research

The review of relevant literature relating to strategies to improve agricultural BMP implementation on working agricultural lands focused on three areas: 1) social science management and decision theory; 2) physical science effectiveness estimates from empirical data; and 3) BMP cost and cost-effectiveness estimates. The literature review identified a wide variety of methodologies, inconsistent findings, and important gaps in the literature. The research presented in the following chapters addresses these limitations in the following ways:

Chapter 2: There have been many research efforts to develop normative and prescriptive decision frameworks (i.e., how decisions should be made, and how to improve decision processes) for improving conservation decisions, some of which are described above in the literature review. However, a framework for the descriptive decision making process (i.e., how decisions are currently made) of conservation managers is notably lacking. Importantly, an understanding of current decision processes could lead to a better understanding of how conservation happens in the context of voluntary agricultural BMP adoptions. Additionally, this lack of a descriptive decision framework is significant because good prescriptive decision frameworks are based on a comprehensive understanding of current, descriptive decision frameworks (Baron 2004).

Chapter 3: To my knowledge, no one has aggregated agricultural empirical BMP studies, estimated BMP physical effectiveness and costs from these individual studies, and used the data to estimate BMP cost-effectiveness for each study. The strength of estimating cost-effectiveness for each individual study is that the aggregated results show a likely range of cost-effectiveness values across different regions of the landscape, along with a median and deviation of many types of agricultural BMPs. Additionally, research is lacking in comparing BMP physical effectiveness estimates to BMP cost-effectiveness estimates. This comparison has been done to a limited extent with modeled data, but as far as I am aware this comparison has not been done based on field-tested, empirical data.

Chapter 4: This research develops a model to analyze sustainable approaches to BMP implementation. Ideally, landowners who provide ecosystem services through BMPs on working lands should benefit from their decision to provide a public good. One possible mechanism for this is through the installation of specific technologies that create market outlets for the products produced from BMPs. For instance, microwave assisted pyrolysis (MAP) units could be installed regionally to process cellulosic biofuels from perennial feedstock BMPs such as buffer strips. Because MAP units can be small, they have the potential to be mobile. The impacts of mobility on BMP cost-effectiveness via these pyrolysis units has not been modeled or studied in depth in the literature. Any discussion of mobile pyrolysis units is rare, even in the grey literature. Additionally, the mobile pyrolysis units were compared to two other non-mobile MAP biofuel systems. This allowed a comparison of system advantages and disadvantages to assess MAP strategies that might be sensible for conservation decision makers to pursue as they are working to increase the provision of environmental services on working agricultural lands.

Key Research Questions

Chapter Two: Focus Groups of Conservation Managers in Minnesota

1) What factors drive the voluntary conservation implementation process, as described by local conservation managers?
2) What criteria do conservation managers cite as evidence that a BMP implementation has been effective in improving water quality?
3) What do conservation managers see as the primary causes of ineffective BMP installations?

Chapter Three: BMP Effectiveness vs. Cost-Effectiveness

1) Based on aggregating previous observed BMP effectiveness studies across five Midwestern states, how effective are various BMPs in reducing total phosphorus loadings?
2) How cost-effective are these BMPs in reducing total phosphorus loadings?
3) How do BMP physical effectiveness rankings compare to BMP cost-effectiveness rankings?
4) How is BMP effectiveness influenced by BMP location, soil type, slope, and study scale?

Chapter Four: A Model to Explore Three Scenarios of Workings Lands Conservation

1) Can a microwave assisted pyrolysis MAP scenario be identified where productive conservation BMPs (such as buffer strips or perennial grasses providing both

biofuel feedstocks and conservation benefits) are financially viable for both landowners and private investors? In this context, how do three different scenarios of MAP (mobile, cooperative, and distributed systems) compare to each other?

2) Are these conservation options a good taxpayer investment if environmental benefits are included in the decision making process?

Tables

Table 1.1. Best management practices for agricultural watersheds.

Table 1.2. Some studies measuring BMP effectiveness in improving water quality (or review papers of BMP effectiveness).

Table 1.1. Best management practices for agricultural watersheds.

BMP Name	Issue(s) Addressed[1]	BMP Location	Mechanism (NRCS)	BMP Type
Conservation Crop Rotation	S*,N*,P*	On field	Avoiding	Vegetative
Contour Buffer Strips	S,N*,P	On field	Avoiding	Vegetative/Tillage
Contour Farming	S,N*,P	On field	Avoiding	Vegetative/Tillage
Cover Crops	S*,N*,P*	On field	Avoiding	Vegetative
Grade Stabilization Structures	S*,P*	Edge of field	Avoiding	Structural
Nutrient Management, Amount	N,P	On field	Avoiding	Management
Nutrient Management, Method	N,P	On field	Avoiding	Management
Nutrient Management, Timing	N,P	On field	Avoiding	Management
Contour Stripcropping	S,N*,P	On field	Controlling	Vegetative/Tilling
Grassed Waterway	S*,P*,F	Edge of field	Controlling	Structural
Irrigation Water Management	S,N,P	On field	Controlling	Management
Mulch till	S,P	On field	Controlling	Tillage
No till/minimum till/strip till	S,P	On field	Controlling	Tillage
Ridge till	S,P	On field	Controlling	Tillage
Riparian vegetation	S,P,F	In-stream	Controlling	Structural
Seasonal till	S,P	On field	Controlling	Tillage
Streambank protection	S,P,F	In-stream	Controlling	Structural

Stripcropping	S*,N*,P*	On field	Controlling	Vegetative/Tillage
Terraces	S,N*,P	On field	Controlling	Structural
Field Border	S*,P*,F	On field	Trapping	Vegetative
Filter Strips	S*,P*,F	Edge of field	Trapping	Vegetative
Sediment Basins	S,P	Edge of field	Trapping	Structural
Water/Sediment Control Basin	S,P	On field	Trapping	Structural
Wetland, Constructed	S,N*,P,F	Edge of field/off field	Trapping	Structural
Wetland, Creation	S,N*,P,F	Edge of field/off field	Trapping	Structural
Wetland, Enhancement	S,N*,P,F	Edge of field/off field	Trapping	Structural
Wetland, Restoration	S,N*,P,F	Edge of field/off field	Trapping	Structural

Sources: Brown et al. n.d.; Miller et al. 2012

[1] S = sediment, N = nitrogen, P = phosphorous, F = flooding. An asterisk (*) indicates possible low to medium effectiveness for this pollutant. (No asterisk indicates generally medium to high effectiveness.)

Table 1.2. Some studies measuring BMP effectiveness in improving water quality (or review papers of BMP effectiveness).

BMP/Practice	**Pollutant/Issue(s) Addressed***	**Short Citation****
Buffers	S,N,P,F	Bentrup 2008
Buffers	S	Liu et al. 2008; Zhang et al. 2008
Buffers	N,P	Muscutt et al. 1993
Buffers	N,P,S	Norris 1993
No-Till	P, S	Richards and Baker 1997
Tillage Systems	N,P,S	Logan et al. 1991
Contour Buffer Strips	S	Coyne et al. 1995
Contour Buffer Strips	S,P	Daniels and Gilliam 1996
Contour Buffer Strips	N,P,S	Dosskey et al. 1999
Cover Crops	N	Kaspar et al. 2008
Contour Stripcropping, Terraces, Filter Strips	N,P,S	Merriman et al. 2009
Conservation tillage	N	Mostaghimi et al. 1991
Conservation tillage	N,P	Schreiber and Cullum 1998
Conservation tillage	N,P,S	Berg et al. 1988
Contour Strip Cropping	N,P,S	Cestti et al. 2003
Cover Crops	N,P,S	Yuan et al. 2002
Cover Crops	N,P,S	Mostaghimi et al. 1997

Crop Rotation	N,P,S	Zhu et al. 1989
Drainage Systems	N,P,S	Cooper and Knight 1990
Drainage Systems	N,P	Deal et al. 1986
Filter Strips	N,P,S	Blanco-Canqui et al. 2004
Filter Strips	N,P,S	Udawatta et al. 2002
Nutrient Management Plans	N	Mostaghimi et al. 1991
Nutrient Management Plans	N,P,S	Mostaghimi et al. 1992
Riparian Forest Buffers	N,P	Lowrance and Sheridan 2005
Sediment Basins	N,P,S	Cooper and Knight 1990
Terraces	N,P,S	Cestti et al. 2003
Wetlands	N,P	Vellidis et al. 2003

* N = nitrogen, P = phosphorous, S = sediment

** See Literature Cited section at the end of this dissertation for the full citation.

Chapter 2

How Conservation Happens:

Focus Groups of Local Conservation Managers to Describe the Voluntary Agricultural BMP Implementation Process

Overview

Conservation managers working to improve water quality in agricultural regions help facilitate agricultural best management practice (BMP) implementation in light of competing objectives and multiple constraints such as limited budgets and socially acceptable practices. Three focus groups were conducted in central and southern Minnesota to better understand factors related to the perceived effectiveness or ineffectiveness of BMP implementation and the decision making process leading to BMP implementation. Perspectives shared by the focus group participants shed light on how conservation managers define criteria for conservation implementation successes, and perceived complications and constraints of BMP implementation. A constant comparative methodology was used to describe the voluntary agricultural BMP implementation process from the perspective of local conservation managers. This research found that the voluntary conservation implementation process is complex, requiring conservation managers to have an understanding of technical, policy, and human dimensions of conservation efforts. The conservation implementation process is largely driven by landowners who take the initiative to seek technical help, and the availability of cost-share programs. Disadvantages of the current system include difficulty integrating systematic tools into the decision process, difficulty implementing cost-effective conservation options, and an insufficient number of engaged landowners willing to implement conservation practices. Encouraging peer exchange through network building, and promoting greater engagement with landowners accompanied by flexible cost-share options would be two meaningful steps to modify the current voluntary framework and make progress in reducing agricultural non-point source pollution.

Introduction

Industrialized agricultural production has succeeded in increasing both total and per acre yields in recent decades (Fuglie and Wang 2012). This has provided profound benefits for global food security, even in the midst of increasing human population and per-capita consumption. However, these benefits have been accompanied by environmental costs externalized to society. One externality that continues to present problems for society is non-point source (NPS) water pollution from modern agricultural production. The causes of agricultural NPS pollution are varied but can include cultivating too often, at the wrong time, or in the wrong places; improper, excessive, or poorly timed pesticide, irrigation water, or fertilizer application; farming close to open water bodies; and increased artificial drainage with decreased natural drainage through wetlands (USEPA 2014; USGS 2007). These practices contribute to problems ranging from methemoglobinemia (blue-baby syndrome) (Greer and Shannon 2005), reduced recreational opportunities such as swimming due to harmful algal blooms that can cause various illnesses (Falconer 1999), the hypoxic dead zone in the Gulf of Mexico (Goolsby et al. 1999), decreased water storage on the landscape (Blann et al. 2009; Cruse et al. 2012), and other issues (Cruse et al. 2012; Dodds et al. 2008; Poor et al. 2001; Ribaudo et al. 1999).

Because of the numerous externalized costs of agricultural NPS pollution, federal, state and local governments spend billions of dollars annually to prevent and treat waterways contaminated with excessive nutrients (USEPA 2012a). And yet, though decades have passed since the Clean Water Act was enacted in 1972 (33 U.S.C. §§ 1288, 1329), many areas in the Mississippi River Basin still face large challenges (Sprague et al. 2011; Turner et al. 2008). The EPA has declared that excessive nitrogen and phosphorous in US waterways is one of “America’s most widespread, costly, and challenging environmental problems” (USEPA 2012a).

Landowners are the final decision makers when implementing conservation measures on their properties to improve water quality. United States courts have repeatedly held up laws giving landowners the freedom to decide how their land is ultimately managed (Theobald et al. 2000). In light of this, the traditional policy mechanism to improve water quality in agricultural regions is a voluntary-based strategy of implementing best management practices (BMPs), often with technical assistance, training, and subsidies provided to help cover the costs of implementing best management practices (BMPs) (Davenport et al. 2013). To promote BMP implementation, research has been conducted to analyze and understand the drivers and constraints of landowners to installing BMPs on their land (Kabii and Horwitz 2006; Norris and Batie 1987). Key drivers identified by Davenport and Olson (2012) to increase BMP adoption include: 1) environmental stewardship values; 2) favorable economics such as cost savings from applying less nitrogen or payments for conserving marginal lands; and 3) personal responsibility for the health of water resources. Constraints included: 1) costs; 2) the belief that their farm was unsuitable for various BMPs; 3) a lack of familiarity with newer BMPs; 4) a desire for autonomy from government programs; and 5) questioning the effectiveness of BMPs due to a lack of data.

Although landowners have significant discretion on the implementation of these practices, the voluntary adoption policy approach places a significant burden on conservation managers to promote BMPs and provide information, education, and technical and financial assistance to landowners (Napier and Bridges 2002). The complicated task of the conservation manager is to facilitate and increase voluntary participation in improving water quality and other conservation efforts (Salafsky et al. 2002). Although landowners make the final decision on BMP implementation, conservation managers are essentially asked to consider various preferences, constraints, objectives, and uncertainties to make a rational choice as to how to best promote voluntary BMP implementation to improve water quality on private lands.

This multi-objective decision making process can be difficult and often comes with competing objectives, which is described in the literature as ‘decision theory’ or ‘rational choice theory’ (Ableson and Levi 1985; Bell et al. 1988). Decision theory can be divided into three types (Bell et al. 1988; Baron 2004; Goodwin et al. 2004):

1) <u>Normative</u> decision theory analyzes what decision makers *ought* to choose in a perfectly ideal and rational world with complete information. It follows the axiom that says if decision makers believe ‘x’, then they should do ‘y’. Normative models describe a theoretical ideal of a rational choice.
2) <u>Descriptive</u> decision theory describes how and why imperfect actors (i.e., humans) *actually* make decisions. Humans, of course, are not completely rational, and the fields of psychology and behavioral economics in particular have described the extent to which humans are (or are not) capable of making rational choices (Bell et al. 1988; Kahneman 2011). The study of descriptive decision making is highly empirical.
3) <u>Prescriptive</u> decision theory analyzes how people can improve the decision making process (Baron 2000; Grant and Van Zandt 2009). Prescriptive decision theory, such as conceptual frameworks or decision support tools, can be evaluated by their “pragmatic value” (Bell et al. 1988). Prescriptive decision tools encourage non-rational human actors to make better, more informed decisions.

Both normative and prescriptive decision theory have been studied in conservation decision making contexts. Evidence-based conservation is what Bell et al. (1988) might describe as an example of "normatively motivated" decision theory. Evidence-based conservationists believe that conservation decisions "should be based on effectiveness as demonstrated by scientific experiment or systematic review of evidence" (Pullin et al. 2004). An evidence-based framework then encourages the flow of information between scientists and decision-makers through collaboration and decision support systems (Pullin and Knight 2003). Sutherland et al. (2004) studied decision making in conservation practices in the UK and advocated for an evidence-based revolution in conservation, parallel to the changes seen in the fields of medicine and public health. A comprehensive list of (prescriptive) decision support systems to facilitate this (normative) evidence-based revolution in conservation would be long, but three examples include: 1) targeting critical source areas with SWAT (Soil and Water Assessment Tool) (e.g. Ghebremichael et al. 2013); 2) the Nutrient Tracking Tool, which estimates nutrient runoff in various management scenarios (e.g. Saleh 2011); and 3) PLOAD, a GIS-based model to estimate nonpoint source pollution loads in watersheds (e.g. Syed and Jodoin 2006).

Prescriptive decision theory can be found in the form of various decision frameworks. For example, an adaptive management framework is a pragmatic combination of "research and action…the integration of design, management, and monitoring to systematically test assumptions in order to adapt and learn" or more simply stated as learning from your mistakes (Lee 1993; Salafsky et al. 2001; Salafsky et al. 2002). Other prescriptive decision-making frameworks proposed for conservation managers include structured-decision making frameworks based on thresholds (Martin et al. 2009), methodological frameworks such as the NRCS Nine-Step Conservation Planning Process (USDA NRCS 2014a), or an ecosystem-services framework (Turner and Daily 2008).

It is critical to step back and put these normative and prescriptive decision theories into a larger context. Importantly, the most insightful models of normative decision theory and the most helpful prescriptive models are based on a clear understanding of current, descriptive decision theory (Baron 2004). As Bell et al. (1988) stated, "…a good normative theory of choice cannot be developed until human decision-making processes are understood." And yet, a descriptive decision framework for conservation managers is not well described in the literature.

This research fills the gap by developing a framework to better understand the current decision-making process of local conservation managers working to improve water quality. An understanding the decision process of conservation managers should provide insight about the drivers of the current voluntary conservation implementation process that has become the primary strategy for voluntary agricultural BMP implementation and overall water quality improvement goals. The three key questions of this research are:

1) What factors drive the voluntary conservation implementation process, as described by local conservation managers?

2) What criteria do conservation managers cite as evidence that a BMP implementation has been effective in improving water quality?
3) What do conservation managers see as the primary causes of ineffective BMP installations?

By addressing these three questions, this research will lead to new insights on how to improve and increase the provision of water quality through the implementation of agricultural best management practices.

Materials and Methods

In the spring of 2012, conservation managers with at least three years of experience implementing BMPs to improve water quality in agricultural regions were invited to attend three separate focus groups, one each in agricultural regions of southcentral, southeast, and central Minnesota. Focus groups are a research tool designed to "obtain perceptions on a defined area of interest" (Krueger and Casey 2009). In a nonjudgmental environment a focus group allows researchers to understand various opinions and gain insight into how people think. While surveys scan broadly, focus groups probe deeply. The focus group format often leads to a rich discussion and exchange of ideas both with the moderator and between participants. A questioning route (Appendix C) was developed by the research team to guide the discussion and elicit insights from participants on the key research questions. The questioning route was reviewed by two external focus group researchers for comments and suggestions for improvement and approved by the University of Minnesota Institutional Review Board. Finally, the questioning route was piloted twice with conservation resource professionals to test the clarity of the questions and the sequence.

Participants were recruited through purposive sampling for data-rich participants using professional networks (Patton 2005). Participants were required to have been working for at least three years to implement agricultural BMPs to improve water quality. Across the three focus groups, 20 conservation managers (13 men, 7 women, all Caucasian) attended. Each group had between 6 and 8 participants. Attendees included professionals from seven counties in central and southern Minnesota, representing soil and water conservation districts (n=11 participants from 6 different counties), Natural Resource Conservation Service (n=3), Minnesota Department of Natural Resources (n=2), and four non-profit groups (n=4). Job responsibilities of focus group participants ranged from providing landowners technical assistance, educating the public about water quality concerns, overseeing the implementation of BMPs, and encouraging technical compliance.

The questioning route for this research started by having participants share which water quality issues were the most pressing in their watersheds and which BMPs they most commonly implemented. Participants were asked to collaboratively brainstorm responses to be written on a large piece of paper in the front of the room. Then participants were asked to individually rank which items from the list were most relevant for them. Participants were then asked to reflect and share BMP implementations that resulted in successful outcomes, and also to share stories of BMP implementations that had failed. The final, key question asked participants to describe how their decisions were made related to agricultural BMP implementation.

Each focus group lasted 90-120 minutes and was led by a trained moderator. Data gathered from the focus group meetings included audio files of the participant discussions (with written consent provided by participants), field notes, a recorded discussion after each focus group between the moderator and the field assistants, and (on one question) individual written responses.

Once the focus groups were completed, the interviews were transcribed verbatim. Data were de-identified and analyzed inductively using the classical analysis strategy described by Krueger and Casey (2009), which is a modified form of grounded theory research (Glaser and Strauss 1967). These are both constant comparative methods, where individual units of data are either coded with a new descriptive label, or grouped under a previously constructed code (Corbin and Strauss 2008; Glaser and Strauss 1967). In this open coding process, each piece of data is constantly compared to all previous pieces of data. In the initial coding process, similar pieces of data are grouped together under a common code, or label. Subsequent rounds of coding were done to relate coded categories into major themes and sub-themes, known as axial coding. This was done to analyze and understand relationships between codes, identify patterns in the data, and observe relationships between ideas (Saldaña 2012; Krueger and Casey 2009). The second and third level codes constructed in the axial coding process were arranged in relationship to each other. These broad categories became the labels, categories, and themes of the decision framework described below. All major themes developed from this constant comparative method were expressed in all three focus groups. All sub-themes identified in the data analysis were shared by participants in at least two of the three focus groups.

The research methodology started as a highly inductive process, or starting with individual quotes or data and described in the literature as the “empirical trenches” (Merriam 2009). In the coding process described above, these individual units of data were assembled into categories, and these categories developed into inferences, key findings, and a decision framework of conservation managers. Once saturation was reached with all data fitting into themes and sub-themes, the analysis became more deductive. Individual units of data were analyzed to confirm that they fit into the decision framework that had evolved from the open coding process. Throughout the entire data analysis process, memoing was done to capture ideas and data observations in an organized, systematic manner. Memoing helped to move the data analysis process from the “empirical trenches” and earlier inductive methods, to the development of a framework and the later deductive mode of analysis to confirm that the decision framework and key findings were reflected in the data (Merriam 2009).

Results

Focus group results are presented below in three sections, followed by a discussion. The first section describes how voluntary agricultural conservation implementation currently happens at the local level. The second section examines conservation managers criteria for success in conservation implementation. The third section describes complications and constraints of the current conservation implementation process. All quotes from focus group participants are illustrative of the larger data set of participant quotes.

1. Describing the Voluntary Conservation Implementation Process

Focus group participants were asked, “How do you decide what conservation practices to implement and where to put them? Walk me through the decision making process.” Major action steps in the decision process (Figure 2.1) are shaded in dark grey. These steps in the voluntary conservation implementation process include: 1) a landowner walking in the door to initiate a conversation about potential conservation options on their land; 2) a consultation between the landowner and the conservation manager; 3) the conservation manager visiting the site; and 4) a decision about BMP recommendations for the landowner. Data that influence the major action steps are shaded in light grey. These include data gathered both externally and internally. Externally gathered data refers to discussions with the landowner/farmer, including discussions about their goals and objectives, their financial situation, and what conservation options are generally acceptable to the landowner. Internally gathered data refers to agency programs such as cost-share availability, observations of a landowner’s motivation, and an evaluation of prior experiences of the conservation manager. These factors are generally not discussed directly with the landowner but rather observed and processed internally.

Arguably the most significant influence in the current voluntary conservation implementation process is the type of landowner who “walks in the door” of conservation offices asking for assistance to address an issue that has been observed on the land (Table 2.1). These are the landowners who conservation managers are working with to address water quality issues.

“I think like 95% of the time people come in and say, ‘This is my problem. What can I do to fix it?’”

“I think generally in [specific county], if they got a problem they come in and tell ‘ya. We aren't working with the ones that don't want to work with us. Generally there’s not enough money to do all of the practices they’d like to do. So, it’s the ones that want to work with us.”

I: “…Walk me through that decision making process. Why did you end up doing this instead of that?”
P: “Because a producer walked in the door.”

Once the landowner walks in the door, there is an “inventory process” or an initial consultation. During this meeting, the conservation manager discusses BMP options with the landowner and is also making observations about the landowner. Important issues to discuss with the landowner include: 1) landowner goals and objectives; 2) social acceptability of various conservation options; and 3) landowner finances and willingness and ability to pay for these options.

P: "Yeah, that inventory process is really pretty important."
I: "Can you tell me more about that?"
P: "The inventory process. Learning about the landowner and their objectives on the land, all this information we have to gather together to help us present options that will work for that individual."

"You always start with what you think is going to be most effective. You know, like, I used to start with contour or contour strips, but I don't even bother any more. And you know, they'll always tell you, 'I can't do that.' They say, 'tractors still have steering wheels on them!' [Laughter.] The machinery has just gotten too big for most operators. So you go down through that litany of things, and maybe we do a lot of basins because they're accepted and they work well."

"Income level of the producer too. I hate to say that too loud but that's pretty important. If a person can't afford something, I'm not going to try and push something expensive on them."

During this discussion with the landowner (or operator) the conservation manager is simultaneously assessing the internal motivations of the landowner. This assessment is not discussed directly but simply observed, and becomes an important factor in the decision making process of what BMPs might be recommended or suggested. Participants frequently mentioned trying to assess landowner motivation, because if motivation is high then there are a wider variety of conservation options that could work, compared to a less motivated landowner. Similarly, if it is clear the landowner's goals are primarily financial, then that might influence the array of practices that the conservation manager encourages or discourages for that particular landowner. One participant described how he could assess landowner motivation for a certain BMP by observing their body language, and how that subsequently influenced the list of BMP options the conservation manager recommended for that landowner:

"[When you're] talking to them, you see, you kind of know right away when you start presenting these practices. You kind of see them drooped and you can see right away what they're thinking. You don't even need to say something. You can see where they're geared for, and where they're not geared for. And then you can work your way off that. But you know right away where their head's at, where they're going."

"For me, you get one piece of information, if the person's motivated or not, and you don't have to find out anything else. I mean, if they're not motivated you're wasting your time. Move on to somebody that's motivated."

"I think a big factor is how motivated they are. I mean if they're motivated and they have a conservation ethic. I mean they see the problem, they want a solution to it. But, I think they have to be motivated for it to be successful."

P1: "Well yeah, I see some that have gone through nutrient management and EQIP and the next year they're spreading manure right along the ditch and not incorporating it. I mean, we give them maps to say incorporate right here!'"
[Laughs.]
P2: "[That's] a good example of determining what the landowner objectives are from the very beginning. If his objectives were just to get a little cash in his pocket, that's exactly what happens."

After an initial consultation, many participants emphasized the importance of going out to do a site visit.

"I get a better feel for it if I am actually out there rather than looking at [tools]. I know LIDAR is really cool but it's still good to get a feel of going out there."

"The first step is to look over the property, try to identify what the problem really is, what causes the problem, you know what kind of soils are you working with, inventory the site."

During the site visit, many things are assessed. What is the problem? How severe is it? What practices would work to solve this problem? What physical data are relevant to the decision? When participants mentioned considering practices that would work in a given situation they were probed to specify how and why they thought a given practice might be the best option or what data they needed. Answers included knowledge of information in technical guides, knowing how the BMP works and its proper setting, knowing if the practice fits the operation size or type, physical data (such as watershed size, soil type, slope, land use) and recalling past experiences with BMPs.

"The practices are all in the field office tech guide, through USDA NRCS. There's a suite of almost every conservation practice you can imagine in there."

"Does that practice fit his operation?"

P1: "The watershed you're dealing with is important…size and what's going on in there. Is it woods? Is it row crops? Asphalt?"
P2: "It's determining watershed size, slope, steepness, residue cover, land use."

“Don't you kinda need to know how each one of those BMPs work and the proper setting for the proper BMP?”

Reliance on past experiences as a factor in making decisions came up frequently in all three focus groups. Participants remembered past efforts that either succeeded or failed, and learned from them.

“And then we use our own judgment and experience to offer options to correct that problem that the farmer has.”

P1: “Well, experience…It just explains doing them all, whatever ones you’re doing.”
P2: “Sounds good on paper, but if it failed before you don’t really want to do it again.”

This experiential knowledge is important both in the technical knowledge of which BMP might work best in a given scenario, but personal experience also was important in understanding and working with various types of landowners, their differing needs, abilities, and motivations. One participant gave an example of how landowner family dynamics and other “cultural stuff” can impact BMP implementation, and how previous experience is helpful in responding to these situations.

"I've been on farms talking to a 45 year old man who says, 'Daddy says this.' And I'm [thinking] 'I'm talking to the wrong guy. Clearly he's not the decision maker here.' So yeah, all the cultural stuff. It takes those experienced people to walk on there. And you're assessing all this stuff as you're there."

P1: "Well, most of us that have been around and doing this for a while, we kind of do all of this without even thinking about it anymore."
P2: "It's instinctive."
P1: "I mean, you're assessing all that stuff before and as you walk on that farm."
P3: "…Now you gotta know the right questions to ask too. And that comes with experience and knowledge."

The site visit was also mentioned as important because it is a chance for the conservation manager to assess the management abilities of a landowner. Conservation managers are observing the conditions of the property, and making inferences about a farmer's ability to manage various BMPs based on their observations of the site.

"And their management ability. Some of these complicated feedlot fixes you go 'This guy can't handle it'. Some of that you can determine as you're driving down the driveway, in his front yard. Is he going to cut it or what, you know?"

"Well yeah…first impressions. You're driving in the yard, the place looks like a junk yard and almost, you know they're not going to take the time to maintain stuff. You're not going to push the more complicated stuff. You're going to go with maybe something a little simpler."

The total cost of a BMP was mentioned a small number of times, but the availability of external funding was frequently mentioned as a significant influence in the decision making process. Landowners are highly motivated by cost-share programs. Conservation managers know this, and sometimes do not bother presenting practices that have no cost-share program attached. The presence or absence of cost-share programs has a high influence early in the decision making process.

"We implement the practices that have programs attached to them."

"So, we're somewhat limited on practices we can do too. If it's not an NRCS standard practice, we can't do them, because of cost-share. So sometimes that kind of limits us. None of them will do it without cost-sharing."

"Actually I think the driving force is probably the Federal EQIP program. And the producers coming in, and basically requesting some type of assistance to correct

the problem, getting compliance. Things of that nature. And, I think that's where it really starts, is most of ours tend to be signing up for some type of financial or technical assistance."

"A lot of this stuff is program driven. I mean, we're not going to offer cover crops if there's no incentive for them to do that. Because it's going to cost the farmer money and time to put cover crops out. So we won't even be offering that. We can mention it, but the chance of that happening is very small."

Focus group participants mentioned that in some situations neighboring landowners play a significant role in the decision making process. If one neighbor is opposed to a BMP installation that would span multiple properties, this can prohibit BMP implementation. Or, if a landowner has a good relationship with their neighbor, this opens up more possibilities for BMP implementations compared to a scenario where there is not a good relationship between neighbors.

"Something that we run into is we have a basin, a natural basin, and one neighbor wants to do it, and the other one doesn't want to do it. And that's a characteristic you can't do anything about really."

“The neighboring fields play a role too, whether or not I can put a basin on the edge there. Neighboring landowners’ willingness to do that or not. If the waterway is spanning multiple fields, if there's erosion on one field it’s just going to fill up the next field’s waterway.”

“Well your neighbor. Sometimes that influences on a weird situation. …Where’s the water going to be dumped if you do this kind of practice? On your neighbor. Well [imitating farmer] ‘I’m not so good of friends with my neighbor so I can’t be putting water his way.’ …Or if you’re holding the water back, you get a free case of beer from the neighbor downstream!”

A final influence in the decision making process are what might be termed broadly as decision aids or tools. These include water plans, TMDLs, methodological frameworks such as the NRCS Nine-Step Planning Process, or technical decision support tools such as physical targeting tools, terrain analysis, or LIDAR. Decision aids or tools were included as part of the decision making process (Figure 2.1), but responses were mixed in terms of how these tools are viewed. Some comments discussed how tools provide good information and help identify problems:

“We've done Terrain Analysis in our county and it's really good information to have and it can pinpoint where erosion can take place.”

"We're also working with the Minnesota Department of Ag and priority management zones. Critical source areas, using LIDAR to indicate or show where there could be potential problems, and then focusing our efforts in those critical source areas."

"And then the other thing is that when we apply for some of these grants now, in particular like BWSR and MPCA, we're kind of having to attach it to a water plan. How are we doing these things? And so that's kind of like in the planning process there too. People want to try and get the practice on the land and sometimes you have to look at the big picture with the water plans. The lakeshed plans, whatever it may be."

Interestingly, all previous portions of the decision framework were largely described in concrete, descriptive "is" terms, while the various discussions on decision tools used a mixture of descriptive "is" and normative, goal-oriented "ought" language. Additionally, some participants described tools as being less important than other parts of the BMP implementation process:

"I get a better feel for it if I am actually out there rather than looking at [tools]. I know LIDAR is really cool but it's still good to get a feel of going out there."

"We do our targeting, we have our programs. But we have to get on the farm. Then we determine what the problem is and the extent of the problem."

"Our TMDL, our rotation plans... those are supposed to help set priorities, especially our water plan…like the [name of a specific] plan."

2. Conservation Implementation: Criteria for Success

This research also provided insight on how conservation managers perceive and define BMP effectiveness. Participants were asked, "Think back on those conservation practices you implemented with the goal of improving water quality. Tell me about some projects that you think were particularly effective in improving water quality. What made these projects so effective?" Participants were reluctant to share success stories and generally gravitated towards sharing stories of BMP implementation failure. However, with persistent refocusing participants shared 33 success stories across the three focus groups. About half of those success stories were very specific in nature, clearly referring to a certain project that had been implemented. The remaining half were less specific, with participants responding in more general terms. The 33 success stories included 12 different types of practices with the most common about buffer projects and conservation tillage projects. A few participants clarified that it is important to have an array of practices or the success stories they shared were of an array of practices working together effectively.

Conservation managers were also asked to describe successful BMP implementations and how they determine if a BMP implementation was successful or not. By far the most two most commonly cited evidences for success were that: 1) participants could "see" a difference; and 2) the installed practice lasted a long time. In sharing their stories, participants stated or alluded to these as evidences of successful BMP installation:

1) They can see an improvement. There was a visible problem, the practice was installed, and afterwards they could not see a problem, so therefore it was effective.

   "Residue management, no-till, strip till. It's something where you can see it. Very obvious. Less soil loss."

2) The installed practice lasted a long time.

   "If you got a really steep slope that's amenable to something like contour strip cropping, as long as that operation remains a dairy operation or a livestock operation, where they need forage, those strips are 'gonna stay out there for a long time…especially if it stays in the same landowners."

3) The program that installed the practice was popular with producers.

   "I think that grass buffer programs we had a few years ago was really popular. It was a niche program that allowed landowners to hay along streams and just maintain that buffer as hay ground and not row crop. It was really popular in our county with dairy farmers where they could concentrate

their alfalfa and orchard mix down there along the creek and not corn and soybeans. It was pretty popular."

4) It is financially efficient.

   "But from sustainability standpoint, I think it's pretty tough to beat things like strip till, no-till, residue management. Because those things are making money for the farmer at the same time."

5) They described the physical process behind the BMP.

   "I think soil health and soil quality…the better structure you have the more you can infiltrate that water. It's your first line of defense sometimes. So anything that can do that, reducing the tillage and adding more soil too."

6) It was a large project and/or many acres were treated.

   "We had a grass waterway that NRCS helped implement…that was a huge, huge project...It was almost five hundred acres that was going through that six hundred feet."

7) It provided multiple ecosystem services.

   "I'd say perennial cover, through our Conservation Reserve Program. Multiple ecosystem services provided by that perennial cover. Including water quality, wildlife, carbon sequestration, pollinators. That's all valuable."

8) All projects can be effective.

   "I think all these are effective. Every one of them. If they're done properly."

9) I don't know which projects were successful.

"Well for my two cents worth, I'm not sure I know that."

One participant shared that he wanted to define success as a reduction of pollutant loads in receiving water bodies: *"When you say water quality I think of receiving water bodies. Not just what's coming off that small area."* However, he clarified that he *"can't document anywhere we've got enough practices in where I'd say we've improved water quality noticeably."* After discussing successful projects, participants in two of the three focus groups shared what a relief is was to discuss what is going well in their work. As one participant commented, *"We need to celebrate our successes!"*

3. Conservation Implementation: Complications and Constraints

Finally, the focus group participants shed light on how conservation managers perceive and define BMP implementation failure, along with potential causes of BMP failure. Participants were much more willing and eager to discuss failures and frustrations in their work than to discuss successes in BMP implementation. Participants were asked, "Again, think back on some conservation practices that you implemented with the goal of improving water quality. Now tell me about some projects that were particularly *in*effective. What do you think made these projects less effective than others?" For this question, participants candidly spoke of causes or sources of project failure, sometimes with great emotion, and at other times more matter-of-fact, as if resigned to the inevitability of failure in some contexts.

All three focus groups broadened this question to include barriers to BMP implementation. For example, the lack of BMP implementation was seen as a major failure (as opposed to only considering installed BMPs that had failed). Additionally, a few stories were shared where a BMP was eventually installed, but it was not what the conservation manager personally believed was the best option for the scenario. This scenario was also viewed as a BMP implementation failure. Of the 63 failure stories or comments that were associated with a specific BMP, the most common practices mentioned were feedlot projects (n=10, but mostly from one focus group), conservation tillage (n=9), waterways (n=9), perennial cover (n=7) and nutrient management (n=6).

Broadly speaking, causes of BMP failure to improve water quality were viewed as either: 1) internal agency issues that decision makers (at varying levels of authority) have some control over; or 2) external issues that are more difficult to influence (Table 2.2). Internal issues were classified as either broad systemic problems or local implementation mistakes. External issues include the unpredictable nature of the weather, economic realities, broader social issues, and landowner/farmer issues. Landowner/farmer issues by far garnered the most concern and discussion of all of the categories. The tone in regard to landowners and farmers was a mix of frustration at the lack of participation, along with acceptance of the reality that many do not want to participate. Although counting responses or comments in focus groups is not necessarily an important indicator of the salience of an issue, the top three categories in terms of frequency mentioned were: 1) landowner/farmer issues (n=47); 2) systemic issues (n=32); and 3) implementation mistakes (n=13).

Systemic Problems. The most common problem raised in this category was the lack of financial incentives for landowners to install BMPs. Participants frequently mentioned popular financial incentive programs that they would like to see renewed.

"I guess I would say conservation tillage [is effective], particularly strip-till and no-till are very cost-effective, but we don't have a lot of good incentives for people to get into it."

A few conservation managers who had been on the job for decades noticed a shift from historically being “door knocking” salesmen for water conservation practices, compared to now where there is a heavier reliance on computer-based tools. These participants emphasized the importance of building relationships and trust in order to find willing participants to implement BMPs.

"I guess it may be old fashioned of me but we seem to have so much reliance on the electronic tools and the 'sit in the office and figure it out' ways that we're losing track of capabilities of going out on doors and trying to sell conservation and be a salesman for what the producer needs...We want to try and do these off-site[things] but you still need people out there that have one-on-one contact to get the people to find someone to adopt it."

Some participants shared that they felt a lack of either time, money, or other staff members to do the needed work or to do the work well.

"[We could use] more time. 'Cause a lot of times you have to rush through. I mean when you're working with somebody you're rushing through it, and if you can take time and talk with them and develop a little rapport, work on their goals, evaluate things better, you're going to do a better job."

Other systemic issues mentioned less frequently included a lack of research, poor communication between agencies, or ineffective/unrealistic regulations.

"Most of the research at the University of Minnesota, or land grant universities, is tied to the commodity groups. There's very little research into the perennial crops, or alternative crops that will make the farmer money to diversify their rotation."

P1: "Yeah, [specific county] has developed a system of analysis of ag areas, or rural areas. And they were saying they got a prototype of that from DNR. So hopefully they don't have two agencies doing the same thing."

P2: "Probably. Sounds like it would happen."

P1: "Yeah. People not talking, agencies never talk anymore. So that sounds about right."

"MPCA…they need to look at their standards. There's no way we're going to meet those standards. And we're going to lose credibility with the farmers."

P1: "But tell me, how many fines have been written in the state for improper manure placement?"

P2: "Not so much."

P3: "Very few."

P1: "<u>Not one!</u> [Pounds fist on table.] Never been one. That's pretty bad."

Implementation Mistakes. Participants were not shy to share their own personal mistakes, sometimes reflecting on what they learned from the experience. For example, sometimes BMPs are placed in locations where they are ineffective in improving water quality.

"Sometimes I think our sediment basins might be ineffective on the fact that, where they're placed, a lot of times a lot of the sediment runoff doesn't reach the pond. You know, it runs to the bottom of the hill and enters a drainage ditch and into the surface sometimes. And so I think sometimes we need to be more careful where we put them."

The most commonly cited implementation mistake is a lack of upland treatment, where a situation perhaps calls for an array of practices but for various reasons that has not happened or may not be possible.

“The issue we run into is if you don’t have the land protective practices, residue management, those things above it [a sediment basin], it will fill up with sediment. Sometimes we’ll do that anyway [install just a sediment basin], just say, ‘well now the landowner will see what’s going on.’ You know, sometimes that works, sometimes it doesn’t, but that’s like where we skipped. They’re supposed to have that before we put that practice on. But sometimes we skip that element.”

Participants gave a few examples of engineering issues that turned out to be problematic.

"We backed up a large area that goes into one of our lakes, with a dyke. And then we take the water, flow it through limestone, which was placed inside the dyke. The engineers, when they designed it, or when they surveyed it, missed an elevation. So the pipes that came out were supposed to be above the lake so that we could test this thing and see if that worked…Well, our pipes ended up under the water in the lake. So we can’t get tests...So that one has been a disappointment."

And a final mistake that conservation managers discussed was when they did not “assess” a landowner properly to determine his management abilities and motivation to maintain a practice.

"If [practices] are maintained, that’s a landowner, operator decision. Sometimes you have to make an assessment [if they’ll maintain it]. And sometimes you assess it wrong."

Mother Nature is Unpredictable. Other causes of BMP failure were seen as external to the conservation manager and largely out of their control. For example, some participants cited examples of practices that were installed but were ruined by unforeseen heavy rains or droughts.

"If a three and a half inch rainfall would come through while you’re in the middle of a project it’s a loss too. You’re dealing with nature there. You put a lot of willow cuttings at the base of those, and if it all gets washed out it’s all for nothing… So we’re dealing with a lot with flashy rivers you know, it’s gotta have a quick time frame.”

Economic Limitations. Conservation managers are realists, and they did not expect landowners to install BMPs that did not make financial sense for that individual. They did not mention wishing that more landowners would be motivated by a conservation ethic. Participants mentioned both the high up-front costs of BMP installation, and the high opportunity costs of taking land out of commodity crop production.

"The way that cost-share is set up too, you know. If it's 50% or 75%, the landowner still has to contribute. So if it's too high they may just walk away and say 'I don't want to do it.'"

"I see that with CRP too. The landowner changes, commodity prices are high. It's hard to keep that [perennials] in when the conservation practice and the CRP doesn't make as much money as if it were corn and soybeans."

Broad Social Issues. Local politics were mentioned as an issue in a few cases, causing feedlot regulators or inspectors to be ineffective.

"But the local politics, in my county, are horrible. I got a feedlot officer that's afraid to take any action. She writes letters, slaps hands. [If] you spread manure over intakes or along a ditch, they write you a nasty letter. You say, 'Well how many letters? When do they get a fine?' Never."

Another frustration was when members of the public had unrealistic expectations of the conservation managers. Conservation managers feel pressure from the public to change certain things that are not realistically going to change.

"With [Specific] Lake in [Specific] County, people want to turn that into a clear lake that you'd find up north. But that was a swamp that was flooded, so it's going to be a mess forever… What was there beforehand? You're not 'gonna turn something that was one thing into something else."

Local Landowner/Farmer Concerns. The issue discussed most in depth in all three focus groups and overwhelmingly the largest concern was a lack of willing landowners to implement or maintain BMPs to improve water quality. Participants emphasized clearly that their most pressing need was for more willing landowners to implement BMPs. According to focus group participants, an increase in willing landowners to implement BMPs is essential to improving water quality outcomes.

"That's part of the problem. We're dealing with a natural world where if we could dictate, 'hey, this is what you got to put on here' you'd get it. But we're dealing with the human side of things as well. And that's a difficult game."

One social dimension was influenced by neighbor issues and how that can become difficult to navigate. The relationship between two adjoining landowners can play a factor in a BMP installation, or lack thereof.

"Something that we run into is we have a basin, a natural basin, and one neighbor wants to do it, and the other one doesn't want to do it, and that's [something] you can't do anything about really."

Participants described how "it's a hard sell" to convince landowners to install BMPs to improve water quality. Even if a landowner theoretically wants to install a BMP, it may resist because change is hard and there are uncertainties involved.

"We had a project kind of like that too. [Name of a location], basins up above were the cheapest, best alternative. But we could just never, never sell the basin idea."

"I guess I would say conservation tillage, particularly strip-till and no-till …it's a major management change for most people, so it's hard to get them to leap to that change."

Some of the frustrations stemmed from poor communication between the owner and operator/farmer. Sometimes absentee landowners could not see the extent of a problem, or simply were not aware of any issues. Conversely, sometimes the owner is willing but the renter is not interested in maintaining the BMP. If either the landowner or renter does not approve of the BMP installation, then the BMP either cannot be implemented or will not be maintained.

"Even some of the renters who can see the problem can't convince the owners too. There's a lot of that out there. We've had lots of renters want to do something with the piece of ground but as long as they are paying cash rent, it stays the way it is."

"At least what I've seen is that we have so many older folks renting out their properties and it's harder to get projects on these properties because the renter doesn't want do it…And the renter comes in, 'Well I don't want to do that, it's gonna hurt my farm.' And so we have a lot of issues with that."

At times a BMP would be successfully installed, but a change in owner or operator could mean that the practice is removed.

"I see that with CRP too…the landowner changes and the new owner wants to put corn down."

Even with a stable landowner and operator, a BMP might be implemented only to soon disappear if incentives run out or a program ends. Even if a farmer has had nutrient management training or was given a map showing where to incorporate manure, the farmer may eventually shift back to previous methods.

"Well yeah, I see some that have gone through nutrient management and EQIP [Environmental Quality Incentives Program] and the next year they're spreading manure right along the ditch and not incorporating it. I mean, we give them maps to say 'incorporate right here!'"

The most commonly cited (n=15) cause of failure is that the landowner or operator does not take care of an installed practice. Examples include not weeding critical seeding areas, waterways narrowed to the point of being defunct, or "abused" feedlot fixes.

"Yeah, and I would agree with that. With the environment we're operating in that's why we went there [to installing structural BMPs]. They stay there. The waterways don't. I mean, sometimes in 3-4 years the waterway is narrowed up to 8 feet and it's not functioning anymore."

Finally, participants emphasized the importance of the landowner to "buy into" the installed practice or else it is less likely to be maintained. If landowners and operators are not convinced of the importance of a BMP, then the time and money to install it is simply wasted time.

"But, it's not really our decision in most cases what to do, it's the landowners' decision. They have to take ownership of the practice, because we can

make all of the recommendations in the world, but if we don't get them convinced that that's the thing to do and to maintain it and to take care of it, then we've really wasted our time."

"Well I think it's really important to get the landowner to buy into the practice, I mean if it's our waterway or our terraces then they're not going to take care of it in the long-term. It's going to fail. You have to get them to buy into it so that it's their waterway or their whatever."

Discussion

Voluntary implementation of agricultural conservation practices on working lands is the primary strategy that state and federal level decision makers have relied on to address non-point source water quality issues. Funding allocation in federal farm bills over the last 20 years have consistently moved funding away from set aside lands programs (such as the Conservation Reserve Program), and towards working-lands programs (such as EQIP) that promote voluntary implementation of agricultural best management practices (USDA ERS 2014). In spite of the growing importance of this voluntary, working-lands focus, relatively little is known about the details of the current BMP implementation process from the perspective of the local conservation managers who implement this strategy. While there are many examples of normative and prescriptive decision processes in the water quality literature, this research sought to understand and describe the local BMP implementation process to learn how conservation is currently being implemented. If new conservation policies or strategies are designed without an understanding of current processes, this can lead to what academics have referred to as the "knowledge-implementation" or "knowing-doing" gap (Pfeffer and Sutton 1999). Otherwise valuable ideas can fail to become reality because there is no obvious way to incorporate the new ideas into the implementation process. An understanding of the current implementation process of conservation measures is crucial to allow state and federal level policy makers to prioritize and design effective future programs, policies, and strategies.

In light of this, three key observations emerged from this research describing the current agricultural BMP implementation process. First, conservation managers implementing BMPs to improve water quality in agricultural regions have a complex job. They are tasked with installing practices to reduce agricultural NPS pollution, but in a context with many constraints towards achieving that goal. The conservation implementation process requires that conservation managers have an understanding of the technical nature of agricultural BMPs, as well as understanding of the various policies and funding programs that are available, and the complex social dimensions of conservation implementation. This social dimension can range from individual landowner motivations, to family and neighbor dynamics, to community priorities and politics, all of which were discussed by focus group participants in the BMP implementation process. The job of conservation manager is often viewed as a technical position by landowners (Kueper et al. 2012) or in the hiring process, but the technical aspects of the job only captures a small (but important) subset of the required skills. An understanding of landowner drivers and constraints, Adult Learning Theory (discussed below), and how to effectively navigate the relational aspects of conservation are all important factors to consider to enable conservation managers to be effective, active participants in the BMP implementation process.

A second key observation from the current conservation implementation framework is the dominance of a reactionary, “who walks in the door” strategy. Many focus groups participants across all three focus groups clearly conveyed that the current process of voluntary conservation implementation is driven by a small subset of landowners who walk in the door asking for assistance, and that more willing landowners are needed to make progress on water quality goals. The current BMP implementation process primarily engages landowners who are motivated enough to walk in the door asking for technical and financial assistance, and are willing and motivated to both implement and maintain a BMP. Many focus group participants were very frustrated with the lack of landowners seeking out this technical help. This “bottom-up” approach and near-exclusive reliance on motivated landowners to “walk in the door” severely restricts conservation efforts to a small subset of potential participants.

This reactionary approach relying primarily on motivated landowners walking in the door has a number of disadvantages. First, it limits the view of conservation managers to the role of technical expert, and therefore reduces their potential effectiveness in educating landowners. Adult Learning Theory (ALT), described by Malcolm Knowles in his book "The Modern Practice of Adult Education", describes some of the unique ways that adults learn, particularly in contrast with children (Knowles 1990). One difference is that adults value collaborative problem solving with equality between the teacher and learner. Adult learners also appreciate when their knowledge and life experiences are validated (Knowles 1990). In the focus groups, participants did robustly describe the process of understanding the goals of each landowner during the consultation phase of conservation implementation process. However, this consultation process was generally viewed as a list of constraints to consider in the implementation process, rather than an opportunity for collaborative problem solving between equals or an opportunity to validate the landowner's experiential knowledge. One participant described this consultation as a time to gather "information" to help "present options that will work for that individual". This view reinforces the idea to both parties that the landowner is the recipient of the technical expertise of the conservation manager, which can become a barrier to effective BMP implementation.

A second disadvantage of a voluntary conservation approach relying primarily on motivated landowners to "walk in the door" is that it limits the potential of systematic approaches to conservation. Proposed systematic approaches (or prescriptive decision tools) are abundant and wide-ranging in the world of conservation, but generally include prioritization methodologies such as decision support tools or targeting strategies. This research supports previous evidence that conservation managers find it difficult to integrate prescriptive decision theories or frameworks (such as decision support or targeting tools) into the current BMP implementation process (e.g. Pullin and Knight 2003; Sutherland et al. 2004). Why the difficulty to integrate systematic approaches into conservation decisions? One possibility, described Jones et al. (1999), emphasizes how "research results must be compatible with *existing* policy-making processes and models" [italics added]. This research also suggests that current decision processes relying on "who walks in the door" are largely incompatible with systematic conservation approaches such as decision support tools or prioritization methodologies. When BMP installation decisions are strongly reliant on landowners who are motivated to seek technical help and what BMPs landowners and farmers are willing to accept, the usefulness of a decision or targeting tool can be significantly reduced. What if the landowner of a "targeted" piece of land never walks in the door? Policy makers should not expect systematic approaches to conservation to be integrated into conservation implementation until the current decision framework is modified.

A third key observation emerging from this research describing the current agricultural BMP implementation process is the high reliance on funding and cost-share programs. Participants described EQIP as being the "driving force" behind conservation implementation, because "none of them [the landowners] will do it without cost-sharing". Contrary to the "who walks in the door" strategy, this program-driven approach is a “top-down” strategy that prioritizes funding to programs that decision makers believe are most important. Focus group participants described examples of “buffer programs” or funding programs that targeted conservation efforts to a certain watershed. This top-down approach was viewed favorably by some focus group participants because these programs are popular with landowners seeking cost-share assistance, and increased the number of landowners walking in the door. Although popular, this approach can be an inefficient way to manage and fund conservation priorities. When funding is tied to a “buffer program”, prioritization based on systematic approaches becomes more difficult. For example, it does not incentivize the consideration of how different contexts influence both the physical effectiveness and cost of a BMP installation, so overall BMP cost-effectiveness is less likely to be evaluated. Even if proposals from willing landowners to implement buffers are ranked based on their expected value, tying funding to a specific buffer program unnecessarily rules out other conservation options that may be more cost-effective. This top-down approach to funding conservation has a significant effect on what BMPs are implemented and where, because the availability of cost-share programs was described as a major driver in the voluntary conservation implementation process.

As described, these three key observations of the current realities of the voluntary implementation process present a number of constraints that reduce the effectiveness how conservation happens on the landscape. But describing and understanding these constraints also presents opportunities to modify the current process. Although it is tempting to focus on strategies that encourage more willing landowners to walk in the door (such as more funding or relying on popular programs to increase interest), one focus group participant aptly described how "we always seem to be tweaking on the edge when we really need something big to happen." What might a re-envisioned voluntary conservation strategy look like?

Two potential solutions were identified that could modify the current conservation implementation framework to engage more landowners. One possible strategy was described by a focus group participant and might be described as a "door knocking" approach:

"I guess it may be old fashioned of me but we seem to have so much reliance on the ... 'sit in the office and figure it out' ways that we're losing track of capabilities of going out on doors and trying to sell conservation. We want to try and do these off-site ways, but you still need people out there that have one-on-one contact to find someone to adopt it."

This "door-knocking" strategy would not primarily rely on willing participants to walk in the door and would require a major cultural shift from the current decision framework. It would ask conservation managers to build relationships with landowners and proactively engage them in a process to encourage participation in water quality improvement goals (Davenport et al. 2013). The process could start by using evidence-based tools to identify the "best" management options ("best" defined according to a given that tool or framework). Then the landowner might be presented with the findings, offered various options and financial assistance to address the issue, and asked if they would be willing to consider participating in water quality improvement efforts.

Importantly, this approach encourages cost-effective, systematic approaches to conservation, as long as funding is flexible and allocated based on predicted outcomes rather than actions (Armsworth et al. 2012; Zabel and Roe 2009). Recent efforts in Scott County, Minnesota, are essentially starting to implement this “door knocking” approach. Local Scott County SWCD personnel are now focused on increasing rates of voluntary BMP adoption through intentional relationship building with landowners. Results of the relationship building approach in Scott County are too early to measure. But the hope is that as “targeted conservation programs [are developed], future requests for landowner participation that come from staff members whom they already know and trust will be much better received” (Davenport et al. 2013).

A second potential strategy to modify the current voluntary implementation framework to engage more landowners is an extension of the “door knocking” strategy, but with potential to reach more participants. Previous research has described the variety of trusted information sources on which landowners rely to make conservation decisions. One highly influential source of trusted information is sharing between peers in landowner networks. This peer exchange is defined by high levels of trust in previously established interpersonal relationships, and allows “self-guided learning on an as-needed basis” (Gootee et al. 2010; Kueper et al. 2012). Prokopy et al. (2008) surveyed the literature regarding factors influencing the adoption of agricultural BMPs, and found that access to information and utilization of social networks are positively associated with BMP adoption rates. Knowing that peer networks are influential in the adoption of conservation practices suggests the consideration of what Coughenour

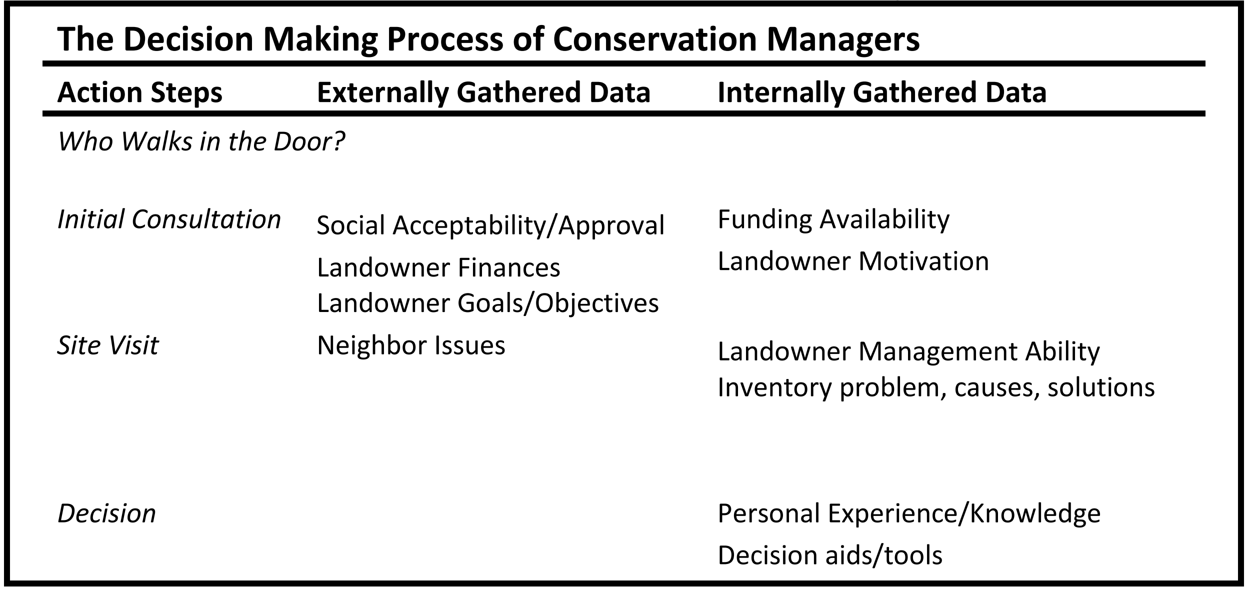
(2003) calls an “actor-network” theory of conservation. This strategy de-emphasizes the role of conservation managers in “expert” driven conservation efforts, but rather encourages conservation managers to find landowners who have embraced conservation efforts and encourage these landowners to share about their conservation efforts in non-threatening peer exchange environments. This peer network exchange might be facilitated by conservation managers through public meetings, demonstration tours, encouraging informal peer-to-peer conversations, or advertising campaigns (Habron 2004; Kueper et al. 2012). In this context, conservation managers come to view themselves less as technical experts, and more as peer network facilitators who enable and encourage conservation adopters to share their experiences in the context of peer networks (Habron 2004; Kueper et al. 2012).

Summary and Conclusions

This research proposes a descriptive framework of the current voluntary implementation process of agricultural BMPs as described by local conservation managers. This is the primary strategy that state and federal level policy makers are relying upon to reduce NPS water pollution from agricultural regions, and yet a descriptive framework is notably absent from the literature. This research found that the voluntary conservation implementation process is a complex, requiring conservation managers to have an understanding of technical, policy, and human dimensions of conservation efforts. The process is largely driven by landowners who take the initiative to “walk in the door”, and the availability of cost-share programs. Disadvantages of this current system include difficulty integrating systematic tools into the decision process, difficulty implementing cost-effective conservation options, and an insufficient number of engaged landowners willing to implement conservation practices. Encouraging peer exchange through network building, and promoting greater engagement with landowners accompanied by flexible cost-share options would be two meaningful steps to modify the current voluntary framework and make progress in reducing agricultural NPS pollution.

Tables and Figures

Table 2.1. The conservation implementation process as described by local conservation managers.



The Decision Making Process of Conservation Managers

Action Steps	Externally Gathered Data	Internally Gathered Data
Who Walks in the Door?		
Initial Consultation	Social Acceptability/Approval Landowner Finances Landowner Goals/Objectives	Funding Availability Landowner Motivation
Site Visit	Neighbor Issues	Landowner Management Ability Inventory problem, causes, solutions
Decision		Personal Experience/Knowledge Decision aids/tools

Table 2.2. Focus group participant perceived complications and constraints of the BMP implementation process.

Complications and Constraints of the Conservation Implementation Process

Source	General Themes	Sub-Themes
Internal Agency Constraints		
	Systemic Issues	
		Lack of incentives for landowners
		Not enough of research
		Lack of salesmanship to promote practices
		Poor communication
		Ineffective regulations and policies
		Lack of time/staff/money to do the work
	Implementation Mistakes	
		Poor BMP placement
		Lack of upland treatment
		Technical or engineering issues
		Didn't evaluate landowner properly
External Constraints		
	Mother Nature is Unpredictable	
	Economic Limitations	
		High implementation costs
		High opportunity costs
	Broad Social Issues	
		Local politics make it difficult
		Unrealistic expectations of public
	Local Landowner/Farmer issues	
		Neighbor complications
		It's a hard sell
		Change is hard
		Poor communication between owners and operators
		Owner or operator changes
		Operator goes back to old ways
		Poor management of the practice

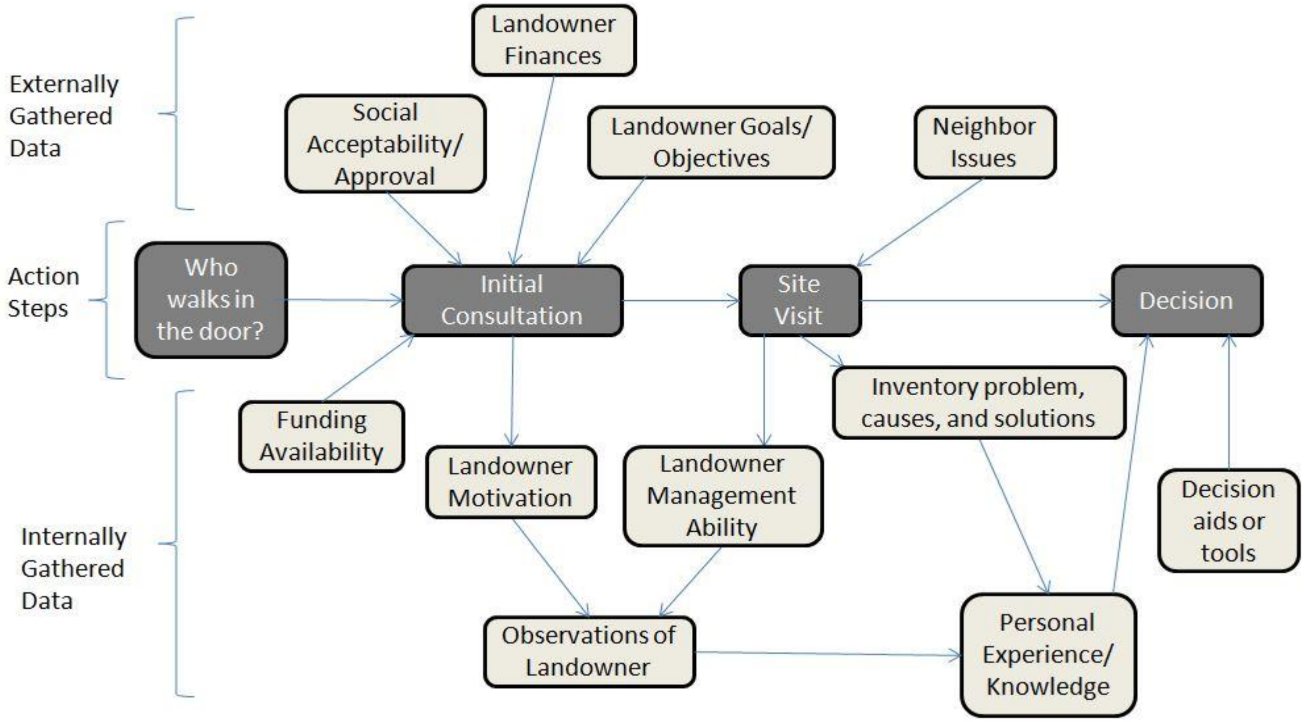


Figure 2.1. The voluntary conservation implementation process as described by conservation managers working to improve water quality in agricultural regions of Minnesota. Major action steps in the decision process are shaded in dark grey. Data that influence the process are shaded in light grey. Externally gathered data refers to discussions with the landowner/farmer. Internally gathered data refers to agency programs, or observations and experiences of the conservation manager.

Chapter 3:

Comparing the Physical Effectiveness and Cost-Effectiveness of Agricultural BMPs in the Upper-Midwest to Reduce Phosphorous Losses to Surface Waters

Overview

Comprehensive decisions on agricultural best management practice (BMP) installation to improve water quality must consider many factors, including social, policy, economic, and physical. This study considers the latter two, based on aggregating results of empirically based studies to estimate BMP cost-effectiveness in reducing nonpoint source (NPS) pollution of phosphorus. In a number of studies to date, researchers suggest "targeting" areas that contribute a disproportionate amount of NPS, often implying or stating that targeting based on a BMP's physical effectiveness is the best way to reduce NPS pollution in a cost-effective manner (e.g. Galzki et al. 2011; Wortmann et al. 2008). In this research, a total of 143 BMP installations were analyzed for both their physical effectiveness and cost-effectiveness in reducing total phosphorus from agricultural runoff. The data presented cover 12 types of

BMPs and were derived from studies conducted in five Midwestern states: Minnesota, Wisconsin, Iowa, Illinois, and Indiana. Summary results suggest that the concepts of physical effectiveness and cost-effectiveness should not be conflated, as 5 of the 12 BMPs studied had significantly different results when their relative physical effectiveness was compared to their relative cost-effectiveness. This stands in contrast to previous research advocating physical targeting strategies as estimates for cost-effective BMP placement. Decision makers may also be interested to observe the large range of BMP cost-effectiveness estimates found by this research.

Introduction

Agricultural nonpoint source (NPS) pollution is a major contributor to water quality issues in the United States today (USEPA 2009). The work of reducing agricultural NPS pollution is often done through the implementation of field-scale best management practices (BMPs), but conservation managers have limited time, knowledge, and funds to address the magnitude of the problem. A necessarily important goal is to effectively target scarce conservation dollars in cost-effective ways so that conservation managers can minimize per-unit pollution reduction costs. Determining the cost-effectiveness of a BMP requires two basic data points: 1) the physical effectiveness (e.g. lbs./acre/year) of a given BMP in reducing pollution; and 2) the costs to install and maintain a

BMP. Cost-effectiveness rankings of BMPs are one piece of data that can help conservation managers, landowners, and policy makers decide how to most efficiently reduce NPS pollution to improve water quality with limited resources.

Despite the clear relevance for decision makers, BMP cost-effectiveness can be difficult to include in the decision making process. Two reasons for this are that cost-effectiveness may be viewed as less important than other competing factors in the decision making process, and reliable BMP cost data (including implementation, opportunity, maintenance, and monitoring costs) are difficult to obtain. Given these limitations, one strategy that has gained momentum with recent advances in GIS technology is "physical targeting" of BMPs. This strategy focuses research efforts on modeling physical processes on the landscape and prioritizing conservation efforts on areas of the landscape that contribute disproportionate amounts of pollution. Physical targeting strategies focus on terrain mapping using GIS technology to identify "critical areas… [that] have a higher likelihood of conveying contaminants to surface waters than other portions of the landscape" (MDA 2015).

There are many examples of tools that use a physical targeting approach to reduce NPS pollution. A LiDAR elevation model can produce detailed terrain data maps and has been used to identify gullies with high sediment delivery potential (Galzki et al. 2011). A second example of physical targeting is the Ecological Ranking Tool managed by the Minnesota Board of Water and Soil

Resources. This tool uses GIS software to model relative erosion risk levels, proximity to water, slope, water flow accumulation, and habitat quality across Minnesota. These various GIS data layers are aggregated and land parcels are ranked as an Environmental Benefits Index score (Mulla et al. 2011). Higher EBI values are considered high targets for conservation efforts.

Recent technological advances have greatly expanded the ability of physical targeting to identify critical source areas of NPS pollution, and it is a compelling development that has opened new, important avenues of research. Physical targeting has clear, practical advantages compared to other strategies such as optimization (discussed below). For example, physical targeting is conceptually simpler, easier to apply broadly, often requires less specific training, and may have lower upfront costs compared to optimization strategies to estimate cost-effective BMP placement. Furthermore, proponents often describe physical targeting as a method that should lead to the most cost-effective BMP placement. Physical targeting research has stated that “the BMPs targeted to these features [critical source areas] can maximize their benefits on water quality and also maximize the efficiency of funding used for conservation” (Galzki et al. 2011). A paper from the Heartland Regional Water Quality Initiative to advise conservation managers on BMP targeting states that “targeting enables cost-effective and efficient use of local, state, and federal resources to improve water quality by promoting effective practices [on] the major pollutant sources” and that “targeting BMPs to important source or mitigation areas is likely to have the most cost-effective impact on water quality" (Wortmann et al. 2008).

However, the potential for using physical targeting to estimate cost-effectiveness is perhaps overstated. BMP placement based on physical targeting strategies is not equivalent to cost-effective BMP placement. In comparing scenarios with different BMP installations, the most cost-effective option (reducing the greatest amount of pollution per dollar spent) may or may not be the scenario that reduces pollution by the greatest total amount. Likewise, the most cost-effective BMP may or may not have the lowest upfront, capital, or total costs over the life of the BMP. Claims made by physical targeting proponents that physical targeting leads to the most cost-effective BMP placement would be analogous to an economist claiming that the lowest cost BMP is the most cost-effective, without considering BMP physical effectiveness.

Subsequent research based on modeled data confirms that physical targeting may not be the most cost-effective option, and may unnecessarily limit conservation efforts to a few lands while also possibly eliminating near-optimal conservation options that may be more socially acceptable (Arabi et al. 2006; Ribaudo 1989b; Veith et al. 2004). Research by Veith et al. (2004) recommends optimization using optimization algorithms (Arabi et al. 2006; Gitau et al. 2004; Veith et al. 2003) as a more accurate way to determine a cost-effective BMP configuration on the landscape. They found that a physical targeting strategy in an agricultural watershed in Virginia reduced sediment loading for a cost of $42/kg/ha/yr, while the optimization strategy reduced sediment loading for just $36/kg/ha/yr.

Another optimization study with similar results estimated the most cost-effective way to meet TMDL (Total Maximum Daily Load) standards for sediment and phosphorus in Lake Pepin. (Dalzell et al. 2012). They used both SWAT (Soil and Water Assessment Tool) and InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) to model ten different land use patterns in two watersheds in the Minnesota River Basin. These spatially-explicit land use and cost data models were used to develop an “efficiency frontier” based on maximizing the percentage of water quality improvement for a specific economic return. They found that this efficiency frontier was about twice as cost-effective as the scenario that targeted high erosion areas (Dalzell et al. 2012).

Knowing that BMP physical effectiveness and cost-effectiveness are not equivalents underscores the need for research that estimates agricultural BMP cost-effectiveness. Previous studies have done this using various methods. A 2002 study examined the cost-effectiveness of eight different BMPs in three different physiographic regions of North Carolina (Wossink and Osmond 2002). They accounted for costs and benefits from the perspective of the landowner, including revenue from various cost-share programs, lower production costs (such as fertilizer management), and land opportunity costs, as well as BMP installation, maintenance, and labor costs. Physical effectiveness benefits of the BMPs (only N-reduction was considered) were based on research done by a local river basin committee, and were considered equal for all three physiographic regions. They found that buffer strips, in most scenarios, are not financially advantageous for N reduction, and note that "CREP [Conservation Reserve Enhancement Program] cost-share payments for grass buffers may not be in line with the relative reduction" (Wossink and Osmond 2002).

Another cost-effectiveness study was conducted in Delaware County, New York (Gitau et al. 2004). This research attempted to place BMPs on a landscape to reduce dissolved P loading in the most cost-effective manner. This study used optimization algorithms, SWAT, and a BMP literature survey tool (discussed in chapter 1) to estimate BMP effectiveness of various BMP configurations ranging from farm-scale up to watershed scale. They found that the most cost-effective scenario reduced 0.6 kg dissolved phosphorus (DP) per dollar spent per year ($0.76/lb. DP/year).

One study based in the Texas high plains used modeled data from APEX (Agricultural Policy/Environmental EXtender) to estimate conservation practice effectiveness in reducing sedimentation (Willis 2008). Costs were measured as a sum of forgone crop yields and BMP installation and maintenance costs. A study based in the Mississippi River delta used a similar approach, but modeling was done with AnnAGNPS (Annual Agricultural Non-Point Source Pollution Model) (Yuan et al. 2002). This study considered four agricultural BMPs and three tillage systems. This study found that the most cost-effective BMPs for the 12 ha site studied included cover crops with various types of edge-of-field and grade-control pipes. They found the marginal cost for sediment reduction from agricultural BMPs to be approximately $7.3/ton ($0.0037/lb.).

The research presented here develops an alternate method for estimating the cost-effectiveness of agricultural BMPs to reduce phosphorus loads and improve water quality. Unlike most previous BMP cost-effectiveness research, this research relies exclusively on empirical (i.e., not modeled) data by aggregating and summarizing BMP physical effectiveness and cost data from studies conducted in the field. Additionally, this research allows for a comparison between BMP physical effectiveness estimates and BMP cost-effectiveness estimates, to determine if the former is a reasonable proxy for the latter. Although this method is supported by field data and therefore not as inherently flexible as modeled results, this method is nevertheless sensitive to various influences on cost-effectiveness, including changes in initial loadings from runoff, field conditions, and economies of scale. This research allows conservation managers, a priori, to compare the range of cost-effectiveness possibilities within and between various agricultural BMPs in order to reduce P loading to local water ways in a cost-effective manner. Specifically, this research addresses the following questions:

1) Based on aggregating previous observed BMP effectiveness studies across five Midwestern states, how effective are various BMPs in reducing total phosphorus loadings?
2) How cost-effective are these BMPs in reducing total phosphorus loadings?
3) How do BMP physical effectiveness rankings compare to BMP cost-effectiveness rankings?
4) How is BMP effectiveness influenced by BMP location, soil type, slope, and study scale?

Materials and Methods

To estimate BMP cost-effectiveness, data were assembled from three general sources (described in sections 1-3). The first section describes the MANAGE Database to establish annual baseline pollution levels. The second section describes the Midwest Ag BMP Effectiveness Database, a summary of BMP effectiveness studies across five Midwestern states. The third section summarizes how BMP costs were estimated. These first three sections are subsequently used in the BMP cost-effectiveness equation (section 4).

1. The MANAGE Database to Estimate Pre-BMP Loadings

To estimate P reduction attributable to a specific BMP implementation, a baseline or pre-BMP annual load was established for each specific BMP installation. Due to different field conditions, it would be inaccurate to assume one baseline measurement of annual TP losses per acre for all study sites. Instead, this study established an annual baseline load to reflect the unique site conditions of each BMP installation (Table 3.1). When possible, annualized pre-BMP loadings were taken directly from the actual research study and used as the baseline in BMP cost-effectiveness calculations. For example, many studies measuring the effectiveness of wetlands were conducted over a multi-year time horizon, and thus average annual pre-BMP loadings were measured, reported, and used for baseline annual loading estimates. However, in the majority of cases (161/213 or 76% for total P and 201/213 or 94% for sediment), the study timeline was shorter than one year as P runoff data were often collected from relatively brief rainfall simulations. Because of this, annualized total P and sediment loading numbers coming off of these fields without a BMP were unknown. In cases where annual pre-BMP loading estimates were not reported in specific studies, the pre-BMP baseline was estimated by querying the Measured Annual Nutrient loads from Agricultural Environments (MANAGE) database. The MANAGE database was originally created in 2005 in Microsoft Access, a project led by Daren Harmel with the USDA, and is summarized in detail in Harmel et al. (2006) and Harmel et al. (2008). The MANAGE database was most recently updated and expanded in May of 2013. Studies were only included in the MANAGE database if loadings were measured for one year or more, so that all numbers could be reported on an annualized basis. Other criteria for inclusion in the MANAGE database include:

1) Single land use.
2) Cultivated agricultural lands (including pasture/hay).
3) Contributing area >0.009ha.
4) N or P loads (not concentrations).
5) A study design that included natural rainfall (not simulated) on an annualized basis with measured (not modeled) results of surface runoff.

The MANAGE database can filter study results by state, specific land use, tillage method, presence or not of BMPs, soil type, slope, average P or N applied, fertilizer type and application method, among other categories. Many states are not represented in the MANAGE Database (due to lack of research identified in those states). If the MANAGE Database was restricted to the smaller geographic area used for the Midwest Ag BMP Effectiveness Database (MN, IA, WI, IL, IN and described in the next section), then there were too few database entries available for many BMPs. Consequently, the MANAGE database was restricted to the states of AR, IA, IL, MD, MN, MO, NE, OH, Ontario, SD and WI. The database was also restricted to only include planted agricultural fields with no structural BMPs present. A summary of the various criteria and assumptions used to estimate baseline annual TP loads per acre for different baseline conditions can be found in Table 3.1.

2. Midwest Ag BMP Effectiveness Database

Second, a Microsoft Access database was populated with agricultural BMP effectiveness studies relevant for this research. The database framework was a modified version of the BMP Effectiveness Tool for Arkansas (Merriman et al. 2009) and was used (with permission) to hold the BMP effectiveness data from the Midwest. To populate the database for this current study, data were gathered from papers that measured BMP effectiveness in reducing dissolved phosphorus (DP), particulate phosphorus (PP), total phosphorus (TP), and sediment (SED) in the Midwest. Additional information on the study location (state), slope (0-3%, 3-8%, 8-15%, 15%+), soil type (hydrologic soil group, e.g. A, B, C, D, A/B, A/C, A/D, B/C, B/D, or C/D), study method (field plot, field, or paired watershed), and study scale (ranging from plots to watersheds). Data were collected on the results of each study and context (Figure 3.1), as well as bibliographic information about the given research (Figure 3.2).

Criteria for inclusion in the Midwest Ag BMP Effectiveness Database are presented in Table 3.2. Research conducted in Minnesota, Iowa, Wisconsin, Illinois, and Indiana were considered for inclusion, with a focus on row crop agriculture. Data collected as far back as 1970 were considered for inclusion in the database. Published (including peer-reviewed, grey literature, and dissertations) as well as unpublished studies were considered for inclusion in the database, although no unpublished data sets were found that met all of the database inclusion criteria. Studies must have reported data as BMP loads (e.g.

kg/ha or lbs/acre) for both a "with" and "without" the BMP scenario. Papers that reported only concentrations were not included. Data were all from physical measurements in the field (i.e., not laboratory or modeled studies). Included studies measured surface runoff, which is known to be the primary route for total P and sediment losses from agricultural fields. However, if data for total P or sediment loads in baseflow (i.e., not surface runoff or shallow subsurface flow) was provided then that was also included in BMP effectiveness estimates. Studies measuring the effect of various aggregated BMPs were not included (e.g. Oquist et al. 2007).

Searching for BMP effectiveness studies that met database criteria (Table 3.2) was done via Google Scholar, Agricola, the National Agricultural Library, Web of Science, the Conservation Effects Assessment Project (CEAP) website, and by searching papers that review agricultural BMPs. Qualifying studies that met all database inclusion criteria were reviewed and descriptive data (slope, soil type, study location, study type, as described above) were recorded. Papers commonly did not directly report BMP effectiveness as a percentage. In these cases, data was read from a table or graph and calculated as a percentage of pollutant removed (Equation 3.1). Positive effectiveness values indicate a reduction in pollution attributable to the BMP, while negative effectiveness values indicate an increase in pollution.

$$Eff = \frac{(Load_{without\ BMP} - Load_{with\ BMP})}{Load_{without\ BMP}} \tag{3.1}$$

Where:

Eff = BMP Effectiveness (as % removal)

$\text{Load}_{\text{without BMP}}$ = Loading without the BMP (usually reported as kg/ha or lbs/acre)

$\text{Load}_{\text{with BMP}}$ = Loading with the BMP (usually reported as kg/ha or lbs/acre)

Database entries were assembled in Microsoft Access (Figure 3.3) and checked at random for errors. The most extreme BMP effectiveness values (95% and higher, or -200% and lower) were also checked for errors. Data were moved to Microsoft Excel for calculations and data analysis. Annual reduction of total phosphorus was calculated using equations 3.2 and 3.3.

$$AR_{TP}\ (lbs.) = ABL_{TP} \times Eff \tag{3.2}$$

Where:

AR_{TP} = Annual Reduction of Total Phosphorus (lbs.)

ABL_{TP} = Annualized Baseline Load of Total Phosphorus (lbs.) (Eq. 3.3)

Eff = BMP Effectiveness as %/100 (unitless) (Eq. 1)

and:

$$ABL_{TP} = Load_{TP} \times Area_{T} \tag{3.3}$$

Where:

Load_{TP} = Pre-BMP or baseline annual TP Loading (lbs/acre)

Area_{T} = Area treated by the BMP (acres)

3. BMP Cost Estimates

This study estimated the full, financial farm-level costs of agricultural BMP implementation borne by the landowner. Final BMP cost-effectiveness estimates were estimated for two scenarios, both with and without the assumption of cost-share assistance. All cost estimates include materials, labor, maintenance, and opportunity costs. Details on cost estimates for each BMP are provided in Tables 3.8 through 3.10. All costs in this research have been converted to 2014 dollars using the US Bureau of Labor Statistics Consumer Price Index (CPI) calculator (USBLS 2015). The BMP cost estimates did not account for external and social costs or benefits of BMP implementation outside of total phosphorus reduction. BMP costs can fluctuate based on location, specific type, scale, location on the landscape, proper maintenance, and other factors. Because of these factors, the process of estimating BMP costs can be difficult and should be viewed as approximate or estimates that may change based on the listed factors. However, to not estimate BMP costs because of the unknowns and variations comes with its own risks and uncertainties in the decision making process.

Costs were estimated using the MN FY 2015 Environmental Quality Incentives Program (EQIP) General Payment Schedule (USDA NRCS 2014b). EQIP is a working lands conservation program that "provides financial and technical assistance to agricultural producers…to implement conservation practices that address natural resource concerns" (USDA NRCS 2015). The

General Payment Schedule is “a collection of payment rates used to reimburse estimated costs incurred by program participants for the installation of conservation practices using conservation programs such as EQIP…” (Xu 2012). EQIP cost data for BMPs are assembled for each state based on national, regional, and local data from the NRCS National Conservation Cost Database (NCCD). The NCCD, although developed to produce EQIP payment schedules for each state, were intended to and have been used by other researchers to estimate BMP costs (Shortle et al. 2013; Xu 2012).

All EQIP reimbursements are estimated net present value costs incurred to a landowner implementing a BMP, including materials, installation, labor, maintenance, forgone income, technical assistance, and administration. Reimbursements are granted up to 75% of the full estimated incurred cost. For this research, EQIP reimbursement rates were divided by 0.75 to estimate a full cost of the BMP over its life. Shortle et al. (2013) argue that EQIP cost-share payments can lead to overestimates of private costs in some cases (such as conservation tillage, due to reduced input costs and long term productivity gains), and thus EQIP reimbursement rates should be viewed as price ceilings. Adjustments were made where possible to account for these differences. For example, costs for reducing nutrient application rates are often negative, or a cost savings (ISU 2013). However, EQIP reimbursement rates do not account directly for these savings. Costs for nutrient management were then estimated as the EQIP reimbursement rate for a nutrient management plan (NRCS code

590), minus the savings in fertilizer costs, estimated at $0.59/lb. P reduced (ISU 2013).

The costs estimated through EQIP payment schedules are somewhat sensitive to economies of scale and specific type of BMP implementation. For example, EQIP reimburses wetland creations (NRCS code 656) differently based on size of the wetland. Medium wetlands (0.1-0.5 acres) are reimbursed at a rate of $25,613/acre, while large wetlands (>0.5 acres) are $22,967/acre. Vegetated filter strips (NRCS code 393) are reimbursed at higher rates if native species are planted. EQIP costs were selected that best matched the BMP type and design used in each specific study, such that EQIP cost estimates in this study are somewhat sensitive to economies of scale and specific type of BMP.

Cost estimates for all BMPs were annualized with equations 3.4-3.6 using a real discount rate of 4%. This rate was also used by both Christianson et al. (2013) and Lazarus et al. (2014) in their BMP cost estimates, and is similar to the rate used for federal water projects (4.125%) in 2011 (Christianson et al. 2013), although this number has increased somewhat in recent years. For consistency, average BMP life spans were estimated from EQIP assumptions, and are generally conservative compared to other BMP lifespan estimates in the published literature.

$$EAC(\$) = TPVC \times CRF \tag{3.4}$$

Where:

EAC = Equivalent Annualized Cost of a BMP ($)

TPVC = Total Present Value Cost ($) (Equation 3.5)

CRF = Capital Recovery Factor (unitless) (Equation 3.6)

and:

$$TPVC = TC \times Area_{BMP} \tag{3.5}$$

Where:

TC = Total Cost (as net present value) of a BMP over its lifetime ($/acre). This includes full establishment costs, and all applicable maintenance/ongoing costs, discounted over n years to a net present value cost.

$Area_{BMP}$ = Area of the BMP (acres)

And:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{3.6}$$

Where:

n = estimated life of BMP, or planning horizon (years)

i = Annual real discount rate (%)

4. Cost-Effectiveness Equation

Data from the above sources were collected and total BMP cost-effectiveness in reducing TP loadings for each entry in the BMP effectiveness database were calculated using equation 3.7. Two types of cost-effectiveness estimates were developed: one assuming no cost-share assistance, and one with 75% cost-share assistance.

$$\frac{EAC\ (\$)}{AR_{TP}\ (lb.)} = \frac{TPVC \times CRF}{ABL_{TP} \times Eff} \tag{3.7}$$

Where:

EAC = Equivalent Annualized Cost of a BMP ($)

AR_{TP} = Annual Reduction of Total Phosphorus (lbs.)

TPVC = Total Present Value Cost ($)

CRF = Capital Recovery Factor (unitless)

ABL_{TP} = Annualized Baseline Load of Total Phosphorus (lbs.)

Eff = BMP Effectiveness as %/100 (unitless)

Results

1. The MANAGE Database to Estimate Pre-BMP Loadings

Results of the pre-BMP loading data used in calculations can be found in Table 3.1. Of the 52 BMP scenarios across 9 papers that reported annualized total phosphorus (TP) loads, pre-BMP loads had an average loss of 6.43 lbs.TP/acre/year, and a median TP loss of 1.93 lbs TP/acre/year. As expected, the data were skewed, so the averages are often inflated by a few very large values. These values were not excluded and were still used in their respective estimates of BMP cost-effectiveness.

The MANAGE Database query (for baseline estimates when studies did not report annualized TP loads) resulted in 20 studies that measured TP loads on an annualized basis. These studies reported an average load of 4.47 lbs TP/acre/year, and a median load of 1.63 lbs TP/acre/year, reasonably close to the measured results gathered from the 52 BMP scenarios in the AG BMP Effectiveness Database reporting TP loads on an annualized basis. All scenarios queried from the MANAGE Database and used for various baseline estimates are shown in Table 3.1. When MANAGE results were used for cost-effectiveness calculations, the median annualized baseline load (not the mean) was always used.

2. Midwest Ag BMP Effectiveness Database Results

Effectiveness by BMP Type

The Midwest BMP Effectiveness Database was queried and results were aggregated by BMP type. Results summarizing the data for particulate phosphorus reduction are shown in Figure 3.4 and Table 3.3, dissolved phosphorus in Figure 3.5 and Table 3.4, total phosphorus in Figure 3.6 and Table 3.5, and sediment in Figure 3.7 and Table 3.6. Tables 3.3-3.6 are ordered by median BMP effectiveness values. One general observation from the percentage effectiveness results in Figures 3.4-3.7 is that results are skewed towards negative numbers. The reason for this is due to how BMP effectiveness is calculated (equation 3.1). BMP effectiveness values are maximized at 100%

(all of the baseline pollution is removed by the BMP, down to zero), while effectiveness values have no theoretical lower limit. For example, a low baseline measurement (e.g. 1 unit) paired with a relatively high post-BMP measurement (e.g. 4 units), results in a BMP effectiveness percentage of (1-4)/1 = -3 = -300%. These examples were not common, but were frequent enough to skew the BMP effectiveness results towards negative effectiveness values. (Positive effectiveness values indicate a reduction in pollution, while negative effectiveness values indicate an increase in pollution.) Median BMP effectiveness values were used in all calculations and results (Bang and Zhao 2012). Median Absolute Deviation (MAD) was used to report the variability in the data. MAD is a robust measure of variation that is less sensitive to outliers and skewed data sets than other measures of variability, such as standard deviation (Leys et al. 2013). It is calculated by starting with the absolute value of residuals of each data point to the median, and then calculating the median of those residuals.

The order ranking of BMP effectiveness results were fairly similar for both particulate phosphorus (PP) and total phosphorus (TP). For example, terraces, no-till, and wetlands were all relatively effective in removing larger percentages of both PP (median reduction of 92%±6, 63%±8, and 55%±9 respectively) and TP (median reduction of 82%±11, 82%±11, and 62%±24 respectively). Conversely, ridge tillage, manure applications (in place of inorganic P), and incorporating phosphorus applications were generally less effective in removing PP (median reduction of 50%±23, 46%±9, and 40%±13, respectively) and TP (median reduction of 44%±4, 19%±34, and 44%±24, respectively). This confirms previous observations that PP and TP are related variables since PP makes up the large majority of TP coming off of most fields.

Dissolved phosphorus (DP), although generally a small percentage of TP, is often measured due to its direct pathway into local water bodies through surface or subsurface flow. Because its movement pathway is different from PP, BMP effectiveness changes when DP effectiveness is considered. For example, no-till is generally effective for reducing PP and TP loads (median reductions of 63%±8 and 82%±11, respectively) due to less soil particle movement and less soil disturbance. However, no-till practices can increase DP loads (median reduction of 0%±80) as no-till soils are less permeable than tilled soils. Less water is infiltrated into the soil in no-till fields which allows more rainwater runoff to leave the field quickly after a storm. Many of the various tillage BMPs were the least effective in reducing DP loads from agricultural fields. Due to the sometimes inverse effects of BMPs on DP and PP loads, TP was used in all cost-effectiveness estimates. TP includes both PP and DP in their respective ratios and is a more accurate measure of total pollutant loads and eutrophication potential in water bodies over time (Allen and Mallarino 2008; Correll 1998).

Effects of slope, soil type, location, and study scale on BMP effectiveness

Data on four factors that potentially influence BMP effectiveness were collected along with the BMP effectiveness percentages. Data were analyzed using IBM's Statistical Package for the Social Sciences (SPSS, version 22) to determine if there is a statistically significant relationship between BMP Effectiveness in reducing TP and: 1) slope of the study location; 2) soil type; 3) location of the study; or 4) scale of the BMP study. Due to how BMP effectiveness is calculated (with an upper bound of 100% effective, but no theoretical lower bound, as explained previously), all data sets were skewed to the left towards negative values. Data were not normally distributed, confirmed by the Shapiro-Wilk test for normality. Various transformations to reduce outliers and normalize the data were attempted but were unsuccessful. Additionally, group sizes were not balanced (Table 3.7), which can make violations of ANOVA assumptions more problematic. Thus, none of the data sets analyzed were appropriate for a one-way ANOVA based on means. Instead, the non-parametric Kruskal-Wallis H Test based on comparing medians was used in all four cases (Table 3.7).

First, the Kruskal-Wallis H test was run to make inferences about the difference in medians between 3 slope levels: "low" (0-3% slope, n= 27), "medium" (3.1%-8% slope, n=89), and "high" (8.1%-15% slope, n=28). Box plots of the three slope classes were visually inspected and distributions were similar for all groups. Median BMP effectiveness percentage was statistically significant between groups, with $\chi^2(2) = 15.587$, and $p < 0.001$. A post hoc test to interpret pairwise comparisons was done using Dunn's (1964) procedure with a Bonferroni adjustment due to multiple comparisons. Adjusted p-values are given. The tests indicated statistically significant differences in median BMP effectiveness percentages between the low (22%) and medium (59%) ($p < 0.001$), and low and high (49%) ($p=0.022$), but not between the medium and high groups.

Second, the Kruskal-Wallis H test (essentially the same as a Mann-Whitney U test when there are only two groups) was run to make inferences about the difference in medians between the two soil types: “B” soils (n=137) and “B/D” soils (n=23). Box plots of the two soil type classes were visually inspected and distributions were similar for both groups. Two BMP effectiveness observations were from B/C soils, but these were grouped with B/D soils due to the very small sample size. Neither of these two data points were outliers in the combined B/C and B/D box plot. Median BMP effectiveness was higher for BMPs implemented on B soil type (55%) compared to B/D soil type (35%). This difference was statistically significant, with $\chi^2(1) = 5.519$, and $p = 0.019$.

Third, a Kruskal-Wallis H test was conducted to see if there were significant differences in BMP effectiveness based on location where the study was conducted. Studies were categorized as either conducted in Minnesota (n=22), or outside of Minnesota, including all studies from Iowa, Wisconsin, Illinois, and Indiana (n=150). Inspection of the box plots of BMP effectiveness indicated similar distributions between these two groups, allowing for medians to be compared. However, median BMP effectiveness scores between the Minnesota based studies (49%) and not-Minnesota (55%) groups were not statistically significant, with $\chi^2(1) = 2.113$, and $p = 0.146$.

Finally, a Kruskal-Wallis H test was conducted to see if there were significant differences in BMP Effectiveness based on the scale of the study. Studies were categorized as either plot (n=96), field (n=25), or watershed (n=53). Inspection of the box plots of BMP effectiveness indicated similar distributions between these two groups, allowing for medians to be compared. Median BMP effectiveness percentage was statistically significant between groups, with $\chi^2(2) = 13.858$, and $p < 0.001$. A post hoc test to interpret pairwise comparisons was done using Dunn's (1964) procedure with a Bonferroni adjustment due to multiple comparisons. Adjusted p-values are given. The tests indicated statistically significant differences in median BMP effectiveness percentages between the plot (47%) and watershed (63%) scale BMPs ($p < 0.001$), but not between the plot and field (53%) or field and watershed scale BMP groups.

3. BMP Cost Estimate Results

Specific BMP costs, BMP life, Equivalent Annual Cost (EAC), and assumptions are shown in Tables 3.8 through 3.10. Total per acre costs for the various BMPs over their expected lifespan ranged from a negative cost of -

$26.87/acre (indicating a cost savings) for reducing P application rates, up to $34,151.04/acre for wetlands[1]. BMPs with negative costs were most commonly examples of P application rate reductions, with costs ranging from $-26.87/acre for large reductions in synthetic P application (64 lbs. reduced P application/acre) to $+2.07/acre for a smaller reductions (23 lbs. reduced P application/acre) in P applied as manure. Cost estimates for nutrient application reduction did not directly include estimates for changes in yield, although EQIP reimbursements for nutrient management (NRCS practice 590) indirectly account for potential yield reductions. Similar to this research, other studies have also found nutrient reduction costs to be negative (e.g. Christianson et al. 2013; Lazarus et al. 2014; ISU 2013). For comparison between BMPs, all costs were based on total treated acres (not BMP installation size) and reduced to their equivalent annual cost (EAC) as described in the methods section. Equivalent annualized costs ranged from a low of $-26.87/acre/year to $3,071.58/acre/year, again for reduced P application rates and wetlands, respectively.

4. Best Management Practice Cost-Effectiveness Analysis

Cost-effectiveness (CE) analysis has been much more widely used in the health sciences compared to the environmental sciences, and economists in the health sciences offer some strategies for thinking about how to accurately

---

[1] See Tables 3.8, 3.9 and 3.10 for details on BMP cost estimates.

analyze cost-effectiveness data. The two key variables to estimating BMP cost-effectiveness can be thought of on a 2-dimensional plane, with BMP equivalent annual costs on one axis and annual TP reduction values on the other, both ranging from low to high values (Figure 3.8). This cost-effectiveness plane can then be divided into 4 quadrants:

1) Highly Favorable BMP installations (where "costs" are negative, and pollution reduction is positive),
2) Highly Unfavorable BMP installations (where costs are positive, and pollution reduction is negative),
3) Cost-Effective (where both costs and pollution reduction are positive), and
4) Questionable (where both costs and pollution reduction are negative).

The first two categories are straightforward in the decision making process. All highly favorable BMPs, also referred to as "dominating" BMPs, should always be implemented as they decrease pollution and save money. All highly unfavorable BMPs should never be implemented, as they increase pollution and cost money. The majority of BMPs fall into the third category, where they are cost-effective in reducing pollution to varying degrees. The fourth category is a rare but difficult case, where decision makers need to decide if a cost savings can offset the expected increase in pollution.

Cost-effectiveness values for each BMP installation in each study were estimated (Equation 3.7) and plotted to view the distribution of the various BMPs in reducing total phosphorus on the cost-effectiveness plane. Results can be seen in Figures 3.9-3.12. Although Figures 3.9-3.12 are all conceptually the same, BMP CE data were placed in four separate figures to enable viewing of a wide range of BMP cost and physical effectiveness scales. A total of 143 BMP installations were analyzed for their cost-effectiveness in reducing total phosphorus. Of the 20 BMPs in the highly favorable/dominating quadrant, nearly all were reducing phosphorus application levels.[2] Of the 11 BMPs in the "highly unfavorable" quadrant, the two most common BMPs were converting from synthetic to manure-based P applications (n=3) and wetlands (n=3). The large majority of BMPs (n=108) fell into the "cost-effective" quadrant, as would be expected. These are the BMPs with positive costs and positive benefits, although CE values ranged dramatically within this quadrant. These are discussed in detail later. There were only four examples of BMPs falling into the "questionable" category. All four were examples of P application reduction.

The cost-effectiveness data in the "cost-effective" and "questionable" categories were pooled and Q1 (slope=m=$3.32/lb. TP reduced) and Q3 (slope=m=$31.98/lb. TP reduced) are plotted on each graph as a line through the cost-effectiveness plane. BMP installations in the "cost-effective" category

---

[2] Studies ranged widely on how they studied P reduction levels. A reduction from 140 lbs. P to 90 lbs. P applied/acre is different from a reduction from 50 lbs. P to 0 lbs. P applied/acre, or a reduction of 50 lbs. to 30 lbs. of P applied/acre. Because of these differences, BMP application rates were divided into classes based on natural breakpoints in the data. High application rates were defined as 101-177 lbs./acre/year, medium as 47-100 lbs./acre/year, and low as 16-46 lbs./acre/year. BMPs were then defined as a change from "high to medium" application rates, or "high to low" application rates etc.

that cost less than \$3.32/lb. TP reduced are more favorable CE ratios (CE ratio <Q1), and are highly cost-effective relative to other BMP installations. BMP installations that cost more than \$31.98/lb. TP reduced have unfavorable CE ratios (CE ratio >Q3) and are much less cost-effective. When the data in the "cost-effective" and "questionable" quadrants are divided based on Q1 and Q3, the entire cost-effectiveness plane can be thought of on a scale of five cost-effectiveness regions, ranging from most to least cost-effective: 1) dominating; 2) cost-effectiveness <Q1; 3) cost-effectiveness ≥ Q1 and ≤ Q3; 4) cost-effectiveness >Q3; and 5) dominated (Figure 3.8).

Data were categorized into these five cost-effectiveness regions based on BMP type with results displayed as relative percentages in each of the five regions (Figure 3.13), with n values ranging from n=2 (low rate of P application to zero) up to n=27 (wetland creation). Many BMPs fell into multiple categories. The BMPs were ordered in Figure 3.8 from relatively more cost-effective to less cost-effective using a weighting scheme. Data were weighted as either +1 (dominating), +0.3, 0, -0.3, -1 (dominated), depending on which of the five cost-effectiveness regions they fell into. An average total score of all of the BMPs were ranked and ordered from most to least cost-effective BMP in Figure 3.13. Of the 143 BMP installations across 14 types of BMPs (with P reduction divided into 3 categories), a change from high to medium rates of P application (n=12) or low rates to zero P application (n=2) consistently fell into the dominating region. Conversely, switching from inorganic fertilizer to manure (n=9), and terraces (n=8) were generally the least cost-effective BMPs in reducing total phosphorus to surface waters.

Cost-effectiveness ratios in the highly favorable (i.e., dominating) and highly unfavorable (i.e., dominated) quadrants both result in negative cost-effectiveness values. A common mistake in BMP cost-effectiveness research is to either report negative CE ratios or use negative cost-effectiveness ratios in statistical analyses (e.g, Christianson et al. 2013; Wortmann et al. 2011). As health science economists have emphasized, reporting or analyzing negative CE ratios is incorrect because the magnitudes of negative cost-effectiveness ratios are effectively meaningless. Negative cost-effectiveness ratios within the same quadrant cannot be compared as they "do not provide information about the relative preferability" of negative CE ratios (Glick 2012; O'Brien and Briggs 2002). For this reason all negative (dominated and dominating) CE ratios were excluded from BMP effectiveness summary box plots and summary statistics (Figure 3.14, Table 3.11, and Table 3.12). In interpreting these box plots is it important to understand that they depict a large subset and not all of the total data. Of the 143 total BMP observations of TP, 31 (22%) had negative CE ratios. Only descriptive statistics (and not inferential statistics) were run on cost-effectiveness data because the restricted sample of non-negative CE values does not accurately represent the larger population, an underlying assumption for inferential statistics. From a decision making standpoint, however, these negative CE ratios all fall into "obvious" decision categories. Either they are clearly a good idea to implement (dominating) or not (dominated). Decisions on relative cost-effectiveness are most important for the remaining 112 BMP examples (the BMPs for which it is not necessarily obvious if they are cost-effective or not).

Of the 112 BMPs with non-negative CE values, the median CE was \$9.26/lb. TP reduced, with a mean of \$125.16/lb. of TP reduced. Non-negative CE values ranged from \$0.00/lb. TP reduced (n=6) up to \$3,506.15/lb. TP reduced (n=1). Data were skewed to the right, towards high CE values. The three highest CE values (CE > \$1,200/lb. TP removed) were all examples of created wetlands that reduced TP by less than 20%. The three most cost-effective BMPs (with positive CE values) were no-till (n=18, median CE=\$3.23/lb. TP reduced), perennial vegetation (n=4, median CE=\$3.30/lb. TP reduced), and lower rates of P application (n=9, median CE=\$4.26/lb. TP reduced). Crop rotations (n=5, median CE=\$34.66/lb. TP reduced), constructed wetlands (n=24, median CE=\$34.83/lb. TP reduced), and terraces (n=7, median CE=\$83.96/lb. TP reduced) ranked as the three least cost-effective BMPs (Figure 3.14, Table 3.11). Cost-effectiveness estimates in Table 3.11 assume that all BMP costs are borne by the landowner. In reality, BMP installations are often implemented with the assistance of a variety of conservation cost-share programs. Cost-effectiveness ratios were also calculated assuming out-of-pocket costs to a landowner were 25% of total costs used in the BMP effectiveness estimates (Table 3.12). Cost-share payments were estimated at

75%, based on the maximum EQIP reimbursement based on estimated incurred costs to a landowner implementing these BMPs.

Discussion

Sources of Uncertainty and Research Limitations

Estimating the physical effectiveness and cost-effectiveness of agricultural best management practices is not a straightforward task and is subject to many limitations. These include:

1) BMP effectiveness and costs vary by location. There is uncertainty in transferring or extrapolating the results of one BMP study location to a different location.
2) There is a noticeable lack of BMP cost data. Projects such as the NRCS National Conservation Cost Database (NCCD) are attempting to fill this void, but they lack context-specific data.
3) Cost estimates are not always transparent in their methods and assumptions.
4) The limited cost data that are available are constantly in need of updating.
5) There are inconsistent estimates of theoretical BMP time horizons.
6) New BMP technologies may be more cost-effective than well established technologies. However, these new BMP technologies suffer from a lack of both physical and cost data, a problem common to any analysis comparing emerging vs. established technologies.

7) This research only estimated the cost-effectiveness in reducing one type of NPS pollution, phosphorus. Other major contributors to regional water quality concerns include nitrogen and sediment. Due to different movement pathways of these three major NPS pollutants, they are each affected differently by different BMPs. BMP cost-effectiveness in reducing P likely does not reflect the cost-effectiveness of the same BMP in reducing nitrogen or sediment.

8) Other non-water quality environmental benefits were not estimated in this research, such as habitat or water storage benefits of wetlands. These are real, potentially significant benefits to society provided by agricultural BMPs and would be of interest to decision makers in a comprehensive analysis of environmental services.

This research used conservative estimates for BMP life spans by using EQIP BMP life span estimates. EQIP life span estimates were generally lower than other sources. This assumption inherently disadvantages BMPs with longer time horizons, such as buffer strips and wetlands, in the final cost-effectiveness results by raising their EAC (see Tables 3.8, 3.9 and 3.10 for BMP life span estimates). This decision was justified since actual BMP life spans often do not reach their theoretical life spans. For example, a buffer strip might be installed but soon removed if the landowner or operator changes. Additionally, focus group participants (see chapter 2) often lamented that BMPs were poorly maintained or destroyed before the end of their useful life. BMPs with short time horizons minimize this risk. For example, wetlands and terraces were estimated in this research to have a life span of 15 and 10 years, respectively. Estimates found in the literature ranged as high as 50 years for wetlands (Christianson et al. 2013) and 25 years for terraces (Feng et al. 2007). With the conservative life span estimates for wetlands (15 years), BMP CE values across the 24 wetland studies ranged from \$2.16/lb. TP reduced up to \$3,506.15/lb. TP reduced, with a median CE value of \$34.83/lb. TP reduced (Table 3.11, Figure 3.14). If life span estimates are raised to 50 years, BMP CE values across the 24 wetland studies ranged from \$1.12/lb. TP removed up to \$1,814.67/lb. TP removed, with a median CE value of \$18.03/lb. TP removed. In other words, increasing wetland BMP life span estimates from 15 years (used in this research) to 50 years (the maximum wetland life span found in the literature) would have lowered wetland CE estimates by 48%. Similarly, increasing terrace BMP life span estimates from 10 years (used in this research) to 25 years (the maximum terrace life span found in the literature) would have lowered terrace CE estimates by 48%, from a median cost of \$83.96/lb. TP reduced, to \$43.59/lb. TP reduced.

Due to these uncertainties in estimating BMP cost-effectiveness, caution should be taken when interpreting all results. However, the difficult nature and uncertainties in estimating BMP cost-effectiveness does not invalidate the process. All research that attempts to generalize data from a sample to a population must accept, acknowledge, manage, and report uncertainty. To not attempt to estimate physical and cost-effectiveness of agricultural BMPs is to leave decision makers blind where aggregating data can provide useful insights, even if not precise estimates. This research has attempted to objectively and clearly lay out the uncertainties while proceeding to discover valuable insights to help decision makers.

BMP Physical Effectiveness and Factor Effects

One attempt to address uncertainty was to record and analyze four factor effects (slope, soil type, study location, and study scale) to determine if there is a relationship between these factor effects and the results of BMP physical effectiveness studies. Slope was divided into three slope classes: 0%-3%, 3.1%-8%, and 8.1%-15%. (No BMP effectiveness studies were found on slopes over 15%.) Soil classes based on soil texture and hydrology were recorded as either “B”, “B/C”, or “B/D.” Location was recorded by state: Minnesota, Iowa, Wisconsin, Illinois, or Indiana. Finally, the scale of the study was recorded as a field plot, field, or watershed.

The significant effect of slope on BMP effectiveness is well established in the literature (Gitau et al. 2005; Liu et al. 2008), and results in this study follow suit. As expected, BMPs are most effective on moderate slopes (3.1%-8%) and high slopes (8.1%-15%). If slopes are less than 3% water runoff moves at a sufficiently slow rate for P to infiltrate the soil without a BMP. If slopes are larger BMP effectiveness can increase as water moves more quickly to local waterways and reduces natural infiltration rates. A slope of 9% has been found to be optimum for sediment trapping in buffer strips (Liu et al. 2008), which correlates with TP movement.

Comparing Minnesota to four other Midwestern states was not a significant factor in BMP effectiveness studies. Other studies have found regional differences in BMP effectiveness across the United States (Gitau et al. 2005). And yet, best management practice research (including this study) commonly aggregate BMP studies at a regional level with the assumption that within-region location effects are small enough to justify the transfer of data. This research confirms this common (but relatively untested) assumption to be valid.

Study scale was a highly significant factor in BMP effectiveness studies, specifically between the field plot and the watershed scales. The significance of study scale is also observed in previous research, with myriad potential reasons for this studied or hypothesized (Almendinger et al. 2014; Sharpley et al. 2009; Trimble and Crosson 2000). One confounding variable in this research between different study scales is that certain types of BMPs lend themselves to different study scales. For example, wetlands, filter strips, and terraces are always or usually studied at field or sub-watershed scales. Other BMPs can more feasibly be studied with edge-of-field runoff plots, including tillage methods and P application rates. Cost limitations also mean these BMPs are most frequently studied at the plot or field scale when possible. Consequently, it is difficult to determine if the significant difference between study scales is perhaps due a third confounding variable that is related to both the dependent and independent variables; in this case perhaps BMP type is a driver of both BMP effectiveness and study scale selection.

Negative Data: Costs, Effectiveness Values, and Cost-Effectiveness Ratios

In the cost-effectiveness analysis, approximately 22% of the 143 data points had negative CE ratios (Figure 3.8). These include cases with either positive costs and negative effectiveness values (i.e. dominated cases), or negative costs and positive effectiveness values (i.e. dominating cases). Of the 24 BMP installations recorded with negative costs, all were examples of lowering P application rates. Negative costs associated with lower levels of nutrient application are commonly reported in the literature (e.g. Christianson et al. 2013; Horrigan et al. 2002; ISU 2013; Lazarus et al. 2014).

Of the 15 BMP installations with negative pollution reduction (i.e., an increase in pollution associated with BMP implementation), 6 were reduction of P application rates, 3 were wetlands, and 3 were switching from inorganic commercial fertilizer to manure-based P applications. The six examples of P application that had negative pollution reduction rates ranged from -10% to -72%, were drawn from four different studies, and all were cases of reducing P application from medium to low levels. The reason for this is not entirely clear, but one possibility is smaller average application reductions between the control and the treatment compared to other P reduction categories.

When BMP cost or effectiveness was negative (but not both), the CE ratio was also negative, with interesting implications. Importantly, negative CE ratios should only be interpreted as categorical variables, since negative CE ratios “have no meaningful ordering” within a quadrant (O’Brien and Briggs 2002). This concept is not necessarily intuitive but can be demonstrated with an example. Imagine three BMP installations. Practice A has a cost of -$50 (i.e., a cost reduction or a savings) and removes 1 lb. of P, Practice B has a cost of -$20 and removes 1 lb. of P, and Practice C has a cost of $-50 and removes 2 lbs. of P. Of these three installations, Practice C is the best. Practice C saves as much or more money than the other two installations and it also removes twice as much pollution as either Practice A or Practice B. However, Practice C does not have the lowest CE ratio. The calculated CE ratio of Practice A is $-50/lb. P reduced, followed by Practice C at $-25/lb. P reduced, and finally Practice B at $-20/lb. P reduced. This is a simplified demonstration of why negative CE ratios are not ordinal, and therefore negative CE ratios should not be reported or analyzed, which would imply that they are meaningful.

This difficulty with and caution regarding negative CE values is discussed in the literature by health science statisticians and economists (Glick 2012; O’Brien and Briggs 2002; Stinnett and Mullahy 1997). However, no cautionary warnings regarding negative CE ratios were found in environmental water quality literature discussing BMP cost-effectiveness. On the contrary, it was not unusual to see negative CE ratios reported, analyzed, and discussed in the BMP cost-effectiveness literature (e.g. Christianson et al. 2013; Wortmann et al. 2011) implying that negative CE ratios are ordinal variables to be included in statistical analyses. This research attempts to apply the concept discussed in the health sciences literature to the environmental water quality BMP literature. This research uses categorical data methods in data reporting when negative CE ratios are included in the data set (Figure 3.13), and excludes the negative CE ratios when ordinal data are reported, such as box plots and tables (Figure 3.14, Table 3.11 and Table 3.12). Because negative CE ratios are excluded, Figure 3.14, Table 3.11 and Table 3.12 represent a subset of the total data sample and should be interpreted in light of this.

Comparison of BMP Physical Effectiveness and Cost-Effectiveness

This research provides evidence that the BMP physical effectiveness (e.g. lbs. of P removed/acre/year) is often not a good estimator of BMP cost-effectiveness (e.g. $/lb. of P removed) (Table 3.13). This evidence found here in empirical data is consistent with other research efforts based on modeled results, which have also found that the most physically effective BMPs are not necessarily the most cost-effective BMPs, and vice versa (Arabi et al. 2006; Gitau et al. 2004; Maringanti et al. 2011; Veith et al. 2003).

Of course BMP physical effectiveness and cost-effectiveness are not independent variables, as physical effectiveness is an input to calculate BMP cost-effectiveness. One should expect that results be at least somewhat related. However, it is interesting to note the influence of cost on some BMPs in estimating their BMP cost-effectiveness. An intuitive and extreme example is looking at the difference between physical effectiveness and cost-effectiveness in lowering rates of P application. When looked at from a physical effectiveness standpoint, lowering rates of P application ranks as only #10 out of the 12 BMPs ranked (Table 3.13). Lowering P application rates does not reduce large percentages of TP runoff (median physical effectiveness of 34% ± 20%) compared to other types of BMPs. However, lowering rates of P application can save money. (The EAC ranged from $-23.23 to $+1.99, depending on the amount of P reduced and type of P in each study.) Consequently, lowering rates of applied P ranked as #1/12 in the list of most cost-effective BMPs.

Other differences in BMP rank in Table 3.13 are less intuitive and perhaps very useful for decision makers to consider. The largest difference in rank between the physical effectiveness and cost-effectiveness lists was for terraces. Terraces can remove significant percentages of Total P (median physical effectiveness of 82% ± 11%, n=8). However, their cost is very high, with an estimated EAC of $71.24/acre/year, bringing their cost-effectiveness rank down to #12/12. Other BMPs that differed significantly in rank between physical effectiveness and cost-effectiveness (defined here as a change of three or more rank spots in the Table 3.13) include wetlands, perennial vegetation, and crop rotations. Crop rotations, perennial vegetation and reduction of P applications are generally more cost-effective than physical effectiveness data would suggest, while terraces and constructed wetlands are generally less cost-effective than physical effectiveness data would suggest.

Summary and Conclusions

This research is the first to use field-scale, empirical data to estimate cost-effectiveness values for 143 BMP installations to reduce TP loads to improve water quality. Results showed that BMP physical effectiveness and BMP cost-effectiveness in reducing TP should not be conflated or assumed to be equal. Additionally, the wide variation in BMP cost-effectiveness ranges between and within different types of BMPs, or observing the minimum and maximum CE values observed should be of interest to decision makers considering program funding or estimating P reduction potential per dollar spent on a given BMP.

Published studies advocating physical targeting to address NPS pollution should consider what exactly they are trying to minimize. Minimizing costs per unit of avoided pollution may lead to more TP reduction in waterways than an effort to specifically target high P source areas with the most physically effective BMPs. Importantly, this research is not attempting to claim that certain BMPs are always more physically effective or more cost-effective in all scenarios. This research should not be interpreted strictly as a summary of "better" or "worse" BMPs to implement. Of course differing field conditions and contexts will impact the effectiveness and cost-effectiveness of any BMP. Factors such as slope, soil type, and study scale were demonstrated to be significant factors in BMP effectiveness.

Explicitly integrating full, financial farm-level BMP cost data into the decision process is an important next-step for decision makers to consider. One problem is the limited availability and consistency of BMP cost data. This research has attempted to estimate equivalent annual costs for a wide range of BMPs. Inclusion of this cost data (or similar) in the BMP decision process should be promoted and incentivized. A second obstacle for integrating cost data into the decision process is one-size-fits-all BMP programs that fund specific BMPs at a given rate, lowering the landowner out-of-pocket costs of specific BMPs. These cost-share programs create a divergence between landowner out-of-pocket costs and full BMP costs, and in effect discourages a full cost accounting of BMP cost-effectiveness.

To address both of these obstacles for including cost data in the BMP decision process, policy makers should allow funding to go towards projects that demonstrate a higher likelihood of being relatively cost-effective. Perhaps policy makers could use the Q1 and Q3 CE estimates from this research (Figure 3.8) to say that projects with an estimated CE ratio below $3.32/lb. TP reduced will receive the highest levels of cost share programs, while projects with estimated CE ratios above $31.98/lb. TP reduced will not be considered for funding. Data from this research summarizing empirical data BMP effectiveness results could be augmented with modeled BMP physical effectiveness results to estimate BMP physical effectiveness of proposed BMP installations in specific locations on the landscape. These physical effectiveness estimates (given on an annual basis), paired with annualized BMP cost estimates from this research (or more contextualized, local cost data such as project bid estimates when known) could be the primary data sources to estimate the CE ratios used in applications for this proposed cost-share program. Efforts such as this to estimate CE ratios of BMP installations should help to stretch public investment dollars in conservation efforts and reduce the environmental footprint of agricultural landscapes in a more efficient manner.

Tables

Table 3.1. Average estimated baseline total phosphorus losses (lbs/acre/year), based on MANAGE database search results.

		Total Annual Phosphorus Losses				
Pre-BMP	**Post-BMP**	**Average**	**Median**	**Min**	**Max**	**n**
General MANAGE Baseline[a]		4.47	1.63	0.02	16.59	20
Conventional Tillage[b]	Conservation Tillage	6.96	6.18	0.27	16.59	12
No Crop Rotation	With Crop Rotation	5.71	2.68	0.02	16.59	13
Inorganic P Fertilizer	Manure Fertilizer	4.47	1.63	0.02	16.59	15
High[c] P Application Rate	Med. P Application Rate	3.85	2.68	0.02	8.74	5
Med.[d] P Application Rate	Low P Application Rate	3.10	1.63	0.02	12.49	6
Low[e] P Application Rate	Zero P Application	3.09	1.41	0.12	12.49	10
Database Papers[f]		6.43	1.93	0.17	35.82	52

[a] Data were included if studies were 1) from the states/provinces of AR, IA, IL, MD, MN, MO, NE, OH, Ontario, SD or WI; 2) were planted agricultural fields; and 3) had no structural BMPs on the fields. General Baseline data were used for BMP baseline estimates including increased drainage spacing, controlled drainage, filter strips, terraces, perennial vegetation, and wetlands.

[b] Includes General Baseline restrictions, plus only pre-BMP data were allowed in the baseline estimate.

[c] Defined as an application rate of 101 to 177 lbs/acre/year.

[d] Defined as an application rate of 47-100 lbs/acre/year.

[e] Defined as an application rate of 16-46 lbs/acre/year.

[f] Data are not from MANAGE, but instead from database papers. Of the 43 papers and 213 scenarios in the BMP effectiveness database, 9 and 60 (respectively) included annualized pre-BMP baseline runoff P and sediment numbers. When possible, these numbers were used in calculations. When papers did not include annualized P runoff, then MANAGE was used to estimate annualized baseline (pre-BMP) runoff.

Table 3.2. Inclusion criteria for the Midwest Ag BMP Effectiveness Database.

	Included	**Not Included**
Pollutant Type	Dissolved Phosphorus Particulate Phosphorus Total Phosphorus Sediment	Nitrogen Potassium Sodium
Land Use	Cultivated Row Crop Agriculture	Animal Feedlots Pasture/Hay Forest Urban
Data Collection Method	Outdoor Field Measurements	Modeled Results Laboratory Studies
BMP Number	Changes Attributable to One BMP Type	Multiple BMP Effects Measured Together
Results	Loads (e.g. kg/ha or lbs/acre)	Concentrations (e.g. mg/L)
Location	MN, IA, WI, IL, IN	other states or other countries
Water Pathway	Surface Runoff Included	Subsurface Flow Only
Time Scale	Any (days to years)	
Physical Scale	Any (Plot to Watershed)	
Rainfall Type	Any (Simulated or Natural)	
Review/Publication Type	Any (including unpublished or not peer-reviewed)	

Table 3.3. Summary statistics of BMP effectiveness (%) in particulate phosphorus removal.

	n	Min	Max	Avg	Std Dev	Q1	Median	Q3	Med Abs Dev
Terraces	8	71	99	89.6	10.0	86	92	97	6
Crop Rotation	1	75	75	75.0	0.0	75	75	75	0
No-till	4	55	89	67.5	16.2	55	63	76	8
Wetland Creation	4	42	76	56.8	14.8	47	55	64	9
Hedgerow Planting	4	17	92	53.0	31.6	36	52	69	22
Ridge till	3	-150	73	-9.0	122.6	-50	50	62	23
Manure (vs. fertilizer) P	4	23	55	42.3	14.9	34	46	54	9
Lower Rate of P Application	13	0	61	33.1	21.4	18	42	49	9
Incorporating P	8	-100	75	24.3	54.3	25	40	51	13

Table 3.4. Summary statistics of BMP effectiveness (%) for dissolved phosphorus removal.

	n	Min	Max	Avg	Std. Dev.	Q1	Median	Q3	Med. Abs. Dev.
Subsurface Injection of P	5	87	99	92.8	5.5	88	92	98	5
Riparian Forest Buffer	3	-23	78	42.7	56.9	25	73	76	5
Residue Management	9	0	85	58.7	29.8	58	69	77	11
Incorporating P	24	-3	98	64.9	30.2	55	66	90	19
Hedgerow Planting	4	41	86	61.3	18.7	52	59	68	11
Lower Rate of P Application	36	0	99	40.9	28.3	15	47	67	22
Vegetated Filter Strips	10	28	100	54.7	25.0	38	45	74	14
Wetland Creation	16	-27	90	45.0	33.5	25	45	74	26
Drainage Water Mgmt.	2	0	75	37.5	53.0	19	38	56	38
Terraces	8	-235	94	-11.8	110.2	-58	27	62	58
Increased Drain Spacing	6	-21	69	31.3	34.0	22	25	58	24
No-till	23	-3,033	100	-244.0	668.1	-240	0	64	80
Crop Rotation	6	-19	73	12.4	36.1	-14	0	30	17
Manure (vs. fertilizer) P	9	-526	64	-77.2	187.0	-117	-2	45	66
Shallow Till	4	-114	50	-23.0	70.3	-56	-14	19	44
Manure Amendments	8	-50	43	-9.3	35.8	-32	-24	18	21
Ridge till	3	-250	-50	-126.7	107.9	-165	-80	-65	30
Strip Till	3	-1,266	40	-797.3	726.9	-1,216	-1,166	-563	100

Table 3.5. Summary statistics of BMP effectiveness (%) for total phosphorus removal.

	n	Min	Max	Avg	Std. Dev.	Q1	Median	Q3	Med. Abs. Dev.
No-till	18	8	96	72.3	24.3	62	82	91	11
Terraces	8	-32	98	63.8	41.5	58	82	85	11
Subsurface Injection Of P	5	68	95	82.2	11.5	77	78	93	10
Vegetated Filter Strips	22	35	96	71.7	18.9	60	75	89	16
Drainage Water Mgmt.	3	25	77	59.0	29.5	50	75	76	2
Wetland Creation	27	-54	99	53.4	39.3	37	62	82	24
Manure Amendments	8	39	71	57.1	13.2	47	60	68	9
Perennial Vegetation	4	10	73	49.8	27.4	46	58	62	8
Ridge till	3	-188	48	-32.0	135.1	-72	44	46	4
Incorporating P	24	-200	90	12.8	78.4	6	44	57	24
Hedgerow Planting	4	28	60	43.3	13.1	39	43	47	8
Lower Rate of P Application	31	-72	85	25.4	36.9	6	34	50	20
Manure (vs. fertilizer) P	9	-161	55	-15.0	80.7	-36	19	39	34
Crop Rotation	6	-21	74	27.7	36.2	13	17	55	21
Shallow Till	2	-57	13	-22.0	49.5	-40	-22	-5	35

Table 3.6. Summary statistics of BMP effectiveness (%) for sediment removal.

	n	Min	Max	Avg	Std. Dev.	Q1	Median	Q3	Med. Abs. Dev.
Terraces	5	92	99	96.0	2.9	94	97	98	2
No-till	15	18	98	80.5	19.9	75	89	92	7
Residue Management	9	48	93	74.6	13.4	68	80	80	3
Crop Rotation	1	76	76	76.0	0.0	76	76	76	0
Vegetated Filter Strips	7	62	95	74.0	10.6	70	70	76	4
Manure Amendments	8	28	75	51.9	15.8	41	54	60	12
Increased Drain Spacing	6	-38	53	28.0	34.8	23	41	51	13
Manure (vs. fertilizer) P	2	24	28	26.0	2.8	25	26	27	2
Subsurface Injection Of P	1	12	12	12.0	0.0	12	12	12	0
Lower Rate of P Application	3	-245	16	-97.7	133.7	-155	-64	-24	80
Ridge till	1	-87	-87	-87.0	0.0	-87	-87	-87	0

Table 3.7. Significance of slope, soil type, study location and scale on best management practice (BMP) effectiveness of total phosphorus reduction.

Factor	**Factor Groups**[1]	**Factor Effects on TP Physical Effectiveness**		
		Count	Median (% Removal)	p-value
Slope	0%-3% (a)	27	22	
	3.1%-8% (b)	89	59	
	8.1%-15% (b)	28	49	
	p-value			**<.001**
Soil Class	Soil Type B (a)	137	55	
	Soil Type B/D[2] (b)	23	35	
	p-value			**0.019**
Location	MN (a)	22	49	
	not MN[3] (a)	150	55	
	p-value			0.146
Study Scale	Field Plot (a)	96	47	
	Field (a)(b)	25	53	
	Watershed (b)	53	63	
	p-value			**<0.001**

[1] Letters in parentheses indicate results of pairwise comparisons.

[2] Includes 2 cases of B/C soils.

[3] Includes studies conducted in Iowa, Wisconsin, Illinois and Indiana

bold numbers are significant at the 95% level of significance

Table 3.8. Best management practice cost estimates and assumptions (continued in Tables 3.9 and 3.10).

BMP Type	n	EQIP Practice Code	2015 MN EQIP reimbursement rate[a]	Estimated BMP Cost per acre	Estimated Life of BMP (years)	Equivalent Annual Cost (EAC)/acre[b]	Notes
Conservation Crop Rotation	1	328	$188.17/acre	$250.89	3	$90.41	Adds 2 years of perennials to the rotation.
Cover crop	3	340	$44.89/acre	$59.85	1	$62.24	Reimbursement rate is for 2 planted species.
Crop rotation (corn/soy)	2	n/a	n/a	$0.00	2	$0.00	Assumed no cost increase from baseline conditions.
Drainage Water Management	3	554	6.63/acre	$8.84	5	$1.99	Costs are from differences in management, not installation (i.e., both scenarios assumed to have same installation costs).
Hedgerow Planting	4	601	$0.08/linear foot	$87.14	1	$90.63	Calculated from Eghball et al. (2000), there were 12,111.8 linear feet of hedgerows across 14.826 acres in the watershed. 12,111.8 × ($0.08/0.75) / 14.826 acres = $87.14/acre
Manure Amendments	8	590	$11.73/acre	$15.64	1	$16.27	Estimated as cost of nutrient management using manure. (EQIP practice 590)
Manure P (v. fertilizer P)	9	590	n/a	$4.75	1	$4.94	The marginal increase of manure costs (vs. inorganic fertilizer P) estimated as EQIP 590 reimbursement for manure ($11.73/acre) - EQIP 590 reimbursement for inorganic P ($8.17/acre) = $3.56/acre. $3.56/0.75 = $4.75/acre

Table 3.9. Best management practice cost estimates and assumptions (continued in Table 3.10).

BMP Type	n	EQIP Practice Code	2015 MN EQIP reimbursement rate[a]	Estimated BMP Cost per acre	Estimated Life of BMP (years)	Equivalent Annual Cost (EAC)/acre[b]	Notes
No-till	23	329	$11.71/acre	$15.61	1	$16.23	
Perennial Vegetation	4	512	$168.18/acre	$224.24	10	$27.65	EQIP 512, used "warm season 2 or more species w/o fertilizer"
Nutrient Management (basic system, no manure)	13	590	$8.17/acre	Ranged from $-26.87/acre to $-9.76/acre	1	$-27.94 to $-10.15	EQIP 590 (Nutrient management) reimbursement was used to estimate baseline costs from P reduction where non-manure fertilizer was used. Then cost of reduced P input was subtracted at a rate of $0.59/lb. of P, specific to each study.
Nutrient Management (basic system, with manure)	24	590	$11.73/acre	Ranged from $-22.12/acre to +2.07/acre	1	$-23.23 to $1.99	EQIP 590 (Nutrient management) reimbursement was used to estimate baseline costs from P reduction where manure fertilizer was used. Then cost of reduced P input was subtracted at a rate of $0.59/lb. of P, specific to each study.
Residue Management, Applying Corn Residue	3	484	$46.14/acre	$61.52	1	$63.98	Price estimated from EQIP 484, mulching with a natural material, partial coverage.
Residue Management, Leaving Corn Residue	6	329	$11.71/acre	$15.61	1	$16.23	Price estimated from EQIP 329, strip till.
Ridge Till	3	345	$22.60/acre	$30.13	1	$31.34	

Table 3.10. Best management practice cost estimates and assumptions (continued from Tables 3.8 and 3.9).

BMP Type	n	EQIP Practice Code	2015 MN EQIP reimbursement rate[a]	Estimated BMP Cost per acre	Estimated Life of BMP (years)	Equivalent Annual Cost (EAC)/acre[b]	Notes
Riparian Forest Buffer	3	391	$687.27/acre	$916.36	15	$82.42	Assumes planting by seeding.
Strip Till	3	329	$11.71/acre	$15.61	1	$16.23	
Terraces	8	600	$2.60/foot	$577.79	10	$71.24	MN EQIP reimb. is $2.60/foot for narrow base, 8 feet or less. This is a mid-range cost for terraces as terrace type in study was not specified. Secchi et al. 2005 used 166.67 feet of terrace per acre. ($2.60/0.75) × 166.67 = $577.79/acre.
Contour Buffer Strips	10	332	$579.87/acre	$773.16	10	$95.32	Assumes multiple native, warm season species planted in strips on the contour.
Vegetated Filter Strip	15	393	$450.02/acre	$600.03	10	$73.98	
Wetland Creation (med)	2	656	$25,613.28/acre	$34,151.04	15	$3,071.58	Medium wetland defined as 0.1-0.5 acres.
Wetland Creation (lg)	25	656	$22,967/acre	$30,623.00	15	$2,754.27	Large wetland defined as >0.5 acres.

[a] EQIP reimbursements are estimated incurred costs including materials, labor, maintenance, foregone income, technical assistance, and administration. Reimbursements are granted up to 75% of the full estimated incurred cost. EQIP reimbursement rates were divided by 0.75 to estimate a full cost to the landowner without subsidies to reflect the various conditions specific to each study. Shortle et al. (2013) argue that NRCS cost-share payments can lead to overestimates of private costs in some cases (such as conservation tillage, due to reduced input costs and long term productivity gains), and should be viewed as price ceilings. Adjustments were made where possible (i.e., reduced P application rates) to account for these differences.

[b] Calculated as full BMP cost (per acre) x Capital Recovery Factor (CRF), using a real discount rate of 4%

Table 3.11. Summary statistics of BMP cost-effectiveness ($/lb. total P removed).

	n	Min	Max	Avg	Std. Dev.	Q1	Median	Q3	Med. Abs. Dev.
No-till	18	2.74	32.84	5.36	6.97	2.89	3.23	4.28	0.42
Perennial Vegetation	4	2.62	19.13	7.09	8.03	3.13	3.30	7.25	0.34
Lower Rate of P Application	9	0.32	17.51	7.34	6.47	2.36	4.26	9.77	3.94
Vegetated Filter Strips	22	0.39	220.62	23.10	49.76	2.29	4.32	17.29	2.80
Drainage Water Mgmt.	3	7.32	22.56	12.47	8.74	7.42	7.52	15.04	0.20
Manure (vs. fertilizer) P	6	5.51	43.27	15.05	14.40	6.23	9.94	14.98	4.33
Ridge till	2	10.56	11.52	11.04	0.68	10.80	11.04	11.28	0.48
Manure Amendments	8	14.05	25.85	18.45	4.89	14.61	16.52	21.31	2.29
Hedgerow Planting	4	20.98	44.96	31.30	9.98	27.20	29.63	33.72	4.50
Crop Rotations (inc. cover crops)	5	0.00	178.66	67.36	77.41	7.36	34.66	116.13	34.66
Wetland Creation	24	2.16	3,506.15	490.56	868.33	4.45	34.83	530.76	32.20
Terraces	7	43.60	220.68	112.30	70.79	61.81	83.96	157.13	39.09

Table 3.12. Median BMP cost-effectiveness ($/lb. total P removed), with and without cost-share payments[a]

		Without cost-share		With cost-share	
	n	Median	Median Absolute Deviation	Median	Median Absolute Deviation
No-till	18	3.23	0.42	0.81	0.11
Perennial Vegetation	4	3.30	0.34	0.83	0.09
Lower Rate of P Application	9	4.26	3.94	1.07	0.99
Vegetated Filter Strips	22	4.32	2.80	1.08	0.70
Drainage Water Mgmt.	3	7.52	0.20	1.88	0.05
Manure (vs. fertilizer) P	6	9.94	4.33	2.49	1.08
Ridge till	2	11.04	0.48	2.76	0.12
Manure Amendments	8	16.52	2.29	4.13	0.57
Hedgerow Planting	4	29.63	4.50	7.41	1.13
Crop Rotations (inc. cover crops)	5	34.66	34.66	8.67	8.67
Wetland Creation	24	34.83	32.20	8.71	8.05
Terraces	7	83.96	39.09	20.99	9.77

[a] Assumes 75% cost-share of estimated incurred full farm-level costs, based on maximum EQIP General Schedule payments and cost-effectiveness estimates from Table 3.11.

Table 3.13. Rank ordering of BMP physical effectiveness and BMP cost-effectiveness. BMPs are ordered from most effective to leave effective.

BMP Rank (based on median)	Physical Effectiveness[a]	Cost Effectiveness[b]
1	No-till	Lower rate of P Application
2	Terraces	Perennial Vegetation
3	Vegetated Filter Strips	No-till
4	Drainage Water Management	Vegetated Filter Strips
5	Wetland Creation	Manure Amendments
6	Manure Amendments	Drainage Water Management
7	Perennial Vegetation	Hedgerow Planting
8	Ridge Till	Wetland Creation
9	Hedgerow Planting	Crop Rotations
10	Lower Rate of P Application	Ridge Till
11	Manure (vs. fertilizer) P	Manure (vs. fertilizer) P
12	Crop Rotations	Terraces

[a] Physical effectiveness based on % of total P removed

[b] Cost effectiveness based on $/lb. of P removed

Figures

Figure 3.1. A screenshot of one entry in the Ag BMP Effectiveness Database. Adapted from Merriman et al. (2009).

Figure 3.2. A screenshot of one bibliographic entry in the Midwest Ag BMP Effectiveness Database. Adapted from Merriman et al. (2009).

Figure 3.3. A screenshot displays 14 entries in the Microsoft Access Midwest BMP Effectiveness Database. Adapted from Merriman et al. (2009).

Figure 3.4. BMP percentage effectiveness in particulate phosphorus removal.

Figure 3.5. BMP percentage effectiveness in dissolved phosphorus removal.

Figure 3.6. BMP percentage effectiveness in Total Phosphorus Removal.

Figure 3.7. BMP percentage effectiveness in Sediment Removal.

Figure 3.8. The five regions in the cost-effectiveness plane for decision making, modified from Obenchain (1999).

Figure 3.9. Cost-effectiveness ratios of small scale BMP implementations.

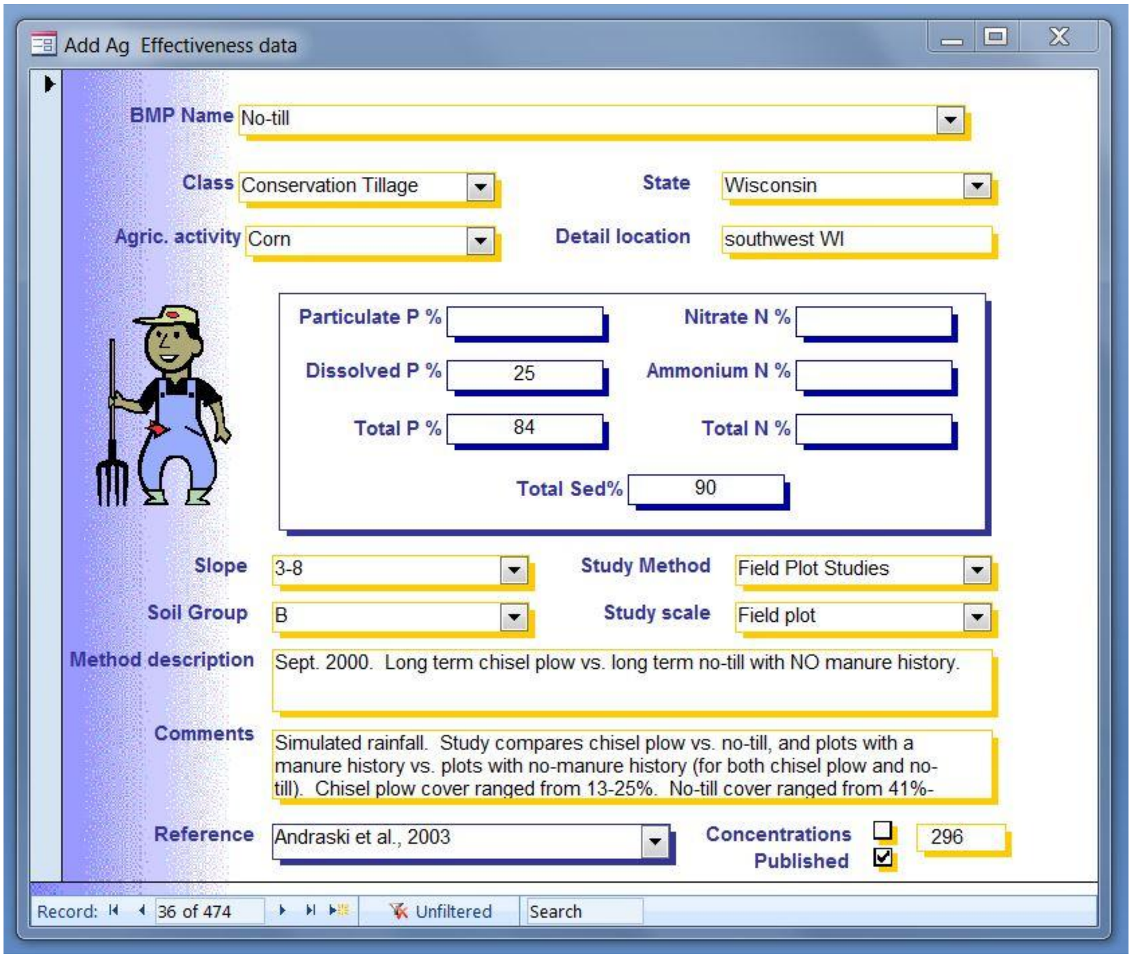
Figure 3.10. Cost-effectiveness ratios of medium-small scale BMP implementations.

Figure 3.11. Cost-effectiveness ratios of medium scale BMP implementations.

Figure 3.12. Cost-effectiveness ratios of large scale BMP implementations.

Figure 3.13. Relative percentage of the five cost-effectiveness regions to reduce phosphorus, by BMP type.

Figure 3.14. Cost-effectiveness of best management practices to reduce phosphorus pollution.



BMP Name: No-till

Class: Conservation Tillage

State: Wisconsin

Agric. activity: Corn

Detail location: southwest WI

Particulate P %:

Nitrate N %:

Dissolved P %: 25

Ammonium N %:

Total P %: 84

Total N %:

Total Sed%: 90

Slope: 3-8

Study Method: Field Plot Studies

Soil Group: B

Study scale: Field plot

Method description: Sept. 2000. Long term chisel plow vs. long term no-till with NO manure history.

Comments: Simulated rainfall. Study compares chisel plow vs. no-till, and plots with a manure history vs. plots with no-manure history (for both chisel plow and no-till). Chisel plow cover ranged from 13-25%. No-till cover ranged from 41%-

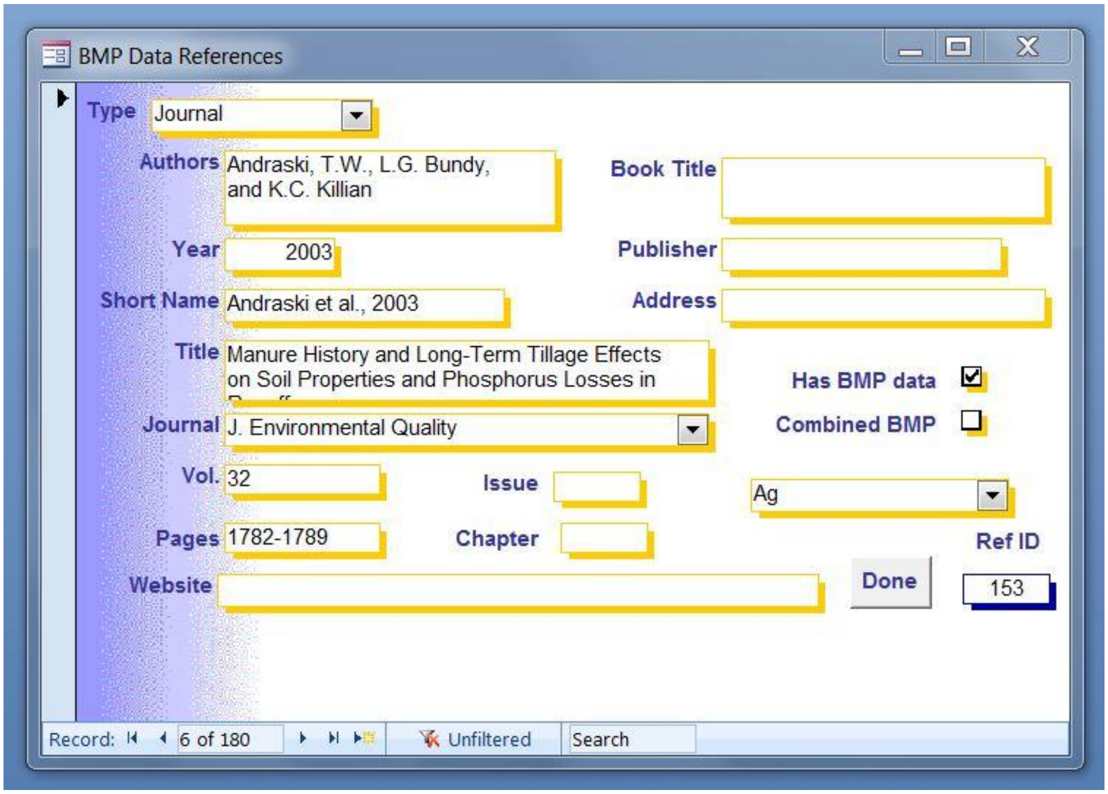
Reference: Andraski et al., 2003

Concentrations ☐

Published ☑

296

Figure 3.1. A screenshot of one entry in the Ag BMP Effectiveness Database. The database was originally created as the BMP Effectiveness Tool for Arkansas and is described in Merriman et al. (2009). It was modified and adapted (with permission) for this portion of the research.



Type: Journal

Authors: Andraski, T.W., L.G. Bundy, and K.C. Killian

Book Title:

Year: 2003

Publisher:

Short Name: Andraski et al., 2003

Address:

Title: Manure History and Long-Term Tillage Effects on Soil Properties and Phosphorus Losses in

Has BMP data ☑

Journal: J. Environmental Quality

Combined BMP ☐

Vol.: 32

Issue:

Ag

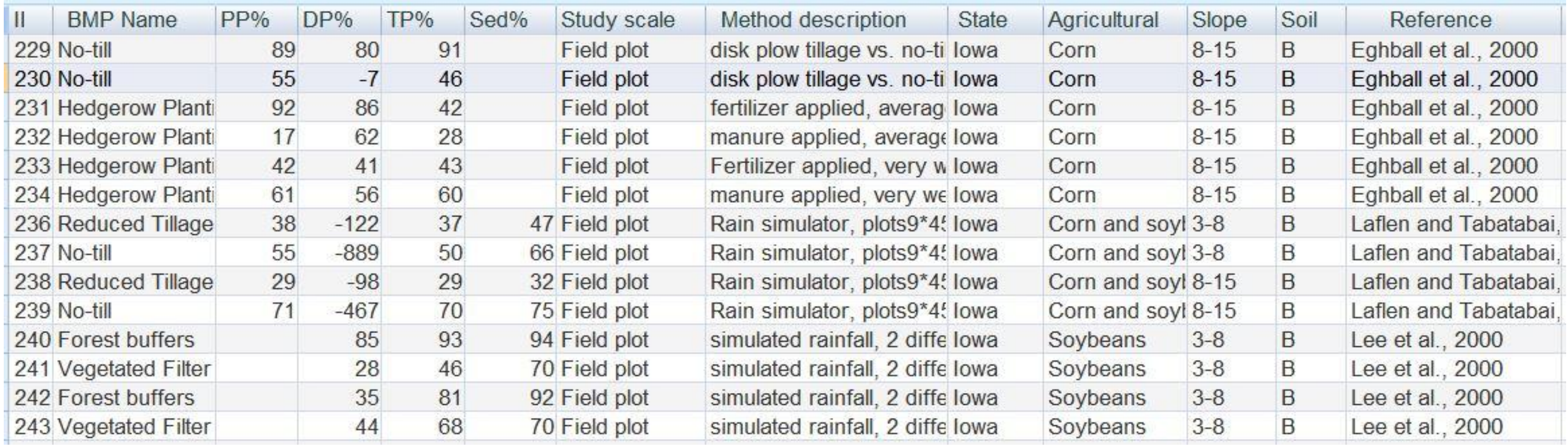
Pages: 1782-1789

Chapter:

Ref ID: 153

Website:

Figure 3.2. A screenshot of one bibliographic entry in the Midwest Ag BMP Effectiveness Database. The database was originally created as the BMP Effectiveness Tool for Arkansas and is described in Merriman et al. (2009). It was modified and adapted (with permission) for this portion of the research.



II	BMP Name	PP%	DP%	TP%	Sed%	Study scale	Method description	State	Agricultural	Slope	Soil	Reference
229	No-till	89	80	91		Field plot	disk plow tillage vs. no-ti	Iowa	Corn	8-15	B	Eghball et al., 2000
230	No-till	55	-7	46		Field plot	disk plow tillage vs. no-ti	Iowa	Corn	8-15	B	Eghball et al., 2000
231	Hedgerow Planti	92	86	42		Field plot	fertilizer applied, averag	Iowa	Corn	8-15	B	Eghball et al., 2000
232	Hedgerow Planti	17	62	28		Field plot	manure applied, average	Iowa	Corn	8-15	B	Eghball et al., 2000
233	Hedgerow Planti	42	41	43		Field plot	Fertilizer applied, very w	Iowa	Corn	8-15	B	Eghball et al., 2000
234	Hedgerow Planti	61	56	60		Field plot	manure applied, very we	Iowa	Corn	8-15	B	Eghball et al., 2000
236	Reduced Tillage	38	-122	37	47	Field plot	Rain simulator, plots9*4	Iowa	Corn and soy	3-8	B	Laflen and Tabatabai,
237	No-till	55	-889	50	66	Field plot	Rain simulator, plots9*4	Iowa	Corn and soy	3-8	B	Laflen and Tabatabai,
238	Reduced Tillage	29	-98	29	32	Field plot	Rain simulator, plots9*4	Iowa	Corn and soy	8-15	B	Laflen and Tabatabai,
239	No-till	71	-467	70	75	Field plot	Rain simulator, plots9*4	Iowa	Corn and soy	8-15	B	Laflen and Tabatabai,
240	Forest buffers		85	93	94	Field plot	simulated rainfall, 2 diffe	Iowa	Soybeans	3-8	B	Lee et al., 2000
241	Vegetated Filter		28	46	70	Field plot	simulated rainfall, 2 diffe	Iowa	Soybeans	3-8	B	Lee et al., 2000
242	Forest buffers		35	81	92	Field plot	simulated rainfall, 2 diffe	Iowa	Soybeans	3-8	B	Lee et al., 2000
243	Vegetated Filter		44	68	70	Field plot	simulated rainfall, 2 diffe	Iowa	Soybeans	3-8	B	Lee et al., 2000

Figure 3.3. A screenshot displaying 14 entries in the Microsoft Access Midwest BMP Effectiveness Database. Some columns (study notes, study method, BMP category, published or unpublished) were hidden to enable display of the figure.

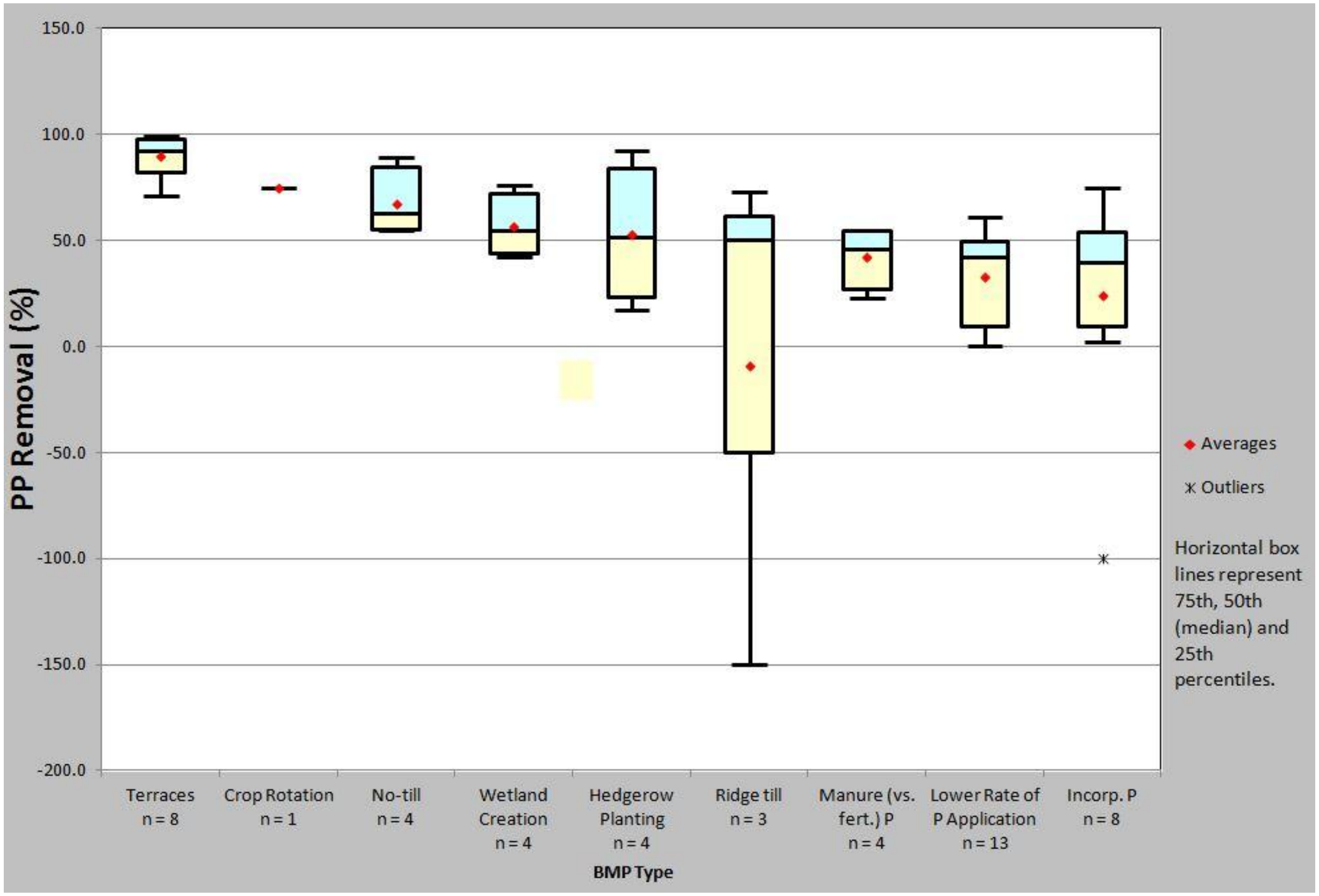


Figure 3.4. BMP percentage effectiveness in particulate phosphorus removal.

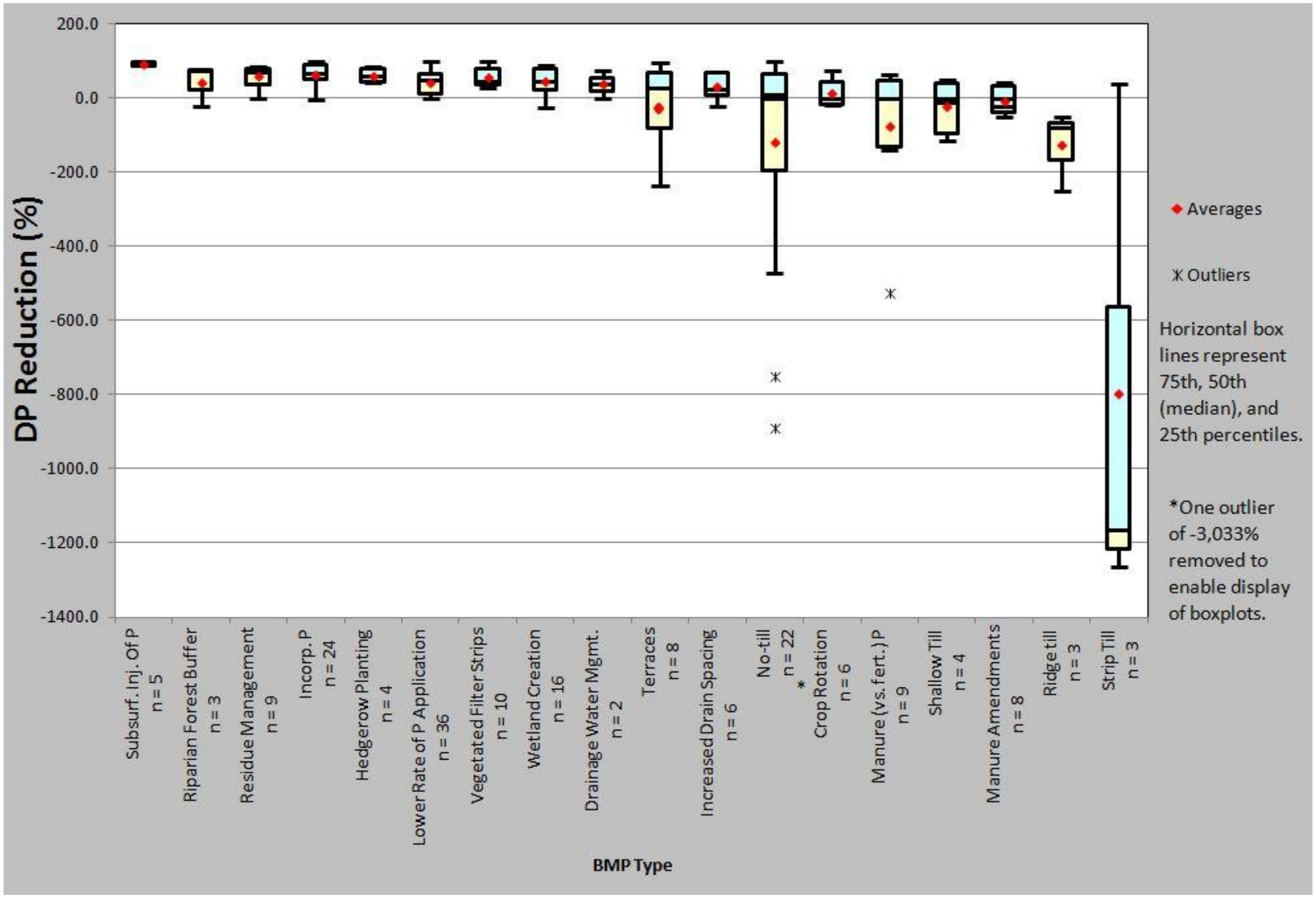


Figure 3.5. BMP percentage effectiveness in dissolved phosphorus removal.

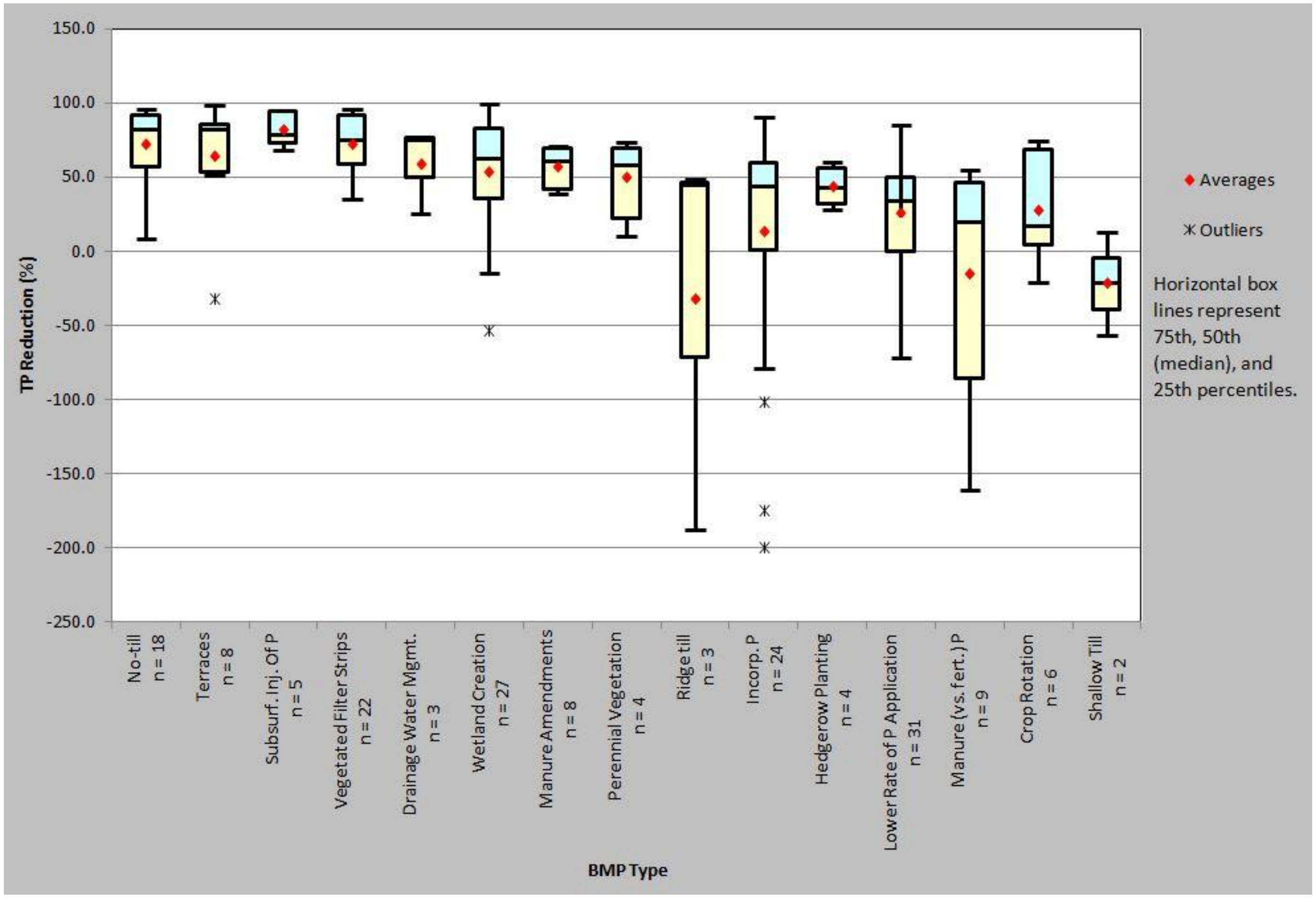


Figure 3.6. BMP percentage effectiveness in total phosphorus removal.

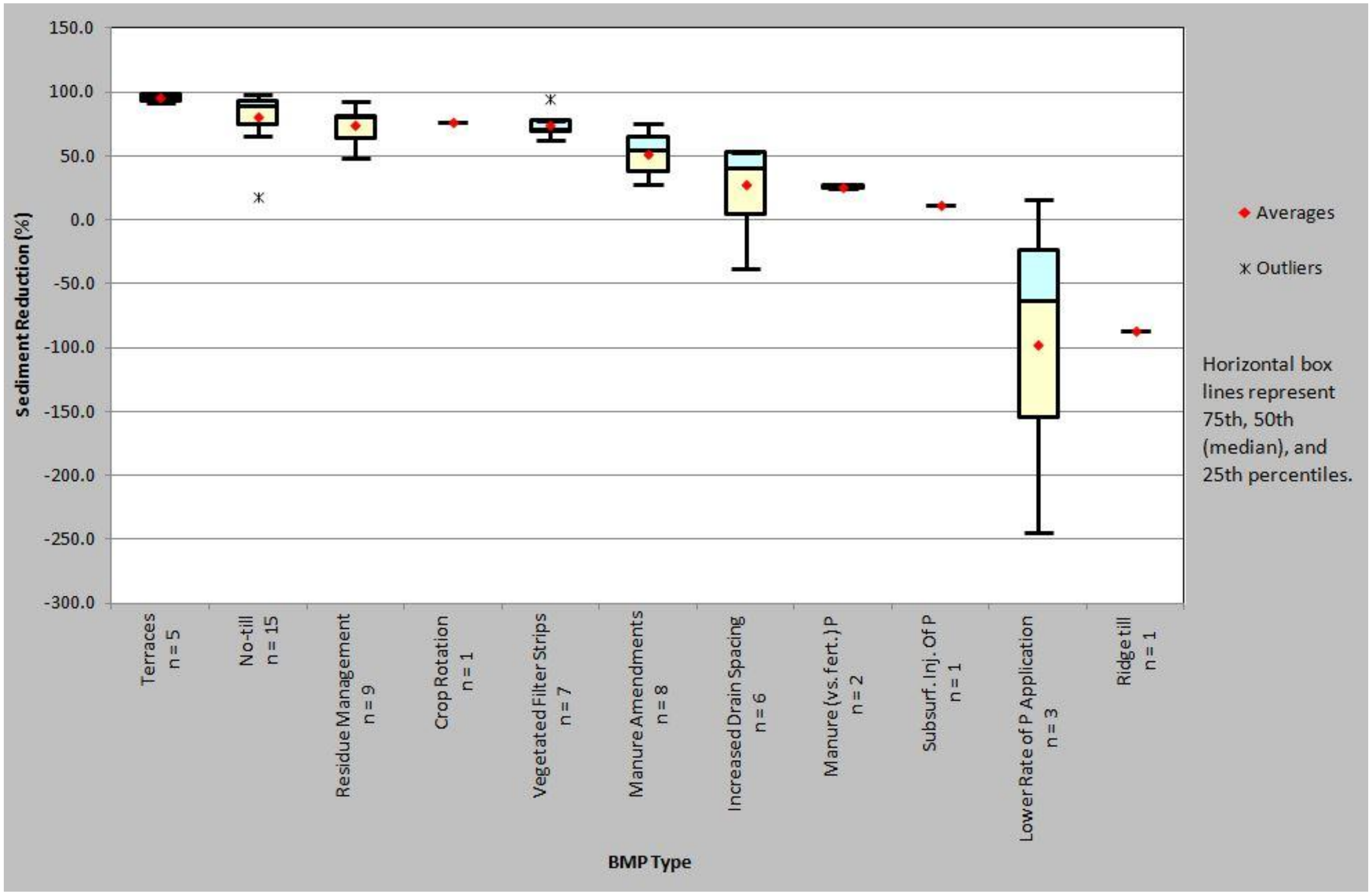


Figure 3.7. BMP percentage effectiveness in sediment removal.

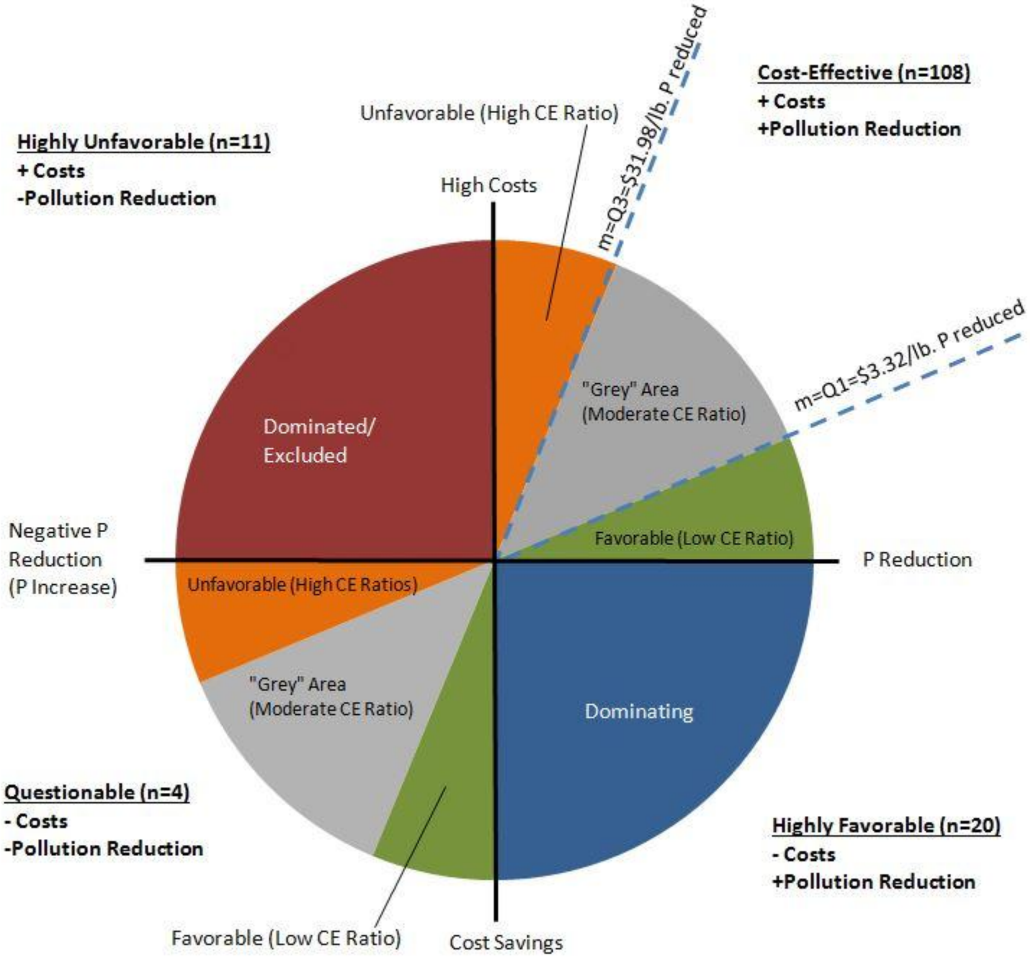


Figure 3.8. The five regions in the cost-effectiveness plane for decision making, modified from Obenchain (1999). Cost-effectiveness (CE) Ratios were measured as $/lb. P removed.

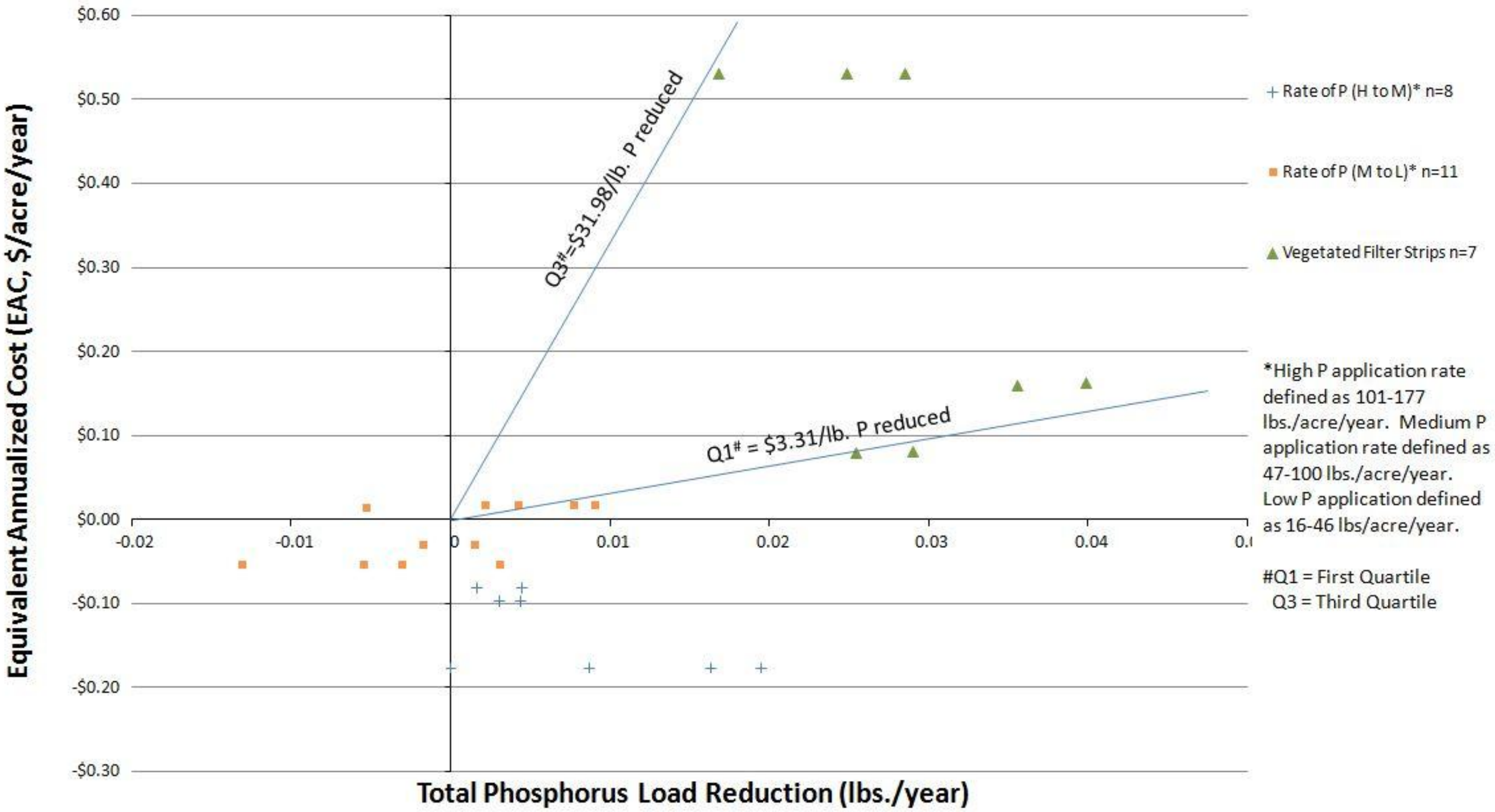
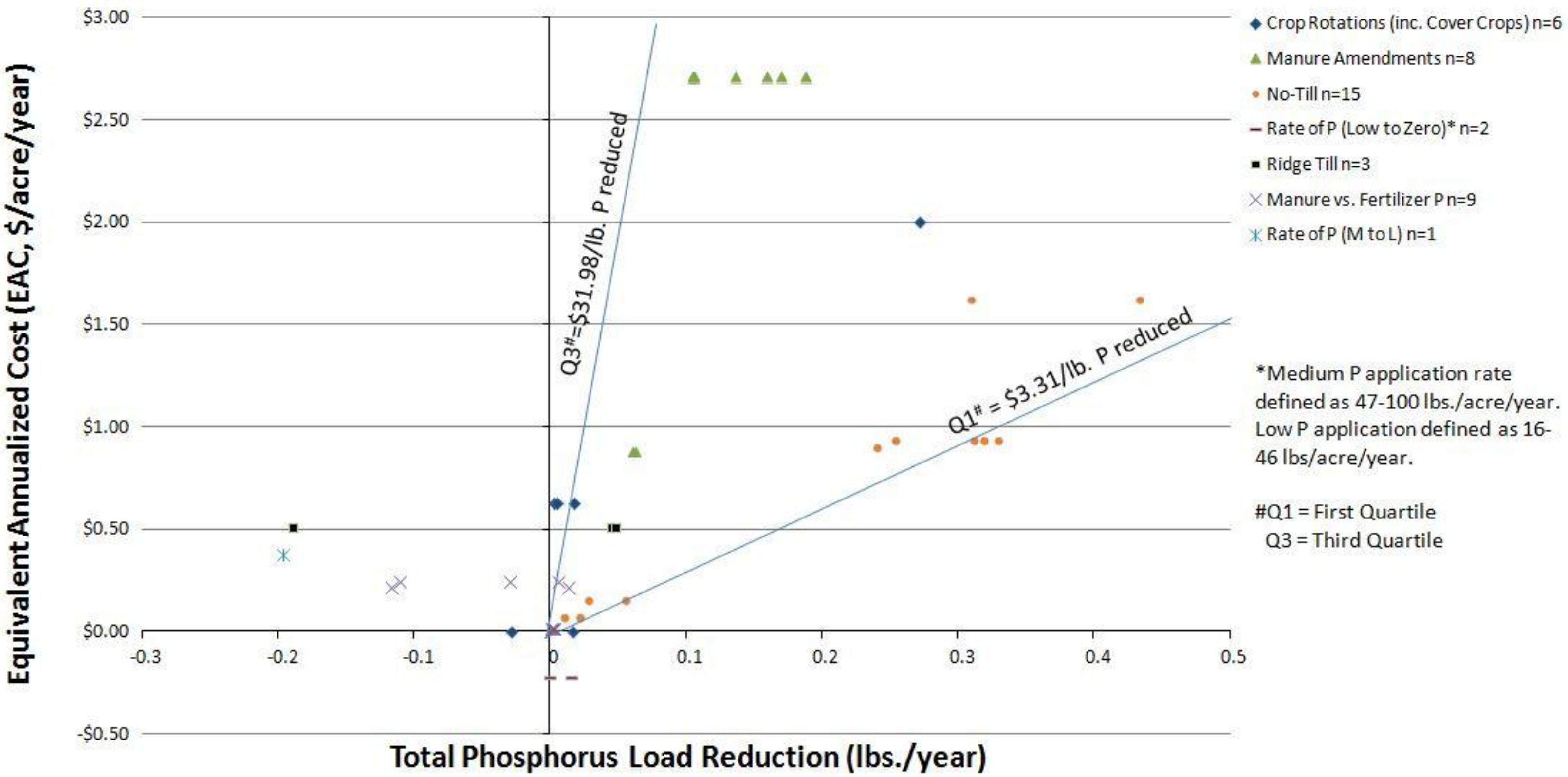


Figure 3.9. Cost-effectiveness ratios ($/lb. P removed) of small scale BMP implementations. BMPs were divided into four scale sizes in Figures 3.9-3.12. Scale sizes were set based on cutoffs that allowed improved readability of the specific data points in each graph.



*Medium P application rate defined as 47-100 lbs./acre/year. Low P application defined as 16-46 lbs/acre/year.

#Q1 = First Quartile
Q3 = Third Quartile

Figure 3.10. Cost-effectiveness ratios ($/lb. P removed) of medium-small scale BMP implementations. BMPs were divided into four scale sizes in Figures 3.9-3.12. Scale sizes were set based on cutoffs that allowed improved readability of the specific data points in each graph.

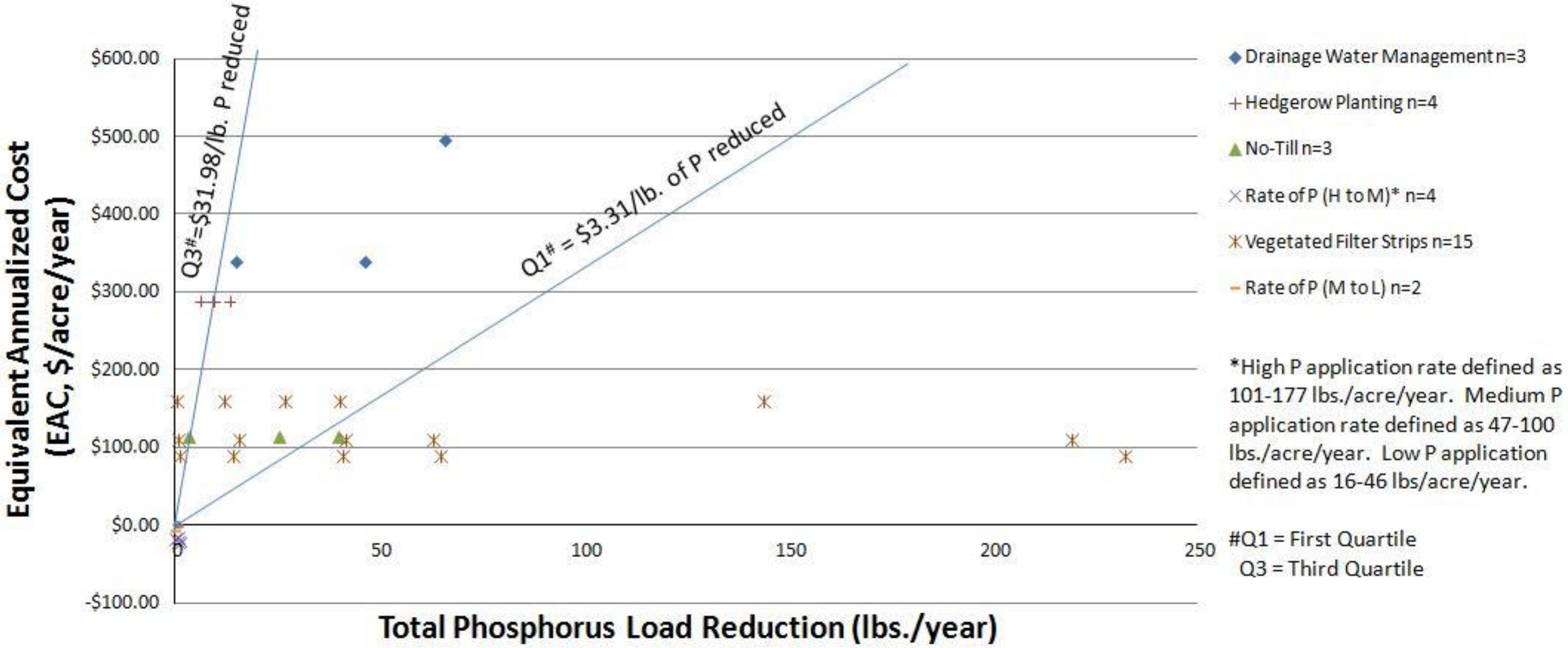


Figure 3.11. Cost-effectiveness ratios ($/lb. P removed) of medium scale BMP implementations. BMPs were divided into four scale sizes in Figures 3.9-3.12. Scale sizes were set based on cutoffs that allowed improved readability of the specific data points in each graph.

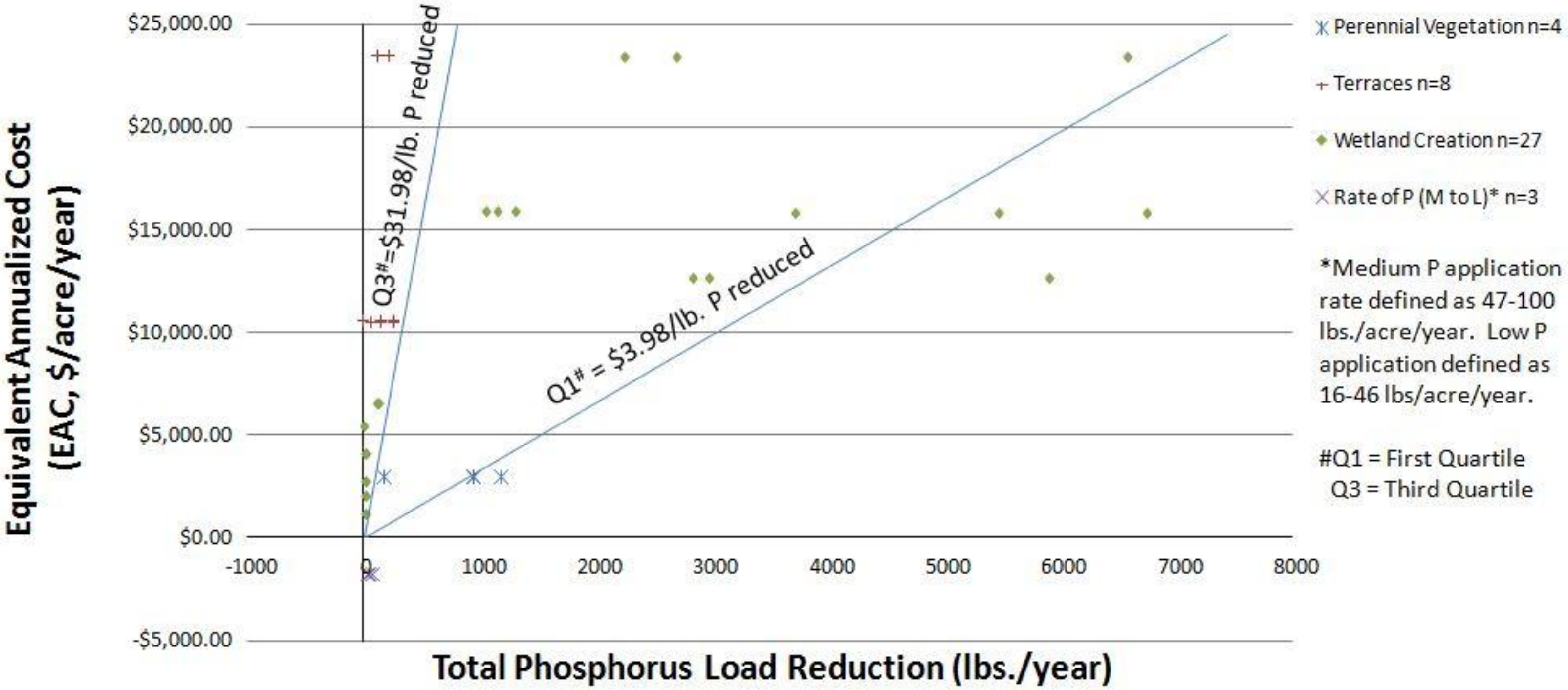
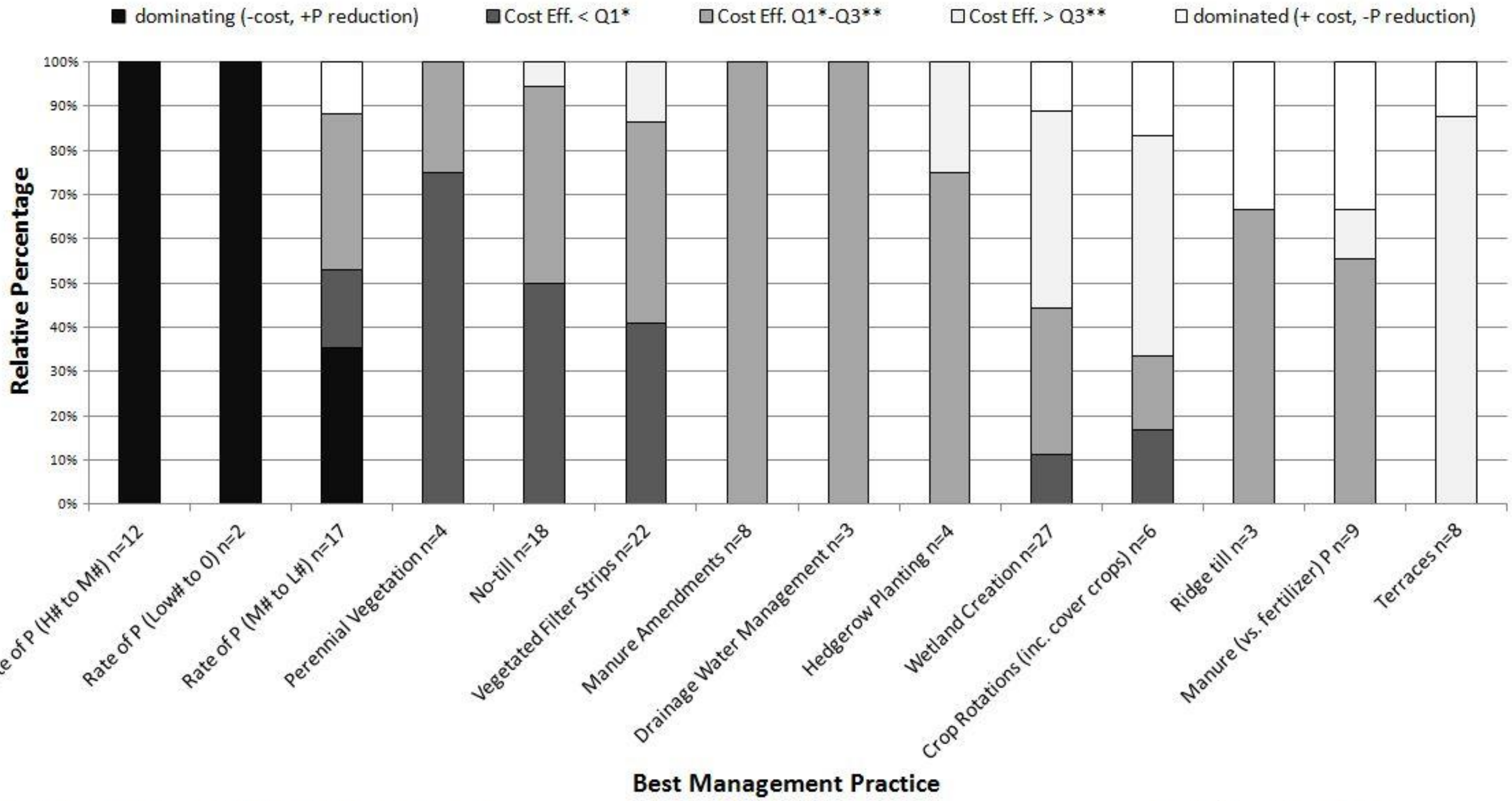


Figure 3.12. Cost-effectiveness ratios ($/lb. P removed) of large scale BMP implementations. BMPs were divided into four scale sizes in Figures 3.9-3.12. Scale sizes were set based on cutoffs that allowed improved readability of the specific data points in each graph.



High P application rate defined as 100+ lbs./acre/year.
Medium defined as 50-99 lbs./acre/year.
Low defined as 1-49 lbs/acre/year.

* Q1 = $3.32/lb. P reduced
** Q3 = $31.98/lb. P reduced

Figure 3.13. Relative percentage of the five cost-effectiveness regions to reduce phosphorus, by BMP type.

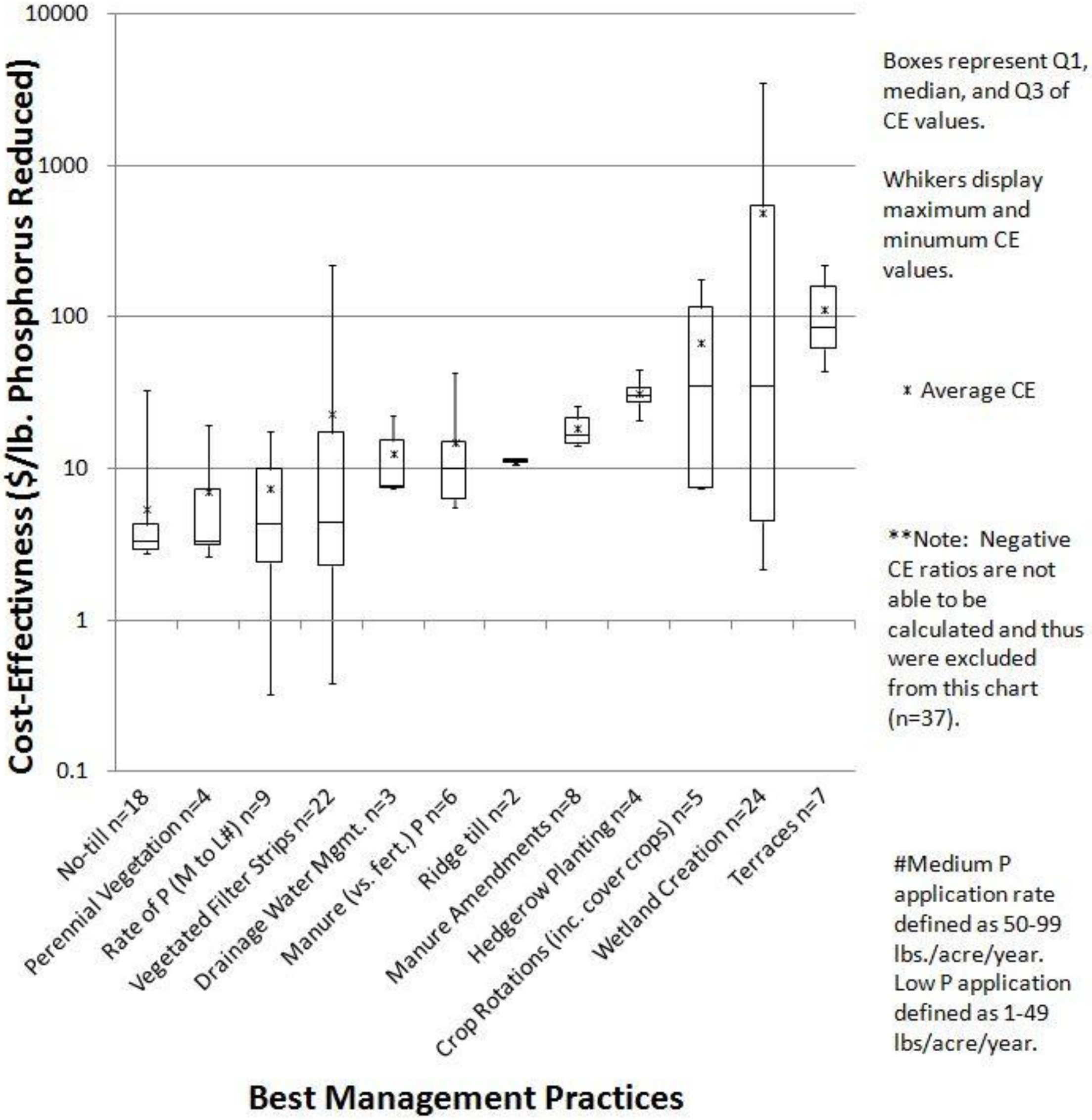


Figure 3.14. Cost-effectiveness (CE) of best management practices to reduce total phosphorus pollution.

Chapter 4:

A Model to Explore Three Scenarios of Working Lands Conservation

A Techno-Economic and Environmental Analysis of Mobile, Cooperative, and Distributed Farm-Scale Systems for Microwave Assisted Pyrolysis

Overview

Landowners providing ecosystem services through BMPs on working agricultural lands should benefit from their decision to provide a public good. A mechanism for this is through the installation of technologies that create market outlets for the products produced from BMPs. One potential example of this is microwave assisted pyrolysis (MAP) units to produce cellulosic biofuels in southern Minnesota from perennial feedstock BMPs such as buffer strips. Because MAP units can be small, they have the potential to be mobile, with interesting financial implications. A techno-economic analysis of mobile MAP units was conducted to determine if mobility of MAP units might make them financially viable. The mobile MAP units were compared to two other non-mobile MAP biofuel systems to allow a comparison of system advantages and disadvantages. Sensitivity analyses were conducted to estimate returns on investment in various scenarios, including scaling up the number of units in operation, changes in feedstock prices, and the consideration of environmental benefits. Results showed that the expected economies of scale gained by the mobility of small-scale pyrolysis units are not sufficient to overcome the increased labor costs, but that stationary small-scale distributed pyrolysis units show some economic promise, particularly if environmental benefits are considered. Decision makers should consider public funding of MAP units as one option to increase the provision of environmental services on working agricultural lands.

Introduction

Conservation managers continue to look for ways to make the provision of environmental services more cost-effective, as described in the previous two chapters. However, a more sustainable and thus longer-term model for environmental conservation would be to pay landowners who provide ecosystem services through best management practices (BMPs) on working lands. This would allow for a more direct accounting of the costs and benefits because it would create a mechanism for privatizing some of the benefits provided by BMPs to the landowners who choose to implement BMPs. Currently the environmental benefits from agricultural BMPs are largely externalized to society and thus relatively unaccounted for by landowners considering BMP implementation. A more efficient system might internalize benefits to the landowner for more comprehensive decision making. Although payments from agricultural BMPs for environmental services, like water quality, have proven difficult to initiate, one potential area undergoing research is to find and develop markets for biofuels from perennial grasses to pay landowners for the products produced via BMP implementation. If biofuel markets for perennial grasses can be developed, then BMPs like buffer strips and conversion to perennials provide not only water quality and other environmental benefits, but income from biofuels produced from the biomass, thus offsetting real or perceived losses in productivity or output.

Biofuel markets based on commodity crop feedstocks (corn and soybeans) are well established. However, research has demonstrated the significant externalities of producing renewable fuels from these commodity crops. These include food security concerns, soil loss due to annual crop production, carbon emissions from various land-use changes and machinery operation, human health impacts, and water and air pollution (Fargione et al. 2008; Hahn and Cecot 2009; Hill et al. 2009; Pimentel 2003; Runge and Senauer 2007). These problems have led to a need to move away from corn and soybean-based transportation fuels. One effort in this direction is to increase the production of advanced, cellulosic biofuels. In 2014, 32 million gallons of cellulosic ethanol were produced in the United States (Yu 2015). This production level technically exceeded the 2014 Renewable Fuel Standard mandated gallons of 17 million gallons. However, annual cellulosic biofuel production goals for 2014 originally had been set at 1.75 billion gallons, but were revised downward to meet more realistic production prospects (USEPA 2013; Yu 2015). Current production remains well short of the 16 billion gallon goal by 2022 (USDA 2010).

Microwave Assisted Pyrolysis Technology

One of the many methods being developed to process cellulosic biofuels is called microwave assisted pyrolysis (MAP). Funded by the United States Departments of Agriculture and Energy, primary research is being conducted at the University of Minnesota by Dr. Roger Ruan and Dr. Paul Chen (UMN 2009). Pyrolysis itself is not a new technology. Similar to gasification, pyrolysis is the thermal decomposition of biomass in the absence (or very low concentrations) of oxygen. However, pyrolysis occurs at temperatures between 500°C and 800°C, while gasification occurs at temperatures over 800°C (Nan et al. 1994). Because pyrolysis is a precursor to gasification, pyrolysis is sometimes referred to as partial gasification. The temperature differentials of these two processes lead to different ratios of liquid and gas production. Because pyrolysis occurs at lower temperatures, its primary product is a liquid, whereas the primary product from gasification is a gas (Bridgwater et al. 1999).

Pyrolysis produces three products: bio-oil, char, and syngas. The syngas is a mixture of mostly carbon monoxide and hydrogen, but also some methane and carbon dioxide (Bridgwater et al. 1999; Zafar 2009). The production ratio of the three pyrolysis products depends on the temperature, pressure, and heating rate of the thermo-chemical reaction, as well as the particle size and moisture content of the feedstock (Bridgwater et al. 1999). In nearly all pyrolysis processes, the syngas is burned to produce the heat needed for pyrolysis. The bio-char, or ash, is a co-product that could potentially be used as a soil amendment (Gaskin et al. 2008). Currently bio-oil can be used to produce electricity, burned directly for heat (similar to #2 heating oil, but about 50% of the heating value), or upgraded to produce a variety of products including biopolyester, bioadhesives, and biopolyurethane (Bridgwater et al. 1999; Ruan and Heyerdahl 2008). The hope is that this bio-oil could be upgraded to produce a transport fuel similar to biodiesel, which will be able to displace conventional petroleum diesel (Zhang et al. 2013; Ruan and Heyerdahl 2008).

The method of pyrolysis used in the MAP technology is called fast pyrolysis, in which feedstocks are heated quickly to carefully controlled temperatures and then products are cooled quickly to maximize condensation and the production of bio-oils, while minimizing char and syngas production (Bridgwater et al. 1999; Ruan et al. 2008). Fast pyrolysis is currently of interest to researchers for many reasons. This process produces a relatively high ratio of bio-oil (around 60%), and the bio-oil produced is a stable liquid which stores easily (Bridgwater et al. 1999). The bio-oil also has a high energy density (about 30 GJ/M^3 for bio-oil, compared to 9 GJ/M^3 for charcoal or 2 GJ/M^3 for straw) that reduces transport and handling costs (Nan et al. 1994).

The unique aspect of microwave assisted pyrolysis (MAP), compared to other fast pyrolysis processes, is that microwaves are used to breakdown the biomass feedstocks. This comes with many advantages over other fast pyrolysis methods in that microwaves are a well understood and relatively cheap technology. They can heat the biomass evenly, and are easy to control (Sobhy and Chaouki 2010). The ability to control temperature is critical in pyrolysis, as higher concentrations of bio-oil are produced if the temperature can be held steady. The use of microwaves also reduces the need for feedstock particle size to be small or uniform, which should reduce feedstock processing costs (Ruan 2011). According to early tests, the microwaves can handle biomass sizes ranging from sawdust to a pile of wood logs (Ruan 2011; Sobhy and Chaouki 2010). MAP can handle mixed feedstocks, including municipal solid bio-wastes, mixed prairie species, switchgrass, corn stover, and woody biomass. Although research is ongoing, there is optimism that MAP will produce syngas that is both cleaner burning and has a higher heating value compared to syngas produced by either gasification or conventional fast pyrolysis technologies (Ruan and Heyerdahl 2008; UMN 2009).

Economies of Scale vs. Diseconomies of Scale

A number of significant hurdles remain for advanced cellulosic biofuels to become commercially viable. Two of these hurdles include: 1) developing cost-effective technologies; and 2) high transport costs due to low feedstock densities. When addressed together, these hurdles present a problem that can be thought of on a spectrum of technological scales (Runge 2010). On one end, cellulosic biofuel production at a small scale does not face prohibitively high feedstock transportation costs since transport distances are minimal. But, small scale cellulosic biofuel production makes it more difficult to develop cost-effective technologies, since it will likely face higher capital costs when measured on a per unit output basis. In other words, small scale cellulosic biofuel production cannot take advantage of economies of scale. On the other end of the spectrum, large scale biofuel production can realize the benefits of economies of scale, but it suffers from high transportation costs necessary to supply a large volume of low density feedstocks. In this context, the question of the scalability of a technology becomes essential to attract investors.

Mobile MAP units present a unique opportunity. An individual MAP unit may be small, but its economically viable feedstock radius is theoretically larger with its mobility, while retaining the potential to take advantage of economies of scale by producing many units. MAP technology is unique in that each MAP unit is compact enough to be mobile with a pickup truck, with interesting implications for feedstock transport. The financial and economic implications of mobile cellulosic biomass processing units for landowners and potential private investors have not been studied in depth in the published literature. The techno-economic portion of the research compares: 1) mobile biofuel units; 2) a cooperative model for biofuels; and 3) stationary farm-scale distributed biofuel units. The goal is to identify a "middle ground" for MAP in various scenarios, where the problems found on each end of the spectrum are minimized. Specifically, this research seeks to answer the following questions:

1) Can a MAP scenario be identified where productive conservation BMPs (such as buffer strips or perennial grasses providing both biofuel feedstocks and conservation benefits) are financially viable for both landowners and private investors? In this context, how do three different scenarios of MAP (mobile, cooperative, and distributed systems) compare to each other?

2) Are these conservation options a good taxpayer investment if environmental benefits are included in the decision making process?

Methods

A techno-economic analysis of MAP units was conducted under three different hypothetical scenarios located in southern Minnesota in Watonwan County: 1) a mobile MAP unit; 2) a stationary MAP unit based on a cooperative model; and 3) a stationary farm-scale distributed MAP units (Figure 4.1).

General Assumptions and Data

A model was developed in Microsoft Excel to analyze the financial and economic costs and benefits of these three scenarios. Table 4.1 lists key baseline assumptions that apply to all three scenarios. All costs in this research have been converted to 2010 dollars using the US Bureau of Labor Statistics Consumer Price Index (CPI) calculator (USBLS 2015). Unless noted otherwise, all values assume one machine in operation with an hourly operating capacity of 0.5 dry tons of feedstock, which is the hourly capacity of a unit built and tested in China (Ruan 2011). Each machine is assumed to be in operation for 10 hours/day and 300 days/year. Any time required for maintenance is assumed to occur outside of these hours in operation. Given these assumptions, each pyrolysis unit can process a maximum of 1,500 tons/year. Assuming that 4% of the landscape is in feedstock production, all necessary feedstocks for one machine can be harvested from an area of 17.23 square miles (a radius of 2.34 miles or 11,029 acres). As an approximation, the model assumes that feedstocks are evenly distributed across the landscape. In reality, feedstocks are more concentrated in certain areas. If the bio-oil refining facility is strategically located near more concentrated areas of feedstock production, then transportation costs could be reduced from the numbers presented in this research.

Other costs considered to operate the pyrolysis units are capital costs, feedstock grinding, syngas to operate the machine, and maintenance costs (Table 4.1). One of the benefits of these pyrolysis units is that minimal feedstock grinding is necessary. However, in anticipation that some grinding may be necessary or make the processing more time and energy efficient, a $10.04/dry ton grinding cost was assumed (Kumar and Sokhansanj 2007). Current best estimates are that the pyrolysis units will consume most or all of the syngas produced (approximately 4.5 mmBTU/dry ton of feedstock). Because of this, syngas is not included in Table 4.1 as a cost or revenue, although this variable is considered in the sensitivity analysis. Maintenance costs of $1.00/operating hour were estimated from information provided by Industrial Microwave Systems, L.L.C. in Morrisville, North Carolina. They make microwaves for industrial applications similar to the microwave-assisted pyrolysis units.

The primary source of revenue for the pyrolysis units is a bio-oil that can be modified for a number of potential uses. Approximately 100 gallons of bio-oil can be produced per ton of dry feedstock. With a small amount of modification, the bio-oil can be used as a heating fuel similar in composition to #2 heating oil, but with about 40% of the heating value. Alternatively, high value chemicals within the bio-oil can be extracted to make a wide range of bio-based products. The bio-oil could potentially be modified into a liquid transport fuel, although this option has both technical and economic hurdles to overcome. For purposes of calculating the value of the bio-oil, it was assumed that the bio-oil would be used as a heating fuel, since only minor upgrades are needed and #2 heating oil prices are available. As of March 14, 2011, #2 heating oil was selling for $3.15/gallon ($3.05 in 2010 dollars). Assuming bio-oil is valued at 40% of #2 heating oil (because the bio-oil has approximately 40% of the heating content of #2 heating oil), the value of bio-oil was estimated at $1.22/gallon. Another potential source of revenue is to sell the char that is produced in the pyrolysis process. Approximately 0.2 tons of char are produced per dry ton of feedstock. Although char values are widely debated, $50/ton of char was used as a baseline estimate. Assuming that 1,500 dry tons of feedstock are processed annually, and the above conversion ratios and prices for bio-oil and char, it is estimated that total annual revenues from one pyrolysis unit will be around $198,000. Of this total, $183,000 is revenue from the bio-oil, and $15,000 is revenue from char.

Mobile System

The mobile MAP unit, constructed in China for a cost of about $250,000, is approximately 5 x 2.5 x 3.5 meters and can be moved by attaching to the back of a pick-up truck (Figure 4.2). Additionally, it will cost about $50,000 for a bin pneumatic auger as a self-feeding mechanism for the biomass, for a total estimated capital cost of $300,000. To estimate the costs of the mobile unit, it is assumed that the pyrolysis unit will be moved to six different roadside locations in south central Minnesota over the course of one year, processing 1/6 of the 1,500 annual tons (250 tons) at each location. One full time worker will be hired to load and unload the MAP unit from the truck, drive the truck, load feedstocks, operate the MAP unit, and ensure public safety and the security of the MAP unit since this unit will operate at the side of public roadways. This requires a skilled full time worker, at an estimated wage of $25/hour, and adds a significant figure of $75,000/year to the operating costs that will be reduced when the units are placed on private properties (as in the co-op and distributed models, discussed below). Non-labor costs are quite minimal for the mobile unit, at just $594/year. This estimate assumes non-labor truck operating costs of $0.66/mile and a diesel cost of $3.50/gallon (Torrell et al. 2008).

Annual costs for a mobile microwave assisted pyrolysis unit, a bin pneumatic auger, a truck to transport the MAP unit, labor to drive the truck and operate the MAP unit, feedstock production, road siding, and storage, unit maintenance and feedstock grinding are estimated at $274,290/year. Revenues from the bio-oil and char are projected to be $198,000/year, for a net annual operating loss of $76,290. This estimate does not include environmental benefits, discussed later in this research. The four most significant costs of the mobile unit are the feedstock related costs ($131,812/year), labor ($75,000/year), capital costs ($48,824/year), and grinding costs ($15,060/year). Feedstock costs, although estimated conservatively here, are not projected to change significantly in the short term. Capital costs can be lowered as this system is scaled up to produce more than one unit. Grinding costs are assumed constant per unit of biomass processed, so will not decrease on a per unit basis even if the system is scaled up.

Cooperative System

The cooperative system for the MAP units assumes biomass transportation similar to modern grain ethanol facilities (Figure 4.1A). Feedstocks are collected from the landscape, loaded onto a truck and transported to a central, stationary processing facility. The central facility converts the feedstocks into bio-oils, and refines the bio-oil into a usable heating oil (or other value-added product). The cooperative system is included in the analysis to serve as a contrast to the distributed biomass system, to better understand system advantages and disadvantages. Feedstock costs, roadsiding costs, storage losses, storage costs, grinding costs, maintenance costs, bio-oil and ash conversion ratios and prices, and capital costs are all assumed to be the same for the three systems, and are discussed above. Labor costs for the cooperative and distributed systems are the same, but different from the labor costs of the mobile unit described above. Transportation costs are different for each system.

Labor costs for both the cooperative and distributed systems were estimated using the same assumptions and data. The cooperative and distributed systems differ from the mobile unit in that they do not need a full time worker to ensure the security of the MAP units and public safety. The requisite level of skill and responsibility is also lower, commanding lower hourly pay. It is difficult to estimate the time that a worker must be present at the stationary MAP units for them to operate, but a conservative (i.e.

high) estimate is that a person is required for 50% of the operation hours (Ruan et al. 2008). Likely this number will be closer to 20%, for the time required to start up the machine, and load feedstocks into the bin pneumatic auger. An hourly wage of $11.70 was estimated, based on the 2010 Iowa Farm Custom Rate Survey (Edwards et al. 2010). Given these assumptions, the cost of labor to load and operate the MAP unit is estimated at $17,550/year. If a person is required for only 20% of operation hours, labor costs drop to $7,020/year.

Transportation of the biomass to a central processing facility was estimated assuming $0.24/ton-mile cost for the fixed and variable trucking costs, including trucking labor (Morrow et al. 2006) (Table 4.1). The average distance required to transport the feedstocks was calculated by multiplying 2.3 miles * 2/3 * 1.4. The maximum feedstock radius for 1,500 tons of biomass is 2.3 miles[3]. If a concentric circle is drawn inside the maximum feedstock circle, with a radius of 2/3 the larger circle, the inner circle represents the line where half of the feedstocks are growing inside the inner circle and half are outside. Consequently, 2/3* radius gives an average direct transport distance within a circle. Finally, a winding factor of 1.4 was used to simulate driving routes (Kumar and Sokhansanj 2007). The assumption was made that bio-oil transport costs would be negligible for the cooperative system since all bio-oil

---

[3] The feedstock radius of 2.3 miles is significantly lower than current ethanol facilities, because MAP units are operating on much smaller scales, 0.5 tons/hour for MAP units, compared to roughly 100 tons/hour for ethanol facilities. In addition, MAP units are not assumed to be running as many hours per year as ethanol facilities, which also decreases the necessary feedstock radius. As a result, total MAP output per year is approximately 150,000 gallons, while an ethanol facility may produce upwards of 20,000,000 gallons/year (NEO, 2011). See section “Effects of Scaling Up the Pyrolysis Units” for more details.

output would be processed and upgraded on site at a refinery. Total transportation costs were estimated at $787/year. Additionally, labor time to load the feedstocks from the roadside storage into the truck is necessary. Assuming 16.2 dry tons/truckload, 93 trucks must be loaded per year. If each truck takes ½ hour to load, ½ hour to unload, and labor costs $25/hour (assuming the truck driver also loads the truck), then truck loading and unloading labor costs are estimated at $2,315/year. Total costs for biomass loading and unloading, feedstock transportation, and bio-oil transportation for the cooperative model are approximately $3,102/year.

Annual costs for a stationary cooperative microwave assisted pyrolysis unit, a bin pneumatic auger, trucks to transport biomass, labor to transport biomass and operate the MAP unit, feedstock production, road siding, and storage, MAP unit maintenance and feedstock grinding are estimated at $219,347/year. The four most significant costs of the stationary cooperative unit are the feedstock related costs ($131,812/year), capital costs ($48,824/year), labor to operate one MAP unit ($17,550/year), and grinding costs ($15,060/year). Revenues from the bio-oil and char are projected to be $198,000/year, for a net annual operating loss of $21,347. This estimate does not include environmental benefits, discussed later in this research.

Distributed System

The distributed system assumes that there are individual stationary MAP units set up across the landscape, with multiple units in each township. Low-density biomass is transported a minimal distance to each farm-scale MAP unit, where it is processed into a high-density bio-oil. This bio-oil is then collected at each farm and transported to a central refinery.

Transportation assumptions are the major change between the distributed system and previous systems. In the mobile and cooperative systems, biomass is round baled and transported to the side of the road with a bale wagon at a cost of $6.26/dry ton, as described in Kumar and Sokhansanj (2007). The biomass in the distributed model is also round bailed, but transported with a bale wagon directly to the distributed farm-scale MAP units. From there, the bio-oils are produced, and the oil must be transported to a central refinery for further processing. A number of transportation efficiencies are created. Due to higher densities, fewer truckloads are needed, and less time is needed to load and unload oil from trucks compared to biomass feedstocks. Loading and unloading labor costs are estimated at $312/year. This assumes 25 truckloads of 6,000 gallons each with a loading and unloading time of 0.5 hours and a labor cost of $25. Per unit transportation costs for the bio-oil were estimated at $0.00122/gallon-mile (Hedley 2007). To transport 150,000 gallons of bio-oil an average of 2.2 miles will cost $401. All transportation costs including loading and unloading time will cost an estimated $713.

Annual costs for a stationary distributed system microwave assisted pyrolysis unit, a bin pneumatic auger, trucks to transport the bio-oil, labor to transport the bio-oil and operate the MAP unit, feedstock production, transport to the MAP unit, and storage, MAP unit maintenance and feedstock grinding are estimated at $216,958/year. The four most significant costs of the stationary cooperative unit are the feedstock related costs ($131,812/year), capital costs ($48,824/year), labor to operate one MAP unit ($17,550/year), and grinding costs ($15,060/year). Revenues from the bio-oil and char are projected to be $198,000/year, for a net annual operating loss of $18,958. This does not include environmental benefits, discussed later in this research.

The operating losses between one stationary cooperative unit and one stationary distributed unit are minimal, only ($21,347-$18,958= $2,329). The transportation savings due to the distributed system are significant as a percentage of total transportation costs ($3,102/year down to $713/year, or a savings of over 75%). However, relative to other costs like feedstock production ($131,812/year) and capital costs ($48,824/year), the savings are minimal. This is consistent with research that finds transportation costs are not large compared to feedstock production costs (Perrin et al. 2008; Sokhansanj et al. 2009). Additionally, if it is assumed that bale wagons must travel farther in the distributed model compared to the other models, these cost savings could quickly be erased. For example, if it is assumed that biomass transportation via bale wagons from the field to the distributed MAP units costs twice as much ($12.52/dry ton) as the roadsiding costs in the co-op model ($6.26/dry ton), then the distributed model costs $226,817/year, compared to the co-op model that costs $219,347/year.

Results

Break-even Costs

Break-even analyses were conducted on the bio-oil selling price, feedstock costs, and capital costs. Results are presented in Table 4.2. All other baseline assumptions discussed in previous sections were held constant and are listed in Table 4.1. Breakeven bio-oil prices range from $1.35/gallon for the distributed unit, up to $1.73/gallon for the mobile unit. This is an increase of 10.7% and 41.8%, respectively, from the baseline bio-oil price of $1.22/gallon. Breakeven feedstock prices are $59/dry ton for the distributed unit, $58/dry ton for the co-op unit, and $23/dry ton for the mobile unit. These are less than current biomass prices in southern Minnesota, although the distributed and co-op systems may be competitive in areas of northern Minnesota that produce woody biomass wastes at roughly $44-$54/dry ton (Dirkswager 2011). Data estimates in the model for yields, harvesting and labor costs, and environmental benefits all assume that MAP units are operating in agricultural areas. Thus, any conclusions in different ecoregions should be drawn with caution. Further analyses could adapt the model to be used in northern Minnesota for woody forest residues.

Effects of Scaling Up the Pyrolysis Units

One of the benefits of MAP technology is that it can easily be scaled up, both for the cooperative model and the farm-scale distributed model. This is expected to reduce capital costs and increase transportation costs for both models. The mobile model was not included in further analyses due to large negative profits, regardless of scale as shown in Table 4.5. Baseline assumptions are for one microwave with a processing capacity of 0.5 tons of biomass/hour. This is the same for the mobile, co-op, and the distributed system models presented above. Five increased capacities were calculated, including 2.5 tons/hour (5 microwaves), 5 tons/hour (10 microwaves), 12.5 tons/hour (25 microwaves), 25 tons/hour (50 microwaves), and 50 tons/hour (100 microwaves).

The scaled up cooperative model (Figure 4.1A) would function like current ethanol facilities, with a large central processing facility and trucks transporting feedstocks. The largest cooperative model facility would process 50 tons/hour and require a feedstock supply radius of nearly 25 miles. This assumes the baseline assumptions that the central facility is in operation only 10 hours/day and 300 days/year and 4% of the landscape is in perennial production. If operation hours are increased to 22 hours/day and 340 days/year, closer to a corn ethanol facility, then the feedstock supply radius increases to 37 miles. The MAP cooperative model scales up by adding microwaves to the central processing facility.

The scaled up distributed model (Figure 4.1B) multiplies the number of units across the landscape. Feedstocks are only transported short distances (not more than 2.5 miles) to the nearest MAP unit. The bio-oil is then collected by a truck and transported to a central processing facility. All machines in the distributed model have just one microwave and can process 0.5 tons/hour. Calculations were done assuming 1, 5, 10, 25, 50 and 100 machines across the landscape.

Capital costs were estimated by assuming that per unit costs would decrease by 50% if a 50 tons/hour machine were ordered (for the co-op system), or 100-0.5 tons/hour individual machines (for the distributed system). A curve was fit between these two points (1-0.5 tons/hour machine and 100-0.5 tons/hour machine) such that per unit costs decreased at a decreasing rate as the capacity or number of machines increased, as shown in Figure 4.3.

Transportation costs are the other variable that changes as both models are scaled up, although the impacts are not as significant as capital costs. Feedstock transportation costs for the co-op model at various scales are displayed in Table 4.3. Table 4.4 presents the bio-oil transportation costs for the distributed model at various scales. Transport costs for feedstocks in the cooperative model contribute more to total production costs than bio-oil transport in the distributed model. But, in the most scaled up version of 50 tons/hour, feedstock transport is only 5.0% of total production costs for the cooperative model, and 2.1% for the distributed model. In the cooperative model, per unit transport costs ($/gallon output) increase due to longer average distances required for feedstock transport. In the distributed model, the average feedstock transportation distance to the nearest MAP machine does not change as more machines are placed on the landscape. However as the number of pyrolysis units on the landscape increases, a truck to collect the bio-oil from each of the machines must drive farther distances to collect the bio-oils to transport them to a central refinery. This increases the per unit bio-oil transportation costs as the scale increases. Annual costs, revenues, and profits for various scales of both the co-op and distributed systems are presented in Table 4.5. All other baseline assumptions given above are held constant.

For the co-op model, annual losses increase as the pyrolysis unit is scaled up, but per unit losses decrease, suggesting that the optimal scale for a MAP co-op model may be a throughput higher than 50 tons/hour. This would likely be conditional on how capital costs decrease beyond this capacity compared to the increase in transportation costs. Annual losses for the distributed model are greatest at 25 machines (12.5 tons/hour) at $-97,123, but decrease until an annual profit of $193,068 is projected for the 100 machines scenario. Similar to the co-op model, per unit production costs for the distributed model continually decrease as the scale is increased. This suggests that the optimal scale may be a throughput higher than 50 tons/hour. However, it is not expected that capital costs would decrease significantly beyond the 50 tons/hour (100 machines) scenario, in which case any small reduction in capital costs would be more than off-set by increases in transportation costs. Importantly, this research suggests that MAP units distributed across the landscape and operated at small scales could turn a small profit on their own, if at least 100 machines are in operation.

Sensitivity Analysis and Key Variables

A sensitivity analysis was conducted, assuming one pyrolysis unit is in operation and a distributed model (Table 4.6). All other parameters are held constant with baseline assumptions. A second sensitivity analysis was conducted assuming 100 pyrolysis units and a distributed model (Table 4.7), since this showed the greatest potential for profit. All other parameters are held consistent with baseline assumptions, discussed previously.

The parameters that have the greatest potential to significantly impact annual returns are the number of hours MAP units are in operation, feedstock costs, labor hours, machine life, bio-oil conversion rate, and bio-oil price. Operation hours are unlikely to decrease below the baseline estimate of 3,000 hours/year, and potentially could increase. If the MAP units are in operation less than 2,700 hours/year, profits evaporate. Because these are on-farm units run by landowners, operating time may not increase to 6,000 hours/year due to time constraints of landowners. But, this analysis suggests that owners may want to contract out the operation of this machine to ensure that it is running as many hours as possible to maximize profits. Baseline feedstock costs are a significant portion of production costs. Because future market prices are unknown and are beyond the control of landowners, the baseline number was estimated conservatively at $71.15/ton. Labor hours were estimated conservatively at 50% of machine operating hours. However, these likely will be less, perhaps around 20%. The machine life is not known, but 10 years was estimated based on engineers estimates, and is the same as estimates used for other pyrolysis units. The average bio-oil conversion rate is unlikely to change from 100 gallons of bio-oil/ton of feedstock. This will change based on feedstock type, but engineers have estimated 100 gallons/ton as an average baseline estimate. Bio-oil prices are very uncertain. Currently no market exists to use the bio-oils produced by these pyrolysis units for bio-plastics or transportation fuels. Estimates range from $0.55/gallon to about $1.68/gallon (Cole

Hill Associates 2004). The estimate for bio-oil price has a large bearing on whether or not these MAP units are profitable or not, and is also one of the values with the most uncertainty.

For 100 stationary and distributed MAP units and baseline assumptions, an investor would see an annual return on investment (ROI) of just 1% over 10 years (Table 4.8). This does not include public environmental benefits, discussed below. If the hours in operation estimate is raised to 6,000 hours/year, and labor is estimated at 20% of total operation hours (these are the parameters with the greatest impact on returns that are also likely to be improved beyond baseline estimates), then the annual ROI is estimated at 13%. Table 4.8 summarizes the financial returns on investment for all three models (mobile, co-op, and distributed) under three scenarios (pessimistic, baseline, and optimistic).

Environmental Benefits

a. Assumptions and Data

Agricultural acres converted to perennial crops provide more ecosystem services than conventionally tilled acres, including improvements in water and air quality, avoided water usage, carbon storage, and potential recreational benefits. For each of these five categories of environmental services, physical and economic data were estimated from published research. Physical data were estimated based on a "with-without CRP" scenario. It is an estimate of, for example, the water quality benefits of an acre enrolled in the Conservation Reserve Program (CRP) compared to a scenario without that acre enrolled in CRP. This method was chosen because estimates of the environmental benefits of CRP can be found in published literature. One important note is that selling harvested feedstocks from CRP lands is currently not allowed. There is discussion that this restriction will change in a future Farm Bill to allow the sale of biomass from CRP lands. Despite this restriction, environmental benefits of CRP lands can provide a good baseline estimate of the environmental benefits that would be provided by perennial feedstocks for MAP units (Table 4.9). More research is needed to confidently estimate the relative environmental impacts of harvested vs. unharvested CRP lands. However, prior research has shown that "permission to harvest CRP biomass for cellulosic biofuel would provide a net climate benefit" (Gelfand et al. 2011). Additionally, other research has called for the allowance of harvesting and sale of biomass from CRP lands (Downing et al. 1995; Walsh et al. 1996; Walsh et al. 2003), concluding that the environmental consequences of harvesting biomass from CRP are minimal, particularly when compared to potential net benefits.

b. Water Quality

The Minnesota River Basin has been cited as one of the most polluted rivers in the United States (Mulla and Mallawatantri 2002). Problems include sedimentation, nitrogen and phosphorous loading, among others. These water pollutants are problematic for their contributions to turbidity and eutrophication of waterways. If perennial crops are planted in place of conventional row crops due to CRP enrollment, water quality benefits of avoided sediment, nitrogen, and phosphorus loading are estimated at $216.65/acre/year (Boody et al. 2005; Kovacs et al. 2010; Ribaudo 1989a) (Table 4.9). Benefits increase when perennial crops are planted closer to waterways, or on environmentally sensitive lands. Current CRP lands are often, though not exclusively, reserved for lands that provide greater environmental benefits (USDA CRP 2011). Given baseline assumptions for one 0.5 MAP unit (441 acres of perennials), this is an annual benefit of $95,581 (Table 4.10).

c. Water Quantity

Water quantity was not included in Table 4.9 or in any calculations of total environmental benefits because it is generally not a concern in south-central Minnesota. However, if MAP units were to operate elsewhere, or if water conditions were to change, the reduction in water used by MAP units (compared to corn ethanol facilities) could become significant. Not including any water for irrigation of feedstocks, the MAP process requires zero additional water inputs. Comparatively, roughly 2.7-3.0 gallons of water are required to produce 1 gallon of corn ethanol (MN Biofuels Association 2015; UIL Extension 2015). Assuming a water price of $0.0041/gallon (Sioux City, Iowa 2011), a bio-oil energy density of 0.97 compared to ethanol, and 150,000 gallons of bio-oil per year (baseline assumption for one 0.5 tons/hour machine in operation), water quantity benefits would be approximately $1,709/year, or $4.06/acre.

d. Air Quality

A University of Missouri report found that each acre enrolled in CRP led to an annual airborne N reduction of 2 lbs./acre, and an airborne P reduction of 0.5 tons/acre (FAPRI-UMC 2007). The Minnesota Land Economics website estimates avoided air borne particulate matter from soil loss at 6 tons/acre/year, calculated as a weighted average across Watonwan County (Taff 2011). These sources did not give dollar value estimates on the benefits of these pollution reductions. A report by Feather et al. (1999) found that air quality benefits from CRP lands come from reduced "health risks and cleaning costs associated with blowing dust" (Feather et al. 1999). They estimate this benefit at $548 million over a 10 year period with a 4% discount rate. With an annual enrollment of 45 million acres in CRP, this is an annualized benefit of $1.35/acre in 2010 dollars. Given baseline assumptions for one 0.5 MAP unit (441 acres of perennials), this is an annual benefit of $596.

e. Carbon

Perennial crops provide carbon benefits in two ways: carbon storage in root systems through the sequestration of carbon, and avoided carbon emissions from not planting conventional row crops. Avoided carbon emissions per acre were estimated at 0.14 tons/acre/year (Lazarus 2010). This assumes that corn would be planted if the land were not enrolled in CRP. Carbon stored as soil organic carbon (SOC) was estimated at 0.4 tons/acre/year. Economic values for carbon are widely debated. Voluntary markets in 2013 were around $4.90/ton. In late 2010, European markets were trading around $75/ton, but this number plummeted to just under $7.72/ton in early 2015. A social cost of carbon is widely agreed to be much higher than recent carbon trading prices. Kovacs et al. (2010) suggest a low range estimate of $54.47/ton as the social cost of carbon. The $54.47 value was selected for this research because it includes the social cost of carbon (like other environmental parameters in this research), is a low-end or conservative estimate, and the report was specific to Minnesota. Given baseline assumptions for one 0.5 MAP unit (441 acres of perennials), this is an annual benefit of $12,977.

f. Recreation and Wildlife Habitat

There is large uncertainty in whether or not perennials used to supply feedstocks for MAP units would provide significant recreational benefits compared to conventional row crop agriculture. CRP lands may not be contiguous or provide corridors for wildlife, they may be in undesirable areas for recreation, or have limited access, all of which could reduce habitat and/or recreational benefits an unknown amount. For these reasons, recreation benefits were not included in Table 4.9 or in final environmental benefit estimates due to large uncertainties in whether or not perennials used to supply feedstocks for MAP units would provide recreational benefits. Additionally, CRP lands are not currently harvested for biomass production, which would presumably increase their recreational value relative to harvested lands for MAP units. In spite of these uncertainties, recreational benefits provided by the MAP perennial feedstocks may be similar to the recreational benefits of unharvested CRP.

Feather et al. 1999, estimated that 45 million acres of CRP provided a recreational benefit of $8,676,000 over a 10 year period with a 4% discount rate. This includes “sport-fishing, small-game hunting, non-consumptive viewing, and waterfowl hunting.” Annualized and converted to 2010 dollars, this is a benefit of approximately $21.26/acre. Given baseline assumptions for one 0.5 MAP unit (441 acres of perennials), this is an annual benefit of $9,379 (Table 4.10). Due to significant uncertainties in recreational benefits from harvested CRP lands, recreational benefits were not included in any aggregated estimates of environmental benefits or in total benefit estimates.

Wildlife habitat benefits of harvested CRP lands are also highly uncertain. Studies show that perennial crops grown for bioenergy can improve wildlife habitat in compared to a baseline of conventional row crops (Hoffman et al. 1995; McLaughlin and Walsh 1998). However, these studies also suggest a mixed species composition of perennial grasses in a contiguous pattern for wildlife corridors, and rotational harvests with limited or no agrochemical application (Hartman et al. 2011; Hoffman et al. 1995). None of these were assumed in this research. Conversely, this research assumed small non-contiguous parcels of CRP (as CRP currently exists) with switchgrass monocultures. This will certainly reduce benefits for wildlife compared to estimates found in the published literature. Because of this large uncertainty, wildlife habitat benefits of MAP units were not included directly in the estimation of net environmental benefits.

g. Cost/Benefit Analysis Including Environmental Benefits

A summary of the estimated annual environmental benefits from one 0.5 tons/hour MAP machine (441 acres or 150,000 gallons) are displayed in Table 4.10. Perennial crops planted as feedstocks for MAP units have an estimated environmental benefit of $247/acre. This would be an annual benefit of $109,154 for each 0.5 tons/hour unit, or $10,915,359 for each 50 tons/hour unit. Every effort was made to estimate environmental benefits conservatively. In other words, environmental benefits are likely higher than the estimates presented in Table 4.10. If environmental benefits are included in NPV and ROI calculations from the previous techno-economic analysis (Table 4.11), then investment in distributed MAP units could be a good investment with returns between 41.6% and 56.7%, depending on how many units are in operation in a distributed model.

Discussion

Impacts on Jobs and Incomes

As ethanol subsidies and CRP payments are both being considered for cutbacks or elimination, farmers may welcome this opportunity for an additional source of income. The model assumes that the MAP unit operator, likely the farmer, is paid $11.70/hour. This could lead to an additional income of between $7,020/year and $17,550/year, depending on how many hours per year the units are operating and how many of those operating hours require labor. Importantly, this income for farmers comes with positive societal environmental benefits, unlike ethanol subsidies with considerable negative environmental effects.

Microwave Assisted Pyrolysis units would also create jobs for farm laborers, truckers, and jobs in a bio-oil processing facility. Labor is required to harvest and transport feedstocks to the distributed MAP units. This would be approximately one job for every 75 MAP units in production (Thorsell et al. 2004). For trucking jobs, the bio-oil transport would require one additional full-time trucking job for approximately every 25 MAP units in production, including the labor to load, drive, and unload the trucks. Finally, an unknown number of jobs would be created to process the bio-oil into a more usable form at a central processing facility.

Proposed Policy Change to Increase MAP Viability

Currently biomass harvested from CRP lands cannot be sold. Although this is a question that must be addressed at the federal level, there are many recommendations in the published literature calling for the allowance of harvesting and sale of biomass from CRP lands (Downing et al. 1995; Gelfand et al. 2011; Walsh et al. 1996; Walsh et al. 2003). A policy change to allow the sale of perennial biomass from CRP lands would both reduce taxpayer costs and incentivize MAP units. As of June 2013 Minnesota had 1,387,909 acres enrolled in CRP, at a cost to taxpayers of $2,925,220/year, or $114.23/acre (USDA FSA 2013). If the MAP units are located near Madelia, Minnesota in Watonwan County, CRP rates are significantly higher. As of June 2013, Watonwan County had 5,999 acres enrolled in CRP, at a cost of $181.93/acre (USDA

FSA 2013). CRP rates in surrounding counties are similar: $173.96/acre (Blue Earth County), $159.97/acre (Jackson County), and $168.78/acre (Cottonwood County)(USDA FSA 2013). If CRP contracts in a future Farm Bill are re-enrolled to allow the harvest and sale of biomass, a portion of the CRP payments could be replaced by biomass supply payments to bring feedstock costs down to levels that would attract private investors to fund MAP technology. If feedstock prices are reduced from $71.15/ton to $51.42/ton, then a private investor could return 20% by investing in MAP technologies. (This assumes 150,000 tons of feedstock supplied from 44,118 acres, or an annual investment of ($71.15-$51.42)/ton*150,000 tons = $2,959,500.) Assuming 3.4 tons of dry biomass are produced per acre, this $19.73/ton shortfall ($71.15-$51.42) translates to biomass producer (landowner) payments of $67.08/acre. In other words, taxpayer costs could decrease from $132.41/acre (a conservative CRP estimate in southern Minnesota) to around $67.08/acre (if biomass is sold). The difference of $65.33/acre saved by the taxpayer is instead paid by the biomass purchaser for MAP units. This would mean savings for taxpayers, little or no revenue changes for CRP enrollees, continued payment for and protection of environmental services that are provided by CRP, and a mechanism to reduce the price of biomass so that the MAP biomass system can become financially viable. For this to happen, the key change is that a future Farm Bill must allow the sale of biomass from CRP lands.

One of the major issues with large-scale cellulosic biofuel production is that the large amounts of biomass required necessarily begin to compete with annual row crops, or else face potentially insurmountable transportation distances. Importantly, this research assumes that no new lands need to be converted from row crops to perennials. This research calculates that small-scale MAP units will be sufficiently supplied by 4% of the landscape, the current amount of land enrolled in CRP in south-central Minnesota. Additionally, MAP units can be placed in areas with relatively dense perennial crop production, which will save on transport costs. Exploiting "pockets" of perennial production is easier to do with small-scale units than large scale facilities.

Summary and Conclusions for Decision Makers

Due to their small scale and distributed biomass structure, microwave assisted pyrolysis (MAP) systems offer opportunities for potential cost savings when compared to large ethanol plants or other pyrolysis technologies. However, even with technological advances such as reduced capital costs and reduced feedstock transportation costs, farm-scale pyrolysis units will not realistically be financed by the private sector under current regulations and economic conditions. Mobile MAP unit returns on investment (ROI) for 100 units and baseline conditions was estimated to by -20.6%. For the distributed pyrolysis units, ROI was estimated at +1.0% for 100 units in operation at baseline conditions. These returns are financial only and do not include environmental benefits. Because markets do not currently exist for environmental services provided in Minnesota, a private investor would not be able to financially benefit from the environmental services provided by their investment in MAP units. However, given the environmental benefits, MAP units would be a good public investment. When environmental benefits of water quality, air quality, and carbon are included in ROI estimates, distributed farm-scale pyrolysis units yield a return on investment between 41.6% and 56.7%, depending on how many MAP units are in production. The environmental benefits that the pyrolysis units provide would be provided to the public in the form of improved water quality, improved air quality, and carbon storage. Providing services where private markets alone are insufficient is an important function of effective governments. Incentivizing MAP units is an opportunity to efficiently provide environmental services through the private market. This should be a financially more efficient way to provide environmental benefits compared to buying and conserving land with no biomass harvesting, since there are the financial benefits of the bio-oil, along with environmental benefits of displacing more carbon-intensive fuels. Decision makers should consider funding MAP units as a potential way to increase the provision of environmental services from working agricultural lands in cost-effective ways.

Tables

Table 4.1. Baseline assumptions for the techno-economic analyses of the three scenarios.

Parameter	Value	Units	Source(s)
Production Assumptions			
Feedstock Production[a]	3.4	dry tons/acre	Lazarus 2010
Landscape in perennial production[b]	4.0	%	Meschke 2011
Feedstock to bio-oil conversion rate	100	gallons/dry ton	Ruan 2011
Feedstock to char conversion rate	0.2	tons char/dry ton	Ruan et al. 2008
Energy content of bio-oil	40	% (of #2 heating oil)	Coleman et al. 2010
Fixed Costs[f]			
Capital Costs[c]	300,000	$/unit	Meschke 2011; Ruan 2011
Variable Costs[f]			
Cost to buy, move, store feedstocks[d]	87.87	$/dry ton	Kumar and Sokhansanj 2007; Lazarus 2010
Cost of grinding unit	10.04	$/dry ton	Kumar and Sokhansanj 2007
Maintenance/repair costs	1.00	$/operating hour	Industrial Microwave Systems 2011
Feedstock transport cost	0.24	$/ton-mile	Morrow et al. 2006
Bio-oil transport cost	0.00122	$/gallon-mile	Hedley 2007
Revenues[f]			
Price of #2 heating oil[e]	3.05	$/gallon	USEIA 2011
Price of char	50	$/ton	Ruan et al. 2008

[a] Switchgrass was the assumed feedstock because data are widely available. However, these units can accept a wide range of feedstocks. All feedstocks are assumed to be dry tons, both in this table and throughout this research.

Table 4.1, continued. Baseline assumptions for the techno-economic analyses of the three scenarios.

[b]The 4% of the landscape in perennial crop production is assumed to be multiple 160 acre blocks evenly spread across the landscape. 4% is the 2011 CRP enrollment near Madelia, MN.
[c] The 0.5 tons/hour unit costs $250,000, including shipping to Minnesota. Additionally, it will cost about $50,000 for a bin pneumatic auger as a self-feeding mechanism. Life of machine is estimated at 10 years. With a 10% interest rate, this is an annualized cost of $48,824.
[d] Includes cost of switchgrass, roadsiding (moving feedstocks from the field to the side of the road), stacking, and storage. Assumes 5% annual storage losses. Cost of switchgrass includes establishment through bailing in the field, and land rents. Assumes $71.15/dry ton as the cost of biomass, without other costs.
[e] Wholesale price.
[f] All dollar values are reported as 2010 equivalents, both in this table and throughout this research.

Table 4.2. Break-even points of mobile, cooperative, and distributed MAP models for various parameters.

	Baseline Assumption	**Mobile Unit**	**Co-op Unit**	**Distributed Unit**
		Break-even Point		
Bio-oil price ($/gallon)	1.22	1.73	1.36	1.35
Capital Costs ($)	300,000	-168,765[1]	168,831	183,512
Feedstock costs ($/ton)	71	23	58	59

[1]The negative capital cost here indicates that the mobile unit would need a cash input of $168,765 in order to break even.

Table 4.3. Feedstock transportation costs for the co-op model at various scales.

Scale (tons/hour)	**Annual biomass (tons/year)**	**Transport costs ($/year)**	**Transport costs ($/gallon output)**	**Percentage of total cost (%)[a]**
0.5	1,500	$3,102	$0.020	1.4
2.5	7,500	$20,373	$0.027	1.9
5	15,000	$48,034	$0.032	2.3
12.5	37,500	$156,240	$0.042	3.0
25	75,000	$393,972	$0.053	3.9
50	150,000	$1,018,438	$0.068	5.04

[a] Calculated as Annual transportation costs ($/year)/Total annual costs ($/year)*100

Table 4.4. Bio-oil transportation costs for the distributed model at various scales.

Scale (# of machines)	**Annual biomass (tons/year)**	**Transport costs ($/year)**	**Transport costs ($/gallon output)**	**Percentage of total cost (%)[a]**
1	1,500	$713	$0.005	0.3
5	7,500	$6,035	$0.008	0.6
10	15,000	$15,775	$0.011	0.8
25	37,500	$57,817	$0.015	1.1
50	75,000	$157,059	$0.021	1.5
100	150,000	$431,286	$0.029	2.14

[a] Calculated as Annual transportation costs ($/year)/Total annual costs ($/year)*100

Table 4.5. Annual costs, revenues, and profits for various scales of both the co-op and distributed systems.

	Model Type	Annual Costs ($)	Annual Revenues ($)	Annual Profits ($)	Profits ($/gallon)
0.5 tons/hour (1 machine)	Mobile	274,292	198,000	-76,292	-0.51
	Co-op	219,347		-21,347	-0.14
	Distributed	216,958		-18,958	-0.13
2.5 tons/hour (5 machines)	Mobile	1,337,338	990,000	-347,338	-0.46
	Co-op	1,069,864		-79,864	-0.11
	Distributed	1,055,527		-65,527	-0.09
5 tons/hour (10 machines)	Mobile	2,618,860	1,980,000	-638,860	-0.43
	Co-op	2,091,797		-111,797	-0.07
	Distributed	2,059,539		-79,539	-0.05
12.5 tons/hour (25 machines)	Mobile	6,426,153	4,950,000	-1,476,153	-0.39
	Co-op	5,145,546		-195,546	-0.05
	Distributed	5,047,123		-97,123	-0.03
25 tons/hour (50 machines)	Mobile	12,642,731	9,990,000	-2,742,731	-0.37
	Co-op	10,163,606		-263,606	-0.04
	Distributed	9,926,693		-26,693	-0.00
50 tons/hour (100 machines)	Mobile	24,921,243	19,800,000	-5,121,243	-0.34
	Co-op	20,194,084		-394,084	-0.03
	Distributed	19,606,933		193,068	0.01

Table 4.6. Results of a sensitivity analysis of 1 pyrolysis unit with a distributed model.

Parameter	Value[a]	Units	Annual Profits ($/year)	Profits ($/gallon output)
Operating Hours	2,000	Hours/year	-28,864	-0.29
	3,000		-18,958	-0.13
	6,000		10,576	0.04
Landscape in Perennial Production	2	%	-19,124	-0.13
	4		-18,958	-0.13
	8		-18,841	-0.13
Feedstock Production[b]	2.4	Dry tons/acre	-19,034	-0.13
	3.4[f]		-18,958	-0.13
	4.4		-18,910	-0.13
	9.4		-18,798	-0.13
	14.4		-18,752	-0.13
Feedstock Costs[c]	51.15	$/dry ton	12,542	0.08
	61.15		-3,208	-0.02
	71.15[f]		-18,958	-0.13
	81.15		-34,708	-0.23
Labor to operate MAP unit	20	% of operating hours	-8,428	-0.06
	50		-18,958	-0.13
	80		-29,488	-0.20
Cost to Transport bio-oil	0.0002	$/gallon-mile	-18,623	-0.12
	0.00122		-18,958	-0.13
	0.0022		-19,279	-0.13

Cost of grinding unit	7.04	$/dry ton	-14,458	-0.10
	10.04		-18,958	-0.13
	13.04		-23,458	-0.16
Maintenance Costs	0.50	$/operating hour	-17,458	-0.12
	1		-18,958	-0.13
	1.50		-20,458	-0.14
Syngas Production[d]	-1,000	mmBTU/year	-20,958	-0.14
	0		-18,958	-0.13
	1,000		-16,958	-0.11
Capital Costs[e]	250,000	$/unit	-10,821	-0.07
	300,000		-18,958	-0.13
	350,000		-27,095	-0.18
Machine Life	5	years	-49,274	-0.33
	10		-18,958	-0.13
	15		-9,576	-0.06
Bio-oil conversion rate	80	Gallons bio-oil/dry ton of feedstock	-55,415	-0.46
	100		-18,958	-0.13
	120		17,500	0.10
Price of bio-oil	1.00	$/gallon	-51,958	-0.35
	1.22		-18,958	-0.13
	1.40		8,042	0.05
Price of char	35	$/ton	-23,458	-0.16
	50		-18,958	-0.13
	65		-14,458	-0.10

[a] Each parameter is divided into three values, a low estimate, the baseline value, and a high estimate.

Table 4.6, continued. Results of a sensitivity analysis of 1 pyrolysis unit with a distributed model.

[b] Baseline numbers assume switchgrass yields. For comparison, hybrid poplar yield 3.8 dry tons/year and willow yield 4.5 dry tons/year. Both numbers are averaged over the stand life and include stump removal (Lazarus 2010). UMN Extension (based on a study by Heaton et al. 2008) estimates Miscanthus yields of 13.2 dry tons/acre, although Miscanthus is not native to the U.S. Prairie cord grass yields are estimated at 2.7 dry tons/acre (Boe and Lee 2007). In trials in southern Minnesota, prairie cordgrass has been yielding between 5.3 and 6.7 dry tons/acre (Gamble 2011).

[c] More than three feedstock prices were included in this sensitivity analysis. $71.15/dry ton represents the baseline value (Lazarus 2010). As of March, 2011, round-baled grass was selling for $61.25/dry ton in Minnesota, based on USDA data (Minneapolis Biomass Exchange 2011). A lower estimate of $51.15/dry ton was also included to reflect the large range of uncertainty in biomass prices.

[d] The low value of -1,000mmBTU assumes that 1,000mmBTU must be purchased each year to run the pyrolysis units. The baseline value of zero assumes that all syngas produced by the pyrolysis units is consumed to run the machines (6,750MMBTU/year given baseline assumptions). The high value of +1,000 assumes that more syngas is produced than is required, and can be sold. Syngas transportation costs are not included, so the assumption is that the excess syngas produced on-site is also used on-site. Syngas prices are estimated at $2.00/mmBTU.

[e] Includes $50,000 cost of a bin pneumatic auger, to automatically feed feedstocks into the MAP unit.

[f] Baseline estimate.

Table 4.7. Results of a sensitivity analysis of 100 pyrolysis units with a distributed model.

Parameter	**Value**[a]	**Units**	**Annual Profits ($/year)**	**Profits ($/gallon output)**
Operating Hours	2,000	Hours/year	-5,076,170	-0.50
	3,000		193,068	0.01
	6,000		16,000,781	0.53
Landscape in Perennial Production	2	%	27,367	0.00
	4		193,068	0.01
	8		310,235	0.02
Feedstock Production[b]	2.4	Tons/acre	116,965	0.01
	3.4[f]		193,068	0.01
	4.4		241,452	0.02
	9.4		352,515	0.02
	14.4		398,721	0.03
Feedstock Costs[c]	51.15	$/ton	3,343,068	0.22
	61.15		1,768,068	0.12
	71.15[f]		193,068	0.01
	81.15		-1,381,932	-0.09
Labor to operate MAP unit	20	% of operating hours	1,246,068	0.08
	50		193,068	0.01
	80		-859,932	-0.06
Cost to Transport bio-oil	0.0002	$/gallon-mile	527,524	0.04
	0.00122		193,068	0.01
	0.0022		-128,273	-0.01

Cost of grinding unit	7.04	$/ton	643,068	0.04
	10.04		193,068	0.01
	13.04		-256,932	-0.02
Maintenance Costs	0.50	$/operating hour	343,068	0.02
	1		193,068	0.01
	1.50		43,068	0.00
Syngas Production[d]	-1,000	mmBTU/year	-6,932	-0.00
	0		193,068	0.01
	1,000		393,068	0.03
Capital Costs[e]	250,000	$/unit	598,646	0.04
	300,000		193,068	0.01
	350,000		212,511	-0.01
Machine Life	5	Years	-1,317,927	-0.09
	10		193,068	0.01
	15		660,660	0.04
Bio-oil conversion rate	80	Gallons bio-oil/dry ton of feedstock	-3,380,675	-0.28
	100		193,068	0.01
	120		3,766,810	0.21
Price of bio-oil	1.00	$/gallon	-3,106,932	-0.21
	1.22		193,068	0.01
	1.40		2,893,067	0.19
Price of char	35	$/ton	-256,932	-0.02
	50		193,068	0.01
	65		643,068	0.04

[a] Each parameter is divided into three values, a low estimate, the baseline value, and a high estimate.

Table 4.7 continued. Results of a sensitivity analysis of 100 pyrolysis units with a distributed model.

[b] Baseline numbers assume switchgrass yields. For comparison, hybrid poplar yield 3.8 dry tons/year and willow yield 4.5 dry tons/year. Both numbers are averaged over the stand life and include stump removal (Lazarus 2010). UMN Extension (based on a study by Heaton et al. 2008) estimates Miscanthus yields of 13.2 dry tons/acre, although Miscanthus is not native to the U.S. Prairie cord grass yields are estimated at 2.7 dry tons/acre (Boe and Lee 2007). In trials in southern Minnesota, prairie cordgrass has been yielding between 5.3 and 6.7 dry tons/acre (Gamble 2011).

[c] More than three feedstock prices were included in this sensitivity analysis. $71.15/dry ton represents the baseline value Lazarus 2010). As of March, 2011, round-baled grass was selling for $61.25/dry ton in Minnesota, based on USDA data (Minneapolis Biomass Exchange 2011). A lower estimate of $51.15/dry ton was also included to reflect the large range of uncertainty in biomass prices.

[d] The low value of -1,000mmBTU assumes that 1,000mmBTU must be purchased each year to run the pyrolysis units. The baseline value of zero assumes that all syngas produced by the pyrolysis units is consumed to run the machines (6,750MMBTU/year given baseline assumptions). The high value of +1,000 assumes that more syngas is produced than is required, and can be sold. Syngas transportation costs are not included, so the assumption is that the excess syngas produced on-site is also used on-site. Syngas prices are estimated at $2.00/mmBTU.

[e] Includes $50,000 cost of a bin pneumatic auger, to automatically feed feedstocks into the MAP unit.

[f] Baseline estimate.

Table 4.8. Annual ROI for mobile, co-op, and distributed systems.

Model Type	**Scenario**	**Annual ROI (%)**
100 Mobile Units (0.5 tons/hour each)[a]	Pessimistic scenario	-24.3
	Baseline scenario	-20.6
	Optimistic scenario	-16.5
1 Co-op unit (50 tons/hour)	Pessimistic scenario[b]	-11.3
	Baseline scenario[c]	-2.0
	Optimistic scenario[d]	8.5
100 Distributed Units (0.5 tons/hour each)	Pessimistic scenario[b]	-9.2
	Baseline scenario[c]	1.0
	Optimistic scenario[d]	13.1

[a] All mobile unit scenarios require labor for 100% of operation hours due to the roadside nature of the mobile unit. The pessimistic, baseline, and optimistic scenarios for the mobile unit assume 2,000, 3,000, and 6,000 annual hours in operation, respectively.

[b] Assumes 2,000 annual hours in operation, and 80% of operation hours require labor.

[c] Assumes 3,000 annual hours in operation, and 50% of operation hours require labor.

[d] Assumes 6,000 annual hours in operation, and 20% of operation hours require labor.

Table 4.9. Baseline estimates of the environmental benefits of CRP lands.

	Physical Data			**Economic Data**[b]		
Parameter[a]	**Value**	**Units**	**Source(s)**	**Value**	**Units**	**Source(s)**
Water Quality Benefits						
Avoided sediment loading	6.5	tons/ac/yr	FAPRI-UMC 2007; Taff 2011	8.27	$/ton	Boody et al. 2005; Ribaudo 1989a
Avoided N loading	20.7	lbs/ac/yr	FAPRI-UMC 2007	0.89	$/lb	Kovacs et al. 2010
Avoided P loading	5.4	lbs/ac/yr	FAPRI-UMC 2007	27.52	$/lb	Kovacs et al. 2010
Air Quality Benefits						
Avoided air pollution	6	tons/ac/yr	Taff 2011	1.35	$/acre	Feather et al. 1999[c]
Carbon Benefits[d]						
Avoided carbon emissions	0.14	tons/ac	Lazarus 2010	54.47	$/ton	Kovacs et al. 2010
Carbon sequestration	0.4	tons/ac	Boody et al. 2005; Kumar and Sokhansanj 2007	54.47	$/ton	Kovacs et al. 2010

[a] Details and assumptions for each of these parameters are discussed in the sections below.

[b] All values have been converted to 2010 dollars.

[c] The Feather et al. (1999) report does not specify the physical data, but instead reports benefits in economic terms only ($/acre). Numbers from the Feather et al. (1999) report are used in final estimates.

[d] All carbon numbers here and throughout this research are carbon only, not carbon dioxide.

Table 4.10. Estimated annual environmental benefits from one 0.5 tons/hour MAP unit.

Environmental Benefits	Annual Value for a 0.5 tons/hour unit ($)[a]	Annual Value for a 50 tons/hour unit ($)[b]
Water Quality	95,581	9,558,132
Water Quantity[c]	1,746	174,600
Air Quality	596	59,559
Carbon	12,977	1,297,668
Recreation and Habitat[c]	9,379	937,941
TOTAL[c]	109,154	10,915,359

[a] Assumes 441 acres in production or 150,000 gallons of bio-oil produced. All baseline assumptions discussed previously apply.

[b] Assumes 44,118 acres are in production or 15,000,000 gallons of bio-oil produced. All baseline assumptions discussed previously apply. This is the equivalent of 100 0.5 tons/hour units.

[c] Water quantity, recreation, and habitat benefits are not included in the total due to high uncertainty, as discussed in the text.

Table 4.11. Costs, benefits, NPV and ROI calculations for 1 and 100 distributed MAP units (0.5 tons/hour).

	<u>1 Distributed MAP Unit</u>		<u>100 Distributed MAP Units</u>	
	<u>Not</u> including Environmental Benefits	Including Environmental Benefits	<u>Not</u> including Environmental Benefits	Including Environmental Benefits
Annual Costs ($)	216,958	216,958	19,606,932	19,606,932
Annual Benefits ($)	198,000	307,153	19,800,000	30,715,358
Annual NPV ($)	-18,958	90,196	193,067	11,108,426
Annual ROI (%)	-8.7	41.6	1.0	56.7

Figures

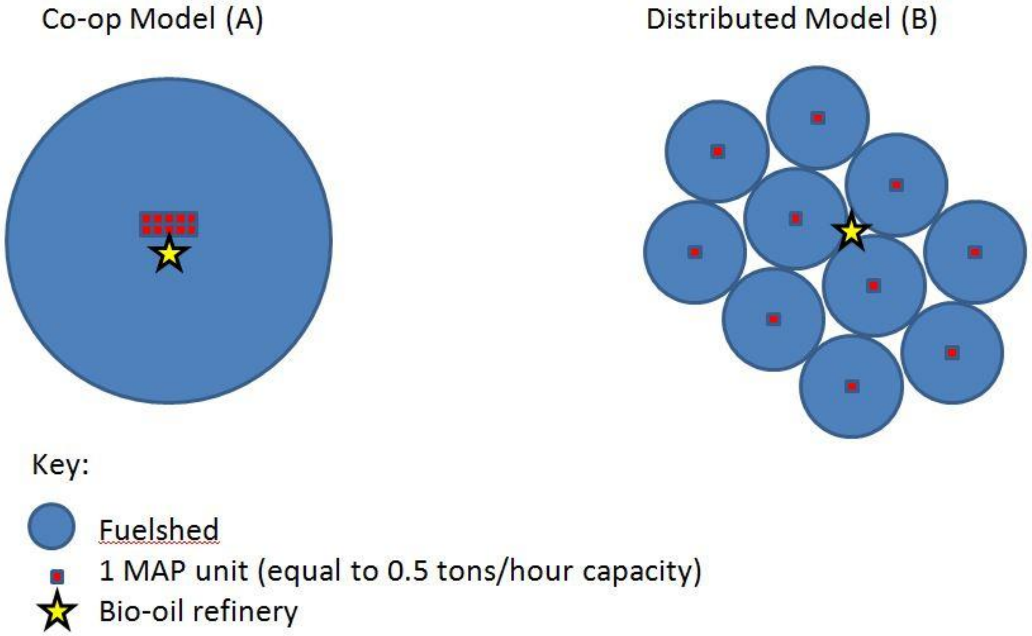


Figure 4.1. Diagram of a stationary co-op model (A) and a distributed model (B) for microwave assisted pyrolysis (MAP) technology. Both models in this figure process 5 tons per hour (ten 0.5 tons/hour MAP units). In the co-op model, a truck transports feedstocks from the entire fuel shed to a central processing facility. In the distributed model, multiple MAP units are set up across the landscape. Feedstocks are transported to the nearest MAP unit, densified into a bio-oil, and the bio-oil is collected by a truck and transported to a central refinery.

Figure 4.2. Photo of a mobile microwave assisted pyrolysis (MAP) unit. This unit can be put on a trailer and moved with a pick-up truck. Dimensions are approximately 5.0 x 2.5 x 3.5 meters.

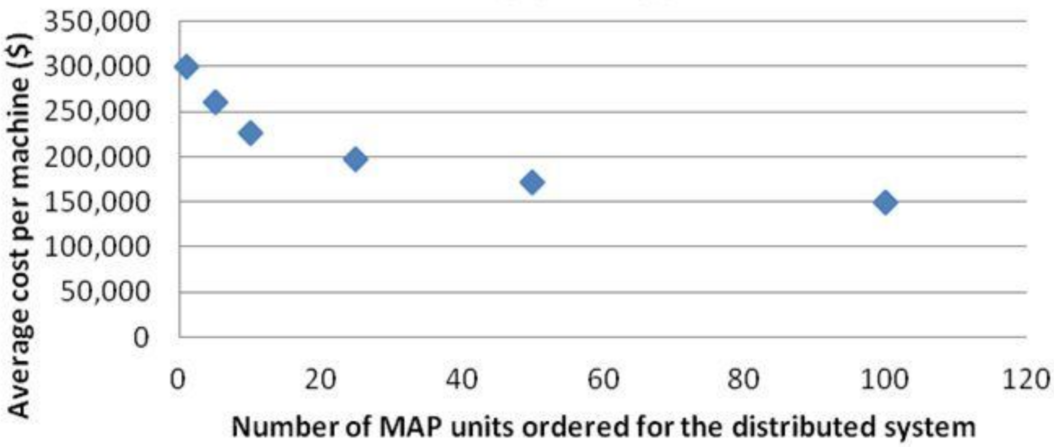


Figure 4.3. Per unit capital costs of distributed system MAP units. Cost estimates are projections by Dr. Roger Ruan, the lead project engineer.

Chapter 5: Conclusions

Introduction and Key Findings

All three major portions of this research (chapters two through four) sought to investigate one primary, over-arching question: What strategies might conservation decision makers consider to increase environmental services through best management practice (BMP) implementation on working agricultural lands?

Chapter 2 addressed this question from a social science perspective, by using focus group methodology to understand the primary drivers of voluntary conservation implementation as described by local conservation managers. Key findings include a framework for the descriptive decision process of conservation managers, and the importance of promoting greater engagement with landowners and facilitating peer exchange networks.

Chapter 3 addressed this question from physical science and economics perspectives, by comparing rankings of BMP physical effectiveness to BMP cost-effectiveness. Key findings include the importance of including cost data (along with pollution reduction data) in decision making processes, and suggestions to use limited conservation resources more efficiently.

Chapter 4 addressed this question from a techno-economic and policy perspective, by developing a model to estimate the economic feasibility and environmental implications of various scenarios of microwave assisted pyrolysis (MAP) units to process cellulosic biofuels from perennial feedstock BMPs. Key findings include that the expected economies of scale gained by the mobility of small-scale pyrolysis units are not sufficient to overcome the increase labor costs, but that stationary small-scale distributed pyrolysis units show some economic promise, particularly if the value of environmental benefits are considered.

Primary Target Audience of this Research

This research is of interest to decision makers at various scales working to improve water quality in the Minnesota River Basin who are working to deploy the limited resources of time, money, personnel, and energy in an efficient, pragmatic, and realistic way. However, the primary and target audience of these research findings are state and perhaps federal-level regulators and policy makers working to design efficient and effective programs to implement agricultural BMPs. Restructuring the voluntary BMP implementation process described in chapter 2 cannot be overcome at the local or county levels. Changes of this magnitude would need to be initiated and addressed by higher level officials. Instead, county-level conservation managers (such as SWCD personnel or local non-profits interviewed in chapter 2) are interested in and incentivized to implement programs funded by state and federal policy makers. If a wetland program is funded, then local conservation managers work to funnel those state or federal dollars to their area to install local wetlands. In their day-to-day work, county-level conservation managers are not incentivized to step back and think about their decision framework described in chapter 2, and how it may or may not be incorporating research or evidence-based conservation efforts. Similarly, local conservation work does not require or incentivize the consideration of comprehensive cost-effectiveness estimates from chapter 3, or think about how to drive and sustain landscape level changes through new technologies (described in chapter 4) to provide environmental services.

These broader issues align more with the concerns of and questions asked by state and federal agencies, including the Minnesota Department of Agriculture, the Minnesota Pollution Control Agency, the Minnesota Board of Water and Soil Resources, and the Natural Resources Conservation Service within the US Department of Agriculture. Findings from chapter 2 allow agencies and other policy makers to understand how and why current agricultural BMP implementation strategies are difficult to reconcile with evidence-based conservation efforts, why focus group participants were frustrated with a lack of landowner participation in conservation efforts, and possible strategies to change these problems. Chapter 3 findings encourage state level policy makers to determine how BMP costs might be more easily estimated and incorporated into the decision process and increasing the efficiency of conservation resource dollars. State or federal level decision makers could use the findings in chapter 4 to consider if funding MAP technology might be a reasonable way for taxpayers to fund innovative technologies in a public-private partnership model. This idea may also appeal to policy makers because pyrolysis units across the landscape would expand the concept of working lands to include lands that provide significant environmental services. These environmental benefits would be attained in a relatively financially sustainable way compared to payments for set aside lands such as the Conservation Reserve Program (CRP) or Reinvest in Minnesota (RIM) Reserve Program. Results of this research offer many potential ideas to be considered by decision makers. Findings in chapters 2, 3, and 4 might even be weighed against each other as possible strategies to pursue to increase the provision of environmental services on working agricultural lands. For example, suggestions for increasing the cost-effectiveness of BMP implementations discussed in chapter three might be considered more realistic in the short term compared to the MAP units discussed in chapter four, but MAP units might be able to make a more significant impact in the longer term. Decision makers would need to consider which of the strategies presented here might be most realistic or feasible for helping Minnesota reach its stated conservation and water quality goals.

Guidelines for Decision Makers and Management Implications

Results from aggregating BMP physical effectiveness studies and cost data (chapter 3) show a very large range of costs expended on reducing one unit of nonpoint source (NPS) phosphorus pollution. Any policy maker protecting taxpayer dollars would want conservation managers to consider cost-effectiveness of a BMP in the decision process. However, this is currently not the case because various stakeholders in the BMP decision process have different assumptions, constraints, and objectives that do not necessarily incorporate BMP cost-effectiveness. These stakeholders include 1) researchers, 2) conservation managers, and 3) landowners. The research community studying BMP effectiveness has at times claimed that BMP effectiveness a reasonable proxy for BMP cost-effectiveness. Many examples were found in the literature where BMP effectiveness was assumed to be a predictor of BMP cost-effectiveness when discussing the targeting of BMPs. This research (chapter 3) suggests that BMP effectiveness is not a good proxy variable for BMP cost-effectiveness. Evidence was also found that conservation managers rarely incorporate cost-effectiveness into their decision process. Focus groups (chapter 2) did mention cost-share programs and direct landowner costs, but they rarely mentioned total BMP cost as an important factor in their decision process, as it was displaced by more pressing or essential factors. Landowners are the driving force behind the BMP installation decision process, and therefore landowner initiative and social acceptability are two primary factors of importance in BMP installations. Landowners certainly consider private out-of-pocket costs of a BMP based on available cost-share programs, but are likely not considering or perhaps even aware of relative cost-effectiveness of BMPs described in chapter 3. Even if landowners are perfectly aware of BMP cost-effectiveness data, they are not incentivized to incorporate this into their decision process, as the costs of pollution reduction are generally shared by the landowner and various cost-share programs, while the benefits of water quality improvement are largely a public good (chapter 4). Similarly, even if the many conservation benefits of the pyrolysis units in chapter 4 were known by the landowner, the costs and risks of conversion to perennial grasses for biofuel production is still borne by the landowner, while the environmental benefits are largely externalized to society.

The misalignment of incentives and lack of consideration of BMP cost-effectiveness in the decision process justifies the consideration of a few different state or federal level policy options. First and perhaps most obviously, this research supports the expansion of payments for the provision of environmental services. Environmental services will be under provided if the supplier is not compensated for their provision. Landowners should not be expected to provide benefits to society while they carry the costs and risks, particularly in high-risk contexts like the adoption of new technologies in chapter 4. Conservation managers in the chapter 2 focus groups lamented the reduction or disappearance of popular cost-share programs that motivated landowners to “walk in the door”, which operate in a sense like payments for environmental services. The cost-benefit analysis of the microwave assisted pyrolysis (MAP) units at the end of chapter 4 indicates that MAP units would be a good investment for taxpayers, as a mechanism to pay landowners to provide environmental services.

A second policy option suggested by this research is to modify the decision process to leverage the knowledge and expertise of local conservation managers. Landowners of course do not want decisions made for them, or to feel pressured or constrained in their options. However, local conservation managers are trusted sources of information in some contexts. This suggests that a more proactive “door-knocking” approach discussed in chapter 2 may be successful. Encouraging conservation managers to consider relatively cost-effective BMPs in their area and approach these landowners would allow the consideration of BMP cost-effectiveness in the overall decision making process. The "door-knocking" approach suggested by this research would simultaneously address the "not my problem" issue described in the literature (Dutcher et al. 2004; Raedeke et al. 2001). Landowners generally agree that water quality is a problem, but less so in my area, and not really on my land. A conservation manager knocking on their door to present a cost-effective BMP installation proposal (chapter 3), or propose ideas that generate both profit for the landowner and ecosystem service benefits (chapter 4), may work to break down the perceived "I'm not the problem" barrier to water quality improvements. This might subsequently activate landowner personal norms to protect water quality. If a conservation manager presenting options is initiating the conversation, this may trigger a sense of community responsibility, but also clearly present a set of potential but concrete options such that the landowner feels they are able to act and are not overwhelmed and demotivated by vague possibilities (Pradhananga 2014).

Application of Research to the Minnesota Buffer Initiative

All three major chapters of this research have interesting applications for Governor Mark Dayton's Buffer Initiative, passed by both houses of the Minnesota Legislature and signed by Governor Dayton in June of 2015. Governor Dayton has made this legislation his signature effort to clean up Minnesota's waterways, reduce soil erosion, and increase wildlife habitat. The Minnesota Buffer Initiative requires landowners to install buffers of perennial grasses or trees along all major streams and rivers. The buffers must average 50 feet wide along waterways, with a minimum of 30 feet (Marcotty 2015). Drainage ditches are not covered under the new law. There is no new money appropriated in this bill, but financial assistance to landowners is available through the Legacy Amendment's Clean Water Fund, Reinvest in Minnesota (RIM), the Conservation Reserve Program (CRP), and other land set aside programs (Smith 2015).

Critics of the law say that this is a one-size-fits-all "land grab" by the state of Minnesota (Steil 2015). Concern has been expressed that this command-and-control regulation is an inefficient way to reduce nonpoint source pollution. Research, including this study, shows that BMP effectiveness is sensitive to specific site factors such as slope, and a blanket buffer policy may not be appropriately sensitive to varying site conditions (chapter 3). Buffer strips ranked as only the fourth most cost-effective BMP of the 12 total that were studied in this research. Given these concerns, is this Minnesota Buffer Initiative a reasonable approach to improve water quality? The answer to this question is "yes", as at least four findings from all chapters of this research support the Minnesota Buffer Initiative in response to these criticisms of the law.

First, the law is more flexible than simply mandating buffer strips, as is often portrayed. There is a provision in the law allowing for other proven alternatives (i.e., approved BMPs found in the USDA Natural Resources Conservation Service Field Office Technical Guide), including but not limited to cover crops, wetlands, terraces, and nutrient management, all of which have cost-effectiveness estimates in chapter 3, and were mentioned by chapter 2 focus group participants as BMPs that conservation managers are working to implement. Acceptable replacement BMPs can be decided at the local level with technical assistance and review from local Soil and Water Conservation Districts (SWCDs). This law is not so much of a one-size-fits-all approach as it is a default setting or starting point which landowners can modify if they find another BMP more socially acceptable or effective. Findings from chapter 3 of this research could be used as evidence that a certain BMP may be more (or less) reasonable than buffer strips. Findings from chapter 2 would support a more flexible, locally-driven decision making process that allows county-level conservation managers to make context-specific recommendations.

A second reason why this research supports the new Buffer Initiative is that buffers are the most cost-effective of the longer term BMPs (chapter 3). Lower rates of phosphorus application and no-till both ranked as generally more cost-effective than conservation buffer strips. However, these BMPs have just a one-year lifespan. They may have lower upfront costs, but they are short-term BMPs with a 1-year planning horizon, allowing for changes to be quickly “undone” relative to buffers. Also, buffers are easier to identify and monitor using satellite technology compared to some other BMPs, due to their long term nature and clear physical presence. It is also worth remembering that this study opted to use relatively conservative lifetime estimates for longer term BMPs. This assumption disadvantaged the cost-effectiveness results for long term BMPs such as buffer strips. Cost-effectiveness data related to buffer strips should therefore be seen as a conservative estimate. It is quite possible that the true median cost-effectiveness of buffers is lower than the $4.32/lb. avoided TP that was estimated by this research. Findings from chapter 3 indicate that buffers are a sensible approach to take to implement long-term changes that are needed to see water quality improvement.

A third reason why this research supports the new Buffer Initiative is that buffers are the most cost-effective of the socially acceptable BMPs. Of course the cost-effectiveness analysis in chapter 3 should not be interpreted in isolation, and landowner social acceptability of BMPs should have significant bearing on policy considerations. In seeking to maximize each of these criteria, buffers rank highly in both cost-effectiveness and landowner social acceptability research. Davenport and Olson (2012) interviewed farmers in southern Minnesota and found that buffer strips were the most popular option of a list of 10 BMPs presented. Similar to these findings, conservation managers interviewed in chapter 2 mentioned the popularity of cost-share programs that funded buffers. In the chapter 3 cost-effectiveness analysis, lower rates of phosphorus application and no-till both ranked as more cost-effective than buffer strips. However these are both BMPs that require a landowner or farmer to change their management practices. Mandating these BMPs may be seen as more controlling, or a higher risk to per acre yields than installing a buffer, which will decrease their social acceptability relative to buffers.

Finally and most importantly, the new Minnesota Buffer Initiative is pivotal in that it changes the decision structure of the BMP installation process, a significant issue highlighted in chapter 2 of this research. With the new Buffer Initiative, the default setting is land with a BMP installation, rather than without. This new law no longer requires motivated, interested landowners who "walk in the door" to initiate and drive the decision process of conservation managers. Instead, this law essentially mandates a form of the "door knocking" strategy discussed in chapter 2, and could encourage peer to peer sharing as landowners seek information from peers about how they are working to comply with the law. It puts more initiative in the hands of the conservation manager to find areas adjacent to rivers and streams in need of BMPs, and to approach and help landowners be in compliance with the law by implementing BMPs (Gunderson 2015). This has been the case in Otter Tail County, MN, where a 50-foot buffer law has been in place since 1992, prompting conservation managers to find problem areas and contact landowners about being in compliance with the local ordinance (Gunderson 2015). If landowners find buffers acceptable, they can accept the default buffer strategy. If they so choose, they can work with local SWCD personnel to design their own NPS pollution mitigation plan as described above. This BMP selection process could, among many other factors, be influenced by research findings presented here in chapters 3 and 4.

Furthermore, the new Buffer Initiative theoretically has interesting implications for the analysis of the pyrolysis units in chapter 4. In the techno-economic analysis, one baseline assumption was a landscape with 4% perennial cover, scattered across the landscape in 160 acre blocks. The new Buffer Initiative changes this, as an estimated "125,000 acres of new land will be put into permanent vegetation under the law" (Buffer Fact Sheet 2015). More lands will be in perennial cover, but perhaps more significantly they will also be aggregated on the landscape. Both of these would theoretically lower biomass transport costs due to increased supply and decreased travel distances. Conversely, if perennial biomass lands are aggregated near streams and rivers, these lands may not be suitable for harvesting due to higher access costs and environmental concerns. The sensitivity analysis conducted in chapter 4 did address the "potential" scenario of more lands being converted to perennial production. The sensitivity analysis conducted at various scales of the distributed MAP model indicated that even a doubling of the landscape in perennial biomass production would not significantly increase either estimated annual profits or profits measured as $/gallon output. This suggests that the new Buffer Initiative would not significantly change the results of the baseline MAP analysis or the major conclusions described in chapter 4.

Contributions to the Literature

Human behavior and decision making processes are hard to change. But any attempt to do this should start with a clear understanding of current decision making processes. Although there are many descriptions of how conservation managers might improve the current decision making process, chapter 2 presents the first descriptive decision framework of conservation manager behavior described in the water quality literature. Currently, the decision process is largely driven by landowners who seek out local natural resource professionals and the availability of cost-share programs. Conservation managers view themselves more as facilitators to aid landowners through a complicated process or to help landowners find financial aid. The current decision process (chapter 2) allows little space for the aid of new tools, frameworks or optimization procedures to guide or influence the decision process of conservation managers at the local level. This research sheds new light on why many new ideas presented to conservation managers to optimize decisions fail to be implemented or have any significant impact. There is no obvious way to implement these new research findings into the current decision making process. Instead, this research suggests a more proactive, “door-knocking” strategy could bridge this knowledge-implementation gap. Additionally, encouraging BMP adopters to engage their peer networks might motivate and engage more landowners. Because of the constraints in the current voluntary BMP implementation process, the cost-effectiveness findings in chapter 3 are unlikely be incorporated into the current decision making process. Similarly, implementing the pyrolysis units described in chapter 4 would require policy makers to lay out and incentivize an expanded vision for working agricultural lands. For example, markets for perennial grasses might generate landowner interest in implementing MAP technology. Implementing these ideas would be more feasible with both the proactive door-knocking and peer networking strategies described in chapter 2. Although chapter 2 findings can help explain why chapter 3 and 4 findings are not likely to gain traction in the current decision making framework, the results from both chapters 3 and 4 should be of interest to conservation managers and state level policy makers, highlighting the need described in chapter 2 to modify decision making processes first.

The chapter 3 summary of BMP cost-effectiveness of P reduction based on aggregated empirical data of this magnitude is currently not found in the BMP water quality literature. By attempting to link cost estimates to each specific empirically-based BMP effectiveness study, the data presented in this research are much more comprehensive than previous research. Average BMP effectiveness and cost data measured or estimated for each BMP study were not aggregated or averaged up front to use one summary statistic of BMP effectiveness or cost, as is common in other BMP effectiveness and cost-effectiveness estimates (e.g. Dinnes 2004). This allowed for 143 data points of BMP cost-effectiveness and a larger sample size of many BMP cost-effectiveness estimates than other empirically-based research. This methodology, not found elsewhere in the BMP water quality literature, led to increased confidence in the median and a potential range of cost-effectiveness values.

Chapter 4 also used new methodologies to approach the techno-economic analysis of MAP units. One unique aspect of MAP units is their small size and mobility options. Generally small-scale biofuel processing units benefit from low feedstock transport costs, but suffer from diseconomies of scale. The added dimension of mobility can theoretically keep feedstock transport costs relatively low, while taking advantage of greater economies of scale. The impacts of mobility on a techno-economic analysis of pyrolysis units has not been modeled or studied in depth in the literature. Any discussion of mobile pyrolysis units is rare even in grey literature. This research did not model mobile pyrolysis units in isolation, but attempted to compare this new biofuel model to both a small-scale distributed model, and a larger, more traditional co-op model. In this unique analysis, results showed that although feedstock transport costs were indeed reduced with the mobile unit, this benefit was more than overwhelmed by the increase in labor costs for the mobile unit. If the labor assumptions of the mobile unit can be modified based on future engineering modifications, this could move the mobile unit towards financial viability. These new insights could guide future engineering efforts ongoing here at the University of Minnesota.

Another contribution to the literature was the mobilization of ideas from other disciplines into the context of current environmental and water quality literature. The decision theory literature (e.g. Bell et al. 1988) summarized the three types of decision theory (normative, descriptive, and prescriptive) and led to the realization that, while the environmental water quality literature offers many normative and prescriptive suggestions for conservation managers, the descriptive category is almost entirely lacking (chapter 2). Decision theory researchers would describe this as a major problem since good prescriptive decision theory is based on a solid knowledge of current descriptive decision theory (Baron 2004). This was augmented by findings in the environmental policy and climate change literature, which identified how this theoretical problem manifests itself in the form of a knowledge-implementation gap. Water quality conservation managers cannot incorporate new knowledge into their decision process if new research is not “compatible with existing policy-making processes and models” (Jones et al. 1999). Finally, the discovery in the biomedical literature about how to interpret (or not interpret) negative cost-effectiveness values was very formative in the analysis of the cost-effectiveness data (chapter 3). There is a robust discussion in the biomedical literature, lacking in the environmental water quality literature, describing why negative cost-effectiveness values “have no meaningful ordering” (O’Brien and Briggs 2002). Because of this, negative CE ratios should only be interpreted as categorical variables, and not included in ordinal statistical summary data such as boxplots or tables. Although this put some unexpected (and at times frustrating) limitations on data analysis of BMP cost-effectiveness from what was originally planned, it is a valuable insight for researchers in the environmental water quality literature in order to accurately report cost-effectiveness values and fairly summarize cost-effectiveness data.

Opportunities for Future Research

Research is always ongoing, as new answers inevitably lead to new questions and suggest directions for future study. The following are some possible directions for future research:

How can conservation decision processes be modified to increase agricultural BMP implementation? This research found that the voluntary conservation implementation process is a complex, requiring conservation managers to have an understanding of technical, policy, and human dimensions of conservation efforts. The process is largely driven by landowners who take the initiative to “walk in the door”, and the availability of cost-share programs (chapter 2). But what modifications would be needed to change this decision making process such that it is compatible? Encouraging peer exchange through network building, and promoting greater engagement with landowners accompanied by flexible cost-share options would be two meaningful steps to modify the current voluntary framework and make progress in reducing agricultural NPS pollution, but other approaches may also be beneficial. More research is needed to study the effects of these proposed policy changes, and how to implement them.

What effects will the new Buffer Initiative have on the cost-effectiveness of buffers? Policy makers will want to know what return they are getting for this greatly increased investment in buffers to provide ecosystem services. This offers an opportunity for more data collection on BMP cost-effectiveness to supplement the findings of this research. This could either confirm or negate the cost-effectiveness estimates found in this research (chapter 3). Perhaps of more interest is that the act of scaling up buffer installations may change cost-effectiveness values of buffers themselves. Maybe more buffer installations will lead to economies of scale and reduce the average buffer cost. For example, if many buffers are aggregated in one area, this could reduce average buffer installation costs due to the large scale of the project. Or perhaps average and median physical effectiveness values for buffers will decrease as buffers are installed on lands that may not benefit significantly from buffers. Larger quantities of data on buffer effectiveness and cost might also open the opportunity for more site specific analysis of BMP cost-effectiveness, or an overall estimate of the cost-effectiveness of the Minnesota Buffer Initiative.

How would inclusion of data on nitrogen, sediment, or other non-point source pollutants impact the cost-effectiveness results? A clear weakness of many BMP studies is their focus on a single pollutant. Although chapter 4 attempted to estimate the benefits of multiple ecosystem services, chapter 3 focused exclusively on phosphorus reduction. Part of this is due to a lack of data. There is little research looking at the effects of BMPs on pesticides or biopharmaceutical loads or concentrations in waterways. Nitrogen and sediment have much more data (even than phosphorus), but it is difficult to estimate how the damages from 1 lb. of nitrogen compare to the damages of 1 lb. of phosphorus or 1 lb. of sediment. Decision makers would benefit greatly from a comprehensive assessment of the cost-effectiveness of multiple pollutants. Methodological hurdles would make it difficult, but if this could be overcome the results of a cost-effectiveness analysis on multiple pollutants would be helpful.

What effects might be expected if biomass harvesting were allowed on lands dedicated for conservation efforts? One key assumption made by this research to allow the MAP units to function viably is legislation permitting the harvesting of above-ground perennial biomass on set aside conservation lands such as the Conservation Reserve Program (CRP) or the new Buffer Initiative (chapter 4). What effects would this have? Would the benefits of increased cellulosic biofuel production offset possible conservation losses on the CRP acres? Or might conservation benefits increase if biomass was harvested? Would it encourage more people to sign up for set aside conservation programs such as CRP? Would it allow federal CRP payments to decrease, if landowners could supplement CRP payments with selling the perennial biomass on these lands? What public response would there be of a “set aside” program that allows harvesting biomass for a profit? Is this politically feasible? Harvesting biomass from lands designated for conservation would likely come with myriad consequences, many of which are lacking research.

Comprehensive Bibliography

Abelson, R.P., and A. Levi. 1985. Decision making and decision theory. The Handbook of Social Psychology 1(3):231-309.

Allen, B. L., and A.P. Mallarino. 2008. Effect of liquid swine manure rate, incorporation, and timing of rainfall on phosphorus loss with surface runoff. Journal of Environmental Quality 37(1):125-137.

Almendinger, J. E., M.S. Murphy, and J.S. Ulrich. 2014. Use of the soil and water assessment tool to scale sediment delivery from field to watershed in an agricultural landscape with topographic depressions. Journal of Environmental Quality 43(1):9-17.

Anderson, D.M., A.D. Cembella, and G.M. Hallegraeff. 2012. Progress in understanding harmful algal blooms: Paradigm shifts and new technologies for research, monitoring, and management. Annual Review of Marine Science 4:143-176.

Arabi, M., R.S. Govindaraju, and M.M. Hantush. 2006. Cost-effective allocation of watershed management practices using a genetic algorithm. Water Resources Research, 42(10):1-14.

Armsworth, P. R., S. Acs, M. Dallimer, K.J. Gaston, N. Hanley, and P. Wilson. 2012. The cost of policy simplification in conservation incentive programs. Ecology letters 15(5):406-414.

Bang, H., and H. Zhao. 2012. Median-based incremental cost-effectiveness ratio (ICER). Journal of Statistical Theory and Practice 6(3):428-442.

Baron, J. 2000. Thinking and Deciding. Cambridge, UK: Cambridge University Press.

Baron, J. 2004. Normative models of judgment and decision making. *In* The Blackwell Handbook of Judgment and Decision Making, ed. Koehler, D.J., and N. Harvey, 19-36. London: Wiley-Blackwell.

Bell, D.E., H. Raiffa, and A. Tversky. 1988. Decision Making: Descriptive, Normative, and Prescriptive Interactions. Cambridge, UK: Cambridge University Press.

Bentrup, G. 2008. Conservation Buffers: Design Guidelines for Buffers, Corridors, and Greenways. General Technical Report SRS-109. Asheville, NC: USDA Forest Service, Southern Research Station.

Berg, W.A., S.J. Smith, and G.A. Coleman. 1988. Management effects on runoff, soil, and nutrient losses from highly erodible soils in the southern plains. Journal of Soil and Water Conservation 43(5):407-410.

Bishop, P.L., W.D. Hively, J.R. Stedinger, M.R. Rafferty, J.L. Lojpersberger, and J.A. Bloomfield. 2005. Multivariate analysis of paired watershed data to evaluate agricultural best management practice effects on stream water phosphorus. Journal of Environmental Quality 34(3):1087-1101.

Blanco-Canqui, H., A.L. Thompson, S.H. Anderson, C.J. Gantzer, and E.E. Alberts. 2004. Grass barrier and vegetative filter strip effectiveness in reducing runoff, sediment, nitrogen, and phosphorus loss. Soil Science Society of America Journal 68(5):1670-1678.

Blann, K. L., J.L. Anderson, G.R. Sands, and B. Vondracek. 2009. Effects of agricultural drainage on aquatic ecosystems: A review. Critical Reviews in Environmental Science and Technology 39(11):909-1001.

Boe, A., and D. Lee. 2007. Genetic variation for biomass production in prairie cordgrass and switchgrass. Crop Science 47(3): 929-934.

Bonham, J.G., D.J. Bosch, and J.W. Pease. 2006. Cost-effectiveness of nutrient management and buffers: Comparisons of two spatial scenarios. Journal of Agricultural and Applied Economics 38(1):17-32.

Boody, G., B. Vondracek, D.A. Andow, M. Krinke, J. Westra, J. Zimmerman, and P. Welle. 2005. Multifunctional agriculture in the United States. Bioscience 55(1):27-38.

Brach, J. 1989. Agriculture and Water Quality: Best Management Practices for Minnesota. St. Paul, MN: Minnesota Pollution Control Agency.

Bridgwater, A., D. Meier, and D. Radlein. 1999. An overview of fast pyrolysis of biomass. Organic Geochemistry 30(12): 1479-1493.

Brook, A., M. Zint, and R.De Young. 2003. Landowners' responses to an Endangered Species Act listing and implications for encouraging conservation. Conservation Biology 17(6):1638-1649.

Brooks, K.N., P.F. Ffolliott, H.M. Gregerson and L.F. DeBano. 2003. Hydrology and the Management of Watersheds. Ames, IA: Iowa State Press.

Brown, L., K. Boone, S. Nokes, and A. Ward. n.d. Agricultural Best Management Practices. Columbus, OH: Ohio State University Extension. http://ohioline.osu.edu/aex-fact/0464.html

Bryan, N.S., and H. van Grinsven. 2013. The role of nitrate in human health. Advances in Agronomy 119:153-182.

Buffer Fact Sheet. 2015. Governor's Buffer Initiative – Funding Fact Sheet – 4/8/15. St. Paul, MN: Minnesota Department of Natural Resources. http://files.dnr.state.mn.us/features/buffers/buffer-funding.pdf

Burdick, C. R., D.R. Refling, and H.D. Stensel. 1982. Advanced biological treatment to achieve nutrient removal. Journal Water Pollution Control Federation 54(7):1078-1086.

Camacho, R. 1992. Financial Cost-Effectiveness of Point and Nonpoint Source Nutrient Reduction Technologies in the Chesapeake Bay basin. Rockville, MD: Interstate Commission on the Potomac River Basin. http://nepis.epa.gov/Adobe/PDF/50000N7O.pdf

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications 8(3):559-568.

Cestti, R., J. Srivastava, and S. Jung. 2003. Agriculture Non-Point Source Pollution Control: Good Management Practices--The Chesapeake Bay experience. Washington, DC: World Bank Publications.

Christianson, L., J. Tyndall, and M. Helmers. 2013. Financial comparison of seven nitrate reduction strategies for Midwestern agricultural drainage. Water Resources and Economics 2:30-56.

Cole Hill Associates. 2004. Bio-oil Commercialization Plan. Sugar Hill, NH: New Hampshire Office of Energy and Planning. http://www.nh.gov/oep/programs/energy/documents/appendixanhbio-oilcommercializationplan.pdf

Coleman, M., D. Page-Dumrose, J. Archuleta, P. Badger, W. Chung, T. Venn, D. Loeffler, G. Jones, and K. McElligott. 2010. Can portable pyrolysis units make biomass utilization affordable while using bio-char to enhance soil productivity and sequester carbon? *In* Integrated Management of Carbon Sequestration And Biomass Utilization Opportunities in a Changing Climate: Proceedings of the 2009 National Silviculture Workshop, Boise, Idaho, June 15-18, 2009, pp. 159-168. Fort Collins, CO: USDA Forest Service Rocky Mountain Research Station.

Cooper, C.M., and S.S. Knight. 1990. Nutrient trapping efficiency of a small sediment detention reservoir. Agricultural Water Management 18(2):149-158.

Corbin, J., and A. Strauss. 2008. Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory. London: Sage Publications.

Correll, D.L. 1998. The role of phosphorus in the eutrophication of receiving waters: A review. Journal of Environmental Quality 27(2):261-266.

Coughenour, C. M. 2003. Innovating conservation agriculture: The case of no-till cropping. Rural Sociology 68(2):278-304.

Coyne, M.S., R.A. Gilfillen, R.W. Rhodes, and R.L. Blevins. 1995. Soil and fecal coliform trapping by grass filter strips during simulated rain. Journal of Soil and Water Conservation 50(4):405-408.

Cruse, R., D.R. Huggins, C. Lenhart, J. Magner, T. Royer, and K. Schilling. 2012. Assessing the Health of Streams in Agricultural Landscapes: The Impacts of Land Management Change on Water Quality. Ames, Iowa: Iowa Water Center.

Dalzell, B., D. Pennington, S. Polasky, D. Mulla, S. Taff, and E. Nelson. 2012. Lake Pepin Watershed Full Cost Accounting Project. Final Report Prepared for the Minnesota Pollution Control Agency. St. Paul, MN: Minnesota Pollution Control Agency.

Daniels, R.B., and J.W. Gilliam. 1996. Sediment and chemical load reduction by grass and riparian filters. Soil Science Society of America Journal 60(1):246-251.

Davenport, M., A. Pradhananga, and P. Nelson. 2013. Increasing voluntary conservation practice adoption through research and relationship building. Water Resources Impact 15:9-12.

Davenport, M.A., and B. Olson. 2012. Use and Determinants of Best Management Practices: A Study of Rush River and Elm Creek. Agricultural Producers Final Report, Submitted to The Minnesota Pollution Control Agency as Part of a Comprehensive Report on Nitrogen in Minnesota Surface Waters. St. Paul, MN*:* Department of Forest Resources, University of Minnesota.

Deal, S.C., J.W. Gilliam, R.W. Skaggs, and K.D. Konyha. 1986. Prediction of nitrogen and phosphorus losses as related to agricultural drainage system design. Agriculture, Ecosystems and Environment 18(1):37-51.

Devlin, D., K. Dhuyvetter, K. McVay, T. Kastens, C. Rice, K. Janssen, and G. Pierzynski. 2003. Water Quality Best Management Practices, Effectiveness, and Cost for Reducing Contaminant Losses From Cropland. MF-2572. Manhattan, KS: Kansas State University.

Dinnes, D.L. 2004. Assessments of Practices to Reduce Nitrogen and Phosphorus Nonpoint Source Pollution of Iowa's Surface Waters. National Soil Tilth Laboratory. Ames, IA: USDA-ARS.

Dinnes, D.L., D.L. Karlen, D.B. Jaynes, T.C. Kaspar, J.L. Hatfield, T.S. Colvin, and C.A. Cambardella. 2002. Review and Interpretation: Nitrogen Management Strategies to Reduce Nitrate Leaching in Tile-Drained Midwestern Soils. Lincoln, NE: USDA-ARS.

Dirkswager, A. 2011. Woody biomass wastes in northern Minnesota. Personal communication.

Dodds, W.K., W.W. Bouska, J.L. Eitzmann, T.J. Pilger, K.L. Pitts, A.J. Riley, J.T. Schloesser, and D.J. Thornbrugh. 2008. Eutrophication of US freshwaters: Analysis of potential economic damages. Environmental Science and Technology 43(1):12-19.

Dosskey, M.G., T.J. Schmitt, and K.D. Hoagland. 1999. Filter strip performance and processes for different vegetation, widths, and contaminants. Journal of Environmental Quality 28(5):1479-1489.

Downing, M., M. Walsh, and S. McLaughlin. 1995. Perennial grasses for energy and conservation: Evaluating some ecological agricultural, and economic issues. *In* Proceedings from Environmental Enhancement Through Agriculture, Boston, Massachusetts, November 16-17, 1995. Medford, MA: Center for Agriculture, Food and Environment, Tufts University.

Dressing, S.A. 2003. National Management Measures to Control Nonpoint Source Pollution From Agriculture. Report no. 841-B-03-004. Washington DC: Environmental Protection Agency.

Dunn, O.J. 1964. Multiple comparisons using rank sums. Technometrics 6(3):241-252.

Dutcher, D.D., J.C. Finley, A.E. Luloff, and J. Johnson. 2004. Landowner perceptions of protecting and establishing riparian forests: A qualitative analysis. Society and Natural Resources: An International Journal 17(4):319-332.

Edwards, W., A. Johanns, and A. Chamra. 2010. 2010 Iowa Farm Custom Rate Survey. Ag Decision Maker, File A3-10. Ames, Iowa: Iowa State University Extension. http://outagamie.uwex.edu/files/2010/06/2010CustomRateSurvey.pdf

Eghball, B., J.E. Gilley, L. Kramer, and T. Moorman. 2000. Narrow grass hedge effects on phosphorus and nitrogen in runoff following manure and fertilizer application. Journal of Soil and Water Conservation 55(2):172-176.

Falconer, I.R. 1999. An overview of problems caused by toxic blue–green algae (cyanobacteria) in drinking and recreational water. Environmental Toxicology 14(1):5-12.

FAPRI-UMC (The Food and Agricultural Research Institute, University of Missouri Columbia). 2007. Estimating Water Quality, Air Quality, and Soil Carbon Benefits of the Conservation Reserve Program. Report No. 01-07. Columbia, MO: University of Missouri-Columbia. http://swatmodel.tamu.edu/media/1331/fapri_umc_report_01_07.pdf

Fargione, J., J. Hill, D. Tilman, S. Polasky, and P. Hawthorne. 2008. Land clearing and the biofuel carbon debt. Science 319:1235-1238.

Feather, P., D. Hellerstein, and L. Hansen. 1999. Economic Valuation of Environmental Benefits and the Targeting of Conservation Programs: The Case of the CRP. Agricultural Economic Report 778. Washington, DC: US Department of Agriculture, Economic Research Service.

Feng, H., M. Jha, P.W. Gassman, and J.D. Parcel. 2007. A recent trend in ecological economic research: Quantifying the benefits and costs of improving ecosystem services. *In* Ecological Economics Research Trends, ed. C.C. Pertsova, 45-81. New York: Nova Publishers.

Fuglie, K. O., and S.L. Wang. 2012. New evidence points to robust but uneven productivity growth in global agriculture. Amber Waves 10(3):1-6.

Galzki, J., A. Birr, and D. Mulla. 2011. Identifying critical agricultural areas with three-meter LiDAR elevation data for precision conservation. Journal of Soil and Water Conservation 66(6):423-430.

Gamble, J. 2011. Prairie cordgrass yields in southern Minnesota. Personal communication.

Gaskin, J., C. Steiner, K. Harris, K. Das, and B. Bibens. 2008. Effect of low-temperature pyrolysis conditions on biochar for agricultural use. Transactions of the American Society of Agricultural and Biological Engineers 51(6):2061-2069.

Gelfand, I., T. Zenone, P. Jasrotia, J. Chen, S.K. Hamilton, and G.P. Robertson. 2011. Carbon debt of conservation reserve program (CRP) grasslands converted to bioenergy production. Proceedings of the National Academy of Sciences 108(33):13864-13869.

Ghebremichael, L.T., T.L. Veith, and J.M. Hamlett. 2013. Integrated watershed-and farm-scale modeling framework for targeting critical source areas while maintaining farm economic viability. Journal of Environmental Management 114:381-394.

Gitau, M., W.J. Gburek, and A.R. Jarrett. 2005. A tool for estimating best management practice effectiveness for phosphorus pollution control. Journal of Soil and Water Conservation 60(1):1-10.

Gitau, M.W., T.L. Veith, and W.J. Gburek. 2004. Farm-level optimization of BMP placement for cost-effective pollution reduction. Transactions of the American Society of Agricultural Engineers 47(6):1923-1931.

Glaser, B., and A. Strauss. 1967. The Discovery Grounded Theory: Strategies For Qualitative Inquiry. Chicago: Aldine De Gruyter.

Glick, H.A. 2012. Cost-effectiveness analysis lecture notes for pharmacoeconomics. University of Pennsylvania Health System, Philadelphia, PA. http://www.uphs.upenn.edu/dgimhsr/documents/1b.introcea.fda12.pdf

Goodwin, P., G. Wright, and L.D. Phillips. 2004. Decision Analysis for Management Judgment. London: Wiley.

Goolsby, D.A., W.A. Battaglin, G.B. Lawrence, R.S. Artz, B.T. Aulenbach, R.P. Hooper, D.R. Keeney, and G.J. Stensland. 1999. Flux and Sources of Nutrients in the Mississippi–Atchafalaya River Basin: Topic 3 Report for the Integrated Assessment on Hypoxia in the Gulf of Mexico. Silver Spring, MD: NOAA Coastal Ocean Program.

Gootee, R. S., K.A. Blatner, D.M. Baumgartner, M.S. Carroll, and E.P. Weber. 2010. Choosing what to believe about forests: differences between professional and non-professional evaluative criteria. Small-scale Forestry 9(2):137-152.

Grant, S., and T. Van Zandt. 2009. Expected utility theory. *In* The Handbook of Rational and Social Choice, ed. Anand, P., P. Pattanaik, and C. Puppe, 21-68. Oxford, UK: Oxford University Press.

Gray, N.F. 2008. Drinking Water Quality: Problems and Solutions. Cambridge, UK: Cambridge University Press.

Greer, F.R., and M. Shannon. 2005. Infant methemoglobinemia: The role of dietary nitrate in food and water. Pediatrics 116(3):784-786.

Gunderson, M. 2015. Counties stake middle ground in clean water, runoff fight. Minnesota Public Radio News. http://www.mprnews.org/story/2015/05/21/buffer-strip-success

Habron, G. B. 2004. Adoption of conservation practices by agricultural landowners in three Oregon watersheds. Journal of Soil and Water Conservation 59(3):109-115.

Hahn, R., and C. Cecot. 2009. The benefits and costs of ethanol: An evaluation of the government's analysis. Journal of Regulatory Economics 35(3):275-295.

Harmel, D., S. Potter, P. Casebolt, K. Reckhow, C. Green, and R. Haney. 2006. Compilation of measured nutrient load data for agricultural land uses in the United States. Journal of the American Water Resources Association 42(5): 1163-1178.

Harmel, D., S. Qian, K. Reckhow, and P. Casebolt. 2008. The MANAGE database: Nutrient load and site characteristic updates and runoff concentration data. Journal of Environmental Quality 37(6):2403-2406.

Hartman, J. C., J.B. Nippert, R.A. Orozco, and C.J. Springer. 2011. Potential ecological impacts of switchgrass (Panicum virgatum L.) biofuel cultivation in the Central Great Plains, USA. Biomass and Bioenergy 35(8):3415-3421.

Heaton, E. A., F.G. Dohleman, and S.P. Long. 2008. Meeting US biofuel goals with less land: The potential of miscanthus. Global Change Biology 14(9):2000-2014.

Heatwole, C.D., A.B. Bottcher, and L.B. Baldwin. 1987. Modeling cost-effectiveness of agricultural nonpoint pollution abatement programs on two Florida basins. Journal of the American Water Resources Association 23(1):127-131.

Hedley, G. 2007. FIDA Engineering Solutions: Remote Bio-Energy Report, Bio-Oil Option. Pukekohe, New Zealand: Alternative Energy Solutions Ltd. http://www.bioenergy.org.nz/documents/liquidbiofuels/AESBiooilOptionsPaper.pdf

Hill, J., S. Polasky, E. Nelson, D. Tilman, H. Huo, L. Ludwig, . . . D. Bonta. 2009. Climate change and health costs of air emissions from biofuels and gasoline. Proceedings of the National Academy of Sciences 106(6):2077-2082.

Hoffman, W., J. Beyea, and J.H. Cook. 1995. Ecology of agricultural monocultures: some consequences for biodiversity in biomass energy farms. *In* Proceedings of the Second Biomass Conference of the Americas: Energy, Environment, Agriculture, and Industry, Portland, Oregon, August 21-24, 1995. Golden, CO: National Renewable Energy Lab.

Horrigan, L., R.S. Lawrence, and P. Walker. 2002. How sustainable agriculture can address the environmental and human health harms of industrial agriculture. Environmental Health Perspectives 110(5):445-456.

Huggins, D.R., W.W. Nelson, D.J. Fuchs, M.P. Russelle, J.L. Anderson, and G.W. Randall. 1997. Nitrate losses through subsurface tile drainage in conservation reserve program, alfalfa, and row crop systems. Journal of Environmental Quality 26(5):1240-1247.

Industrial Microwave Systems, L.L.C. 2011. Frequently asked questions. http://www.industrialmicrowave.com/faqs.htm

ISU (Iowa State University). 2013. Iowa Nutrient Reduction Strategy: A Science and Technology-Based Framework to Assess and Reduce Nutrients to Iowa Waters and the Gulf of Mexico. Ames, IA: Iowa State University. http://www.nutrientstrategy.iastate.edu/sites/default/files/documents/NRSfull-130529.pdf

Jones, S.A., B. Fischhoff, and D. Lach. 1999. Evaluating the science-policy interface for climate change research. Climatic Change 43(3):581-599.

Kabii, T., and P. Horwitz. 2006. A review of landholder motivations and determinants for participation in conservation covenanting programmes. Environmental Conservation 33(01):11-20.

Kahneman, D. 2011. Thinking, Fast and Slow. New York: Macmillan.

Kaspar, T.C., E.J. Kladivko, J.W. Singer, S. Morse, and D.R. Mutch. 2008. Potential and limitations of cover crops, living mulches, and perennials to reduce nutrient losses to water sources from agricultural fields in the Upper Mississippi River Basin. In Upper Mississippi River Sub-basin Hypoxia Nutrient Committee Final Report, p. 127-148. St. Joseph, MI: American Society of Agricultural and Biological Engineers.

Knowles, M. 1990. The Adult Learner: A Neglected Species. Houston, TX: Gulf Publishing.

Kovacs, K. F., D. Pennington, B. Keeler, D. Kessler, J.O. Fletcher, S. Polasky, and S. J. Taff. 2010. Return On Investment In Conservation: An Economic Analysis of Ecosystem Services From Land Acquisitions by the Minnesota Department of Natural Resources. University of Minnesota, St. Paul, MN.

Krueger, R.A., and M.A. Casey. 2009. Focus Groups: A Practical Guide for Applied Research. London: Sage Publications.

Kueper, A. M., E.S. Sagor, and D.R. Becker. 2013. Learning from landowners: examining the role of peer exchange in private landowner outreach through landowner networks. Society and Natural Resources 26(8):912-930.

Kumar, A., and S. Sokhansanj. 2007. Switchgrass (Panicum vigratum, L.) delivery to a biorefinery using integrated biomass supply analysis and logistics (IBSAL) model. Bioresource Technology 98(5):1033-1044.

Lazarus, W. F. 2010. Minnesota crop cost and return guide for 2011.University of Minnesota Extension. http://faculty.apec.umn.edu/wlazarus/documents/cropbud.pdf

Lazarus, W. F., D.J. Mulla, and D. Wall. 2014. A spreadsheet planning tool for assisting a state agency with cost-effective watershed scale surface water nitrogen planning. Journal of Soil and Water Conservation 69(2):45A-50A.

Lee, K.N. 1999. Appraising adaptive management. Conservation Ecology 3(2):3-26.

Leys, C., C. Ley, O. Klein, P. Bernard, and L. Licata. 2013. Detecting outliers: Do not use standard deviation around the mean, use absolute deviation around the median. Journal of Experimental Social Psychology 49(4):764-766.

Liu, X., X. Zhang, and M. Zhang. 2008. Major factors influencing the efficacy of vegetated buffers on sediment trapping: A review and analysis. Journal of Environmental Quality 37(5):1667-1674.

Liu, Z., J. Schieffer, W. Hu, and A. Pagoulatos. 2011. Nonpoint source abatement costs in the Kentucky River watershed. Paper presented at the Agricultural and Applied Economics Association Annual Meeting, Pittsburgh, PA, July 24-26, 2011.

Logan, T.J., R. Lal, and W.A. Dick. 1991. Tillage systems and soil properties in North America. Soil and Tillage Research 20(2):241-270.

Lowrance, R., and J.M. Sheridan. 2005. Surface runoff water quality in a managed three zone riparian buffer. Journal of Environmental Quality 34(1):1851-1859.

Lyman, W. J., A.E. Glazer, J.H. Ong, and S.F. Coons. 1987. An Overview of Sediment Quality in the United States. Prepared for the EPA Office of Water Regulation and Standards. Washington, DC: US Environmental Protection Agency. http://water.epa.gov/polwaste/sediments/cs/upload/overview.pdf

MARC (Mid-America Regional Council). n.d. What is Sediment Pollution? Kansas City, MO: Mid-America Regional Council. http://cfpub.epa.gov/npstbx/files/KSMO_Sediment.pdf

Marcotty, J. 2015. New Minnesota law beefs up buffers along waterways. Star Tribune. http://www.startribune.com/new-minnesota-law-beefs-up-buffers-along-waterways/304356361/

Maringanti, C., I. Chaubey, M. Arabi, and B. Engel. 2011. Application of a multi-objective optimization method to provide least cost alternatives for NPS pollution control. Environmental Management 48(3):448-461.

Martin, J., M.C. Runge, J.D. Nichols, B.C. Lubow, and W.L. Kendall. 2009. Structured decision making as a conceptual framework to identify thresholds for conservation and management. Ecological Applications 19(5):1079-1090.

McLaughlin, S.B., and M.E. Walsh, M.E. 1998. Evaluating environmental consequences of producing herbaceous crops for bioenergy. Biomass and Bioenergy 14(4):317-324.

MDA (Minnesota Department of Agriculture). 2012. Best management practices. http://www.mda.state.mn.us/protecting/bmps.aspx

MDA (Minnesota Department of Agriculture). 2015. Targeting Best Management Practices (BMPs) to Critical Portions Of The Landscape. University of Minnesota, Department of Soil, Water and Climate. Saint Paul, MN: University of Minnesota. http://www.mda.state.mn.us/protecting/cleanwaterfund/research/targetingbmps.aspx

Merriam, S.B. 2009. Qualitative Research: A Guide to Design and Implementation. San Francisco, CA: John Wiley & Sons, Inc.

Merriman, K.R., M.W. Gitau, and I. Chaubey. 2009. A tool for estimating best management practice effectiveness in Arkansas. Applied Engineering in Agriculture 25(2):199-213.

Meschke, L. 2011. Microwave assisted pyrolysis technical and cost specifications. Personal communication.

Miller, T.P., C.F. Peterson, C.F. Lenhart and Y. Nomura. 2012. The Agricultural BMP Handbook for Minnesota. St. Paul, MN: Minnesota Department of Agriculture.

Minneapolis Biomass Exchange. 2011. Biomass pricing by feedstock. https://www.mbioex.com/pricing/feedstock_form_chart?feedstock_form_id=7

Minnesota Biofuels Association. 2015. Facts about ethanol. https://www.mnbiofuels.org/resources/facts-about-ethanol

MNRCS (Minnesota Natural Resoucres Conservation Service). 2011. Minnesota EQIP conservation practice payment schedule. http://efotg.sc.egov.usda.gov/references/public/MN/2011EQIPpayschedMAR9.pdf

Morrow, W. R., W.M. Griffin, and H.S. Matthews. 2006. Modeling switchgrass derived cellulosic ethanol distribution in the United States. Environmental Science and Technology 40(9):2877-2886.

Mostaghimi, S., S.W. Park, R.A. Cooke and S.Y. Wang. 1997. Assessment of management alternatives on a small agricultural watershed. Water Research 31(8):1867-1878.

Mostaghimi, S., T.M. Younos and U.S. Tim. 1991. The impact of fertilizer application techniques on nitrogen yield from two tillage systems. Agriculture, Ecosystems and Environment 36(1):13-22.

Mostaghimi, S., T.M. Younos, and U.S. Tim. 1992. Effects of sludge and chemical fertilizer application on runoff and water quality. Journal of the American Water Resources Association 28(3):545-552.

MPCA (Minnesota Pollution Control Agency). 2015a. Minnesota's impaired waters and TMDLs. http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/minnesotas-impaired-waters-and-total-maximum-daily-loads-tmdls.html

MPCA (Minnesota Pollution Control Agency). 2015b. Dashboard 2015: Environmental and performance measures related to the work of our agency. http://www.pca.state.mn.us/index.php/view-document.html?gid=22558

Mulla, D.J., and A.P. Mallawatantri. 2002. Minnesota River Basin water quality overview. University of Minnesota Extension Service. http://www.extension.umn.edu/distribution/naturalresources/DD7079.html

Mulla, D.J., S.J. Taff, G. Host, J. Galzki, T. Brown, A. Lewandowski, and J. Nelson. 2011. Statewide Ranking of Ecological Value of CRP and Other Critical Lands. St. Paul, MN: Minnesota Board of Soil and Water Resources. http://www.bwsr.state.mn.us/ecological_ranking/Ecological_Ranking_Final_Report_06July2011.pdf

Muscutt, A.D., G.L. Harris, S.W. Bailey, and D.B. Davies. 1993. Buffer zones to improve water quality: A review of their potential use in U.K. agriculture. Agriculture, Ecosystems and Environment 45(1):59-77.

Nan, L., G. Best, and C. Neto. 1994. Chapter 7: The research progress of biomass pyrolysis processes. *In* Integrated Energy Systems in China - The Cold Northeastern Region Experience, ed. L. Nan. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/t4470e/t4470e0a.htm

Napier, T.L., and T. Bridges. 2002. Adoption of conservation production systems in two Ohio watersheds: A comparative study. Journal of Soil and Water Conservation 57 (4):229-235.

Norris, P.E., and S.S. Batie. 1987. Virginia farmers' soil conservation decisions: An application of tobit analysis. Southern Journal of Agricultural Economics 19(1):79-90.

Norris, V. 1993. The use of buffer zones to protect water quality: A review. Water Resources Management 7(4):257-272.

Obenchain, R. L. 1999. Resampling and multiplicity in cost-effectiveness inference. Journal of Biopharmaceutical Statistics 9(4):563-582.

O'Brien, B. J., and A.H. Briggs. 2002. Analysis of uncertainty in health care cost-effectiveness studies: An introduction to statistical issues and methods. Statistical Methods in Medical Research 11(6):455-468.

Oquist, K., J. Strock, J., and D. Mulla. 2007. Influence of alternative and conventional farming practices on subsurface drainage and water quality. Journal of Environmental Quality 36(4):1194-1204.

Panuska, J.C., and K.G. Karthikeyan. 2010. Phosphorus and organic matter enrichment in snowmelt and rainfall–Runoff from three corn management systems. Geoderma 154(3): 253-260.

Parker, S.W., S. Mostaghimi, R.A. Cooke, and P.W. McClellan. 1994. BMP impacts on watershed runoff, sediment, and nutrient yields. Journal of the American Water Resources Association 30(6):1011-1023.

Patton, M.Q. 2005. Qualitative Research. Minneapolis, MN: John Wiley & Sons, Ltd.

Perrin, R., K. Vogel, M. Schmer, and R. Mitchell. 2008. Farm-scale production cost of switchgrass for biomass. Bioenergy Research 1(1):91-97.

Pfeffer, J., and R.I. Sutton. 1999. Knowing what to do is not enough: Turning knowledge into action. California Management Review 42(1):83-108.

Pimentel, D. 2003. Ethanol fuels: Energy balance, economics, and environmental impacts are negative. Natural Resources Research 12(2):127-134.

Plastina, A., A. Johanns, and S. Weets. 2015. 2015 Iowa Farm Custom Rate Survey. Ag Decision Maker. File A3-10. Ames, IA: Iowa State University Extension and Outreach. https://www.extension.iastate.edu/agdm/crops/pdf/a3-10.pdf

Poor, P.J., K.J. Boyle, L.O. Taylor, and R. Bouchard. 2001. Objective versus subjective measures of water clarity in hedonic property value models. Land Economics 77(4):482-493.

Pradhananga, A.K. 2014. A Moral Obligation Model of Landowner Conservation Norms and Behavior. PhD dissertation, University of Minnesota.

Prokopy, L.S., K. Floress, D. Klotthor-Weinkauf, and A. Baumgart-Getz. 2008. Determinants of agricultural best management practice adoption: Evidence from the literature. Journal of Soil and Water Conservation 63(5):300-311.

Pullin, A.S., and T.M. Knight. 2003. Support for decision making in conservation practice: An evidence-based approach. Journal for Nature Conservation 11(2):83-90.

Pullin, A.S., T.M. Knight, D.A. Stone, and K. Charman. 2004. Do conservation managers use scientific evidence to support their decision-making? Biological Conservation 119(2):245-252.

Rabalais, N. N., R.E. Turner, and W.J. Wiseman Jr. 2002. Gulf of Mexico hypoxia, AKA "The dead zone". Annual Review of Ecology and Systematics 33:235-263.

Raedeke, A.H., C.H. Nilon, and J.S. Rikoon. 2001. Factors affecting landowner participation in ecosystem management: A case study in South-Central Missouri. Wildlife Society Bulletin 29(1):195-206.

Ribaudo, M. O. 1989a. Targeting the conservation reserve program to maximize water quality benefits. Land Economics 65(4):320-332.

Ribaudo, M. O. 1989b. Water Quality Benefits from the Conservation Reserve Program. Agricultural Economics Report No. 606. Washington, DC: Economic Research Service, US Department of Agriculture.

Ribaudo, M.O., R.D. Horan, and M.E. Smith. 1999. Economics of Water Quality Protection from Nonpoint Sources: Theory and Practice. Agricultural Economics Report No. 782. Washington, DC: U.S. Department of Agriculture, Economic Research Service.

Richards, R.P., and D.B. Baker. 1997. Twenty Years of Change: The Lake Erie Agricultural Systems for Environmental Quality (LEASEQ) Project. Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development.

Ruan, R. 2011. Microwave assisted pyrolysis technical and cost specifications. Personal communication.

Ruan, R., and P. Heyerdahl. 2008. Distributed biomass conversion slideshow. Rural Advantage. http://ruraladvantage.org/pdf/microwave_pyrolysis.pdf

Ruan, R., P. Chen, R. Hemmingsen, V. Morey, and D. Tiffany. 2008. Size matters: Small distributed biomass energy production systems for economic viability. International Journal of Agricultural and Biological Engineering 1(1):64-68.

Runge, C. F., and B. Senauer. 2007. How biofuels could starve the poor. Foreign Affairs. http://www.ce.cmu.edu/~gdrg/readings/2007/05/22/Runge_HowBiofuelsCouldStarveThePoor.pdf

Runge, C.F. 2010. Comment made in a classroom discussion of APEC 5711. Fall term, 2010.

Russelle, M.P., G.W. Randall, and D.R. Huggins. 2001. Subsurface drain losses of water and nitrate following conversion of perennials to row crops. Agronomy Journal 93(3):477-486.

Salafsky, N., R. Margoluis, and K. Redford. 2001. Adaptive management: A Tool for Conservation Practitioners. Washington DC: Biodiversity Support Program.

Salafsky, N., R. Margoluis, K.H. Redford, and J.G. Robinson. 2002. Improving the practice of conservation: A conceptual framework and research agenda for conservation science. Conservation Biology 16(6):1469-1479.

Saldaña, J. 2012. The Coding Manual for Qualitative Researchers. London: Sage Publications.

Saleh, A., O. Gallego, E. Osei, H. Lal, C. Gross, S. McKinney, and H. Cover. 2011. Nutrient tracking tool—A user-friendly tool for calculating nutrient reductions for water quality trading. Journal of Soil and Water Conservation 66(6):400-410.

Schreiber, J.D., and R.F. Cullum. 1998. Tillage effects on surface and groundwater quality in loessial upland soybean watersheds. Transactions of the American Society of Agricultural Engineers 41(3):607-614.

Secchi, S.S., P.W. Gassman, M. Jha, L. Kurkalova, H.H. Feng, T.Campbell, and C.L. Kling. 2005. The Cost of Clean Water: Assessing Agricultural Pollution Reduction at the Watershed Scale. Ames, IA: Center for Agricultural and Rural Development, Iowa State University. http://www.card.iastate.edu/environment/items/idnr_assess.pdf

Seyfried, P.L., R.S. Tobin, N.E. Brown, and P.F. Ness. 1985. A prospective study of swimming-related illness: Morbidity and the microbiological quality of water. American Journal of Public Health 75(9):1071-1075.

Sharpley, A.N., T. Daniel, G. Gibson, L. Bundy, M. Cabrera, T. Sims, R. Stevens, ... and R. Parry. 2006. Best Management Practices to Minimize Agricultural Phosphorus Impacts on Water Quality. Washington, DC: USDA Agricultural Research Service. http://naldc.nal.usda.gov/download/26763/PDF

Sharpley, A.N., P.J. A. Kleinman, P. Jordan, L. Bergström, and A.L. Allen. 2009. Evaluating the success of phosphorus management from field to watershed. Journal of Environmental Quality 38(5):1981-1988.

Shortle, J., Z. Kaufman, D. Abler, J. Harper, J. Hamlett, and M. Royer. 2013. Building Capacity to Analyze the Economic Impacts of Nutrient Trading and Other Policy Approaches for Reducing Agriculture's Nutrient Discharge into the Chesapeake Bay. Final Report. Washington DC: USDA. http://www.usda.gov/oce/environmental_markets/files/EconomicTradingCBay.pdf

Simon, H. A. 1957. Models of Man: Social and Rational- Mathematical Essays on Rational Human Behavior in a Social Setting. London: Wiley.

Sioux City, Iowa. 2011. Water utility rates for irrigation. http://www.siouxcenter.org/index.aspx?NID=132

Smith, D. 2015. Dayton signs bill to mandate buffers to improve water quality and habitat. Star Tribune. http://www.startribune.com/dayton-signs-bill-to-mandate-buffers-to-improve-water-quality-and-habitat/307270551/

Smolen, M.D., and F.J. Humenik. 1989. National Water Quality Evaluation Project 1988 Annual Report: Status of Agricultural Nonpoint Source Projects. Washington, DC: U.S Environmental Protection Agency, Office of Water Regulations and Standards Division.

Sobhy, A., and J. Chaouki. 2010. Microwave-assisted biorefinery. Chemical Engineering Transactions 19:25-30.

Sokhansanj, S., S. Mani, A. Turhollow, A. Kumar, D. Bransby, L. Lynd, and M. Laser. 2009. Large-scale production, harvest and logistics of switchgrass (panicum virgatum L.)–current technology and envisioning a mature technology. Biofuels, Bioproducts and Biorefining 3(2):124.

Sprague, L.A., R.M. Hirsch, and B.T. Aulenbach. 2011. Nitrate in the Mississippi River and its tributaries, 1980 to 2008: Are we making progress? Environmental Science and Technology 45(17):7209-7216.

Steil, M. 2015. Plan to curb runoff too costly, unworkable, farmers tell Dayton. Minnesota Public Radio News. http://www.mprnews.org/story/2015/04/02/dayton-buffer-plan

Stinnett, A.A., and J. Mullahy. 1997. The negative side of cost-effectiveness analysis. Journal of the American Medical Association 277(24):1931-1932.

Stubbs, M. 2010. Environmental Quality Incentives Program (EQIP): Status and Issues. Washington, DC: Congressional Research Service.

Sutherland, W.J., A.S. Pullin, P.M. Dolman, and T.M. Knight. 2004. The need for evidence-based conservation. Trends in Ecology and Evolution 19(6):305-308.

Syed, A.U., and R.S. Jodoin. 2006. Estimation Of Nonpoint-Source Loads of Total Nitrogen, Total Phosphorous, and Total Suspended Solids in the Black, Belle, and Pine River Basins, Michigan, by Use of The PLOAD Model. US Geological Survey Scientific Investigations Report 2006-5071. Reston, VA: U.S. Geological Survey.

Taff, S. 2011. Minnesota land economics. http://www.landeconomics.umn.edu/

Theobald, D.M., N.T. Hobbs, T. Bearly, J.A. Zack, T. Shenk, and W.E. Riebsame. 2000. Incorporating biological information in local land-use decision making: Designing a system for conservation planning. Landscape Ecology 15(1):35-45.

Thorsell, S., F.M. Epplin, R.L. Huhnke, and C.M. Taliaferro. 2004. Economics of a coordinated biorefinery feedstock harvest system: Lignocellulosic biomass harvest cost. Biomass and Bioenergy 27(4):327-337.

Tilman, D. 1999. Global environmental impacts of agricultural expansion: The need for sustainable and efficient practices. Proceedings of the National Academy of Sciences 96(11):5995-6000.

Torrell, R., W. Riggs, and D. Griffith. 2008. Find out how much a truck costs per mile. http://magissues.farmprogress.com/wfs/WS03Mar08/wfs038.pdf

Trimble, S.W., and P. Crosson. 2000. US soil erosion rates--myth and reality. Science 289:248-250.

Turner, R.E., N.N. Rabalais, and D. Justic. 2008. Gulf of Mexico hypoxia: Alternate states and a legacy. Environmental Science and Technology 42(7):2323-2327.

Turner, R.K., and G.C. Daily. 2008. The ecosystem services framework and natural capital conservation. Environmental and Resource Economics 39(1):25-35.

Udawatta, R.P., J.J. Krstansky, G.S. Henderson, and H.E. Garrett. 2002. Agroforestry practices, runoff, and nutrient loss: A paired watershed comparison. Journal of Environmental Quality 31(4):1214-1225.

UIL Extension (University of Illinois Extension). 2015. Water use for ethanol production. http://web.extension.illinois.edu/ethanol/wateruse.cfm

UMN (University of Minnesota). 2009. Pilot microwave assisted pyrolysis system. Center for Biorefining. http://biorefining.cfans.umn.edu/research/

USBLS (U.S. Bureau of Labor Statistics). 2015. CPI inflation calculator. http://www.bls.gov/data/inflation_calculator.htm

USDA (U.S. Department of Agriculture). 2010. USDA Biofuels Strategic Production Report: A USDA Regional Roadmap to Meeting the Biofuels Goals of the Renewable Fuels Standard by 2022. Washington DC: USDA. http://www.usda.gov/documents/USDA_Biofuels_Report_6232010.pdf

USDA CRP (U.S. Department of Agriculture Conservation Reserve Program). 2011. Conservation reserve program. http://www.apfo.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp

USDA ERS (U.S. Department of Agriculture, Economic Research Service). 2007. Environmental quality incentives program data. http://webarchives.cdlib.org/sw12j6951w/http:/www.ers.usda.gov/Data/eqip/

USDA ERS (U.S. Department of Agriculture, Economic Research Service). 2014. Conservation spending seeks to improve environmental performance in agriculture. http://www.ers.usda.gov/topics/natural-resources-environment/conservation-programs/background.aspx

USDA FSA (U.S. Department of Agriculture Farm Service Agency). 2013. The Conservation Reserve Program 45th signup, County by County Summary. Washington DC: USDA Farm Service Agency https://www.fsa.usda.gov/Internet/FSA_File/su45county0813.pdf

USDA NRCS (U.S. Department of Agriculture Natural Resources Conservation Service). 2014a. The nine-step conservation planning process. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/mn/home/?cid=nrcs144p2_015695.

USDA NRCS (U.S. Department of Agriculture Natural Resources Conservation Service). 2014b. EQIP – General Contracting Guidance Document – FY 2015. List of Eligible Conservation Activity Plans, Practices and Program Guidance. St. Paul, MN: Minnesota NRCS.

USDA NRCS (U.S. Department of Agriculture Natural Resources Conservation Service). 2015. Environmental Quality Incentives Program. http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/

USEIA (U.S. Energy Information Administration). 2011. Weekly heating oil and propane prices (October - March). http://www.eia.gov/dnav/pet/pet_pri_wfr_dcus_nus_w.htm

USEPA (U.S. Environmental Protection Agency). 2003. National Management Measures to Control Nonpoint Source Pollution From Agriculture. Washington DC: USEPA. http://water.epa.gov/polwaste/nps/agriculture/agmm_index.cfm

USEPA (U.S. Environmental Protection Agency). 2005. Agricultural NPS fact sheet http://water.epa.gov/polwaste/nps/agriculture_facts.cfm

USEPA (U.S. Environmental Protection Agency). 2009. An Urgent Call to Action: Report of the State-EPA Nutrients Innovations Task Group. Washington, DC: USEPA. http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/upload/2009_08_27_criteria_nutrient_nitgreport.pdf

USEPA (U.S. Environmental Protection Agency). 2012a. Nutrient pollution. http://www.epa.gov/nutrientpollution/

USEPA (U.S. Environmental Protection Agency). 2012b. Drinking water contaminants: National primary drinking water regulations. http://water.epa.gov/drink/contaminants/index.cfm

USEPA (U.S. Environmental Protection Agency). 2012c. What is nonpoint source pollution? http://water.epa.gov/polwaste/nps/whatis.cfm

USEPA (U.S. Environmental Protection Agency). 2013. EPA proposes 2014 renewable fuel standards, 2015 biomass based diesel volume. http://www.epa.gov/oms/fuels/renewablefuels/documents/420f13048.pdf

USEPA (U.S. Environmental Protection Agency). 2014. Water: Polluted runoff from agriculture. Available from http://water.epa.gov/polwaste/nps/agriculture.cfm.

USEPA (U.S. Environmental Protection Agency). 2015. Water: Contaminated sediments basic information. http://water.epa.gov/polwaste/sediments/cs/aboutcs.cfm

USGS (U.S. Geological Survey). 2007. Investigating the environmental effects of agriculture practices on natural resources. http://pubs.usgs.gov/fs/2007/3001/pdf/508FS2007_3001.pdf

Valdovinos, C., and C. Balboa. 2008. Cercarial dermatitis and lake eutrophication in South-Central Chile. Epidemiology and Infection 163(3):391-394.

Veith, T.L., M.L. Wolfe, and C.D. Heatwole. 2003. Optimization procedure for cost-effective BMP placement at a watershed scale. Journal of the American Water Resources Association 39(6):1331-1343.

Veith, T.L., M.L. Wolfe, and C.D. Heatwole. 2004. Cost-effective BMP placement: Optimization versus targeting. Transactions of the American Society of Agricultural Engineers 47(5):1585-1594.

Vellidis, G., R.K. Hubbard, R. Lowrance, and P. Gay. 2003. Nutrient transport in a restored riparian wetland. Journal of Environmental Quality 32(2):711-726.

Wade, T.J., R.L. Calderon, E. Sams, M. Beach, K.P. Brenner, A.H. Williams, and A.P. Dufour. 2006. Rapidly measured indicators of recreational water quality are predictive of swimming-associated gastrointestinal illness. Environmental Health Perspectives 114(1):24-28.

Walker, J.F. 1994. Statistical techniques for assessing water-quality effects of BMPs. Journal of Irrigation and Drainage Engineering 120(2):334-347.

Walsh, M. E., D. Becker, and R.L. Graham. 1996. The Conservation Reserve Program as a means to subsidize bioenergy crop prices. *In* Proceedings of the Seventh National Bioenergy Conference, Nashville, Tennessee, September 15-20, 1996. Oak Ridge, TN: Oak Ridge National Laboratory. http://www.osti.gov/bridge/servlets/purl/772466-pGz7sY/webviewable/772466.pdf

Walsh, M.E., E. Daniel, H. Shapouri, and S.P. Slinsky. 2003. Bioenergy crop production in the United States: Potential quantities, land use changes, and economic impacts on the agricultural sector. Environmental and Resource Economics 24(4): 313-333.

Waters, T.F. 1995. Sediment in Streams: Sources, Biological Effects, and Control. Bethesda, MD: American Fisheries Society.

Weirich, C.A. and T.R. Miller. 2014. Freshwater harmful algal blooms: toxins and children's health. Current Problems in Pediatric and Adolescent Health Care 44(1): 2-24.

Willis, D.B. 2008. Cost-effectiveness of on-farm conservation practices to protect Playa Lake hydroperiod in the Texas high plains. Paper presented at Southern Agricultural Economics Association Annual Meetings, Dallas, TX, February, 3-6, 2008.

Wortmann, C., L.W. Morton, M. Helmers, C. Ingels, D. Devlin, J. Roe, . . . and M. VanLiew. 2011. Cost-Effective Water Quality Protection in the Midwest. Heartland Regional Water Coordination Initiative. Lincoln, NE: University of Nebraska-Lincoln.

Wortmann, C., M. Helmers, B. Gelder, L. Morton, D. Devlin, C. Barden, . . . T. Regassa. 2008. Targeting of Watershed Management Practices for Water Quality Protection. Heartland Regional Water Coordination Initiative. Lincoln, NE: University of Nebraska-Lincoln Extension Publications.

Wossink, G.A.A., and D.L. Osmond. 2002. Farm economics to support the design of cost-effective best management practice (BMP) programs to improve water quality: Nitrogen control in the Neuse River Basin, North Carolina. Journal of Soil and Water Conservation 57(4):213-220.

Wright, A.S., and B. Shindler. 2001. The role of information sources in watershed management. Fisheries 26(11):16-23.

Xu, M. 2012. Developing a comprehensive national conservation cost database. Slideshow presented at the Soil and Water Conservation Society Annual Conference, Fort Worth, TX, July 22-25, 2012.

Yescott, R.E. 1989. Observations on the ecology and control of swimmers' itch at Shadow Cliffs Lake, Alameda County, California. Bulletin of the Society for Vector Ecology 14(1):1-5.

Yu, Y.S. 2015. EPA Releases 2014 RIN Data, Uncovering the truth about cellulosic biofuel production. Lux Research Analyst Blog. http://blog.luxresearchinc.com/blog/2015/02/epa-releases-2014-rin-data-uncovering-the-truth-about-cellulosic-biofuel-production/

Yuan, Y., S.M. Dabney, and R.L. Bingner. 2002. Cost-effectiveness of agricultural BMPs for sediment reduction in the Mississippi Delta. Journal of Soil and Water Conservation 57(5):259-567.

Zabel, A., and B. Roe. 2009. Optimal design of pro-conservation incentives. Ecological Economics 69(1):126-134.

Zafar, S. 2009. Biomass pyrolysis. Alternative Energy eMagazine. http://www.altenergymag.com/emagazine.php?issue_number=09.02.01&article=pyrolysis

Zhang, L., R. Liu, R. Yin, and Y. Mei. 2013. Upgrading of bio-oil from biomass fast pyrolysis in China: A review. Renewable and Sustainable Energy Reviews 24:66-72.

Zhang, M., X. Zhang, and X. Liu. 2008. Major factors influencing the efficacy of vegetated buffers on sediment trapping: A review and analysis. Journal of Environmental Quality 37(5):1667-1674.

Zhu, J.C., S.H. Anderson, P.R. Beuselinck, C.J. Gantzer and E.E. Alberts. 1989. Runoff, soil, and dissolved nutrient losses from no-till soybean with winter cover crops. Soil Science Society of America Journal 53(4):1210-1214.

Appendices

Appendix A. A Review of Decision Support Tools to Address Water Quality.

Appendix B. Focus Group Introduction Script.

Appendix C. Focus Group Questioning Route.

Appendix D. Project Summary for Focus Group Participants.

Appendix A: A Review of Decision Support Tools to Address Water Quality

All of the projects listed below are:
1) Decision support tools (or related to decision support tools)
2) Related to water quality and/or quantity (storage) improvements
3) In agricultural settings
4) Applicable to Midwest U.S.

Project ID #: 1
Tool Name: Cover Crop Decision Tool
Description: A cover crop decision maker to assist farmers in selecting cover crops. Recommended cover crop is based on county, cash crop, soil drainage, and desired cover crop attributes. The tool creates a customized information sheet based on inputs.
Website or contact for more info: http://mcccdev.anr.msu.edu/ A project of the Midwest Cover Crops Council (MCCC).
Completed or In Progress?: Completed.
My Notes:
Related to Ag BMPs? (Y/N): Yes
A tool to select between different BMPs? (Y/N): No. (Only recommends cover crops.)
Physical effectiveness estimate for BMPs? (Y/N): No.
Financial component? (Y/N): No.
BMP Cost-effectiveness ranking? (Y/N): No.
Applicable to Midwest US? (Y/N): Yes.
MN specific? (Y/N): No.
Based Observed Data? (Y/N): Probably, but data sources are not clear.

Project ID #: 2
Tool Name: Fish Habitat Partnerships Habitat Assessment
Description: A model to prioritize and evaluate aquatic habitat. Model uses landscape, stream and lake data. Model then creates stressor-response functions and predictor variables. Outputs turn into "Natural Habitat Quality Index" or "Human Impact Index". Ultimately these indices will be developed into a GIS based decision support system. i.e., tool will tell you what the landscape can support with respect to a given fish species. Goal is to identify thresholds, set baselines, strategic planning.
Website or contact for more info: www.midwestfishhabitats.org has a link to a YouTube video on this tool. Maureen Gallagher (FWS Region 3 National Fish Habitat Partnership)
Completed or in progress?:In progress.
My Notes: heard of this from an email forwarded from Steve
Related to Ag BMPs? (Y/N): Yes.
A tool to select between different BMPs? (Y/N): Yes.
Physical effectiveness estimate for BMPs? (Y/N): Yes.
Financial component? (Y/N): No.

BMP Cost-effectiveness ranking? (Y/N): No.
Applicable to Midwest US? (Y/N): Yes.
MN specific? (Y/N): No.
Based Observed Data? (Y/N): No.

Project ID #: 3
Tool Name: Watershed Nitrogen Reduction Planning Tool
Description: Three parts: 1) A nitrogen budget to assess N-loading in 36 different agro-ecoregions throughout MN, to determine where problem areas are. 2) An economic tool to run a cost-effectiveness analysis of various BMPs according to the unique conditions in each agro-ecoregion. Goal is to determine the most economic ways of utilizing multiple BMPs in a cost-effective manner. 3) A social study, interviewing farmers about personal attitudes on BMP implementation.
Website or contact for more info: Bill Lazarus (wlazarus@umn.edu) or Bjorn Olson (olso6198@umn.edu)
Completed or in progress?: In progress, nearly complete as of July 2012
My Notes: Only looks at N. The N-budget is based on SWAT. The BMPs evaluated were: wetlands, controlled drainage, bioreactors, two-stage ditches, variable rate technology, buffer/filter strips, an alfalfa crop rotation, planting cover crops, and using the University of MN nitrogen application recommendations.
Related to Ag BMPs? (Y/N): Yes.
A tool to select between different BMPs? (Y/N): Yes.
Physical effectiveness estimate for BMPs? (Y/N): Yes.
Financial component? (Y/N): Yes.
BMP Cost-effectiveness ranking? (Y/N): Yes.
Applicable to Midwest US? (Y/N): Yes.
MN specific? (Y/N): Yes.
Based Observed Data? (Y/N): No.

Project ID #:4
Tool Name: eLINK (electronic link between state and local government)
Description: A web-based, GIS-enabled software package designed to help state and local government cooperate in natural resource management. It helps local governments plan and track conservation projects, prioritize and target financial assistance programs, map locations of projects, evaluate costs and benefits of conservation projects, estimate pollution reduction benefits, track projects for long-term monitoring. It helps state agencies evaluate effectiveness of programs, complete and analyze data at various scales, track grant funding, review grant applications. It helps field staff technicians identify problem areas, plan BMP implementation, manage landowner contact information, customize plans for landowners, and generate reporting data. SWCDs use this as a reporting tool for already installed projects, not as a planning tool.
Website or contact for more info: http://www.bwsr.state.mn.us/outreach/eLINK/manual/index.html or email conor.donnelly@bwsr.state.mn.us Supported by MN BWSR. For a report sample, see: http://www.blueearthswcd.org/BlueEarth_LeSueurRiverE.pdf

To log into eLINK: http://www.bwsr.state.mn.us/outreach/eLINK/index.html , see Conor's email for my log in and PW.

Completed or in progress?: Completed. (Although a new eLINK version is due to be released in spring 2013.)

My Notes: See email conversation with Conor for more details. eLINK data he sent me are in the eLINK folder. SWCDs use eLINK to report their projects.

Related to Ag BMPs? (Y/N): Yes.

A tool to select between different BMPs? (Y/N): No.

Physical effectiveness estimate for BMPs? (Y/N): Yes. User enters an estimate based on various tools, largely models like RUSLE2. And effectiveness estimates are usually done after installation, to report results to BWSR.

Financial component? (Y/N): Yes. Project costs are given.

BMP Cost-effectiveness ranking? (Y/N): No.

Applicable to Midwest US? (Y/N): Yes.

MN specific? (Y/N): Yes.

Based Observed Data? (Y/N): No. Although projects are real, pollution reduction estimates are based on models or equations, not measured observations

Project ID #:5

Tool Name: Conservation Effects Assessment Project (CEAP)

Description: "CEAP Goal... To improve efficacy of conservation practices and programs by quantifying conservation effects and providing the science and education base needed to enrich conservation planning, implementation, management decisions, and policy." Goal is to "develop the science base for managing the agricultural landscape for environmental quality." This will help provide "scientifically credible estimates of the environmental effects obtained from USDA conservation programs." Three main parts to CEAP: 1) national assessments, 2) watershed assessment studies, and 3) bibliographies and literature reviews

Website or contact for more info: Robert Kellogg Robert.kellogg@wdc.usda.gov or go to http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/ceap

Completed or in progress?: in progress.

My Notes: This website: http://www.nal.usda.gov/wqic/Bibliographies/ceap-scholarly.shtml#scholarly has a list of publication which might be relevant for the database I'm constructing. (This database is run through AGRICOLA.) Read this book: http://www.swcs.org/en/publications/environmental_benefits_of_conservation_on_cropland/index.cfm CEAP isn't really a tool. More a multi-pronged effort to quantify the environmental effects of conservation practices.

Related to Ag BMPs? (Y/N): yes.

A tool to select between different BMPs? (Y/N): yes.

Physical effectiveness estimate for BMPs? (Y/N): yes.

Financial component? (Y/N): no.

BMP Cost-effectiveness ranking? (Y/N): no.

Applicable to Midwest US? (Y/N): yes.

MN specific? (Y/N): no.

Based Observed Data? (Y/N): sort of. Sample points are selected to serve as representative fields, then these sample points are used to run field-level process models. There is also a bibliography of observed field studies.

Project ID #:6
Tool Name: Water Research Inventory Database
Description: "This project will develop and begin a user-friendly, searchable database to provide researchers, water planners, and the public with fast access to a centralized inventory of all types of research related to water in, or relevant to, Minnesota. The inventory will include non-peer reviewed 'gray literature' as well as peer-reviewed research, primarily from the year 2000 forward."
Website or contact for more info: https://www.mda.state.mn.us/protecting/cleanwaterfund/~/link.aspx?_id=A42E3C28A00E41E7B7DE60CE0F4836A9&_z=z, Barbara Weisman Barbara.weisman@state.mn.us or Christine Yaeger, yaeger@state.mn.us
Completed or in progress?: in progress
My Notes: see notes on my computer for more info
Related to Ag BMPs? (Y/N): yes.
A tool to select between different BMPs? (Y/N): no.
Physical effectiveness estimate for BMPs? (Y/N): no.
Financial component? (Y/N): no.
BMP Cost-effectiveness ranking? (Y/N): no.
Applicable to Midwest US? (Y/N): yes.
MN specific? (Y/N): yes.
Based Observed Data? (Y/N): yes and no (it's a database of all water quality related literature)

Project ID #:7
Tool Name: Minnesota Agricultural Best Management Practices Database
Description: A database of info related to agricultural BMPs in Minnesota. Data will be largely from the EOR Handbook (Project ID #8). "This project will attempt to answer questions and provide information in a comprehensive, easily accessible format. Information about the application, effectiveness and value of agricultural BMPs will be compiled in a database, used to create web-based tools and posted on a webpage."
Website or contact for more info: http://www.legacy.leg.mn/projects/agricultural-best-management-practices-assessment-and-tracking-tool or Stephanie Johnson sjohnson@houstoneng.com
Completed or in progress?: in progress.
My Notes: Go to http://mdabmp.houstoneng.net/ and type in the username and password. See email I sent to myself on July 26th for log-in and password to access the tool. I emailed Joshua Stamper in late July for a project update. Constructed by Houston Engineering, hosted by the MDA.
Related to Ag BMPs? (Y/N): yes.
A tool to select between different BMPs? (Y/N): yes.
Physical effectiveness estimate for BMPs? (Y/N): yes.
Financial component? (Y/N): no? (I didn't see it on the website, but I thought this was included…)

BMP Cost-effectiveness ranking? (Y/N): no.
Applicable to Midwest US? (Y/N): yes.
MN specific? (Y/N): yes.
Based Observed Data? (Y/N): y/n (it can be either included in the database, but I see some modeled data in the database right now)

Project ID #:8
Tool Name: The Agricultural BMP Handbook for TMDLs in Minnesota
Description: "The purpose of this handbook is to present the findings of a comprehensive inventory of agricultural Best Management Practices (BMPs) that address water quality impairments in Minnesota. This handbook provides Total Maximum Daily Load (TMDL) practitioners with the information necessary to identify suitable agricultural-BMPs for TMDLs and implementation plans in the agricultural watersheds of Minnesota." The handbook has one section for each BMP. Each section includes a BMP definition, explanation of potential water quality benefits, design considerations, cost information, operation and maintenance considerations, and references. Handbook also includes a table of references for both Minnesota and nationally, divided by pollutant and BMP type.
Website or contact for more info: Adam Birr (adam.birr@state.mn.us) or http://www.legacy.leg.mn/projects/agricultural-bmp-handbook-tmdls-minnesota
Completed or in progress?: in progress, estimated completion date of July 2012?
My Notes: Project done by Emmons and Oliver Resources, Inc. (EOR) consulting firm. See subfolder for April 2012 draft of the handbook. I emailed Joshua Stamper in late July for a project update.
Related to Ag BMPs? (Y/N): yes.
A tool to select between different BMPs? (Y/N): yes.
Physical effectiveness estimate for BMPs? (Y/N): no.
Financial component? (Y/N): yes.
BMP Cost-effectiveness ranking? (Y/N): no.
Applicable to Midwest US? (Y/N): yes.
MN specific? (Y/N): yes.
Based Observed Data? (Y/N): yes.

Project ID #:9
Tool Name: Revised Universal Soil Loss Equation, Version 2 (RUSLE2)
Description: A computer program that "estimates rates of rill and interrill soil erosion caused by rainfall and its associated overland flow. Accounts for four major factors: climate, soil, topography, and land use.
Website or contact for more info: http://www.ars.usda.gov/research/docs.htm?docid=6010 or http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm
Completed or in progress?: completed.
My Notes: Used frequently by BWSR and SWCDs. Required for BWSR spreadsheets and eLINK reporting.
Related to Ag BMPs? (Y/N): yes.
A tool to select between different BMPs? (Y/N): yes.
Physical effectiveness estimate for BMPs? (Y/N): yes.
Financial component? (Y/N): no.

BMP Cost-effectiveness ranking? (Y/N): no.
Applicable to Midwest US? (Y/N): yes.
MN specific? (Y/N): no.
Based Observed Data? (Y/N): no.

Project ID #:10
Tool Name: The Nine-step Conservation Planning Process
Description: "The purpose of the steps is to develop and implement plans that protect, conserve, and enhance natural resources within a social and economic perspective." The 9 steps are: Identifying Problems and Opportunities, Determine Objectives, Inventory Resources, Analyze Resource Data, Formulate Alternatives, Evaluate Alternatives, Make Decisions, Implement the Plan, and Evaluate the Plan.
Website or contact for more info: http://www.nh.nrcs.usda.gov/technical/ConservationPlanning/9step_planning_process.html Promoted by the NRCS.
Completed or in progress?: Completed.
My Notes: Source is from Dennis Fuchs and Focus Group #3 participants.
Related to Ag BMPs? (Y/N): Yes.
A tool to select between different BMPs? (Y/N): No.
Physical effectiveness estimate for BMPs? (Y/N): No.
Financial component? (Y/N): Yes.
BMP Cost-effectiveness ranking? (Y/N): No.
Applicable to Midwest US? (Y/N): Yes.
MN specific? (Y/N): No.
Based Observed Data? (Y/N): Can be, not does not need to be.

Project ID #:11
Tool Name: BMP Effectiveness Tool (A Tool for Estimating BMP Effectiveness for Phosphorous Pollution Control)
Description: A tool to estimate BMP effectiveness in reducing P pollution, based on data available in the literature. Tool contains a database of observed data studies, and users can search based on site soil, slope conditions, and geographic location. Designed for use in NY, but can be applied elsewhere.
Website or contact for more info: Margaret Gitau at Margaret.gitau@famu.edu
Completed or in progress?: completed.
My Notes: See her paper for more info: "Gitau, M.W., W.J. Gburek, and A.R. Jarrett. 2005. A tool for estimating BMP effectiveness for phosphorus pollution control. J. Soil and Water Conservation, 60(1): 1-10." The tool itself and this paper is in the folder on my computer.
Related to Ag BMPs? (Y/N): yes.
A tool to select between different BMPs? (Y/N): yes.
Physical effectiveness estimate for BMPs? (Y/N): yes.
Financial component? (Y/N): no.
BMP Cost-effectiveness ranking? (Y/N): no.
Applicable to Midwest US? (Y/N): yes.
MN specific? (Y/N): no.
Based Observed Data? (Y/N): yes.

Project ID #:12

Tool Name: BMP Effectiveness Tool for Arkansas

Description: "…a BMP tool was developed for use in Arkansas. The underlying database contains over 120 references and includes 163 agricultural BMPs grouped into 14 classes and 147 urban BMPs grouped into 8 classes. This tool will facilitate effectiveness-based BMP selection for agricultural and urban applications by providing BMP effectiveness estimates based on site characteristics." Tool addresses P, N, and sediment, urban and rural BMPs. Based on a database containing observed data studies.

Website or contact for more info: K.R. Merriman (email?) or Margaret Gitau (Margaret.gitau@famu.edu)

Completed or in progress?: completed.

My Notes: This tool is based on Margaret Gitau's P Tool (Project ID #11). See paper for more info: "A Tool for Estimating BMP Effectiveness in Arkansas" (located in the subfolder, along with the tool itself and documentation)

Related to Ag BMPs? (Y/N): yes.

A tool to select between different BMPs? (Y/N): yes.

Physical effectiveness estimate for BMPs? (Y/N): yes.

Financial component? (Y/N): no.

BMP Cost-effectiveness ranking? (Y/N): no.

Applicable to Midwest US? (Y/N): yes.

MN specific? (Y/N): no.

Based Observed Data? (Y/N): yes.

Project ID #:13

Tool Name: Nutrient Tracking Tool (NTT)

Description: "The Nutrient Tracking Tool (NTT) compares agricultural management systems to calculate a change in nitrogen, phosphorous, sediment loss potential, and crop yield. Agricultural producers and land managers can enter a baseline management system and an alternative conservation management system and produce a report showing the nitrogen, phosphorous, sediment loss potential, and crop yield difference between the two systems." Modeling is based on APEX. Assumes all acres of a given soil type and slope are identical. User enters a baseline cropping, irrigation, and nutrient input scenario, and an alternative scenario. Results show total N, P, runoff, and sediment per acre, a % reduction, and a total reduction for the specified area.

Website or contact for more info: http://nn.tarleton.edu/NTTWebARS/

Completed or in progress?: completed, latest release was March 2012

My Notes: Summary report compares a baseline scenario to an alternative scenario, and estimates changes in N, P, sediment and crop yields.

Related to Ag BMPs? (Y/N): Yes, by selecting different cropping scenarios

A tool to select between different BMPs? (Y/N): yes, at least different cropping scenarios.

Physical effectiveness estimate for BMPs? (Y/N): yes.

Financial component? (Y/N): no.

BMP Cost-effectiveness ranking? (Y/N): no.

Applicable to Midwest US? (Y/N): yes.

MN specific? (Y/N): no.

Based Observed Data? (Y/N): no.

Project ID #:14
Tool Name: LiDAR (Light Detection and Ranging)/LiDAR-based Terrain Analysis
Description: LiDAR is an active remote sensing technology that uses laser light to detect and measure surface features on the earth. A method of collecting digital elevation data. A few applications: 1) in Nicollet County this was used to find likely sites of gully erosion, as predicted by a LiDAR based model. Field inspections verified the model. 2) analyzing sediment accumulations in Lake of the Woods county, based on slope estimates and RUSLE 3) A targeting project to ID the top 50 source locations of erosion and runoff in the Zumbro watershed. Once the 50 are identified, in-field assessment techniques will plan BMPs appropriate for these locations.
Website or contact for more info: Minnesota Geospatial Information Office: http://www.mngeo.state.mn.us/chouse/elevation/lidar.html
Completed or in progress?: In progress. (But completed for most parts of Minnesota.)
My Notes: One application of LiDAR:
Related to Ag BMPs? (Y/N): yes.
A tool to select between different BMPs? (Y/N): no.
Physical effectiveness estimate for BMPs? (Y/N): no.
Financial component? (Y/N): no.
BMP Cost-effectiveness ranking? (Y/N): no.
Applicable to Midwest US? (Y/N): yes.
MN specific? (Y/N): no.
Based Observed Data? (Y/N): no.

Project ID #:15
Tool Name: Ecological Ranking Tool
Description: The conservation value of a parcel of land is based on three factors: soil erosion risk, water quality risk, and habitat quality. These three data layers are summed to calculated the Environmental Benefits Index (EBI). Resource managers can see a high resolution map of EBI scores for most areas of Minnesota, to estimate relative importance of a piece of land. Users can see how EBI scores change under different scenarios. The EBI score is a 1-300 scale with 300 being lands that are most valuable from a conservation perspective. Interactive map is available on the website below.
Website or contact for more info: http://www.bwsr.state.mn.us/ecological_ranking/ Point person: Aaron Spence, MN Board of Water and Soil Resources, aaron.spence@state.mn.us
Completed or in progress?: completed.
My Notes: A BWSR tool. I think mentioned in the focus groups.
Related to Ag BMPs? (Y/N): yes.
A tool to select between different BMPs? (Y/N): yes.
Physical effectiveness estimate for BMPs? (Y/N): no.
Financial component? (Y/N): yes.
BMP Cost-effectiveness ranking? (Y/N): no.
Applicable to Midwest US? (Y/N): yes.
MN specific? (Y/N): yes.
Based Observed Data? (Y/N): no.

Project ID #:16
Tool Name: A Crop Choice Model for Post-CRP Decisions
Description: Complement to the Ecological Ranking Tool. An economic model "to predict CRP parcel owners' decisions under different economics and policy scenarios…Essential components of this are crop choices, crop yields, crop production costs, and crop prices. Owners are assumed to select the option with the highest annual net return." When used in conjunction with the ERT (Project ID #15) managers can see what lands are likely to leave CRP enrollment and also estimate how to balance land conservation, surface water quality, and economic objectives.
Website or contact for more info: http://beaver.nrri.umn.edu/EcolRank/economic-analysis/ or email Steve Taff sjtaff@umn.edu
Completed or in progress?: completed
My Notes:
Related to Ag BMPs? (Y/N): yes (at least different crops)
A tool to select between different BMPs? (Y/N): yes.
Physical effectiveness estimate for BMPs? (Y/N): no.
Financial component? (Y/N): yes.
BMP Cost-effectiveness ranking? (Y/N): no.
Applicable to Midwest US? (Y/N): yes.
MN specific? (Y/N): no.
Based Observed Data? (Y/N): no.

Project ID #:17
Tool Name: BWSR Pollution Reduction Estimator for Water Erosion
Description: There are 4 water erosion types (tabs in Excel) that the user chooses from: 1) sheet and rill erosion, 2) gully stabilization, 3) stream bank/ditch stabilization, and 4) filter strip projects. The user enters data into Excel, and the spreadsheet calculates soil loss reduction, sediment reduction and P reduction due to a BMP implementation. Estimators for Sheet and rill erosion and for filter strip projects require input from RUSLE2. As an example, inputs for the "sheet and rill erosion" tab include distance to surface water, units soil type, units applied (acres), acres contributing to hydrologic system, and if a filter strip is present before installation or not, and RUSLE2 before and after calculations. BMP pollutant removal is then estimated.
Website or contact for more info: http://www.bwsr.state.mn.us/elinkupdate/Pollution_Reduction_Calculator_Manual.pdf
Completed or in progress?: Completed.
My Notes: To download tool, go to: http://www.bwsr.state.mn.us/outreach/eLINK/index.html Data from this tool is commonly used in eLINK, along with RUSLE2.
Related to Ag BMPs? (Y/N): Yes.
A tool to select between different BMPs? (Y/N): Yes. (Or, it could be. In reality it is used to report project outcomes on eLINK, post project installation.)
Physical effectiveness estimate for BMPs? (Y/N): Yes.
Financial component? (Y/N): No.
BMP Cost-effectiveness ranking? (Y/N): No.
Applicable to Midwest US? (Y/N): Yes.
MN specific? (Y/N): Yes.

Based Observed Data? (Y/N): No.

Project ID #:18
Tool Name: Prairie Pothole Region Integrated Landscape Conservation Strategy (PPRILCS)
Description: Project Goal: "To develop an integrated package of tools to guide efficient and coordinated management of wildlife habitat, water quality, flood reduction, and agricultural conservation programs throughout the prairie pothole region of MN and Iowa." Project is trying to ID strategic spatial priorities, evaluate outcomes of different management scenarios, and integrate tools/plans that already exist or are in development. Goal is to be accountable in terms of outcomes, not dollars spent or acres in conservation. This toolset can be applied to: 1) identify spatial priorities for conservation actions, 2) evaluate the outcomes of different management options, and 3) compare costs and benefits.
Website or contact for more info: Ryan Drum, USFWS Wildlife Biologist. Ryan_drum@fws.gov Or, see the wiki page for this project: http://pprilcs.wikispaces.com/
Completed or in progress?: in progress
My Notes: See IonE minigrant meeting notes. Ryan presented at this meeting. This project is still in progress, so I think some of the answers below are uncertain. They do want to build on past tools, to coordinate management.
Related to Ag BMPs? (Y/N): Yes.
A tool to select between different BMPs? (Y/N): Yes.
Physical effectiveness estimate for BMPs? (Y/N): I think no, but maybe.
Financial component? (Y/N): Yes…if financial tools are included in the final product. Ryan's presentation did NOT include info on the financial component.
BMP Cost-effectiveness ranking? (Y/N): No.
Applicable to Midwest US? (Y/N): Yes.
MN specific? (Y/N): Yes.
Based Observed Data? (Y/N): No.

Project ID #:19
Tool Name: Identifying Priority Management Zones (PMZs) for Best Management Practice (BMP) Implementation in Impaired Watersheds
Description: Main goal is to develop a process to determine Priority Management Zones and Critical Source Areas to restore impaired waters. **"**This [project] provides a listing of the available tools and models that may be considered for completing [watershed] assessments at various scales and tiers of complexity. Tier I corresponds to tools/models that may be used at a local level with no outside assistance. Tier II tools/models require outside training or technical assistance for their application and Tier III corresponds to models that would require outside assistance for a higher level of expertise." Deliverable is a "compendium of assessment tools that quickly rates benefits/limitations and recommendations for use/refinement of chosen tools."
Website or contact for more info: barr.com, need user log in info (see below). PIs include Dr. David Mulla (UMN), Greg Wilson (Barr Engineering), Jim Klang (Kieser & Assoc.) Dennis Fuchs (Stearns SWCD), Craig Mell (Chisago SWCD) , and Jay Riggs (Washington Conservation District) are collaborators.

Completed or in progress?: In progress. Not much completed yet on the Excel spreadsheet. Est. completion of June 2013.

My Notes: -Barr Engineering Priority Management Zone BMP Implementation in Impaired Watersheds, see folder. Website: Barr.com, click client services, see email I sent to myself on July 26th for user name a password information. Scheduled completion date of June 2013, this is a project to compare watershed assessment tools. See folder within this folder for an Excel spreadsheet listing different PMZ tools…do I have all of these on this list?

Related to Ag BMPs? (Y/N): Yes.

A tool to select between different BMPs? (Y/N): Yes.

Physical effectiveness estimate for BMPs? (Y/N): Yes.

Financial component? (Y/N): No.

BMP Cost-effectiveness ranking? (Y/N): No.

Applicable to Midwest US? (Y/N): Yes.

MN specific? (Y/N): No.

Based Observed Data? (Y/N): Mostly no. They will project response/indicators "against real world studies"

Project ID #: 20

Tool Name: Integrated Valuation of Environmental Services and Tradeoffs (InVEST)

Description: A family of GIS-based tools to value goods and services from nature. "InVEST enables decision-makers to assess the tradeoffs associated with alternative choices and to identify areas where investment in natural capital can enhance human development and conservation in terrestrial, freshwater, and marine ecosystems." Models are spatially explicit, and results can be either in biophysical terms, or economic terms. Spatial resolution is flexible. There are models for both sediment and nutrient retention. Water and sediment models run on an average annual basis.

Website or contact for more info: http://ncp-dev.stanford.edu/~dataportal/invest-releases/documentation/current_release/waterpurification.html#summary and http://ncp-dev.stanford.edu/~dataportal/invest-releases/documentation/current_release/sediment_retention.html#summary

Completed or in progress?: Tier 1 is done. Further Tiers are in progress.

My Notes:

Related to Ag BMPs? (Y/N): yes.

A tool to select between different BMPs? (Y/N): yes.

Physical effectiveness estimate for BMPs? (Y/N): yes.

Financial component? (Y/N): yes.

BMP Cost-effectiveness ranking? (Y/N): yes.

Applicable to Midwest US? (Y/N): yes.

MN specific? (Y/N): no.

Based Observed Data? (Y/N): no.

Project ID #:21

Tool Name: GIS Pollutant Load (PLOAD)

Description: An ArcView GIS tool to calculate non-point sources of pollution in watershed and stormwater projects. The model calculates pollutant loads on an average annual basis "for any user-specified pollutant", using either an export coefficient or the EPA's

Simple Method approach. Data required include landuse data, watershed data, pollutant loading rates, and impervious terrain (and other optional data are possible).

Website or contact for more info: http://ebmtoolsdatabase.org/tool/pload-pollutant-loading-application

Completed or in progress?: completed

My Notes: Latest version is 3.0. Is an extension of EPA's BASINS water quality software.

Related to Ag BMPs? (Y/N): yes.

A tool to select between different BMPs? (Y/N): yes.

Physical effectiveness estimate for BMPs? (Y/N): yes.

Financial component? (Y/N): no.

BMP Cost-effectiveness ranking? (Y/N): no.

Applicable to Midwest US? (Y/N): yes.

MN specific? (Y/N): no.

Based Observed Data? (Y/N): no.

Project ID #:22

Tool Name: Paper is titled "Quantifying the impact of stream alteration and accelerated streambank erosion on sediment and phosphorous load to the Minnesota River"

Description: The goal is to identify main sediment sources on a stretch of the MN River and estimate how stream alteration have influenced sediment and nutrient runoff. Done through both field studies and modeling (using HEC-RAS, CONCEPTS and ArcGIS).

Website or contact for more info: http://www.mncorn.org/images/stories/research/W9-Quanitifying-the-Impact-of-Stream-Alteration.pdf?phpMyAdmin=3be2c011603cc873735e3342b6328d12 or Chris Lenhart

Completed or in progress?:in progress

My Notes: Not sure if this really fits in with this decision support tool review. It is an analysis of one area, and not designed to answer questions about any other areas. BUT, it does do some targeting work to ID areas that are contributing relatively large amounts of sediment.

Related to Ag BMPs? (Y/N): yes, but not really a tool per se

A tool to select between different BMPs? (Y/N): no.

Physical effectiveness estimate for BMPs? (Y/N): no.

Financial component? (Y/N): no.

BMP Cost-effectiveness ranking? (Y/N): no.

Applicable to Midwest US? (Y/N): yes.

MN specific? (Y/N): yes.

Based Observed Data? (Y/N): Y/N (some based on observed data, some on modeled data)

Project ID #:23

Tool Name: Watershed Assessment Tool (WAT)

Description: Uses 5 categories (hydrology, geomorphology, biology, connectivity, and water quality). These 5 categories are divided into 18 indices based on 39 data layers to describe and compare watershed health for each of Minnesota's 81 Major Watershed Management Units. Web based.

Website or contact for more info: www.dnr.state.mn.us/watershed_tool/index.html Beth Knudsen, MN DNR, beth.knudsen@state.mn.us or Andy? From DNR who presented on this tool at the IonE mini-grant meeting.

Completed or in progress?: In progress, just starting phase 3
My Notes: see notes from IonE meeting. Lots of good GIS data and metadata found here: http://www.dnr.state.mn.us/watershed_tool/data_layers.html
Related to Ag BMPs? (Y/N): Yes, sort of.
A tool to select between different BMPs? (Y/N): No.
Physical effectiveness estimate for BMPs? (Y/N): No.
Financial component? (Y/N): No.
BMP Cost-effectiveness ranking? (Y/N): No.
Applicable to Midwest US? (Y/N): Yes. (But only MN data are loaded in the tool.)
MN specific? (Y/N): Yes.
Based Observed Data? (Y/N): No.

Project ID #:24
Tool Name: Minnesota Phosphorous Index (MNPI)
Description: "The Minnesota Phosphorus Index (P Index) is a management tool to estimate the relative risk that phosphorus is being lost from an agricultural field and delivered to a nearby ditch, stream, or lake. It allows the user to evaluate management options that can reduce the risk." A model for individual fields. Accounts for sediment-bound P, and dissolved P for both rainfall and snowmelt. The calculated index value "represents the relative long-term average risk of P losses for a given site and set of management practices."
Website or contact for more info: http://www.mnpi.umn.edu/ or email John Moncrief
Completed or in progress?: completed.
My Notes: Requires RUSLE2 as an input.
Related to Ag BMPs? (Y/N): yes.
A tool to select between different BMPs? (Y/N): yes.
Physical effectiveness estimate for BMPs? (Y/N): no. (model gives a unitless index score)
Financial component? (Y/N): no.
BMP Cost-effectiveness ranking? (Y/N): no.
Applicable to Midwest US? (Y/N): yes.
MN specific? (Y/N): yes.
Based Observed Data? (Y/N): no.

Project ID #:25
Tool Name: Phosphorous Index (PI)
Description: "The Phosphorus Index is a tool used to assess the potential for phosphorus (P) to move from agricultural fields to surface water. It uses an integrated approach that considers soil and landscape features as well as soil conservation and P management practices in individual fields. These characteristics include source factors such as soil test P; total soil P; rate, method, and timing of P application from commercial fertilizer, manure, and other organic sources; and erosion. Transport factors include sediment delivery, relative field location in the watershed, soil conservation practices, precipitation, runoff, and tile flow/subsurface drainage. Erosion, runoff and drainage factors for a site or field are used in a mathematical equation to determine whether the phosphorus movement risk is
very low, low, medium, high or very high."

Website or contact for more info: ftp://ftp-fc.sc.egov.usda.gov/IA/news/phosphorus.pdf or http://www.sera17.ext.vt.edu/Documents/P_Index_for_%20Risk_Assessment.pdf
Completed or in progress?: competed.
My Notes:
Related to Ag BMPs? (Y/N): yes.
A tool to select between different BMPs? (Y/N): yes.
Physical effectiveness estimate for BMPs? (Y/N): no. (gives a relative importance ranking)
Financial component? (Y/N): no.
BMP Cost-effectiveness ranking? (Y/N): no.
Applicable to Midwest US? (Y/N): yes.
MN specific? (Y/N): no.
Based Observed Data? (Y/N): no.

Project ID #:26
Tool Name: SNAP-Plus
Description: A nutrient Management planning software program designed for the preparation of nutrient management plans.
Website or contact for more info: www.snapplus.net Developed by U of WI-Madison Dept. of Soil Science.
Completed or in progress?: Completed
My Notes:
Related to Ag BMPs? (Y/N): Yes.
A tool to select between different BMPs? (Y/N): No. (Only does nutrient management plans.)
Physical effectiveness estimate for BMPs? (Y/N): Not sure.
Financial component? (Y/N): No.
BMP Cost-effectiveness ranking? (Y/N): No.
Applicable to Midwest US? (Y/N): Yes.
MN specific? (Y/N): No. Developed in accordance with Wisconsin's Nutrient Management Standard Code 590.
Based Observed Data? (Y/N): No. Based on RUSLE2 and a rotational P Index.

Project ID #:27
Tool Name: Bank Stability and Toe Erosion Model (BSTEM)
Description: An Excel-based model that calculates bank Factor of Safety for new or existing banks.
Website or contact for more info: http://ars.usda.gov/Research/docs.htm?docid=5044 Eddy J. Langendoen, Email: eddy.langendoen@ars.usda.gov
Completed or in progress?: Completed.
My Notes:
Related to Ag BMPs? (Y/N): Yes.
A tool to select between different BMPs? (Y/N): No. Only does BMPs related to bank stabilization.
Physical effectiveness estimate for BMPs? (Y/N): Yes. (At least in terms of a Factor of Safety, if not tons of sediment.)
Financial component? (Y/N): N
BMP Cost-effectiveness ranking? (Y/N): N

Applicable to Midwest US? (Y/N): Y
MN specific? (Y/N): N
Based Observed Data? (Y/N): Either observed or modeled data can be used.

Project ID #:28
Tool Name: Agricultural Non-Point Source Pollution Model (AGNPS)
Description: "…a tool for use in evaluating the effect of management decisions impacting water, sediment and chemical loadings within a watershed system." It predicts NPS pollution in agricultural watersheds. It is "designed to assist with determing BMPs, the setting of TMDLs, and for risk and cost/benefit analyses."
Website or contact for more info: http://go.usa.gov/KFO Supported by the USDA NRCS.
Completed or in progress?: Completed.
My Notes:
Related to Ag BMPs? (Y/N): Yes.
A tool to select between different BMPs? (Y/N): Yes.
Physical effectiveness estimate for BMPs? (Y/N): Likely yes.
Financial component? (Y/N): Not sure.
BMP Cost-effectiveness ranking? (Y/N): Not sure, probably not.
Applicable to Midwest US? (Y/N): Yes.
MN specific? (Y/N): No.
Based Observed Data? (Y/N): No.

Project ID #:29
Tool Name: Nitrogen Loss and Environmental Assessment Package with GIS Capabilities (NLEAP-GIS 4.2)
Description: This tool can be used to assess the "effects of management practices on N losses to the environment across risky landscape and cropping system combinations." Inputs include soil type, weather, rooting depth, and user specified management scenarios. Field scale computer model. Output is nitrate leaching indices for agricultural areas.
Website or contact for more info: http://www.ars.usda.gov/SP2UserFiles/ad_hoc/54020700NitrogenTools/NLEAP_GIS_4_2_Manual_Nov_29_2010.pdf or contact Jorge Delgado at jorge.delgado @ars.usda.gov Or see: http://www.ars.usda.gov/research/projects/projects.htm?accn_no=408566
Completed or in progress?: Completed (version 4.2)
My Notes:
Related to Ag BMPs? (Y/N): yes
A tool to select between different BMPs? (Y/N): yes
Physical effectiveness estimate for BMPs? (Y/N): yes
Financial component? (Y/N): no
BMP Cost-effectiveness ranking? (Y/N): no
Applicable to Midwest US? (Y/N): yes.
MN specific? (Y/N): no.
Based Observed Data? (Y/N): no.

Project ID #:30

Tool Name: ArcView Generalized Watershed Loading Function (AVGWLF)
Description: Simulates runoff, sediment, N and P loadings from a watershed. Continuous simulation model that uses daily time steps for weather data and water balance calculations. No spatial routing. Multiple land uses allowed, but each type is considered homogeneous. Erosion and sediment are based on the USLE.
Website or contact for more info: http://www.avgwlf.psu.edu/overview.htm
Completed or in progress?: completed.
My Notes:
Related to Ag BMPs? (Y/N): yes (at least can do land cover)
A tool to select between different BMPs? (Y/N): yes.
Physical effectiveness estimate for BMPs? (Y/N): yes.
Financial component? (Y/N): no.
BMP Cost-effectiveness ranking? (Y/N): no.
Applicable to Midwest US? (Y/N): yes.
MN specific? (Y/N): no.
Based Observed Data? (Y/N): no.

Project ID #:31
Tool Name: CONservational Channel Evolution and Pollutant Transport System (CONCEPTS)
Description: CONCEPTS is a stream corridor and bank erosion model. It simulates the long-term morphology of incised channels, from degradation, channel widening, aggradation, more widening, and finally a quasi-equilibrium. CONCEPTS simulates this evolution to "evaluate the long-term impact of rehabilitation measures to stabilize stream systems and reduce sediment yield."
Website or contact for more info: http://www.ars.usda.gov/Research/docs.htm?docid=5453
Completed or in progress?: completed
My Notes: Designed and maintained by the USDA Agricultural Research Service (ARS)
Related to Ag BMPs? (Y/N): yes.
A tool to select between different BMPs? (Y/N): yes. (if related to steambank stabilization)
Physical effectiveness estimate for BMPs? (Y/N): yes.
Financial component? (Y/N): no.
BMP Cost-effectiveness ranking? (Y/N): no.
Applicable to Midwest US? (Y/N): yes.
MN specific? (Y/N): no.
Based Observed Data? (Y/N): no.

Project ID #:32
Tool Name: MODular 3D finite-difference ground-water FLOW model (MODFLOW)
Description: Used by hydrogeologists to simulate the flow of groundwater through aquifers. Data requirements include initial conditions, hydraulic properties, stresses. Primary output is hydraulic head, but also can estimate drawdown and budget data. (Hydraulic head data can then be used to predict where water will flow in aquifers.)
Website or contact for more info: http://water.usgs.gov/nrp/gwsoftware/modflow2000/Mf2k.txt
Completed or in progress?: Completed (MODFLOW 2005 is latest version)
My Notes: Developed by the USGS

Related to Ag BMPs? (Y/N): yes. (at least ag BMPs related to groundwater, such as BMPs affecting wells, evapotranspiration, flow to drains, etc).
A tool to select between different BMPs? (Y/N): yes.
Physical effectiveness estimate for BMPs? (Y/N): yes. (water quantity estimates)
Financial component? (Y/N): no.
BMP Cost-effectiveness ranking? (Y/N): no.
Applicable to Midwest US? (Y/N): yes.
MN specific? (Y/N): no.
Based Observed Data? (Y/N): no.

Project ID #:33
Tool Name: Gridded Surface Subsurface Hydrologic Analysis (GSSHA)
Description: Combines LiDAR, soils, land use, surface water flow, ground water, other data. Physics-based, distributed, hydrologic, sediment and chemical fate and transport model. Spatially explicit, ideal for NPS pollution assessment and abatement. Surface and groundwater model.
Website or contact for more info: Greg Eggers, MN DNR, greg.eggers@state.mn.us or http://www.gsshawiki.com/gssha/Main_Page or http://chl.erdc.usace.army.mil/gssha
Completed or in progress?: Completed (version 2.0)
My Notes: developed and used by the US Army Corps of Engineers
Related to Ag BMPs? (Y/N): yes.
A tool to select between different BMPs? (Y/N): yes.
Physical effectiveness estimate for BMPs? (Y/N): yes.
Financial component? (Y/N): no.
BMP Cost-effectiveness ranking? (Y/N): no.
Applicable to Midwest US? (Y/N): yes.
MN specific? (Y/N): no.
Based Observed Data? (Y/N): no.

Project ID #:34
Tool Name: Agricultural Policy/Environmental eXtender (APEX)
Description: "…for use in whole farm/small watershed management. The model was constructed to evaluate various land management strategies considering sustainability, erosion (wind, sheet, and channel), economics, water supply and quality, soil quality, plant competition, weather, and pests. Management capabilities include irrigation, drainage, furrow diking, buffer strips, terraces, waterways, fertilization, manure management, lagoons, reservoirs, crop rotation and selection, pesticide application, grazing, and tillage."
Website or contact for more info: http://epicapex.brc.tamus.edu/ Designed and Maintained by Texas A&M and the USDA.
Completed or in progress?: Completed.
My Notes:
Related to Ag BMPs? (Y/N): Yes.
A tool to select between different BMPs? (Y/N): Yes.
Physical effectiveness estimate for BMPs? (Y/N): Yes.
Financial component? (Y/N): Yes.
BMP Cost-effectiveness ranking? (Y/N): Not sure, but unlikely.

Applicable to Midwest US? (Y/N): Yes.
MN specific? (Y/N): No.
Based Observed Data? (Y/N): No.

Project ID #:35
Tool Name: Soil and Water Assessment Tool (SWAT)
Description: "SWAT is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds." The model's objective is to "predict the effect of management decisions on water, sediment, nutrient, and pesticide yields with reasonable accuracy on large, ungauged river basins."
Website or contact for more info: swatmodel.tamu.edu
Completed or in progress?: Completed and actively supported.
My Notes:
Related to Ag BMPs? (Y/N): Yes.
A tool to select between different BMPs? (Y/N): Yes.
Physical effectiveness estimate for BMPs? (Y/N): Yes.
Financial component? (Y/N): No.
BMP Cost-effectiveness ranking? (Y/N): No.
Applicable to Midwest US? (Y/N): Yes.
MN specific? (Y/N): No.
Based Observed Data? (Y/N): No.

Project ID #:36
Tool Name: Hydrological Simulation Program—Fortran (HSPF)
Description: "HSPF simulates for extended periods of time the hydrologic, and associated water quality, processes on pervious and impervious land surfaces and in streams and well-mixed impoundments. HSPF uses continuous rainfall and other meteorologic records to compute streamflow hydrographs and pollutographs. HSPF simulates interception soil moisture, surface runoff, interflow, base flow, snowpack depth and water content, snowmelt, evapotranspiration, ground-water recharge, dissolved oxygen, biochemical oxygen demand (BOD), temperature, pesticides, conservatives, fecal coliforms, sediment detachment and transport, sediment routing by particle size, channel routing, reservoir routing, constituent routing, pH, ammonia, nitrite-nitrate, organic nitrogen, orthophosphate, organic phosphorus, phytoplankton, and zooplankton. Program can simulate one or many pervious or impervious unit areas discharging to one or many river reaches or reservoirs. Frequency-duration analysis can be done for any time series. Any time step from 1 minute to 1 day that divides equally into 1 day can be used. Any period from a few minutes to hundreds of years may be simulated. HSPF is generally used to assess the effects of land-use change, reservoir operations, point or nonpoint source treatment alternatives, flow diversions, etc."

Website or contact for more info: http://water.usgs.gov/cgi-bin/man_wrdapp?hspf
Completed or in progress?: completed.
My Notes:
Related to Ag BMPs? (Y/N): yes.
A tool to select between different BMPs? (Y/N): yes.

Physical effectiveness estimate for BMPs? (Y/N): yes.
Financial component? (Y/N): no.
BMP Cost-effectiveness ranking? (Y/N): no.
Applicable to Midwest US? (Y/N): yes.
MN specific? (Y/N): no.
Based Observed Data? (Y/N): no.

Appendix B: Focus Group Introduction

May 14, 2012

Hello everyone. Welcome, and thanks for taking time out of your busy schedules to talk about the development of this decision support tool. My name is Ann O'Neill, and I'm part of a research team at the University of Minnesota working on water quality issues in the Minnesota River Basin. Also here assisting me is Dean Current, who is the head of CINRAM (Center for Integrated Natural Resource and Agricultural Management) at the U and Charlene Brooks, who used to work for the SWCD in Nicollet County.

We're here today because the Minnesota Pollution Control Agency and the Environmental Protection Agency have funded a grant to help us develop a decision support tool for conservation managers to rank the cost-effectiveness of various practices on the landscape in reducing non-point source water pollution. At this point we are looking for input from future potential users as we design this tool. We'd like to ask you some questions in two general areas: 1) First we'd like to hear your experiences about what conservation practices you've worked with that you've found to be either effective or ineffective at reducing non-point source pollution in the area, 2) Second we want you to help inform the development of this decision support tool so that, when completed, you find this tool to be useful to your work on the ground.

You were invited to participate in this focus group because of your role or job with a local SWCD, the NRCS, a conservation NGO, or similar natural resource management group, and because you are making decisions that impact water quality. So, you're familiar with the conservation practices that can be implemented to improve water quality in the region, and you likely have a sense of their effectiveness and costs and what information is lacking that would be helpful for you to have.

Thank you for taking the time to read and sign the consent forms when you walked into the room. As a reminder, all questions are optional and you do not need to answer any questions that you don't want to. We do want you to know that we're audio recording this session, just so we can catch important details of what you've said. But please know that we're not attaching names to our reports. Everything said today will be de-identified when we analyze the data and write the reports. The reports on these focus groups will simply be used to help us decide what is or is not important in developing this decision support tool. Of course when we're done with the development of this tool we'll be glad to show you what we've developed and what we've learned.

Before I dive into the questions, I'd like to encourage a discussion format for our time together. It would be most helpful if this is not just me drilling you with questions, but rather a conversation about these questions. There are no right or wrong answers to these questions. We are interested in both positive and negative comments about your experiences, how to develop this decision support tool, and how to improve water quality. We expect that there will be differing opinions on these topics, and that's okay and even encouraged so that we're hearing all opinions.

Appendix C: Focus Group Questioning Route

Target audience: Conservation managers in southern Minnesota. These include personnel from Soil and Water Conservation Districts, Natural Resource Conservation Service, Minnesota Department of Agriculture, and the Minnesota Pollution Control Agency, and local NGOs. All focus group participants have significant knowledge in natural resource management and on the ground experience with water quality issues in the Minnesota River Basin.

Purpose of study: We want insight into the current decision making process of conservation managers and some input into a decision-support tool that is in development.

Questioning Route:

1) Please tell us who you are, what organization you work with, and what you enjoy doing in your free time.

2) What do you think are the most significant water quality issues in your watershed? *(Charlene will jot down answers. Allow response time.)* Next, we'd like each of you to grab a marker, and mark a "1" and a "2" next to the two that you think are the top two priorities. *(Give time to make marks…summarize results for group, get additional input.)*

3) What are some common conservation practices that you have implemented in the last three years to address water quality issues? *(Charlene will jot down answers. Allow response time.)* Again, we'd like each of you to grab a marker, and mark a "1", "2" *and*

"3" next to the three practices that you think are the most common. *(Give time to make marks…summarize results for group, get additional input.)*

4) Think back on those conservation practices you implemented with the goal of improving water quality. Tell me about some projects that you think were particularly effective in improving water quality. What made these projects so effective?

5) Again, think back on some conservation practices that you implemented with the goal of improving water quality. Now tell me about some projects that were particularly *in*effective. What do you think made these projects less effective than others?

6) How do you decide what conservation practices to implement and where to put them? Walk me though the decision-making process.

7) What information do you need to make decisions about selecting conservation practices? *(Charlene will jot down answers. Allow response time.)* Next, we'd like each of you to grab a marker, and mark a "1" and a "2" next to the two that you think are the top two pieces of information that would help with decision making about conservation practice installation. *(Give time to make marks…summarize results for group, get additional input.)*

8) What decision tools would be helpful to make better decisions about selecting conservation practices?

-At this point the moderator will take a moment to describe the decision support tool. This will be a roughly 5 minute "presentation" explaining our goal of developing a tool to help conservation managers rank the cost-effectiveness of conservation practices for their impacts on water quality. As a part of that, we will define cost-effectiveness to be sure the focus group understands what we mean. See document titled "explanation of tools for focus group…" for the information we'll share with focus group participants.

9) Think back on some previous projects to improve water quality that you've worked on. Were there any that were particularly *cost*-effective? How did you know?

10) What physical factors on the landscape do you think increase the effectiveness of various BMPs in improving water quality? (*Pass around the handout for each person to fill out. Give time to fill out. Discuss. Collect responses.) [Note: This key question will require probing, such as asking for examples in specific scenarios. But we want to start broad to not influence their answers.]* For a non-BMP example, if I asked you what factors would increase walk-up ticket sales at Twins games, you might say: sunny weather, low ticket prices, and a winning record.

11) Are there other tools that you already use or are aware of to address the cost-effectiveness of conservation practices? If so, how useful or not are they?

12) Can you give me some examples of decision support tools you use that are particularly well designed and user friendly?

13) What version of ArcGIS do you use? What licensing do you have (ArcView, ArcEditor, or ArcINFO)? Are there any other GIS platforms that you use?

14) Is there any advice you'd like us to keep in mind as we develop this decision support tool or other comments you'd like to share that you didn't get a chance to say earlier?

Appendix D: Project Summary for Focus Group Participants

A summary to read aloud (or summarize) during the focus groups

- This project, funded by an EPA 319 grant and administered through the MPCA, is attempting to address non-point source pollution in the Minnesota River Basin.
- Our part of this project is to develop a decision support tool that will help conservation managers rank conservation practices for their cost-effectiveness in improving water quality.
- The tool will likely address many water quality indicators, like nitrogen, phosphorous, and sediment, depending on what we hear from focus groups.
- BMPs included in the tool could be conservation practices like buffer strips, wetlands, fertilizer management, two-stage ditches, conservation tillage, etc. Either of these two lists could change after the focus groups are completed, based on what we hear from focus groups.
- The tool will be designed to estimate both the physical effectiveness and the cost of a given BMP in a specific scenario. With this information we can rank BMPs based on their cost-effectiveness.
- To clarify, when we say “cost-effective” we are asking which BMP can give us the most “bang for our buck”, or the lowest per-unit cost to reduce NPS pollution. With tight budgets, it makes sense to ask what the most cost-effective ways to reduce pollution are. The end goal is to be able to give conservation managers a quick and simple ranking of what BMPs might be most cost-effective in a certain scenario.

- Again, our primary goal is to develop a decision support tool that will rank conservation practices based on their cost-effectiveness in improving water quality. Are there any questions about the general goal of this decision support tool that I can answer before we move on to a few more focus group questions about the details of the tool?
  - *(Move on to the rest of the focus group questions…)*

Appendix E: Focus Group Information and Consent Sheet

INFORMATION SHEET FOR RESEARCH

Designing a Decision-Support Tool for Conservation Managers to Improve Water Quality in Agricultural Settings

You are invited to be in a research study on the decision making process of conservation managers and development of a decision-support tool. You were selected as a possible participant because you have at least three years of experience in implementing conservation measures to improve water quality in agricultural settings. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

This study is being conducted by:

1) Ann O'Neill, Department of Forest Resources, Natural Resource Science and Management Research Assistant, University of Minnesota

2) Dean Current, Department of Forest Resources, Center for Integrated Natural Resources and Agricultural Management, University of Minnesota

Procedures:

If you agree to be in this study, we would ask you to participate in answering a series of focus group questions about the decision making process of conservation managers and the development of a decision-support tool. We want to hear a variety of viewpoints and would like to hear from everyone. We ask that only one individual speak at a time in the group and that responses made by all participants be kept confidential. This focus group will last two hours or less.

Confidentiality:

The session will be audio taped, but all information will be de-identified before the final analysis and report. In any sort of report we might publish, we will not include any information that will make it possible to identify a subject. Research records will be stored securely, only research team members will have access to the records, and the tape recordings will be erased before the study is completed (July 2013).

Voluntary Nature of the Study:

Participation in this study is voluntary. Your decision whether or not to participate will not affect your current or future relations with the University of Minnesota. If you decide to participate, you are free to not answer any question or withdraw at any time without affecting those relationships.

Contacts and Questions:

The researchers conducting this study are Ann O'Neill and Dean Current. You may ask any questions you have now. If you have questions later, you are encouraged to contact them at:

Ann O'Neill
University of Minnesota, Green Hall
1530 Cleveland Avenue N.
St. Paul, MN 55108
651-955-9501
oneil368@umn.edu

Dean Current
University of Minnesota, Green Hall
1530 Cleveland Avenue N.
St. Paul, MN 55108
612-624-4299
curre002@umn.edu

If you have any questions or concerns regarding this study and would like to talk to someone other than the researchers, you are encouraged to contact the Research Subjects' Advocate Line, D528 Mayo, 420 Delaware St. Southeast, Minneapolis, Minnesota 55455; (612) 625-1650.

You will be given a copy of this information to keep for your records.

Statement of Consent:

I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature:____Date: _____________