Key Elements of Nutrient Credit Markets:

An Empirical Investigation of Wisconsin's Market-like Phosphorus Control Policy

By

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ABSTRACT

Previous empirical studies of market-like environmental policy focus on policy description and evaluation rather than the participants in the markets. To bridge this gap, I examine stakeholders' behaviors in Wisconsin's point-nonpoint source phosphorus credit markets. This inquiry consists of three sections that investigate the point source permittees' decision-making, the social networks around the key stakeholders of the markets, and the role of brokers in the markets. A dataset on point source permittees is compiled to capture the status of Wisconsin's nutrient credit markets. Expanding upon the dataset, I employ a mixed-method approach (interviews, document analysis, and a multinomial logistic regression model) to delineate the point source permittees' decision-making process and identify the important factors related to municipal permittees' decisions to participate in the markets. Limited by lack of information, high initialization cost, and rigid timeframes associated with permitting systems, the nutrient credit markets move in a slow manner compared with traditional markets for other goods and services. Permittees' participation in the markets is positively related to more stringent phosphorus criteria, more time to make the decision, and serving larger municipalities in more urbanized areas, indicating the strong influences of institutions, readiness of the market, and socio-economic context of the communities. I also conduct a case study that analyzes nutrient credit trading cases from a social network perspective. It recognizes key stakeholders of the markets and the approaches taken by point source permittees to connect with agricultural producers. It suggests that the rural-urban relationship is an essential foundation for nutrient credit trading and that trading, in return, shapes the relationship. The third section discusses how the county land and water conservation departments as brokers can help reduce transaction cost and control risk in local nutrient markets.

Chapter 1. Introduction and Overview

1.1 Background

1.1.1 Water quality regulations and policies in the U.S.

Excessive amounts of phosphorus and nitrogen in surface water and groundwater are among the most important stressors of water quality across much of the U.S. (Menció et. al. 2016; U.S. EPA 2017). For example, 50% of impaired rivers and 60% of impaired lakes are having trouble with eutrophication, a major consequence of excessive nutrient load (Carpenter et. al. 1998). The nutrients come from two sources: point source defined as “discernible, confined and discrete conveyance” and a more dispersed source, known as nonpoint source, such as agricultural and urban land runoff (Clean Water Act 1972). Point sources and urban runoff are subject to regulations from Environmental Protection Agency (EPA) authorized by the Clean Water Act (CWA). Agricultural nonpoint source dischargers may control their load through conservation practices called best management practices (BMPs), the implementation of which is not mandatory but is incentivized by a variety of cost-sharing programs. The programs are enabled by the recurring farm bill (most recently the Agriculture Improvement Act of 2018) and administered by Natural Resources Conservation Service (NRCS) and the Farm Service Agency (FSA).

Substantial progress has been made on regulation of point source pollution in the past several decades. The 1970s witnessed the inception of its legal and regulatory framework: EPA was created in 1970 and major amendments to the CWA were passed by Congress in 1972, 1977, and 1987. Under this framework, the point source polluters are required to meet either the technology-based permit limits or the water quality-based permit limits in order to get the

National Pollution Discharge Elimination System (NPDES) permits from EPA. As of 2019, 47 states have delegated authorities and run their own NPDES programs (U.S. EPA 2019). The CWA also mandates the states to list their waters not meeting applicable water quality standards as impaired waters and for each impairment of each water body listed to develop a Total Maximum Daily Load (TMDL). The TMDL allocates discharge quotas among different contributing sources in the impaired watersheds. Since the inception of these regulations, pollution loads from point sources have been significantly reduced.

In contrast, nonpoint source pollution is not adequately addressed by regulations. The CWA largely leaves the authority to manage nonpoint source, especially agricultural runoff, to the states, but the states generally do not take command-and-control type approaches. Instead, incentive or voluntary programs are common policy instruments used for nonpoint source pollution reduction. As noted, the most important incentive programs are created by the Farm Bill (renewed regularly and most recently as the Agriculture Improvement Act of 2018) and operated by NRCS. For instance, the Environmental Quality Incentive Program (EQIP) aims at improving the compatibility of agricultural production and environmental quality, and the Conservation Reserve Program (CRP) focuses on taking highly erosive and other marginal lands out of production. Although covering a significant amount of farmland, these programs have not provided sufficient resources to systematically solve the problem. Moreover, their cost-effectiveness is also questionable (Shortle et. al. 2012). Consequently, nonpoint source has become the main contributor of water pollution in the U.S. As of the late 20th century, 84% of phosphorus and 82% of nitrogen loads are from nonpoint sources (Carpenter et. al. 1998).

1.1.2 Introduction to nutrient credit markets

With enactment of more stringent water quality standards and development of TMDLs across the U.S., the permitted point source polluters, especially the small dischargers in rural communities, are facing technological and economic challenges coping with increasing demand for pollution reduction. Meanwhile, nonpoint source pollution has higher reduction potential with lower abatement cost, but deficient incentives constrain the reduction capacity.

Nutrient credit markets provide one solution for the two sources. By EPA's definition, pollution credit trading is "an approach that … [achieves] water quality goals on a watershed basis. It allows one source to meet its regulatory obligations by using pollutant reductions created by another source that has lower pollution control costs" (U.S. EPA 2003). In this research, a nutrient credit market is defined as a venue created by a state-initiated program for purchase and sale of nutrient pollution credits within designated areas and time periods. The pollution credits are pollution load reductions greater than the baseline requirements achieved by credit sellers and recognized by the regulators. Depending on the forms of markets, determination of numbers of trades that have occurred in a market is complicated (U.S. EPA 2008). In this research, if not otherwise specified, one point source permittee reaching a binding trading agreement with another point source or any number of nonpoint sources is considered one trade.

The idea of pollution credit trading was proposed in the late 1960s by economist John Dales in his book *Pollution, Property, and Prices* (1968). In the early 1980s, Wisconsin launched the nation's first pollution credit trading program that allowed wastewater treatment plants in Fox River Basin to trade credits of biological oxygen demand, but only one trade happened in 1995, ten years after the inception of the program (Jarvie & Solomo 1998; O'Neil 1983). In the early 2000s, as TMDL became a widespread policy instrument for state water quality agencies, many states started their own pilot trading programs for various pollutants, and EPA formalized its water quality trading policy in 2003 (Willamette Partnership 2012). Despite a large number of pollution credit trading programs implemented, projected trades rarely transpire in most of the cases. As of 2008, only 100 trades had occurred among more than 20 trading programs across the U.S., and 80% of them were from one point-point source pollution trading program (U.S. EPA 2008). Point-nonpoint source pollution trading programs experience additional difficulties as agricultural communities need to be involved. There are some cases in which single point sources purchased credits from multiple nonpoint source sellers, but most of the programs trying to engage nonpoint sources in trading have not been successful (Heberling et. al. 2018). The limited success is attributed to uncertainties in nonpoint source pollution control measurements, lack of policy drivers to create enough supply and demand, and high transaction costs, as well as many other barriers in policy design and program delivery (Fisher & Olmstead 2013; Ribaudo & Gottlieb 2011).

1.1.3 Wisconsin's nutrient credit markets

Wisconsin approved statewide numeric phosphorus standards in 2010. As a result, point sources applying for permits after December 2010 are subject to more restrictive water-quality based effluent standards but are granted 7-9 years for achieving compliance. The economic impact on the point source dischargers can be significant. As a way to alleviate economic pressures and direct new financial resources toward nonpoint sources, three market-like programs were developed between 2010 and 2017, that allow transaction of total phosphorus credits between agricultural producers and regulated dischargers. The Water Quality Trading

(WQT) program provides permitted point source polluters the option of purchasing discharge credits from other permitted point source and (unregulated) nonpoint source polluters; a related Adaptive Management (AM) compliance option allows all the nutrient sources in the same watershed to coordinate efforts to meet the ambient phosphorus standard; and a third Multi-Discharger Variance (MDV) option allows qualifying permitted dischargers (e.g., small rural municipalities) to pay a fixed price into a fund for agricultural nonpoint source pollution control within the watershed in exchange for credits. Compared to previous efforts, Wisconsin's new approach has catalyzed a relatively large volume of transactions between point source and nonpoint source polluters, and thus opens the door to empirical research on nutrient credit markets. These three programs (WQT, AM, and MDV) define the opportunities for transactions and establish the parameters for multiple localized nutrient credit markets across Wisconsin.

1.2 Gaps in the nutrient credit market literature

Researchers from the fields of agriculture/environmental economics, environmental management, and environmental/rural sociology and social psychology contribute most of the knowledge and experience on market-like environmental policies.

Beyond initially proposing the idea of pollution trading (Dales 1968), economists have contributed three strains of research on nutrient credit markets that parallel the implementation of trading programs on air quality, water quality, water quantity, greenhouse gas, and wetlands. First, microeconomic models help predict and understand the behaviors of market participants and the implications of different policy components. For example, some scholars pay close attention to transaction costs and their influence on the market equilibrium (Montereo 1998; Stavins 1995). Other elements analyzed include optimum spatial scopes of the markets (Doyle et.

al. 2014), definition of commodities in the markets (Atkinson & Tietenberg 1982; Hahn 1986), trading-ratio (Horan & Shortle 2005), baseline of permits generating (Ghosh et. al. 2011), and relationships among different conservation funding sources (Woodward 2011). Second, simulation is applied in case studies to either inform the policymaking in specific programs or demonstrate the implications of the economic theories (Eheart et. al. 1987; Nguyen et. al. 2013; O'Neil 1983; Wang 2018). Third, emerging perspectives such as game theory and behavioral economics are used to rationalize the market participants' behaviors. For example, some scholars look at how market powers manipulate the pollution credit markets to minimize compliance costs or to crowd out the competitors (Dickson & MacKenzie 2018; Johansson & Moledina 2005).

Although the economic research provides an important perspective, it misses two critical aspects of point-nonpoint pollution credit trading: 1) as most of the existing programs are designed for air pollution and point-point water pollution trading, the unique characteristics of point-nonpoint trading have not been thoroughly researched; 2) economic theories pay little attention to non-economic elements such as norms and beliefs in the analysis, while these elements are considered key factors in producer adoption of agricultural conservation practices. Researchers in the fields of watershed management and environmental sociology and psychology offer insights that bridge these knowledge gaps.

Watershed management researchers study specific pollution credit trading programs implemented at the watershed scale. These qualitative case studies provide valuable firsthand information learned in practice and open the door to many important research topics such as brokers' role in the market (Newburn & Woodward 2012) and the negative impacts of trading thresholds and transaction costs (Stephenson 2010). Wardropper et. al. (2018) and Konopacky

(2017) contributed the earliest accounts of Wisconsin's current nutrient credit markets. Wardropper et. al. (2018) examined the AM project led by Madison Metropolitan Sewage District in Yahara Watershed to analyze the risks for stakeholders derived from the uncertainty of monitoring and modeling. It also highlighted the watershed partnership opportunities brought about by AM. Konopacky (2017) described three AM cases in Wisconsin and characterized them as permittee-led watershed planning comparable to green infrastructure and stormwater planning. Watershed management researchers' work on other watershed management issues such as social characteristics of the watersheds (Prokopy et. al. 2009), adaptive management (Williams & Brown 2014), and social factors in nonpoint source pollution control (Breetz et. al. 2005; Taffand & Senjem 1996; Yeboah et. al. 2015) also shed light on point-nonpoint nutrient credit trading.

Environmental and rural sociology and psychology concentrate insight on behavior change. They are closely related to point-nonpoint trading and many other watershed management topics because they explain people's motivations to take actions, which are critical for voluntary or incentivized environmental protection programs. Building on the sociology and social psychology theories such as planned behavior (Ajzen 1992) and value-belief-norm (Stern et. al. 1999), researchers explored the individual and socio-economic influences on the conservation practice adoption (Genskow & Wood 2009). A substantive amount of studies has been conducted globally to examine farmers' behavior changes and their relationships with farmers' socio-economic states, beliefs, and norms (Beedell & Rehman 2000; Fielding et. al. 2005; Willy & Holm-Müller 2013; Zhang et. al. 2016). The concept of social embeddedness is also applicable to pollution credit trading. Researchers argue that the embeddedness, i.e., the social networks and trust among partners in watersheds, is a critical element of successful trading programs (Breeze et. al. 2005; Mariola 2012).

The previous literature provides valuable knowledge for policymakers, regulators, and researchers. However, due to the limited number of point-nonpoint source trading cases, there is a gap between theories and practices. The environmental scientists and economists oftentimes make oversimplified assumptions when theorizing the market-like approach. Specifically, the characteristics of the trading partners are reduced to two parameters: discharge volume and abatement cost. Other characteristics such as risk preference, bounded rationality, private information, strategic action, and social attitudes are understudied. Moreover, the trading process is also overlooked by the assumption of perfectly competitive markets in which buyers and sellers find each other immediately and trades take place in no time as long as theoretical demand and supply fit mathematically. On the other hand, researchers are also aware of the barriers in practices such as point and nonpoint source dischargers' reluctance to participate, the difficulties in finding trading partners, and the high transaction costs, but they are unable to identify and discuss the problems in a systematic approach. The gap between theories and practices is caused by lack of empirical studies of the markets; most of the previous studies focus on policy design. While some researchers do pay attention to implementation, their inquiries concentrate on regulators and rarely extend to the market participants. To bridge this gap, empirical studies are needed to understand who the market participants are and how they interact with each other.

1.3 Research Questions

In this study, I attempt to fill the research gaps by conducting empirical research on Wisconsin's nutrient credit markets. As the markets in Wisconsin have attracted a substantial amount of point source participants, they present an opportunity to detect commonalities among participants with different characteristics and examine if the key factors for success or barriers identified by single-case studies in previous literature could be applied to a larger population of point source permittees. To do so, I will investigate the implementation of the market-like policy from the perspective of the credit buyers and their partners. I attempt to answer three questions: 1) How did point source permittees make their decision regarding nutrient credit transactions and what factors are related to their decision to participate? 2) For these point sources who decided to participate in nutrient credit markets, how did they find their trading partners and how did the trading process interact with the local social networks? 3) Would markets centered around brokers address the key issues with nutrient credit trading? Specifically, can brokers help reduce transaction costs and uncertainty in trading?

1.4 Significance of the Research

These three research questions encompass credit buyers, their relationships with credit sellers and other partners, and the brokers, a group of partners of special importance. This study contributes to the research on markets for environmental goods in three ways. First, this is the first attempt to compile and study a large group of point source permittees in one region. While a rich collection of pollution credit trading cases has been described by previous literature, those cases are scattered across different trading programs whose temporal, spatial, and institutional backgrounds vary significantly. Informative as they are for comparison of program designs, the previous cases do not allow for a comparative analysis on the key actors of the markets, point source permittees. By looking into point source permittees' decision-making process and the factors related to the process, I will conduct an in-depth discussion of the markets on participation level.

Second, I also examine the non-participants. Bounded by the small proportions of trading participants in other trading programs, previous literature often had to focus on the cases in which actual transactions were generated. As a result, the point source permittees who were eligible for trading but chose not to participate have been overlooked. In this study, I include the point source permittees who are required to reduce phosphorus load but decide to meet their new permit limits by taking other approaches such as facility upgrade. Modeling their behaviors can greatly expand our understanding of nutrient credit trading.

Third, I inspect the process of trading from the perspective of social networks. I provide a detailed description of how point source permittees connect with agricultural producers. More importantly, I reveal the importance of social context for trading.

This work's significance for planning scholarship resides in its focus on an emerging phenomenon and its attention to the influence of non-economic factors on environmental market outcomes. It discusses the role of important planning elements, such as trust building, social capital, and watershed partnership as key elements for implementing market-like water quality control approaches. It will also inform planning practice by recognizing the key factors related successful market-like water quality programs. For regulators, local practitioners, and watershed groups in and out of Wisconsin, the lessons learned from this research will provide not only a roadmap for working with the point source permittees but also a guidance on coordination of valuable resources.

1.5 Road Map to the Dissertation

The rest of the dissertation proceeds as follows. The second chapter answers research question one by looking into point source permittees' decision-making process, the factors related to decisions to participate in nutrient credit markets, and the auxiliary policies that could facilitate nutrient credit transactions. The third chapter is a response to research question two. It reveals how point source permittees in Wisconsin's nutrient credit markets find their trading partners and trading's interactions with local social networks. The fourth chapter discusses brokers' roles in nutrient credit trading. The discussion is based on an innovative phosphorus trading program called Multi-Discharger Variance (MDV). The fifth chapter summarizes the findings and contributions of this study. It also points out the limitations of the study and suggests future research directions.

Chapter 2. Understanding Point Source Permittee Decision-making in Wisconsin's Nutrient Credit Markets

2.1 Overview

Phosphorus is an essential nutrient for aquatic plants and algae. It has become the most important nutrient factor that controls the growth of algae in Wisconsin's waters. However, excessive amounts of phosphorus can cause algal blooms and reduced water quality. Therefore, controlling phosphorus from point and nonpoint sources is critical to Wisconsin's water environment protection. The regulation of phosphorus lays the foundation for Wisconsin's nutrient credit markets. In this chapter, I outline and examine key issues for understanding point source decision-making for phosphorus. After a background section that introduces Wisconsin's regulatory options and nutrient markets, I briefly review the previous research that explored the key factors related to decision-making in point-nonpoint source nutrient credit trading. I introduce the research methods of this study in the third section and conclude with discussion of the findings and implications.

2.1.1 Background – Regulatory options of point source permittees

Wisconsin's phosphorus rules consist of three sections of the state administrative code: NR102 sets the maximum allowable phosphorus concentration in surface waters, NR217 mandates the effluent standards of point source permittees, and NR151 addresses discharge from nonpoint sources (Wis. Admin. Code Ch. NR 102 2021; Wis. Admin. Code Ch. NR 151 2021; Wis. Admin. Code Ch. NR 217 2021). For point sources, Wisconsin Department of Natural Resources (WDNR) oversees regulated discharges by Wisconsin Pollutant Discharge

Elimination System (WPDES), through authority delegated by the U.S. Environmental Protection Agency (U.S. EPA). Point sources must obtain WPDES permits and renew the permits every five years to discharge their wastewater. The permits specify the limits of pollutants including phosphorus.

Point source permittees can face one or more effluent phosphorus concentration requirements from three types of limits. First, since 1993, point source permittees have been required to meet the technology-based effluent limit (TBL), which equals to 1 mg/L, a target that could be achieved at reasonable costs by available technologies. TBL applies to most of the point source permittees except for 1) small dischargers (e.g., municipal wastewater treatment plants that discharge less than 150 lb of phosphorus per month), or 2) communities that would see severe social and economic impacts if the limit was to be enforced. The former would be directly exempted from this limit and the latter could apply for individual variance on a case-by-case basis. Second, if the receiving water of a point source permittee is formally identified as an impaired water and a Total Maximum Daily Load (TMDL) for phosphorus is established, the permittee should also meet a mass limit in accordance with the phosphorus waste-load allocation derived from the TMDL model. Third, a point source permittee can be subject to a water quality-based effluent limit (WQBEL) calculated from the ambient numeric phosphorus criterion of the receiving water. According to the calculation equation, the WQBEL oftentimes is equal to the stringent ambient numeric phosphorus concentration limit unless 1) the water quality of the receiving water has already been better than the criterion, and 2) the permittee's contribution to the phosphorus load is minimal.

The relationships of these three limits and their applicability to permittees are not always straightforward. While most of the point source permittees need to meet the TBL concentration limit, the TMDL-based mass limit and WQBEL concentration limit are often mutually exclusive; when a point source permittee is under a phosphorus TMDL, the TMDL-based limit will alter the WQBEL, whether the TMDL-based limit is more stringent or not. Most of the point source permittees have been in compliance with the TBL for several permit terms since the 1990s, but meeting new more stringent TMDL-based limits or WQBELs could pose significant challenges.

WQBELs have become the most stringent limits for many permittees since the revision of NR102 in December 2010. The revised statute stipulates the numeric phosphorus criteria for most of the waters in Wisconsin except for small lakes and reservoirs (with surface areas less than 5 acres), wetlands, waters with limited aquatic life, and ephemeral streams. The 2010 update makes Wisconsin one of the only five states in the U.S. with numeric phosphorus criteria (the others are Hawaii, Minnesota, New Jersey, and Florida) (U.S. EPA 2020). The phosphorus control goals of NR102 are ambitious: the limits for river and stream are 0.1 mg/L and 0.075 mg/L while the limits for lakes and reservoirs range from 0.015 mg/L to 0.04 mg/L.

With WQBELs, these limits become the default point source effluent limits via NR217. According to the effluent concentration equation, when the phosphorus concentration in the receiving water is higher than the criterion (which is the most common scenario), the point source permittee needs to reduce the phosphorus concentration of its limit down to the level of the ambient water criteria. For example, a point source permittee discharging into a stream needs to reduce the six-month average phosphorus concentration in its effluent to 0.075 mg/L or lower. Considering the inevitable temporal variation of water quality, WDNR allows the monthly-average limit to be three times as high as the six-month average limit, which means the monthly-average phosphorus limit for the aforementioned permittee would be 0.225 mg/L. Compared to the TBL of 1 mg/L, the new WQBEL is much more stringent and is difficult to achieve, especially for facilities built several decades ago. According to the economic impact analysis conducted by Wisconsin Department of Administration and WDNR, the new phosphorus rule would force 600 permittees to upgrade their facilities, incurring a gross capital cost of $7 billion, and thus would "cause substantial and widespread adverse social and economic impacts on a statewide basis" (WDOA & WNDR 2015). Due to the potential negative impacts on point source permittees, three alternative compliance options besides facility upgrade were designed by WDNR. The details of the options could be found in Table 2.1.

The first option is called Water Quality Trading (WQT). The focus of the WQT program is to meet permit criteria. Its framework is the same as the classic model of pollutant credit trading: phosphorus dischargers (credit buyers) with higher abatement cost can pay other dischargers (credit sellers) with lower abatement cost to reduce the seller's phosphorus load. In return, the buyers can discharge as much as the same amount of phosphorus it helped to reduce on top of its permitted phosphorus load. Trade ratios have been developed to ensure no net increase of phosphorus accrual in the water. Given the relative locations of the buyers and sellers in a watershed, the level of uncertainty in phosphorus reduction practices, and deposition and reaction of phosphorus in receiving waters, the trade ratio equation determines the converting factor between buyers and sellers. If the trading ratio was 1.2:1, the buyer would need to pay the seller to reduce 1.2 lb of phosphorus in order to discharge an additional 1 lb of phosphorus. The buyer has to find sellers in a proximate or upstream area to make sure that the reduction of phosphorus load by the seller precedes or concurs with the discharge of phosphorus from the buyer. Trading with downstream sellers could only happen when the buyer and seller are operating under the same TMDL. Timing of the trading is also strictly regulated. The buyer

Table 2.1 Comparison of WQT, AM, and MDV Programs

Program Features	Water Quality Trading (WQT)	Adaptive Management (AM)	Multi-Discharger Variance (MDV)
Subject	Phosphorus in effluent	Phosphorus in ambient environment	Phosphorus in effluent
Applicability	All point sources	All point sources	Point sources that are in eligible areas with relatively low median household income and need major facility upgrade for compliance
Mode	Point source-Point source, Point source-Nonpoint source	Point source-Point source, Point source-Nonpoint source	Point source-County*
Location Requirements for Trading Partners	Defined by TMDL or hydrological relations	Defined by TMDL or hydrological relations	Point source-County: within the same county
Program Duration	WQT is a permanent compliance method	AM is a permanent compliance method	MDV is a temporal compliance method. Currently, the program is set to be expired in 2027
Enforcement	Point sources can only use credit when reduction is observed	Point sources need to submit an AM plan; Implementation of the project will be overseen and enforced by WDNR	Point sources pay the county to implement conservation projects; Counties report phosphorus reduction to WDNR annually.

Note: More modes are available for MDV participants but county land and water conservation departments are the most common recipients of MDV payments.

needs to demonstrate phosphorus reduction first to be able to use the credits. The trading could happen between point sources or point sources and nonpoint sources.

The second option, Adaptive Management (AM), is a watershed-based trading program and the emphasis is ambient water quality. A point source may work with other sources, primarily nonpoint sources, to improve the ambient water quality together. The ambient water quality would be measured at a confluence point downstream of the point source permittee as determined by WDNR. This option requires a stronger collaboration among dischargers (point and nonpoint) in a watershed and means that the point source permittee itself has less control over the implementation. Nevertheless, this program has two advantages. First, once deciding on this option, the point source permittee will be granted 20 years, i.e., four permit terms, to achieve compliance, during which it needs to meet the gradually increasing reduction requirement. This extremely long compliance period gives the permittee more flexibility. Second, AM enables point source permittees who locate in the far upstream reaches of a watershed to trade with downstream sources that would not be available to them through WQT.

The third option is Multi-Discharger Variance (MDV). Unlike a traditional individual variance application that must be reviewed and approved by EPA, MDV provides a special channel for WDNR to manage the phosphorus variance application. The participants of MDV would pay a third-party entity a certain amount of money for each pound of phosphorus they discharge above their limits. The initial price for the MDV option was set as $50/lb in 2017 and increases at the same pace with Consumer Price Index each year. The third-party entity would use the payment to implement conservation projects to reduce phosphorus load in the watershed. By making the payment, the discharger will transfer the liability of phosphorus reduction to the third party. The third party is usually the county land and water conservation departments, though WDNR or other willing entities could also be the recipients of the payment under certain circumstances. MDV is not open to all point source permittees. Only point sources that need major facility upgrade for compliance but will suffer substantial economic impacts by doing so could apply for it. Moreover, MDV is a temporary program that helps facilities facing economic hardship to transit to other permanent compliance options. EPA only approved a ten-year window starting from 2017 for this program. Efforts have been made to extend it for another ten years, and the future of this program has yet to be determined by federal and state policymakers.

When a permittee applies for permit renewal, its compliance status is evaluated by WDNR. If WDNR determines that the permittee is subject to a more stringent phosphorus limit and it is not able to achieve compliance easily, WDNR would issue the new permit along with a nine-year compliance schedule. The compliance schedule requires the permittee to optimize its operation and work with major contributors of influent for source reduction for the first two years of the schedule. If the permittee was not able to achieve compliance with its current facility, it would have to evaluate all the alternative compliance options, compare them with other brick-and-mortar options (such facility upgrade and regionalization), and select the most cost-effective solutions to achieve compliance in the Third- and Fourth-year Alternative Compliance Reports.

2.1.2 Research Questions

Economic theory suggests that only when stringent regulations significantly increase the compliance expenses will point source permittees turn to a nutrient credit market for low-cost credits. However, according to the lessons learned from the past trading programs in the U.S., even with strong economic incentives, most of the point sources have chosen more costly facility upgrade instead of nutrient credit trading (U.S. EPA 2008). One study on nutrient credit trading markets (GAO 2017) shows that among 19 trading programs in 11 states, only 3 of them were active in 2014 (Wisconsin’s then newly launched programs were not counted). Most of the trading took place between point sources, and nonpoint source dischargers played only a trivial role in terms of credit generating (GAO 2017). Besides the simple abatement cost calculation, it is evident that point sources decision-making includes more factors that have not been fully accounted and understood. However, lack of trading cases between point source and nonpoint source dischargers significantly undermined previous researchers' ability to capture the motivations and behaviors of the market (non)participants. In comparison, almost one decade after the revision of the state's phosphorus criteria, about 150 point source permittees in Wisconsin have indicated interest in WQT, AM, or MDV over facility upgrade options to achieve compliance. This situation establishes Wisconsin's phosphorus credit market one of the largest nutrient credit trading markets in the U.S. and the largest market for point-nonpoint source pollution trading. Wisconsin's nutrient credit markets provide an opportunity to study the critical factors related to point source permittees' decisions about entering the market.

In an effort to understand these factors, I ask three questions in this research: 1) how do point sources make their compliance decisions, 2) what are the critical factors in their decision-making, and 3) what auxiliary policies could be applied to facilitate trading?

2.2 Literature Review

Multiple disciplines have sought to explain mechanisms for decision-making. Besides the rational choice theory held by economists, sociologists find that social factors can be important in certain circumstances, and psychologists argue that psychological traits of the decision-makers should also be factored into the inquiry (Beedell & Rehman 2000; Fielding et. al. 2005; Willy & Holm-Müller 2013; Zhang et. al. 2016).

In terms of point-nonpoint source nutrient credit trading, few researchers have directly examined the decision-making process and factors related to compliance decisions made by permitted point sources. Analysis of the literature examining challenges and barriers in previous point-nonpoint source trading programs suggests six types of factors that may influence these decisions: physical, environmental, institutional, organizational, social, and economic. Each is described below.

2.2.1 Physical Factors

Buyers in nutrient credit markets are incentivized by cost savings. In other words, the demand for nutrient credits must be created by stringent effluent limits that could not be easily met by the permittees. The physical conditions of the point source permittees can directly influence their ability to achieve compliance by themselves. Wallace (2007) found that point source permittees in North Carolina did not participate in nitrogen credit trading due to discovery of affordable on-site nitrogen control technology. This same reason was also identified in Virginia's point-nonpoint source nitrogen market—point source permittees realized that the marginal cost of purchasing credits from nonpoint sources was not lower than the marginal cost of reducing nitrogen load themselves (Stephenson et. al. 2010). Wisconsin experimented with phosphorus credit trading among point sources in the 1990s in the watersheds of Rock River and Fox-Wolf Basins. Researchers were optimistic about the market volume, estimating that 53 wastewater treatment plants would participate in credit trading due to the newly enacted TBL of 1 mg/L (David et. al. 1980). However, these programs failed to generate enough transactions as most of the permittees were able to meet the effluent limit with their own facilities or by upgrading their facilities at reasonable costs (Javier & Solomon 1998). Therefore, the physical conditions of the point source treatment plants (and related technical options available to them) can directly influence their willingness to look for solutions outside of the facilities.

2.2.2 Environmental Factors

Environmental factors are also acknowledged by many researchers. Unlike traditional commodities, pollution permits are heterogenous and location dependent. The availability and value of credits depend on the participants' locations. For a point source permittee, co-existence of nonpoint sources in the same watershed, the permittee's relative location with respect to the nonpoint sources, and the pollution reduction potential of the nonpoint sources can all influence its decision regarding trading. Lack of willing nonpoint source credit sellers is one of the most pervasive reasons that undermine trading programs (Fisher & Olmstead 2013). Hoag and colleagues (2017) emphasized that trading could only happen when point and nonpoint sources co-located in the same watersheds. Applying the filter of co-location and other two thresholds, they found that only 5% of the nutrient impaired water bodies in the U.S. were suitable for nitrogen trading and 13% of them were suitable for phosphorus trading (Hoag et. al. 2017).

2.2.3 Institutional Factors

Third, institutional factors are also among the most mentioned determinants of pollution market performance. Many previous programs failed to generate enough trades due to complicated permitting system or high uncertainty about the trading policy (Heberling et.al. 2018). Among all the phosphorus control rules, it is the effluent baseline that creates incentives for trading. For point sources, if the baseline is too low and the allowable effluent limits are set too high, there will be no trades. For example, in many states, the TMDLs are among the most common drivers of trading since they reduce nutrient discharge limits. In some cases, when a TMDL could not be developed, the potential demand for trading also disappeared (Fisher & Olmstead 2013). In contrast, in Wisconsin, with its relatively low ambient water quality standards, the WQBEL is usually more stringent than TMDL-base limit and could potentially be a stronger driver for trading participation. WNDR also rules that the credits generated by nonpoint sources under a phosphorus TMDL are transferable but could only be used temporarily and will expire in five years (WDNR 2013a). The threshold may drive away potential sellers from trading and thus hinder trading in watersheds under TMDLs (Ghosh et. al. 2011; Ribaudo & Gottlieb 2011). According to the findings of previous literature, WQBEL seems to be a better baseline to boost trade participation compared with TMDL.

2.2.4 Organizational Factors

The first three sets of factors could all be understood under the framework of rational choice theory. There are three additional types of factors that represent more aspects of the decision-making process. The fourth type, organizational factors, i.e., existence of brokers, quasi-brokers, and other partners, as well as their willingness and ability to work with point sources, are considered to be important determining factors in trading programs by some researchers (Mariola 2012). Researchers found that nonpoint sources (agricultural producers) were not familiar with the nuance of complicated trading schemes and thus tended to work with entities trusted by them (O'Grady 2011). To facilitate trading, many programs involve independent third parties such as a credit exchange entity (Wallace 2007), conservation districts (Newburn & Woodward 2012), and watershed organizations (O'Grady 2011). Availability of partners who can connect point source permittees with nonpoint source dischargers, especially agricultural producers, can strongly influence the feasibility of nutrient credit trading.

2.2.5 Social Factors and Economic Factors

The last two are social and economic factors. Social factors, i.e., those related to community interaction and civic engagement, may impose positive or negative influence on participation in nutrient credit trading. Economic factors refer to measures of the economic capacity of a local community. Few published studies on pollution trading have examined the relationship between trades and socio-economic context. In the field of watershed planning, Genskow and Prokopy (2011) developed a tool called Social Indicator Planning and Evaluation System (SIPES). In order to evaluate watershed programs in the short- and medium-terms, SIPES establishes a set of social indicators, i.e., variables about local social background, to measure intermediate changes expected to lead to water quality improvements (Genskow & Prokopy 2011; Prokopy et. al. 2009). By the same logic, since point-nonpoint source pollution trading involves implementation of conservation practices and the socio-economic background in which it takes place should be closely scrutinized.

In this study, I make the assumption that a permitted point source discharger is more likely to participate in nutrient credit trading when 1) its physical condition nullifies the solution of facility upgrade, 2) it is proximate to abundant nonpoint source dischargers, 3) it is under more stringent regulation, 4) it is well connected with third-party entities who can facilitate trade, and 5) it locates in a sufficiently connected community with higher social and economic capitals to support trading. These assumptions will be tested by a decision-making model as explained in the next section.

2.3 Methods

2.3.1 Analytical Strategy

I take a concurrent mixed-method research approach (Creswell 2014) by combining qualitative information (mainly from interviews) with a quantitative dataset on point source permittees to support exploration of point source decision-making mechanisms. The mixed-method approach is gaining attention from social science scholars due to its ability to accommodate a large scope of issues and provide deeper insight on the study subjects. Each type of method has strengths and limitations, and in this study, the qualitative and quantitative methods interact and play critical roles in different sections of the research. For example, qualitative data collection and analysis allows for detailed description and understanding of dynamic procedures and decision factors; yet resource constraints make it impractical to use the method on a large number of study subjects—it is beyond available resources to interview all point source permittees in Wisconsin. Besides, quantitative statistical techniques are more effective for revealing relationships among a large group of observations, in this case for the full population of point source permittees.

Specifically, I carried out this study in a sequential way such that the leading qualitative analysis guides the quantitative data collection and analysis, and in turn the quantitative modeling results are explained and validated by the qualitative findings. This is known as the method-level combination of qualitative and quantitative methods (Sandelowski 2000). The data analysis software of R was used for quantitative analysis and NVivo 11 was applied in qualitative analysis. Figure 2.1. illustrates the analytical framework.

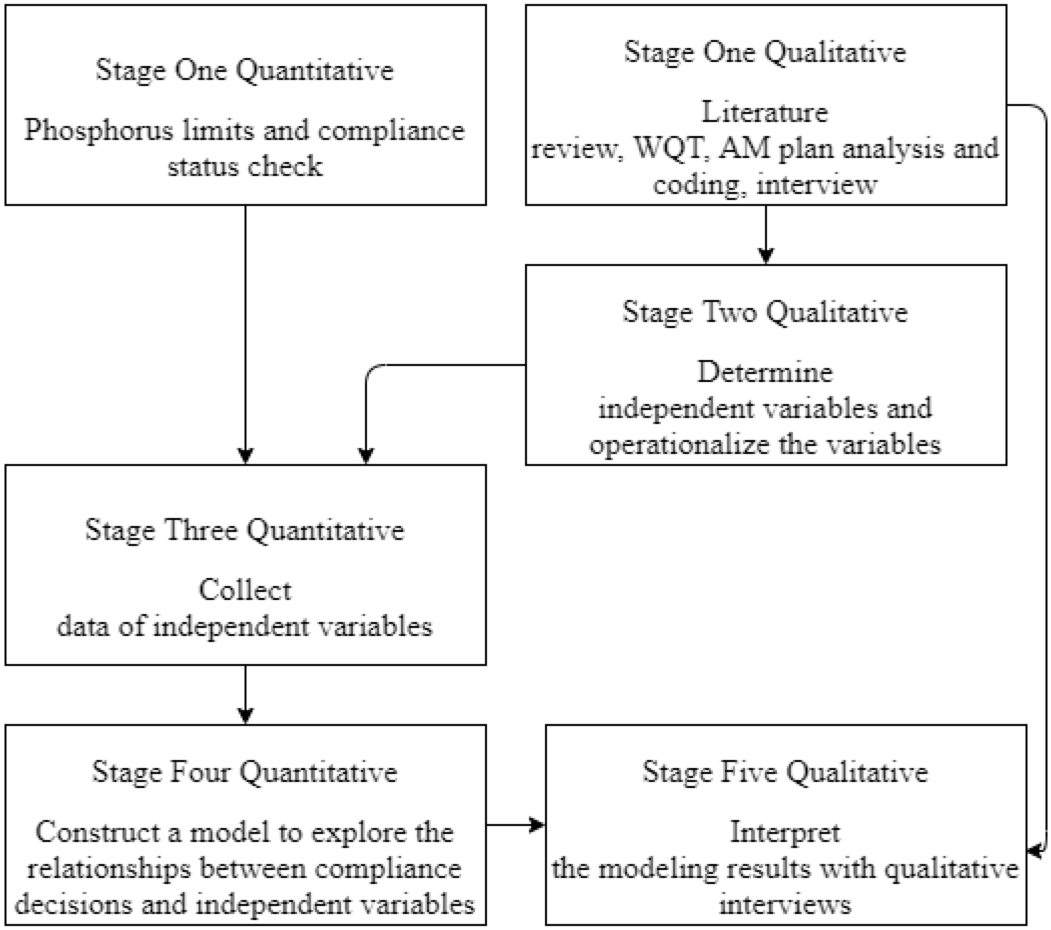


Figure 2.1 Analytical Framework of the Mixed-method Approach for Point Source Decision-making Study. Qualitative and Quantitative methods are applied in a sequential manner

2.3.2 Study area, time span, unit, and scope

As the focus of this study is Wisconsin's nutrient credit markets, all point source permittees in Wisconsin are examined and relevant ones are selected for further analysis. All three trading programs are designed to help point source permittees to cope with the phosphorus criteria update in the year of 2010. Therefore, I only examine the incidences and activities that took places in and after 2010.

The analytical unit is one single point source permittee. A point source permittee is an entity that holds and actively maintains a WPDES permit issued by WDNR and thus is allowed to discharge wastewater into the waters of Wisconsin. A permittee usually owns and operates one wastewater treatment plant and thus is also called a facility. It can be a municipal wastewater treatment plant that receives and treats sewage from the whole or a part of a single municipality, or a group of municipalities through a combined regionalized system. The municipal wastewater treatment plants can also receive discharge effluent from industrial sources. Conversations with municipal wastewater treatment plant informants indicate that when a municipal wastewater treatment plant serves multiple municipalities and industrial sources, the leading municipality wields the authority on day-to-day management and makes critical investment and compliance decisions, while other dischargers are service users and rarely influence the decision-making process. Thus, for facilities with multiple users, only the primary user (and permit holder) is considered as the decision maker. A permittee can also be an industrial source such as electricity generating plants, dairy production factories, and fish hatcheries.

I narrow the scope of inquiry to one type of pollutant, phosphorus. The AM and MDV are alternative options only for phosphorus compliance. The WQT program also enables trading of other pollutants such as total suspended solid and nitrogen. In practice, only two point sources out of 33 WQT participants utilize it for trades of other pollutants (total suspended solid), and both of them are trading phosphorus and total suspended solid at the same time. Hence, considering both relevance to Wisconsin’s nutrient credit markets and the importance of the pollutant, I focus solely on phosphorus. Lessons learned from point-nonpoint source phosphorus trading could inform markets for other pollutants as they require implementation of similar conservation projects.

2.3.3 Data Collection and Analysis

2.3.3.1 Data Sources, Collection, and Cleaning

WDNR is authorized by EPA to issue the WPDES permits and has the most accurate information on point source permittees in Wisconsin. Though the list of all point source permittees discharging into surface waters of Wisconsin is publicly available from the WDNR website, it includes only limited information such as the names and addresses of the permittees. Constructing a database of relevant WDPES permittee information for this analysis required substantial additional efforts. Beginning with the website list of names, I filed an open records request for additional data on the permittees' basic information and compliance status from WDNR. The response to this request revealed that WDNR did not have sufficient resources to maintain an up-to-date and accurate dataset of compliance information. While WDNR staff were very helpful and accommodating, the dataset provided in response to the open records request was missing critical operational information such as design flow, serving population, and descriptions of the permitted facilities, nor did it contain compliance requirement or status. In other words, the WDNR data as organized could not identify which point source permittees face more stringent phosphorus regulations. To fill the information gap, in November 2019, I submitted another open record request to WDNR for the original (raw data) documents regarding each permitted facility. Those documents and their content are listed in Table 2.2. The documents were pulled from WDNR's system and delivered as digital files in March 2020.

Table 2.2 Description of Three Types of Documents Requested from WDNR and the Key Information from the Documents

Document	Description	Key Information
Permittee Fact Sheet	A document that records the operation status of the facility. It is submitted by the permittee to WDNR and is prepared in a stipulated format.	It contains a paragraph of description of the facility which accounts for the serving population, serving region, treatment technology, and other outstanding issues of the facility. It also contains effluent pollutant limits and compliance schedule.
Third-year Alternative Compliance Plan	A document that analyzes and compares different phosphorus compliances options.	It describes the phosphorus compliance situation of the facility and compares compliance options such as facility upgrade, WQT, AM, and MDV.
Fourth-year Alternative Compliance Plan	A document that indicates the final phosphorus compliance method.	After a comprehensive analysis in the Third-year Alternative Compliance Plan, this report selects the most cost-effective approach to meet phosphorus limit.

The documents were subjected to two rounds of data collection. For the first round, I screened all point source permittees in Wisconsin to determine their phosphorus limits and compliance methods. The dataset complied by WDNR indicates whether the point sources have phosphorus limits and whether they have phosphorus compliance schedules. However, these two indicators are not reliable enough to tell the actual status of all permittees. As a result, each fact sheet of most of the point source permittees had to be read and reviewed individually to confirm and update their compliance information. Many facilities were not relevant to this analysis as they were not subject to more stringent phosphorus limits and thus did not need to take any actions. Among the 966 point source permittees with outfalls, 199 of them were considered relevant to this study as they 1) are subject to stringent phosphorus limits, 2) cannot meet the limits easily with existing facilities, and 3) have finalized their compliance decisions. The second round of data collection is described in section 2.3.3.3.

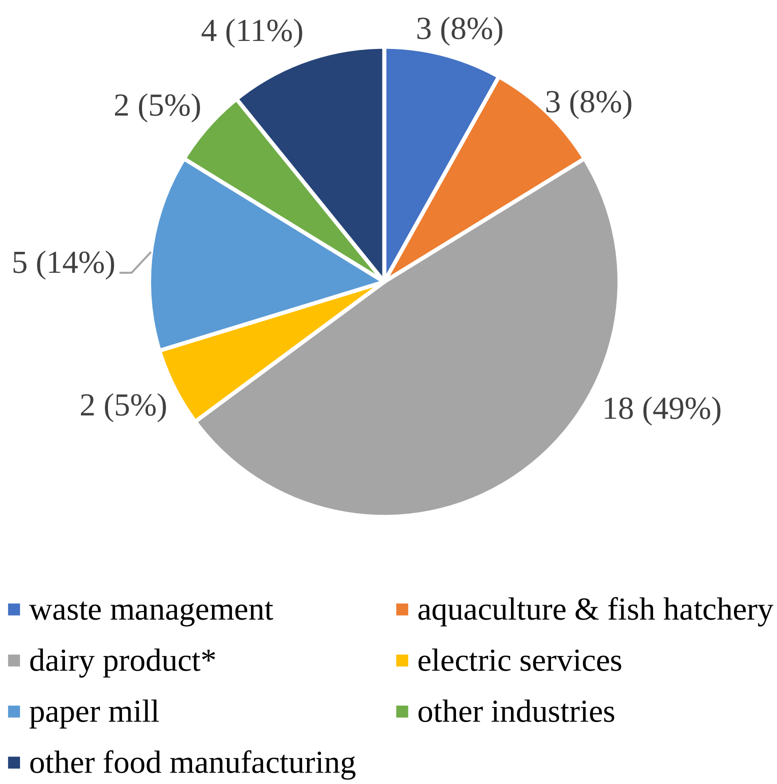
2.3.3.2 Dependent Variables

For these 199 permittees, their compliance decisions were coded as “Trading”, “MDV”, or “facility upgrade”. The category of “Trading” includes WQT and AM. These two programs are combined since both require collaborations with other dischargers, mainly agricultural producers. “MDV” represents Multi-Discharger Variance. “Facility upgrade” includes facility upgrade and regionalization, which involve modification of facilities. The compliance status consisting of the three categories would be the dependent variable of the multinomial regression model.

2.3.3.3 Independent Variables

Construction of the multinomial regression model was accomplished by an inquiry combining findings from literature review and qualitative analysis. I conducted a literature review to summarize the key elements in successful nutrient credit trading projects and barriers identified in previous trading practices. I have also collected implementation plans from six WQT participants and eight AM participants, which discussed their motivations to utilize these two programs. The relevant sections were imported to and coded with NVivo 11. Interviews with 19 key informants from ten wastewater treatment facilities included questions about the underlying rationale for participating into these two programs. Those information sources identified six categories of key factors that may relate to decisions to participate in nutrient credit trading, and each was operationalized.

After constructing the independent variables, 37 industrial permittees and 22 permittees with missing independent variable data were removed from the dataset. One hundred and forty municipal wastewater treatment plants were kept as the study subject. The industrial sources were removed because of the large variation among sectors included in the group. Figure 2.2 shows the sector distribution of the industrial permittees. Different sectors can follow completely different operational logics and they are largely not comparable with each other. Moreover, different industries can also have different interactions with the socio-economic backgrounds of their communities. These variations would undermine the validity of the model and thus the industrial permittees were not included in the same model with the municipal wastewater treatment plants.



Note: The category of dairy product consists of five different specific sectors ranging from fresh milk to protein products.

Figure 2.2 Sectoral Distribution of Industrial Permittees (removed from further analysis). Thirty-seven industrial permittees distribute in seven types of industries with completely different operational logics, making it impossible to compare them with one model

For these 140 permittees, I conducted the second round of data collection by thoroughly reading their fact sheets and compliance alternative plans. The goal of the collection is to capture the characteristics of these permittees. Other independent variables of these facilities are also collected. Table 2.3. shows the six factors, the independent variables constructed, and the data sources.

2.3.3.4 Cluster Analysis and Multinomial Regression Model

Through the interviews with informants, we realized that most of the small- and mid-sized wastewater treatment plants could not singlehandedly coordinate the capital-intense activity of facility upgrade or nutrient credit trading, and it is the municipalities who typically own and operate the facilities that play the most vital role in compliance decision-making. Without characterizing the municipalities, the study on permittees would miss important insights into nutrient credit trading. Thus, I used demographic characteristics (population of the municipalities, percentage of urban population of the county, population trend) and financial characteristics (municipal revenue, debt level, and budget surplus/deficit of the municipalities) to capture the conditions of the municipalities. Social characteristics, especially the level of civic engage and the economic capacity of the residents, is another important facet of the communities. Researchers have been using voter turnout rate and the number of registered non-governmental organizations (NGOs) within the geographical units (Kim & Marcouiller 2016; Kim et. al. 2018), as well as median household income and education attainment (Prokopy et al. 2011) to measure the communities' capacities. I follow their practices for this study.

Table 2.3 Independent Variables and Their Data Sources of the Multinomial Logistic Regression Model

Aspect	Variable	Source	Collection Process
Environmental factors	Point source nonpoint source phosphorus load ratio in the HUC10 watershed	WDNR PRESTO2 model (Diebel et. al. 2013)	Retrieve data from the model's GIS file and match to permittees via WPDES ID
	Total area of upstream area	WDNR PRESTO2 model	Retrieve data from the model's GIS file and match to permittees via WPDES ID
Physical factors	Annual phosphorus load	WDNR PRESTO2 model	Retrieve data from the model's GIS file and match to permittees via WPDES ID
	Phosphorus concentration	Fact sheet	Read fact sheet and extract actual flow data. Calculate concentration with phosphorus load and actual flow data
	Facility condition	Fact sheet	Read fact sheet and extract the information. Technologies are coded as primary, secondary, and tertiary treatment. The actual flow is divided by designed flow to calculate the remaining capacity of the facility. When the rate is higher than 0.8 or the technology is "primary", then the condition will be coded as "bad". Otherwise, it will be coded as "good"
Organizational factors	Number of county conservation staff	County conservation department directory (Wisconsin Land and Water Conservation Association 2021)	The conservation department directory lists county conservationists from county land and water conservation departments of all counties in Wisconsin. The numbers of conservationists and relevant staff are counted for each county
	Number of years between Fourth-year compliance report due date and 2010, i.e., number of years before compliance decision-making	Fact sheet	Retrieve data from the compliance schedule of fact sheet
Economic factors	Population of the town	Wisconsin Department of Revenue (WDOR) County and Municipality Revenues and Expenditures Reports	Retrieved from WDOR's website and manually attached to municipalities
	Trend of population between 2014 and 2019		
	Total revenue of the municipality		
	Population trend of the municipality		
	Revenue trend of the municipality		
	Deficient of the municipality		
	Percentage of urban population in the county	U.S. Census Bureau	Retrieved from U.S. Census Bureau's website

Aspect	Variable	Source	Collection Process
	Median Household Income of the municipality		
Social factors	Voter turnout by municipality	Wisconsin Election Commission (WEC)	Retrieve data from WEC's website. The average turnout rate for each municipality in the 2012, 2016, and 2020 general elections
	Per capita registered 501 NGOs	Internal Revenue Service (IRS)	Retrieve data from IRS's website
	Resident education attainment	U.S. Census Bureau	Retrieve data from U.S. Census Bureau's website. Percentage of residents with bachelors' degree among all residents who are above 25-year-old
Institutional factors	Phosphorus regulation (TMDL vs. WQBEL)	WDNR permittee dataset	Retrieve data from WDNR's permittee dataset

For the 140 municipalities, there are eleven variables related to their social and economic situations. Most of the variables are proxies of economic and social capitals, and none of them are directly related to trade participation. Including all eleven of these independent variables in a model with only 140 observations can undermine the validity and interpretability of the model. It is necessary to reduce the number of variables and convert them to a variable more directly connected to wastewater water compliance decisions. Therefore, a cluster analysis of the 140 municipalities was conducted with the social and economic variables to divide the municipalities into different categories; the classification of municipalities would be the final independent variable representing social and economic factors. The kernel k-means algorithm was applied to classify the municipalities into different categories. The core idea of k-means cluster analysis is to divide all observations into several clusters so that each observation goes to a cluster with a nearest mean (represented by a centroid in a multi-dimensional space where the number of the dimensions is the number of variables used to do the cluster analysis). The first step of k-means cluster analysis is to standardize the data. For each variable, the mean of the variable was subtracted from the individual values and then the difference was divided by the standard deviation so that the standardized variable could have a mean value of zero and standard deviation of one. The second step is to determine the number of clusters. I used Silhouette width, a parameter that measures the level of similarity for observations assigned in the same clusters, as well as level of dissimilarity among observations that are in different clusters. Higher values indicate better clustering results (Rousseeuw 1987). I trialed the clustering analysis from one cluster to ten clusters and found that dividing the municipalities into two groups led to the highest Silhouette width. The Total within sum of squares, another measurement for quality of clustering, was also calculated and the result supported the two-group division scheme. As a final step, the 140 municipalities were divided into two groups and each wastewater treatment facility was tagged as "cluster 1" or "cluster 2" as an indicator of the social and economic conditions of the communities.

With those clusters in place, a multinomial logistic regression model was built to delineate the relationships between the compliance decisions and the key factors that may influence them (see Table 2.3 for the factors and the model below). The independent variables include three binary variables, which are facility condition, applicable phosphorus limit, and type of municipality. These variables divide the 140 observations into eight categories and the numbers of observations in each category range from six to forty-two. The Cochran–Mantel–Haenszel test result (Mantel-Haenszel chi-squared = 0.57, df = 1, p-value = 0.45) indicates that there are no associations among these binary variables (Cochran 1954; Mantel & Haenszel 1959). A correlation matrix was created to examine the correlations among the independent variables and no correlation coefficients exceeds 0.1 (see the correlation matrix in Appendix I). The variance inflation factor (VIF) aligns with the correlation coefficient as all VIF values are between 1 and 2, indicating low risk of multicollinearity.

Compliance Decision *(WQT&AM, MDV, Facility upgrade) =* ***f*** *(LR, A, PC, PL, C, L, Co, T, M)*

LR = PS:NPS Phosphorus load ratio

A = area of upstream watershed

PC = average phosphorus concentration in effluent

PL = facility phosphorus load

C = facility condition

L = applicable phosphorus limit

Co = number of conservation staff

T = number of years before decision-making

M = type of municipality

After the model was developed, Generalized Hosmer–Lemeshow test was applied to test goodness of fit (Fagerland & Hosmer 2012). The findings from qualitative analysis were applied to corroborate the modeling outcomes and contradictory findings from qualitative and quantitative analysis were also discussed. The next section shows all the findings of this study.

2.4 Findings

2.4.1 Current state of Wisconsin nutrient credit markets

As outlined in Section 2.1, Wisconsin's nutrient credit markets are driven by compliance decisions made by permitted point source wastewater dischargers. Through interview and data analysis, I compiled all point source permittees' compliance status in Wisconsin and established the landscape of credit buyers (permitted dischargers) for Wisconsin's nutrient credit markets. Table 2.4 introduces all the phosphorus compliance scenarios for those point source permittees in

Wisconsin, and Figure 2.3 illustrates the distributions of the permittees across categories. Three outstanding issues were identified in this preliminary data compiling.

Table 2.4 Point Source Permittee Compliance Scenarios. Each of the nine hundred and sixty-six point source permittees in Wisconsin fits one of the thirteen compliance scenarios. Many of the scenarios do not require further actions for phosphorus load reduction

Compliance Scenario	Description	Number of Permittees
All scenarios	**Total number of point source permittees included in this analysis**	**966**
Groundwater	Point sources treat their wastewater by land application and the effluent joins groundwater. As land application is subject to different phosphorus rules from the technologies discharging to surface water and is exempted from the stringent phosphorus limit, these point sources are not relevant to this study.	210
Undecided	Point sources who may be subject to more stringent phosphorus limits but have not decided on their compliance approaches. Some point sources have not finished the alternative compliance studies per their compliance schedules and others have not determined the compliance methods passing the due dates of the alternative compliance reports. It is impossible to study the decisions of these permittees. So they are dropped out of this analysis.	185
No phosphorus limits	Some point sources do not have phosphorus limits as there are no or minimal amounts of phosphorus in their effluent due to the nature of their operations. For example, many industrial sources discharge non-contact cooling water that does not contain phosphorus.	183
The Great Lakes as receiving water	Many point source permittees discharge into Lake Michigan or Lake Superior. Lake models will be developed in the future to further regulate these permittees. So far, these permittees have not been required to take any actions.	23
PSs discharging minimal amounts of phosphorus	Some point sources discharge small amounts of phosphorus into waters with low environmental phosphorus concentrations. In these cases, by the WQBEL equation, the limits of these permittees are not stringent. Some point source permittees can have WQBEL exceeding 10 mg/L and thus the TBL of 1 mg/L become their final limits.	69
Individual variance	If the cost of compliance for a municipal wastewater treatment plant increases the sewage rate to be greater than 2% of the median household income, the facility may be eligible for an individual variance. This option is available for many of the small rural communities with lagoon systems.	35
Loose TMDL-based phosphorus limit	If a TMDL for phosphorus has been developed and the permittee's current phosphorus load is lower than its waste-load allocation, it does not need to take further actions.	60
Compliance by optimization of current facility's operation	It is required that point source permittees to reduce their phosphorus loads by operation optimization before looking into other compliance options. The most popular optimization method is to increase the dose of chemical additions. Many facilities will couple other compliance options with operation optimization. There are a few facilities that are in good conditions can achieve compliance by only optimizing the current operation.	2

Compliance Scenario	Description	Number of Permittees
Water Quality Trading	Some point source permittees choose to participate in WQT.	33
Adaptive Management	Some point source permittees choose to participate in AM.	18
Multi-Discharger Variance	Some point source permittees choose to achieve compliance temporarily by participating in MDV.	99
Facility upgrade	Some point source permittees choose to achieve compliance by facility upgrade.	46
Regionalization	Some point sources permittees find it is hard to achieve compliance by themselves and thus choose to deliver their wastewater to an adjacent treatment facility with higher capacity.	3

First, determining the applicable phosphorus rules is not a straightforward task for permittees except for those who discharge to groundwater or who do not discharge phosphorus. These two types of permittees, accounting for about 40% of the total permittees in Wisconsin, were not subject to the new phosphorus rules released in 2010. However, the remainder of the permittees had to take a series of actions to learn what exact rules would apply to them. Understanding what rules apply to which permittees has also been a challenging issue for WDNR; when phosphorus limits for all point source permittees in Wisconsin were requested for this research in 2019, WDNR did not have that data and was not able to deliver the information.

Second, one decade after the phosphorus rule update in 2010, there are still 185 permittees (about 20% of the permittees in Wisconsin) who have not yet decided how they will achieve compliance. Some permittees encountered change of regulations or compliance plans during this period and thus were not able to meet the deadlines for their Fourth-year Alternative Compliance Plans. For example, since 2010, a TMDL has been developed for the Wisconsin River and Upper Fox-Wolf River Basins, and many permittees in those areas are still working to understand the implications of these new developments for their phosphorus compliance.

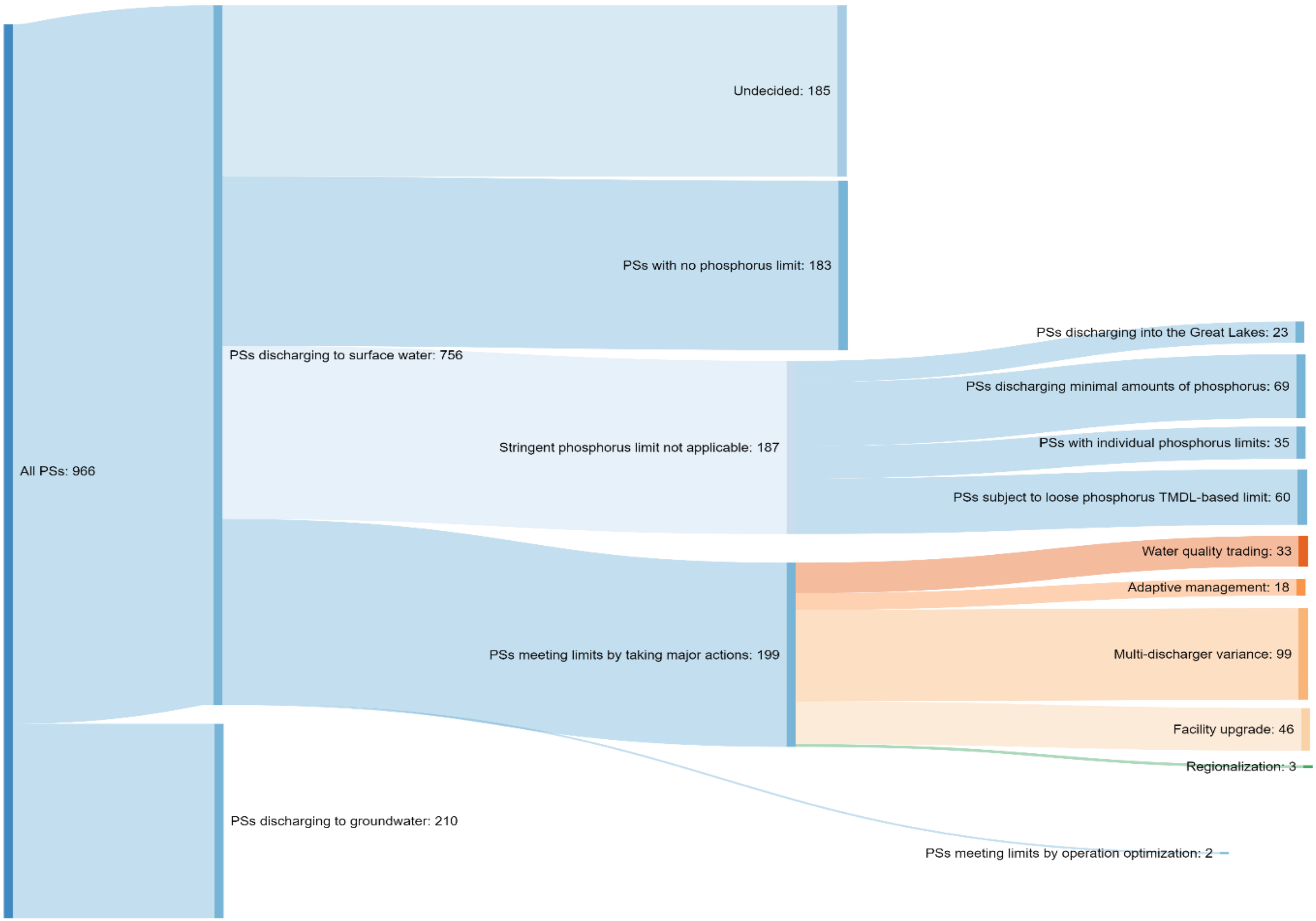


Figure 2.3 Distribution of Point Source Permittees among All Phosphorus Compliance Scenarios (see Table 2.4 for a detailed accounts of the compliance scenarios)

A group of 113 of the permittees are in the undecided category because their Fourth-year Alternative Compliance Plans had not been submitted to WDNR by March 2020 when the dataset for this study was shared. If a permittee obtained a permit right before the change of phosphorus rules in 2010, it would not be assigned a nine-year compliance schedule until the renewal of its permit in 2015 and the due dates of its Fourth-year Alternative Compliance Plan would be in 2019. Theoretically, even for the most extreme scenario described above, the point source permittee should have indicated its compliance plan by the time of this study. One of the reasons for this significant delay of compliance plan submissions can be attributed to understaffing and other resource constraints in the permitting unit of WDNR leading to a permit processing and compliance backlog. Per rule, if it is WDNR who delayed the permitting process, the previous permit term would be automatically extended. Consequently, the compliance schedules were postponed for these permittees. Though the nutrient credit trading is a new program, it had to be built on the existing policy framework. If the existing system is not functioning timely, the efficiency of the policy innovation would also be influenced.

Third, as part of their compliance plan, most of the point source permittees choose to optimize their operations by increasing the doses of chemical additions for phosphorus precipitation. The alum- or iron-based additions form sedimentation with phosphorus during the wastewater treatment process. One key advantage of this technology is that it requires only operational change rather than infrastructure modification. However, due to limitations related to local hydraulic conditions and costs of the chemicals, only two point source permittees in this study were able to achieve compliance by simply applying more chemical additions. For most of the permittees, reaching compliance involves combining chemical additions with WQT, AM, or MDV.

2.4.2 The process of point source permittee decision-making

Questions about how treatment facilities made their decisions to participate in trading were discussed in the interviews with 19 informants from ten permitted wastewater treatment facilities. Interviewees, especially the key decision makers such as directors of public works of the municipalities and the directors of the wastewater treatment facilities, described the timeline of the compliance decision-making, important events that happened throughout the process, and the key actors involved in the process. Additional information was collected from alternative compliance plans and final AM/WQT plans for those facilities. For each permittee studied, a timeline with critical events mapped on it was created. Drawing from those responses, Figure 2.4 shows a typical decision-making process of point source permittees in Wisconsin.

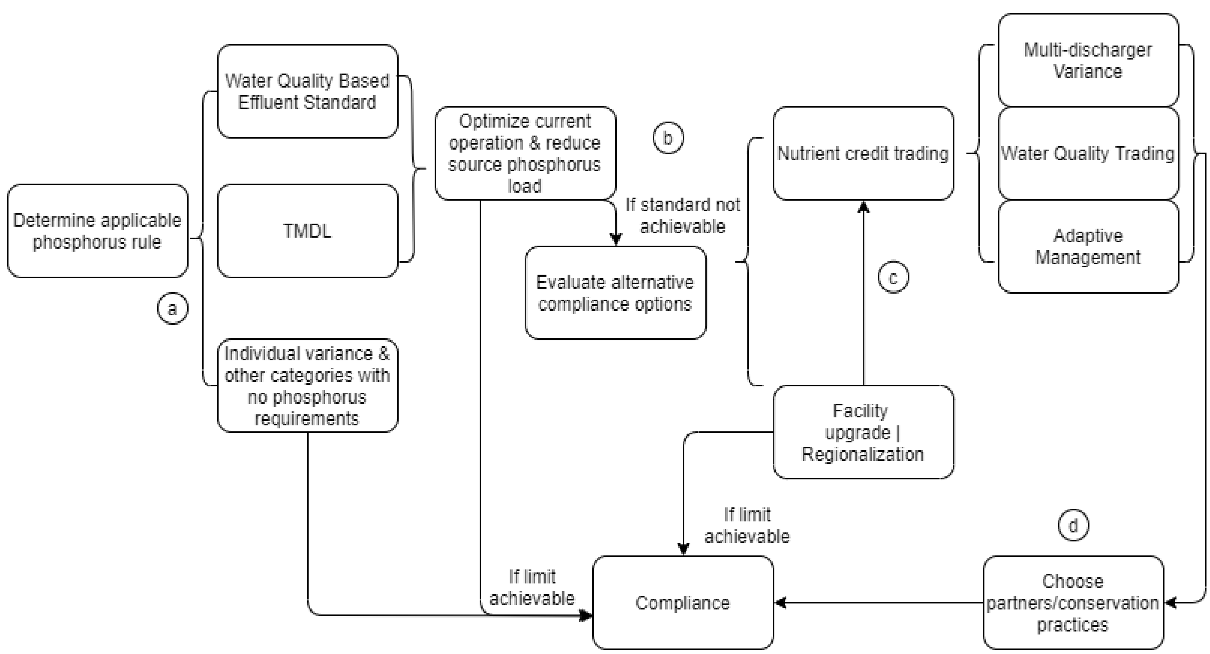


Figure 2.4 Compliance Decision-making Process. The process of how a point source permittee determine its compliance options with all key decision points highlighted

A point source permittee would start with determining the applicable phosphorus rule and then the specific limit it needs to meet with the help of WDNR permit writers (see point a on Figure 2.4). At this stage, most likely an engineering consulting firm would be hired to help with this study and all other following activities. This happens at the point of permit renewal and is similar to the traditional permit application process that the permittees and their consultants are familiar with. The difference is that for WQBEL calculation, the point source permittee needs to acquire the phosphorus concentration data of the receiving water. The data are not always readily available. In many cases, there are only a few data points scattered along a period of several years, if not decades. The WQBEL would usually be established on these data points. Despite the possible inaccuracy of the data, this would be the point source permittee's first look outside of the facility limit and at the surrounding waters.

After reviewing the permit application, if WDNR determined that the permittee was subject to a stringent phosphorus limit that could not be met easily, a compliance schedule would be granted and the permittee would move on to the second phase: optimization of its operation. Two activities are usually involved: 1) working with major dischargers who deliver their wastewater to the treatment facilities to achieve source reduction, and 2) increasing the dose of chemical additions (see point b on Figure 2.4). This is a re-evaluation of the facility's treatment capacity. If the permittee was capable of meeting the phosphorus limit by optimization, it would inform WDNR and proceed with the improved operation plan in the second year of its nine-year compliance period. Otherwise, it would be required to carry out a comprehensive evaluation of all other viable compliance options in the third year; options include facility upgrade, regionalization with adjacent treatment facilities, WQT, AM, and MDV (see point c on Figure 2.4).

Entering this phase, the point source permittee would have to work with more partners to evaluate the feasibility of taking advantage of WQT or AM. Additionally, for receiving waters without accurate water quality data, the point source permittees may conduct water quality monitoring themselves with the help of a consulting firm and other partners, after which the WQBEL may be adjusted. This phase could lead to one of four decisions: 1) the permittee would pursue facility upgrade or regionalization; 2) the permittee would use MDV as a temporary compliance method; 3) the permittee would participate in either AM or WQT; or 4) the permittee would combine two out of the three options of facility upgrade, MDV, and WQT. The fourth approach was prohibited by WDNR initially but was approved later, and very few permittees have chosen the fourth approach. These activities would all take place during the third and fourth year of the nine-year compliance schedule. During this window, the point source permittees would learn more about its surrounding environment including the receiving water, the watershed, the nonpoint source dischargers (i.e., agricultural producers) and other partners in the watershed. If it were to participate in WQT or MDV, it would also need to determine the amount of nutrient credit it might need from farmers or county land and water conservation departments.

The compliance research stops here if the permittee chooses facility upgrade, regionalization, or MDV and the permittee would start implementing the option selected. If it selects AM or WQT, then it will move to the next phase of decision-making: finding farmers who are willing to work with them and deciding on the conservation practices (see point d on Figure 2.4). This is considered as the post-trade decision since it happened after the permittees decided to participate in AM or WQT. This part of the decision-making is discussed in following chapters of this dissertation.

As illustrated by this description, the decision to enter the nutrient credit markets is complex. It involves a series of pilot study, monitoring and modeling activities, as well as interactions with local communities. The process has four features in particular worth noting.

Time

The process is time consuming and usually takes three or four years in the of the compliance schedule. Immediate response to the nutrient credit trading policy is infeasible and should not be assumed in studies of nutrient credit markets. It could take several years for a regulator to launch trading program and even more years for the markets to mature.

Availability of information

Information necessary for trade decisions is not always readily available. In previous research, especially with modeling work that predicts market volume or permittee behaviors, scholars generally assume full or partial access to information (Hung & Shaw 2005; Corrales et. al. 2017). However, through this study, it is found that the permittees often start with little or no information. It takes the help of consulting firms and WDNR permit writers for the permittees to even know what phosphorus rules would apply to them, not to mention other types of information that is completely foreign to the permittees. Researchers should be cautious with the assumptions about information availability when analyzing behaviors of point source permittees.

Cost and quality of information

While the quality of the information influences the quality of the decision-making, not all permittees have equal access to information essential to decision-making, primarily due to the cost of information acquisition. For example, the quality of the alternative compliance plans varies significantly among point source permittees. Permit holders with more financial and human resources could compile detailed reports of more than one hundred pages. Meanwhile, some permittees with minimal resources were only able to submit short descriptions of their situations along with hand-drawn facility layouts. When it comes to the decision to participate (or not participate) in nutrient credit trading, some permittees were able to establish the decisions on a comprehensive watershed inventory investigation while others would simply rule out the trading options due to those resource limitations.

Iterative learning process

The decision-making involves an iterative learning process for the point source permittees. Before the phosphorus rule update in 2010, point source permittees were mostly only in charge of and responsible for what happened within the boundaries of their facility. The new phosphorus rule drove permittees to learn more about the receiving waters, the watersheds, and the neighboring communities. Many study informants with engineering backgrounds indicated that these were all new fields to them. The need for new learning about agricultural nonpoint source pollution control was especially common and was often accomplished with help from third-party partners such as county conservationists. Another example is increased awareness of the ambient water quality and related issues. Some point source permittees would depend on historical ambient water quality data collected by government agencies such as WDNR and USGS to calculate their phosphorus limits. The limits might be revised later by monitoring activities conducted by the permittees themselves. During the process, preliminary decisions could be altered or adjusted because of the newly obtained water quality information. Without changing the basic framework of permitting and phosphorus compliance, the dynamic and iterative process of decision-making could be defined as single-loop learning by the theory of adaptive management (Fernandez-Gimenez et. al. 2008; Stankey, Clark & Bormann 2005).

2.4.3 Results of the cluster analysis

As noted previously, using eleven characteristics of the municipalities, I conducted the k-means cluster analysis and divided 140 municipalities into two categories. Figure 2.5 illustrates the distribution of the two categories. The x and y axes are the two characteristics that contribute the most in the division of the municipalities. These are not the raw characteristics, but rather, they are the principal components extracted from the demographic, financial, and social characteristics.

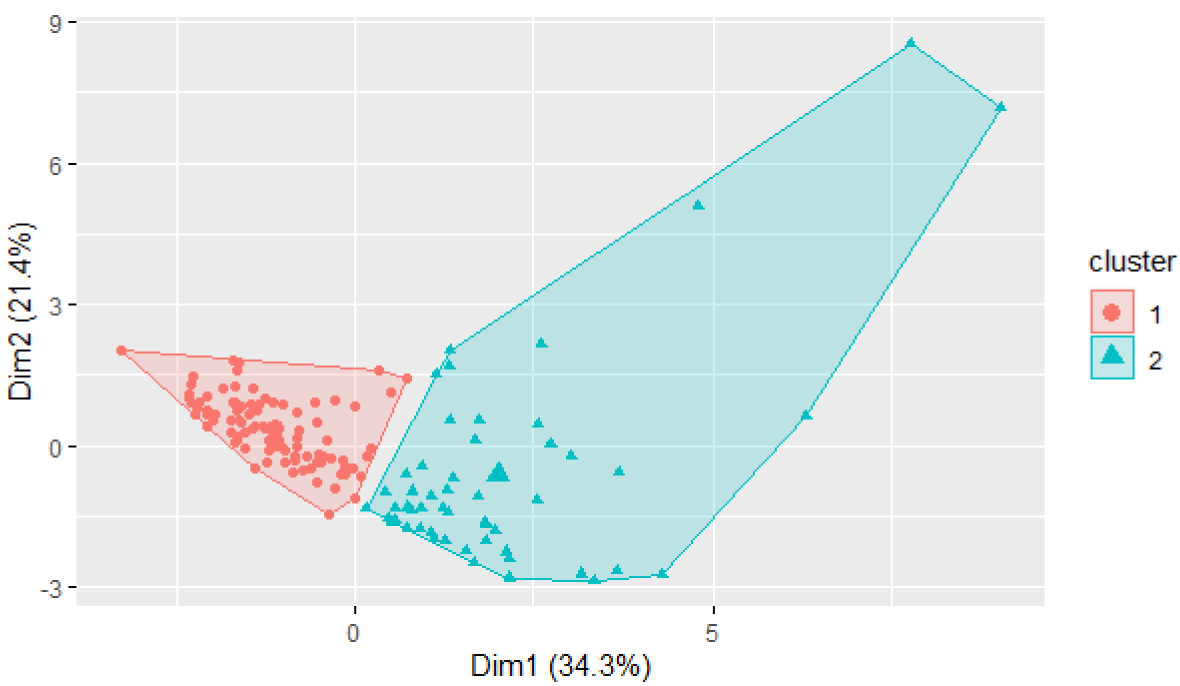


Figure 2.5 Result of Clustering Analysis. The 140 municipalities included in the model are divided into two clusters: cluster 1 has the smaller municipalities locating in less urbanized areas while cluster 2 is the larger municipalities in more urbanized areas.

The k-means cluster analysis depends on quantitative calculation and classifies the municipalities without pre-defined rules, thus it is able to avoid researchers' subjective judgement on the municipalities. The interpretation of the clustering results followed the clustering analysis. Table 2.5 compares the characteristics of the two groups.

Table 2.5 Demographic, Financial, and Social Characteristics of Two Clusters of Municipalities

	Cluster 1	Cluster 2
Observation	N = 89	N = 51
Average population in 2019	1662	9125
Average population trend between 2014 and 2019 (%)	0	3.3%
Average percentage of urban population in county	31%	70%
Average voter turnout rate	63%	73%
Average percentage of bachelor's degree holder	15%	29%
Average number of registered NGOs	20	78
Average median household income	41,116	57,963
Mean municipal revenue	2,315,356	13,730,874
Standard deviation of revenue over mean revenue	0.24	0.21
Surplus over revenue (%)	2.5%	1.9%
Debt over revenue	0.62	0.98

The table shows more municipalities in cluster 1. This group of municipalities has much lower average population compared to those in cluster 2. Percentage of urban population stands out as another important difference with cluster 1 at 31% and cluster 2 at 70%. This means municipalities in cluster 2 are more likely to be part of metropolitan areas. Cluster 2 could be identified as a group of larger municipalities in urban areas and cluster 1 is a group of smaller municipalities in rural areas. The "large urban" group has positive population trend, higher voter turnout rate, higher percentage of bachelor's degree holders, higher number of per capita registered NGOs, and higher and more stable municipal revenue, but it also has higher budgetary deficit level and debt level. Figure 2.6 maps the municipalities in these two clusters. Most of the municipalities in cluster 2 are concentrated in southeastern and southcentral Wisconsin.

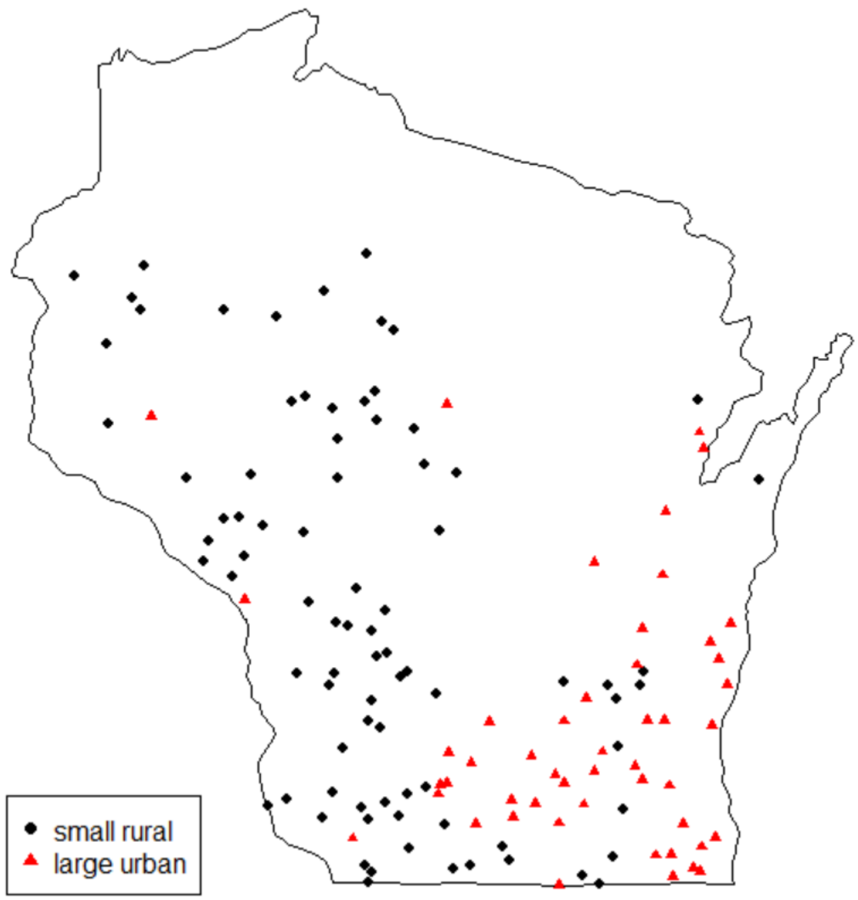


Figure 2.6 Spatial Distribution of Municipalities in Two Clusters. Cluster 1 is the small rural municipalities which mainly locate in the eastern side of the state. Cluster 2 is the large urban municipalities, most of which center around Milwaukee and Madison Metropolitan areas.

2.4.4 Factors related to permittee decision-making

Table 2.6 summarizes the dependent and independent variables of the multinomial logistic regression model. Facility upgrade is set as the baseline choice of compliance. As for other categorical independent variables, small communities in rural areas and facilities in good condition are set as the baseline situation of the facilities. It is worth noting that the baseline setting does not influence the outcome of the model. Table 2.7 presents the result of the model. It shows how the variation of each variable shift the permittees' compliance plan from facility upgrade to MDV or WQT/AM.

Table 2.6 Compliance Decisions and Characteristics of Point Source Permittees. The compliance decision is the dependent variable of the multinomial logistic regression model. Point source permittees choose one of the three options to achieve compliance. Other factors in the table are the independent variables of the model

Observations	N = 140
Compliance decisions	
WQT & AM (%)	35 (25%)
MDV (%)	74 (52.9%)
Facility upgrade (including regionalization) (%)	31 (22.1%)
Environmental factors	
PS:NPS phosphorus load ratio in the HUC10 watershed	1.22 (sd = 1.72)
Area of upstream watershed (acre)	311.64 (sd = 1110.55)
Physical factors	
Facility design flow (million gallon per day)	0.93 (sd = 1.80)
Phosphorus concentration in effluent (mg/L)	2.33 (sd = 2.38)
Facility condition	
Bad – w/ primary treatment or actual flow over 80% of design flow (%)	36 (25.7%)
Good – w/ advanced treatment technologies or redundant capacity (%)	104 (74.3%)
Organizational factors	
Number of conservation staff in the county	7.48 (sd = 6.41)
Number of years before decision-making	7.45 (sd = 1.10)
Social and Economic Factors	
Type of municipality	
Municipality group 1 – small rural (%)	89 (63.6%)
Municipality group 2 – large urban (%)	51 (36.4%)

Four variables have statistically significant correlations with the compliance decision-making. First, comparing with point source permittees subject to WQBEL, the permittees under TMDL are less likely to participate in WQT, AM ($p < 0.001$), and MDV ($p < 0.001$). The odds of a permittee under TMDL choosing MDV is only 0.37 of the odds of a permittee under WQBEL choosing MDV. The odds ratio for choosing WQT or AM is 0.46. The odds ratio shows that permittees under TMDLs have lower possibility to participate in the nutrient credit markets. This suggests that the institution of phosphorus control can influence participation of nutrient credit markets.

Table 2.7 Results of Multinomial Logistic Regression Models on Point Source Permittee Decision-making

	Model 1 MDV (reference group = facility upgrade)		Model 2 WQT & AM (reference group = facility upgrade)	
	β (SE)	OR (95%CI)	β (SE)	OR (95%CI)
Constant	1.93*** (.01)	6.91 (6.74, 7.08)	-1.5*** (.01)	.22 (.22, .23)
Number of conservation staff	-.05 (0.04)	.95 (.87, 1.03)	.03 (.03)	1.03 (.96, 1.1)
Applicable phosphorus limit, reference group = WQBEL	-.98*** (.27)	.37 (.22, .63)	-.78*** (.22)	.46 (.3, .7)
Phosphorus concentration in effluent	.11 (.26)	1.11 (.9, 1.37)	-.18 (.2)	.83 (.63, 1.1)
Phosphorus load of the facility	-.00003 (.0001)	1 (1, 1)	.00004 (.0001)	1 (1, 1)
Condition of the facility, reference group = Good	-.24 (.33)	.78 (.41, 1.5)	-.1.04*** (.23)	.35 (.22, .55)
Time between 4-yr plan due and 2010	-.03 (.07)	.97 (.85, 1.1)	.29*** (.07)	1.34 (1.18, 1.53)
Cluster of municipalities, reference group = small rural	-1.42*** (.28)	.24 (.14, .42)	-.11 (.24)	.89 (0.55, 1.44)
Area of upstream watershed	.0002 (.0003)	1 (1, 1.001)	.0001(.0003)	1 (.999, 1.001)
PS:NPS phosphorus load ratio in watershed	.28 (.18)	1.32 (.93, 1.87)	0.06 (.2)	1.06 (0.72, 1.56)

Note: 1. *$p < .05$; **$p < .01$; ***$p < .001$. OR = odds ratio, CI = Confidence interval, SE = Standard error.
2. The generalized Hosmer and Lemeshow test of this model has chi-square = 19.762, df = 16, p = 0.2311 > 0.05. The null hypothesis that the observed and expected proportions are the same across all compliance categories is not rejected.

Second, the condition of the facility is also highly correlated to the decision to choose WQT or AM. When the condition of the facility is not ideal, it is less likely to use WQT or AM for compliance ($p < 0.001$). A facility in “bad” condition increases the odds of choosing facility upgrade over WQT or AM by 185%, indicating that the physical condition of the treatment facility plays a critical role in the decision to participate in WQT or AM. However, the influence on MDV participation is not clear. This phenomenon is caused by an intuitive reason: when the facility is in bad condition (meaning it still uses primary treatment technologies or its actual effluent volume is close to its design capacity), the permittee will have to upgrade its facility anyway to address many other concerns beyond phosphorus control. The cost to upgrade a facility might also be lower for these permittees than for the permittees who already operate the state-of-the-art treatment technologies. In comparison, WQT and AM work better for permittees whose facilities are in “good” shape because their effluent phosphorus concentration is already low and driving down the concentration further is extremely expensive.

Third, organizational factors are also important. Interviews and document analysis tell us that permittees received various types of support from other organizations who were also part of the nutrient credit markets. For example, consulting firms help permittees with general permitting process and feasibility study of the alternative compliance plans. County land and water conservation departments and the NRCS can offer knowledge about agriculture nonpoint source pollution control and information on specific conservation projects. The assumption follows that when organizational partners are well equipped with knowledge and capacity to assist the implementation of conservation projects, the permittees are more likely to choose nutrient credit trading.

Two variables were used to measure the capacity and knowledge of organizational factors. The first variable relates to time and the compliance cycle and is the number of years between 2010 (when the phosphorus rule was updated) and the due date of the permittee's Fourth-year Alternative Compliance Plan. In the early years after the new phosphorus rule, the idea of phosphorus credit trading was new to these organizations. Details of the policy were still under development, and even WDNR staff were not able to answer some of the questions from permittees. As time passed, partners accumulated more experience with WQT, AM, and MDV. For example, since the opportunity of nutrient credit trading emerged some consulting firms that previously only worked on wastewater engineering projects have been gradually building their capacity to include conservation projects. The variable of "time between" does not measure the capacity growth of a specific type of partner. Rather, it assumes that all parties involved are likely to be more helpful on nutrient credit trading in later years. This variable is usable because the permitting cycle of a permittee is unrelated to any of its characteristics except for the year of its first permit application. Therefore, the value of this variable does not confound with the permittees' other features.

The second variable pays attention to one kind of partner—the county land and water conservation departments. For potential WQT and AM participants, the counties have been instrumental in sharing knowledge with permittees and consulting firms on agriculture nonpoint source pollution control. More importantly, counties are the recipients of any MDV payments from facilities that use that option. The model shows that point source permittees who made the compliance decisions in later years were more likely to choose WQT or AM over a facility upgrade. Having one more year to make the decision increases the permittee's odds of choosing WQT or AM over facility upgrade by 34% ($p < 0.001$). However, the influence of time on MDV participation is not significant. The number of the conservation staff in a county is also not correlated to WQT/AM nor MDV participation. This is not a surprise as the permittees' responsibility in MDV is just to make the payments; they are not liable for the phosphorus reduction. The decision to participate in MDV does not depend on any partners' knowledge and experience on agriculture nonpoint source pollution control. Thus, although county conservation departments are key to MDV implementation, their capacity would not necessarily be factored in the permittees' decision.

The fourth factor is the social and economic conditions of the municipalities. The categorical variable of municipality clustering was used as the indicator. Municipalities recognized as "large and urban" are less likely to participate in MDV. The odds of these municipalities to choose MDV over facility upgrade is only 24% of the odds of the municipalities in the "small and rural" group to make the same choice ($p < 0.001$). Per WDNR's rule, permittees in four relatively wealthy counties, Dane County, La Crosse County, Saint Cross County, and Eau Claire County, are not eligible for MDV. Among the 140 permittees investigated, seven of them are located in these counties. Removing those seven permittees and rerunning the model confirmed that the conclusion still holds ($\beta = -1.38$, $p < 0.001$). Indeed, while MDV can greatly relieve the responsibility of point source permittees, it is just a temporary policy instrument for permittees to buy more time before they achieve compliance. It may be a less attractive option for more resourceful communities.

The municipality type does not influence the possibility to participate in AM or WQT, implying a more sophisticated relationship between AM/WQT participation and the social and economic capital of the municipalities. On one hand, participating in AM or WQT often means the municipalities have to pay partners outside of their municipal limits—an idea that raised concerns and objections from some municipal leaders in this study. It takes strong financial capacity and progressive thinking for municipal governments to support these compliance options. On the other hand, nutrient credit trading is meant to help permittees who face unbearably expensive facility upgrade costs. Permittees serving large municipalities in urban area usually have more advanced treatment technologies and are more likely to meet the limits by themselves. Therefore, AM and WQT participation's correlation with the type of municipalities is not significant in this model.

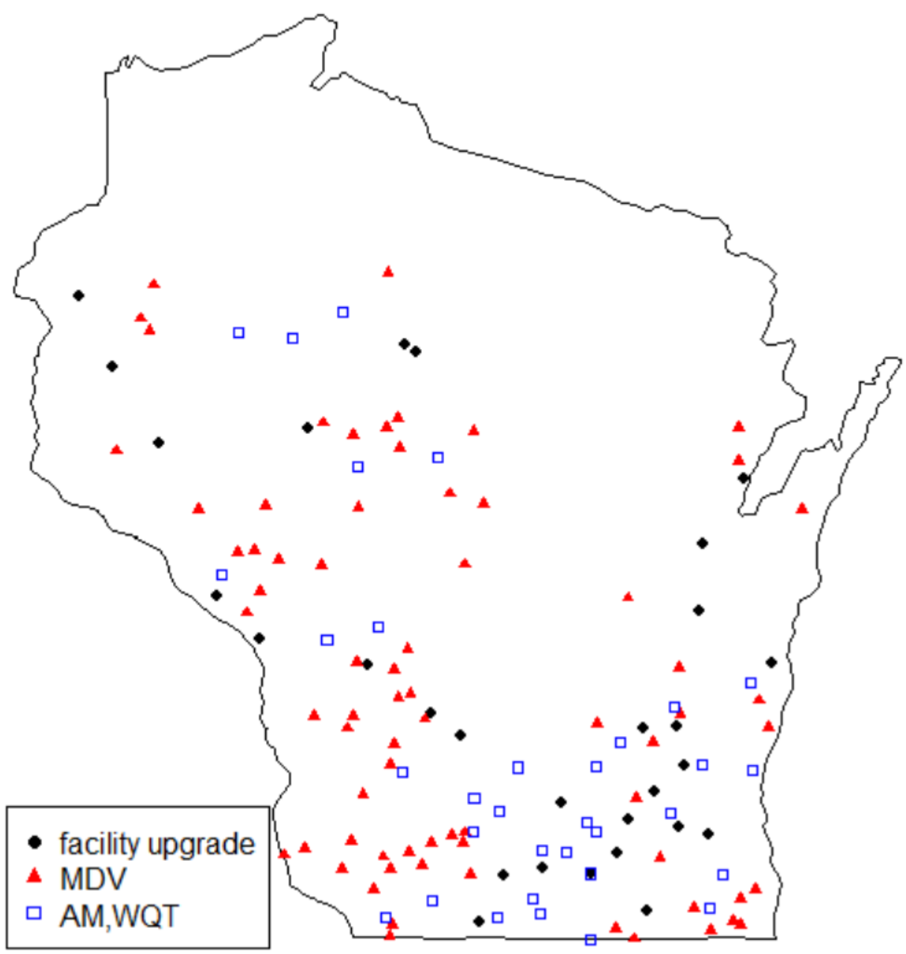


Figure 2.7 Compliance Choices of Municipalities. The map demonstrates the spatial distribution of point source permittees choosing different compliance options. Small municipalities in rural areas are more likely to utilize the MDV option

Lastly, environmental factors, the area of upstream watershed and the ratio of phosphorus load from point sources and nonpoint sources in the HUC10 watershed, are not correlated to participation in the nutrient credit markets. The lack of significance is intriguing. According to previous literature, one of the key challenges in nutrient credit trading is engaging nonpoint source partners (Stephenson et. al. 2010; Hoag et. al. 2017). However, the model shows that the availability of nonpoint source credits is not a constraining factor in compliance decision-making. There are two possible explanations. First, the phosphorus credit demand is low, and the potential supply is abundant in most of the watersheds, which essentially removes the constraint on the supply end. Before the new phosphorus rule, Wisconsin had already maintained a relatively low phosphorus limit, the TBL of 1 mg/L, for most of the point source permittees. A more stringent phosphorus limit would only marginally reduce the total phosphorus load into the waters and not create a large amount of phosphorus credit demand. In contrast, a high proportion of land in Wisconsin is used by agriculture sectors and the farms neighboring the point source permittees are plentiful. This explanation could be supported by the statistics: for the 140 permittees, the median phosphorus load from upstream nonpoint sources is 18,271 lb/yr while the median phosphorus load from their own facility is 764 lb/yr, representing 4% of the potential tradable credits. The average amount of phosphorus credits purchased in six implemented WQT projects is 220 lb/yr. Engaging farmers in a complex program that tags them as polluters could be challenging, but point source permittees are likely able to accomplish nutrient credit trading by only working with a limited number of farmers out of a big group.

The second explanation is that this model only examines nutrient credit trading participation and does not study the implementation phase. Working with nonpoint source dischargers could be difficult but actual implementation details are deferred to a later stage of the project. This is especially true for AM. Four permit terms equal to 20 years would be granted to a permittee who chooses AM for final compliance. Many permittees acknowledge in their AM plans that they intend to start with AM but probably would switch to other compliance options later. For these permittees, the situations of the watersheds might not be a major concern in their decision-making.

2.5 Conclusions and Discussion

Point source permittees' decision-making is examined in this research. Specifically, it discusses three subjects: the point source permittees' decision-making process, the critical factors that could influence the decision-making, and the policy implications of the findings.

I first establish a complete list of eligible point source permittees and delineate their typical decision-making process regarding participation in Wisconsin's nutrient credit markets versus other compliance options. This decision-making is an iterative learning process for the permittees, which can take several years to accomplish. It heavily depends on various types of information regarding institutions, the condition of the facility, ambient water environment, and neighboring agricultural communities. Therefore, permittees generally need to input significant amounts of resources and engage partners from public and private sectors to acquire the requisite information. As a result, permittees with limited capacity and resources may not have access to adequate information for thorough decision-making.

These compliance decisions examined with a multinomial logistic regression model show that socio-economic and institutional factors are instrumental in the decision to participate in the MDV option. Smaller municipalities in rural areas that are under more stringent WQBEL are more likely to choose MDV over a facility upgrade. MDV is a less capital-intensive yet is only a temporary compliance method. It was meant to help and (and has attracted) the less advantaged communities. The model also shows that municipal permittees under WQBEL and whose facilities are in good condition are more likely to participate in AM or WQT. The facilities who have already deployed secondary treatment technologies and have ample redundancy of treatment capacity usually face higher costs in order to further upgrade their facilities. The permittees who have more years to make compliance decisions after the launch of the markets are also more likely to choose AM or WQT. This finding can relate to the maturation of the market—when all parties in the markets are more familiar with the policy, it becomes easier for the permittees to take advantage of the nutrient credit trading.

The common factor that influences both AM/WQT and MDV participation is an institutional one: TMDL versus WQBEL. Compared with TMDL-based limit, WQBEL lead to higher participation rate in nutrient credit markets. Multiple mechanisms may contribute to this division. First, TMDL undermines the nonpoint sources' ability to generate long-term credits. Nonpoint sources under TMDL can only create tradeable long-term phosphorus credits if their phosphorus loads are under the TMDL waste-load allocations. Second, the TMDL-based mass limits are usually less stringent than the WQBEL. Many facilities have already achieved compliance with the TMDL-based limits and do not need to take further actions, thus are not included in this model. The rest of the facilities are troubled by monthly variation of phosphorus loads and usually only violate the limits periodically. This may indicate lower costs for them to upgrade their facilities.

The findings lead to four policy implications. First, the timescale of nutrient credit markets is greatly different from timescales of other markets, and all participants (including policy makers) should expect a slow-moving process. On a policy design level, the parameters of

AM, WQT, and MDV were constantly modified by WDNR in the early phase of market launch. Early participants found that WDNR was not able to answer some of their questions regarding the policy, and to their credit, over several years, WDNR incorporated lessons learned from the early cases into the policies and program implementation. A similar finding was made in a case study on Minnesota's point-nonpoint source pollution trading program. By comparing the two trades that took place in the markets, researchers found that the regulator took much more time to approve the first trading case than the second case (Fang et. al. 2005).

On a policy implementation level, the multinomial logistic regression model shows that the more time that had elapsed after the new phosphorus rule the higher was the participation rate of AM and WQT. This suggests that all parties in a nutrient credit markets need time to adapt to the new policy. Nutrient credit trading becomes a more attractive option as intellectual and social capital for trading accumulate. For individual permittees, even if the policy was streamlined and resources were readily available, it was still normal to spend several years deciding whether or not to participate in trading. Importantly, on the transaction level, one permit term lasts five years during which the trading arrangements are rarely changed. The nonpoint source pollution control projects required for point-nonpoint trading also have their own life cycle, and the point source permittees must reach relatively long-term agreement with nonpoint sources. Though in theory the transaction happens on an annual basis, the trading arrangement would change in an even slower manner. As the markets mature, the issues on policy design, implementation, and individual permittee decision-making would be resolved. However, the permitting cycle would still significantly slow the pace of market transactions and consequently undermine its ability to cope with the ever-changing environment. To have a more dynamic market, the regulator could enable a more flexible permitting system that allows point source permittees to make changes to their trading arrangements without renewing the entire permit.

The second implication is recognition that the existing policy landscape imposes great influence on nutrient credit markets. Markets are built on existing policy infrastructure including point source effluent permitting, monitoring, enforcement, and nonpoint source management/regulation. For example, the applicability of phosphorus criteria for an individual permittee can directly impact trading participation. The WQBEL is more stringent than the TMDL-based mass limit for many point source permittees. After the update of phosphorus rule in 2010, two major TMDLs on phosphorus were developed: the Wisconsin River TMDL and Upper Fox and Wolf River TMDL. The applicable criteria for the point source permittees in these watersheds were then changed from WQBEL to TMDL-based mass limit, reducing incentives to participate in trading programs.

During the development of these TMDLs, it was in the best interest of these permittees to know the applicable rules before making any decisions. If the TMDL waste-load allocation exceeded the permittees current phosphorus load level, no new compliance response would be needed. In the Alternative Compliance Plans, several permittees noted that their compliance strategy was to wait for the waste-load allocation result of the TMDLs. Another example is the regulation of the Great Lakes. WDNR would develop special lake models to determine the phosphorus criteria for point sources directly discharging into Lake Michigan and Lake Superior. As the models have yet to be developed, these point sources are still subject to the old phosphorus limits and have not become part of new markets.

The policy for nonpoint source dischargers also influences trading behaviors. Though compliance of nonpoint source dischargers under TMDLs was not mandatory, these nonpoint sources could only generate long-term credits after reducing their phosphorus loads below their TMDL-determined waste-load allocations. Otherwise, the conservation projects could only generate temporary credits. However, most of the agricultural management practices are not able to reduce the nonpoint source phosphorus loads to the allocated load level. As a result, land retirement becomes the only viable option for nonpoint source permittees to get permanent credits. The unintended consequence of setting the entrance threshold for nonpoint sources under TMDL is that the management practices that would sustain farming on the land could not be used for nutrient credit trading. The interactions among different phosphorus management policies should be carefully examined to better orchestrate the policy instruments. Similar conclusions were made by Wardropper et. al.(2015) in their investigation on spatial targeting for nutrient reduction in Wisconsin's Yahara Watershed. The authors analyzed the multilevel governance's influence on implementation of water quality policy and emphasized the importance of coordination at the landscape-level.

Third, guaranteeing equal access to the markets would reduce the aggregated abatement cost and lead to better environmental outcomes. The threshold of participation, i.e., the cost of information collection and collaboration with producers, can hinder the decision to participate in trading. Small communities in rural areas are more likely to participate in MDV as it has a lower threshold: the permittees need only to calculate the amount of credits and pay the county land and water conservation departments to implement the nonpoint source pollution control projects. However, MDV is just a transitional tool. To engage these less advantaged communities in the long run, different market forms such as exchange and clearing house could be explored to relief the financial pressure of AM and WQT participants. Coalitions of small dischargers in the same watersheds could also be encouraged (and further incentivized) to achieve economies of scale in the trading markets.

Fourth, for a sustainable policy, it is critical to engage and empower the array of partners involved in making trading work, especially on local level. The infrastructure of a market (its broader institutional landscape) includes not only regulatory authorities and the regulations, but also third-party partners, such as engineering consultants, NGOs, and relevant governmental agencies, who proved to be instrumental in most of these trading cases. Another important yet largely missed piece is the University of Wisconsin Extension, who thus far has provided general information on watershed conservation in outreach and education events. To facilitate trading, it is more important to cultivate potential brokers, co-investors, and educators than just work with point source permittees. Auxiliary policies could be designed to incentivize these partners so they could keep investing on their capacities related to nutrient credit trading. For example, counties could be encouraged to charge the permittees for their services on AM and WQT. Combinations of trading and other watershed projects could also be considered.

In summary, Wisconsin's market-like trading programs are still relatively new and maturing through their initial growing pains. There is great interest and potential, and WDNR, local partners, and others are working with point source permittees to explore this new opportunity for improving watershed health. Ultimately, it is the decisions of individual WDPES permittees that will determine participation and policy impact. As discovered in this study, many factors that influence those decisions are ripe for review and action.

Chapter 3. The Role of Rural-urban Social Network in Wisconsin's Nutrient Credit Markets

3.1 Overview

3.1.1 Background

Pollution credit markets and traditional commodity markets have divergent characteristics. In a pollution credit market, the goods (the pollution credits) are not standard due to spatial and temporal heterogeneity of pollution discharge activities. Therefore, the credit buyers and sellers must cooperate closely to design and implement case-specific trading plans. Due to this reason, some researchers even described some forms of market-like approaches as offset projects (Breetz et. al. 2004; Morgan & Wolverton 2008).

This phenomenon is especially true for point-nonpoint source pollution trading involving agricultural activities. Agricultural nonpoint sources face less stringent regulations and are less incentivized to participate in nutrient discharge reduction activities. In addition, farmers' decisions and behaviors regarding agricultural management can be guided by a unique set of values, norms, and beliefs (Vanclay & Geoffrey 1994). As a result, point sources face great challenges finding trading partners in these settings and forming binding relationships with them. Even in the cases where point source permittees managed to do so, the cost of engaging producers and reaching transaction agreements, i.e., the transaction cost, could be extremely high (Motallebi et. al. 2017; Stephenson et. al. 2011). Auxiliary mechanisms that facilitate transactions can be critical to point-nonpoint source nutrient credit markets.

Since 2010, Wisconsin has been exploring nutrient credit trading policies to help point source permittees comply with newly stringent phosphorus criteria. Three programs, Water

Quality Trading (WQT), Adaptive Management (AM), and Multi-Discharger Variance (MDV) were launched and attracted a large number of participants. Point source permittees participating in WQT need to purchase phosphorus credits from point or nonpoint source partners in upstream watersheds, while the AM participants work with a larger group of partners in the watershed to reduce the phosphorus concentration in the receiving waters. These two programs can provide valuable insights on how pollution credit trading takes place in a watershed.

3.1.2 Research questions

This research is a case study on Wisconsin's nutrient credit markets, specifically, the markets developed through Wisconsin's WQT and AM programs. By investigating a series of trading cases in which the point source permittees have started working with nonpoint source partners, I attempt to answer three questions. First, how do the point sources find their trading partners? Second, to what extent does the existing social network structure influence trading viability? Third, how do the trading relationships fit into or change local social networks?

Answering these three questions contributes to the field of watershed planning in three ways. First, I highlight the role of social networks in the practice of nutrient credit trading. Networks among point sources and nonpoint sources have not been emphasized by regulators in policy design. By discussing the significance of social networks, this study could inform future policy making and implementation. This issue also has important implications for policy evaluation. Watershed programs are intended to improve water quality, and it is challenging to measure their effectiveness in the short term. Thus, other indicators, especially social indicators, could be developed to evaluate the short- and mid-term impacts of the programs (Prokopy et. al. 2009; Prokopy & Genskow 2015). Examining the nutrient credit markets' influence on local social networks, and in a broader sense, the local community, contributes an important element to current evaluation of the nutrient credit markets.

Second, I propose a framework to understand point-nonpoint source pollution trading through the lens of rural-urban relationships. The interaction between rural and urban areas is an important topic in planning literature. This is the first empirical research that expands the discussion to point-nonpoint source pollution trading.

Third, the relationship between pollution credit buyers and sellers in the point-nonpoint source pollution markets have not been thoroughly studied by researchers from the fields of economics, environmental science, and planning. When modeling the behaviors of market participants or the potential impact on water quality, researchers usually assume a perfectly competitive market in which the buyers and sellers immediately find each other. In this research I explore the details of how connections are made within the trading process and help establish a foundation for more sophisticated environmental and economic models on point-nonpoint source pollution trading.

The next section reviews literature on social network analysis and social capital and thus lays out the theoretical foundation of the study. The methods applied in this chapter are discussed in the following section. The fourth section presents the findings of my study.

3.2 Literature review

The significance of social relationships in pollution credit markets has been highlighted by only a few researchers. Breetz et. al. (2005) argued that social embeddedness, the extent of social relationships and reciprocity, was a key element in water pollution credit trading. In their case study on 12 water pollution credit trading programs, the authors explored farmers’ participation behaviors and found that trustworthy third parties and existing ties among farmers can facilitate the implementation of the programs. Echoing their research, Mariola (2012) examined 15 point-nonpoint source nutrient credit trading programs in North America and found that the market intermediary who connected with farmers was the most important driver of program implementation. He also examined how the socially embedded entities facilitate trading via information-sharing, collective problem-solving, and trust (Mariola 2012). Both of these studies with their direct focus on pollution credit markets, draw upon two strains of literature that are especially relevant to this issue: the literatures on social network analysis and social capital.

3.2.1 Literature on social network analysis

Social network analysis is a powerful tool to analyze the relationships among different agents and to use the relational perspective to understand social and physical subjects and processes. It has been applied to economics, sociology, mass communication, criminal justice, and many other applied social sciences (Borgatti et. al. 2009). Topology analysis, the study of the geometric properties and spatial relations, of the social network elements is the key technique for this application. It pays attention to qualitative characteristics of a network such as its structure and quantitative parameters such as network density and centrality (Butts 2008). Social network analysis has not been widely applied to study nutrient credit markets. Since point-nonpoint source pollution trading involves working with agricultural producers to implement conservation practices, I reviewed the literature which utilizes social network analysis in the field of agricultural conservation activities.

Social network analysis can study two types of networks. The “egocentric network” depicts a subjective network from the perspective of the person/entity of interest. The “whole network" describes the relationships among all members within a network (Chaudhary & Radhakrishna 2018). Both types of networks have been studied in the field of planning and natural resources conservation. The whole network study is more informative as it reveals all existing ties, but it can be highly resource intensive. In some cases, instead of the whole network, researchers only care about the subjective network and its influence on the person/entity of interest. For example, Knoot and Rickenbach (2011) interviewed private forestry landowners in Wisconsin to examine the relationship between the people they know and their decisions on forestry best management practices. Interviewing all the parties identified by the landowners would expand this egocentric network to a whole network but it would require much greater resources to interview and analyze, and the relationships among those additional parties are considered closely relevant to the landowners' behaviors of interest.

To apply social network analysis to agriculture conservation practices, three problems should be clearly defined. First, the boundary of the network should be clarified. Without a clear boundary, there will always be more entities and people to attach to the network. A social network analysis should be carefully designed to make sure that all parties included in the network are relevant to the research topic (Chaudhary & Radhakrishna 2018).

Second, the ties within a network could be divided into different types. Researchers could either focus on specific types of substances sharing or simply the existence of connections. For example, Rissman & Smail (2015) studied the reporting network, i.e., the sharing of performance information by reporting, among conservation organizations. An opposite example is the study of kinship among farmers and adoption of agricultural conservation technology (Warriner & Moul 1992). While the former narrowed the scope of relationships to official reporting among governmental entities, the latter did not stipulate the types of information shared by farmers and instead studied the general relationships.

Third, the basic unit of the social network analysis could be people or organizations. Sometimes it could also be a role-based network in which each role of the network represents a group of people/entities. Cohen et. al. (2012) studied the environmental governance networks in Solomon Islands and mapped relationships of entities instead of personnel. Gorris et. al. (2019) compared the fishery resources management network on four Indonesia islands and in the analysis, all actors were divided into four roles: government, civil society, academia, and environmental user.

Social network analysis could be used in the study of point-nonpoint source pollution trading. Economists find that non-economic factors, i.e., social networks, can play central roles in certain markets. Trading through networks has many benefits. For example, compared with a cold-call attempt, identifying credit sellers through a network reduces searching cost. Another benefit is that the buyers and sellers with a long-term relationship and strong trust may be more likely to pursue trading to meet the compliance requirements. However, at the same time, depending on networks for trading creates fragmented markets and decelerates price discovery. Moreover, it makes less-connected point sources and farmers worse off or disadvantaged (Granovetter 2005).

3.2.2 Literature on social capital

The literature on social capital is closely related to social network analysis literature. Putnam defined social capital as connections among individuals and further specified this concept as “social networks and the norms of reciprocity and trustworthiness that arise from them" (Putnam 2000). Paxton (1999) claimed that this concept consisted of two themes: trust and association. Social capital is widely regarded as critical to the success of collective actions (Larson et. al. 2004).

Scholars have divided social capital into two types: "bonding social capital" refers to the strong ties within a community while the "bridging social capital" is the extra-community ties that span across groups (Woolcock 1998; Cramb 2005). Vidal (2004) found that bonding capital brought closer people who had already known each other and could help less advantaged communities to get by, while bridging capital was more promising in creating opportunities for the communities.

3.3 Methods

3.3.1 Case study protocol

This case study is part of the empirical investigation of Wisconsin's two nutrient credit trading programs, WQT and AM. Its primary goal is to study the relationships between social networks within the local communities and the nutrient credit trading activities. A case is defined as a point source permittee involved with either the WQT or AM trading programs, as well as other partners and all the events relevant to its phosphorus compliance. Other definitions of cases have also been explored. Previous researchers have used whole trading programs (Mariola 2012) or watersheds (Horan et. al. 2004) as the basic analytical units. However, I focus on neither comparison of different trading programs nor pollution control solutions for individual watersheds. Therefore, the point source permittee was designated as the core of the analytical unit.

I took four steps to select cases that 1) were representative of WQT and AM participants, 2) covered different environmental and societal contexts, and 3) had entered the implementation phase or at least made implementation plans. First, through public notice records of WQT and AM participation by WDNR, I identified 30 WQT participants and 17 AM participants. Second, only some of these participants had submitted the final implementation plans and the rest only indicated their intention to participate. I removed the participants who did not have the final plans.

Third, I read the AM/WQT plans of the remaining permittees to determine their relevance to this analysis. Many point source permittees acknowledged in their AM plans that they were only using AM as a temporary compliance method and would most likely turn to other options after exploring AM for one or two permit terms (5-10 years). These permittees were removed from the study. Four permittees in the Yahara River Basin were also excluded from this analysis. These permittees led by Madison Metropolitan Sewage District decided to work on one combined AM project. Permittees and other community members in this watershed have a long tradition of watershed-level collaboration and a substantial history of precedent efforts to reduce nonpoint source pollution loads, which give rise to this joint AM project. These four Yahara River Basin cases do not reflect the typical situation faced by the majority of point sources in Wisconsin and thus were not included. As for WQT participants, the point sources implementing best management practices on their own properties were removed. These transactions, known as internal trading, did not require engagement of external partners and thus could not provide meaningful insight on social networks.

Finally, after removing the irrelevant permittees, seven WQT participants and four AM participants remained in the candidate pool of the case study. By analyzing the WQT and AM plans, I extracted the permittees' critical characteristics and complied them into three categories (see Table 3.1). By examining the characteristics, permittees with similar traits were grouped and for each group, one permittee was selected as the representative case.

After the case selection process, four WQT participants and four AM participants were identified as the subjects for the case study. One WQT participant was later removed from the list as the target informant declined the request of interview. Two other WQT participants were added via snowball sampling method as supplementary information sources. The total number of cases is nine.

Table 3.1 Characteristics for Case Selection. The location, sector, and size of the WQT and AM participants are used as parameters to select cases for the study

Variable	Description	Information Source
Location	Climate, geology, and hydrology background of the permittee	The whole state was divided into several regions according to natural characteristics. The permittees were tagged by the regions where they locate.
Sector	Nature of the treatment facility (municipal wastewater treatment plant or industrial source)	WDNR permittee dataset
Size	Size of treatment plant	Effluent volume and serving population extracted from WDNR's documents

The next step was creating a case study protocol and a general question list. For each case permittee, I compiled a dataset by 1) researching and downloading all the publicly available information about the permittee via search engine, and 2) requesting its permit, fact sheet, and WQT/AM plan from WDNR. The publicly available information includes news articles from news outlets, newsletters from the permittees, official documents released by the permittees, journal articles, and presentation slides introducing the progress of the WQT/AM projects. By analyzing all the documents, I wrote a case description of the permittee and created a spreadsheet for all entities involved in the case and the key events mentioned in the documents. The question list would also be customized for the specific permittee.

After compiling the information of the permittees, the key informants of these cases, i.e., the persons who had played the most critical roles in the WQT/AM projects, were contacted and interviewed. In most of the cases, the document analysis would lead me to the key informant(s) of the projects. For municipal wastewater treatment plants, the most important informant was oftentimes the municipality's director of public works or the manager of the wastewater treatment plant. For industrial permittees, the operation managers were usually responsible for the effluent compliance and thus were the best information sources. For cases with scarce publicly available information, I started with interviews of staff in county land and water conservation departments who had been working with the permittees on the compliance issue and asked them to help connect me with the permittees.

Sixteen interviews with nineteen interviewees were conducted between April 2020 and January 2021. Given the pandemic situation, all interviews were carried out remotely via either Zoom or phone. All the interviews were recorded as consented by the interviewees. The audio records were transcribed by an online transcription tool called Otter.ai and coded by NVivo 11.

3.3.2 Data

Table 3.2 shows all the cases and the numbers of informants interviewed. The professions of the interviewees include wastewater treatment facility managers, municipal leaders, managers of industrial source permittees, staff of county land and water conservation departments, leaders of local NGOs, and staff of engineering consulting firms. A sample of the question list could be found in Appendix II. The main information collected by pre-interview document analysis and the interviews is summarized in Table 3.3.

Table 3.2 Description of the Cases. Five WQT participants and four AM participants, representing permittees in different regions of Wisconsin, are selected for the case study

Case	Compliance Method	Number of informants interviewed*
An industrial permittee in southwestern Wisconsin	WQT	1
An industrial permittee in southern Wisconsin	WQT	2
An industrial permittee in northeastern Wisconsin	WQT	2
A municipal permittee in southern Wisconsin	WQT	4
A municipal permittee in northern Wisconsin	WQT	1
A municipal permittee in southeastern Wisconsin	AM	5
A municipal permittee in eastern Wisconsin	AM	2
A municipal permittee in southern Wisconsin	AM	5
A municipal permittee in central Wisconsin	AM	4

Note: Many informants played critical roles in multiple projects. Thus, the sum of the numbers in this column exceeds 19, the total number of interviewees.

Table 3.3 Categories of Information Collected in Case Study. Five categories of information are collected in the case study via document analysis and interview

Type of Information	Information Source
Physical conditions of the facility, applicable phosphorus rules, socio-economic background	Document analysis
Timeline of compliance activities	Document analysis, interview
Key partners for phosphorus compliance and their relationships with the key informant	Document analysis, interview
The approaches taken to connect and trade credits with farmers	Interview
Challenges and surprises in nutrient credit trading	Interview
Reasons to participate in WQT/AM	Document analysis, interview

3.3.3 Analytical Strategy

Four rounds of analysis were conducted. In the first round, a fact sheet was created based on each transcription. It was a collection of all information regarding the "what" questions, which were the basic facts about the permittee and its compliance decisions (see Appendix III for the template of the case report).

Then the transcriptions were coded by NVivo 11. An iterative approach was taken for the coding. A preliminary codebook was built based on the research questions and literature on pollution credit trading. It consisted of two sections: 1) the themes that were related to the research questions; and 2) the common issues discussed by previous literature such as typical pitfalls in policy design and challenges in implementation. The first three transcriptions were coded with the preliminary codebook, and the codebook was substantially modified and refined during this process. The most relevant themes were further broken down into expanded sub-themes and preliminary themes that proved to be irrelevant were dropped. The revised codebook was applied to the coding of all transcriptions. As new potentially important themes emerged, they were tagged and if enough materials around a theme accumulated, it was added to the codebook. Ninety-two (92) sub-themes were finally identified during the coding process. Table 3.4 demonstrates the content of the codebook (see Appendix IV for the details of the codebook and Appendix V for the whole procedure of case study).

Patterns in individual cases were recognized and analyzed through pattern matching and explanation building. Then a comparative analysis was conducted with all the cases. Pattern matching compares the findings derived from the cases and predictions of trading patterns based on propositions from literature (Yin 2017). It was mainly applied to the analysis of the social networks for these cases. There could be multiple alternative predictions according to different theories related to the study subject; the goal is to find the prediction that aligns best with the situation, thereby validating and developing theories and concepts. Explanation building is different from pattern matching as it does not develop the propositions before analysis. Instead, the findings come from inductive and deductive analysis of the raw materials (Yin 2017). This method was applied to the analysis of other themes related to the nutrient credit markets.

Table 3.4 Content of Codebook. The interview transcripts were coded by two sections of code covering social network analysis and other common themes. Each has four main categories

Code Section	Code Category	Description
Social network analysis	Outreach strategies	The strategies taken by the permittees to connect with nonpoint source partners
	Partnership process	Description of process of partnership development
	Partnership mode	Description of the nature of partnership
	Partnership benefit	Descriptions of the benefits of the partnership
Other common themes	Challenge	Challenges in WQT and AM including
	Uncertainty	Uncertainties embedded within the projects or the whole market
	Institution	Institutional background that influence the projects
	Agriculture	Themes on agricultural communities

3.4 Findings and Discussion

3.4.1 Key actors in Wisconsin's nutrient credit markets

Seven main categories of entities in the nutrient credit markets were identified in the social network analysis. They are point source permittees, county land and water conservation departments, producers and farm-led groups, engineering consulting firms, WDNR, other citizen groups, and other governmental agencies. Each of these key actors and the roles they played in the markets are presented below.

3.4.1.1 Point source permittees

Point source permittees are the most important actors in the nutrient credit markets. The markets depend on phosphorus caps created by policy, and trading would only happen if the point source permittees deem WQT or AM as their best compliance method. For municipal permittees, the decisionmakers are usually managers of the wastewater treatment facilities or the municipalities' directors of public works. With the help of other partners, they make the preliminary plans to achieve compliance. Those compliance decisions need to be consented by the leaders of the municipalities such as city councils. Once a municipality decides to participate in WQT or AM, the manager of the wastewater treatment facility or the director of public works would continue playing central roles coordinating the implementation of the projects. The whole life cycles of the trading projects would also be overseen by the municipality leaders. For industrial permittees, the administrative structures are relatively simpler, and the managers of the operations would be the primary decisionmakers.

3.4.1.2 County land and water conservation departments

According to WDNR's guidebooks on WQT and AM (WDNR 2013a; WDNR 2013b), county land and water conservation departments could provide brokerage services to the nutrient credit markets. In practice, county land and water conservation departments were present in almost all of the trading cases with a variety of roles. First, most of the permittees were not familiar with nonpoint source pollution control, and the county conservationists could share the knowledge with the permittees. The information regarding the watershed and local nonpoint source discharge oftentimes came from the counties as well. Second, the county governments could help the permittees to identify specific nonpoint source pollution control projects with their expertise and existing relationships with producers. Third, if a land and water conservation department have enough capacity and strong ties with the producers, it could provide brokerage services to the permittees. As a broker, the county would work with the producers on behalf of the permittees, generate credits for them, and charge service fees proportional to the amount of phosphorus credits created. Comparing with WQT, AM participants do not need brokers to trade phosphorus by mass, because AM focuses on ambient water quality instead of phosphorus reduction. Nevertheless, it could still benefit from quasi-brokerage services. In an AM project, county governments could charge flat fees on specific services. Many of the conservation departments provided technical services and professional opinions free of charge. The main motivation of the county conservation departments was to implement more best management practices. Many of the conservationists interviewed considered the nutrient credit markets as a good opportunity to expand the funding source for the local conservation activities.

3.4.1.3 Producers and farmer-led groups[1]

Producers are essential partners of the point-nonpoint source pollution trading scheme. Theoretically, producers would benefit from the markets as the payments from point source permittees exceed the costs of best management practices. However, engaging the producers has always been one of the largest challenges in nutrient credit trading due to various of reasons.

First, it takes time and resources for producers to participate in trading. When participation is not mandatary, many producers may not take time to learn about the programs. Second, farming inherently involves balancing multiple uncertainties, and even marginal changes could break the financial equilibrium of a farm operation. Worrying about the potential adverse

[1] Producers were not identified and interviewed in this case study to protect their privacy. General descriptions of producers and farmer-led groups were collected from interviewees with other entities.

impacts, producers may prefer continuing without additional disruptions to their original operation plans. Third, producers may be concerned about future regulations brought about by trading. Currently, nonpoint sources face less stringent regulations than point sources. Agricultural producers tend to not consider themselves as polluters. Participating in point-nonpoint source pollution trading may add to concerns that their farms would be tagged as pollution sources and information about them would be collected by government agencies for future regulation. Fourth, land retirement is one of the most popular best management practices in the WQT and AM projects, and producers may dislike the practice of land retirement as it reduces land available for farming. Sometimes due to regulatory considerations, it becomes the only eligible practice that can generate long-term credits. Though it is usually a small parcel that is retired for trading, it is considered by many a challenge to farming culture and lifestyle.

On top of the aforementioned concerns, point source permittees traditionally do not collaborate with the producers. They can be oblivious about farming activities, nonpoint source pollution control, and more importantly, the agricultural community. The lack of connection, together with the concerns of the farmers, substantially constrains trading opportunities.

However, producers could be motivated to join the nutrient credit markets. Many producers are attracted by the financial returns especially after witnessing successful cases in neighboring communities. Some progressive producers acknowledge that their farming activities are causing nonpoint source pollution and want to be part of the solution. They are more willing to adopt best management practices and thus are more open to nutrient credit trading. Many environmentally progressive farmers in Wisconsin are engaged in farmer-led groups with the help of University of Wisconsin Extension and Wisconsin Department of Agriculture, Trade, and Consumer Protection. These groups attempt to address the local water quality issues by adopting conservation practices. The farmer-led groups could be an important intermediary between the point source permittees and producers.

3.4.1.4 Consultants

Wastewater engineering consultants are vital partners for point source permittees. Historically, the consultants focused on wastewater treatment facility design, permitting, and other technical services. Most of the point source permittees had been relying on consultants for WPDES permit application before the new phosphorus rule was enacted in 2010. After those regulatory changes, they continue hiring the consultants to evaluate the phosphorus compliance options. Under certain circumstances, the consultants also help with the implementation of the nutrient credit trading. Three outstanding features of the consultants should be noted.

First, most of the consultants did not have experience in nonpoint source pollution control before the enactment of the new phosphorus rule. Like the point source permittees, they had to learn about watershed conservation practices. In the early trading cases, the consultants were not able to fully assist the implementation of the projects. Rather, they either relied on other partners such as the land and water conservation departments or only focused on the permitting aspects of the trades. Nevertheless, the consultants were able to develop their capacity on nonpoint source pollution control projects as they acquired more experience with nutrient credit markets. One consultant interviewed indicated that experiences with nutrient markets was moving that firm to offer watershed conservation services.

Second, the consulting market is highly localized, and point source permittees usually hire consultants with a presence in their own regions. Even consultants serving the whole state set up several regional offices to work with their local clients. As a result, there are a large number of consultants, and through normal competition, all of them need to explore the nutrient credit trading policy independently. According to WDNR's early statistics on WQT and AM plans, by October 2019, the first 28 alternative compliance plans choosing AM or WQT came from 14 different consultants. The average number of nutrient credit trading cases handled by the consultants was two and the maximum number was five. Each point source permittee needs to experience a steep learning curve on nonpoint source pollution control, and at least during the early stages of theses nutrient credit markets, the consultants did not enjoy economies of scale.

Third, the relationships between consultants and their clients predate the new phosphorus rule. The consultants' initial experience and capacity in nutrient credit trading was irrelevant due to pre-existing relationships with permittees. For many of the municipalities, the consultants provide technical services to not only the wastewater treatment facilities, but also other infrastructure. Even if the relationship was only about wastewater treatment, the consultant would need to work on a much broader scope of pollutants besides phosphorus. According to the interviews, the schedule of AM and WQT implementation could be postponed due to unresolved issues on other pollutants which delayed the renewal of WPDES permits. Despite their vital role in nutrient credit trading, the consultants' partnership with the permittees is not completely built on phosphorus compliance.

3.4.1.5 Wisconsin Department of Natural Resources

WDNR regulates water quality in Wisconsin and operates the WPDES permitting system. This state-level government agency designed and manages the nutrient credit markets in Wisconsin. It reviews and approves all the alternative compliance plans submitted by point source permittees. It also requires post-implementation monitoring and reporting and has the authority of enforcement. Although WDNR designed the WQT and AM programs, it had not streamlined all the details of these programs by the time when they were launched. WDNR has continued working with the early participants and their consultants to develop and modify the programs. While certainly viewed as a key actor in the process, WDNR generally does not provide specific services on project implementation and thus is not considered as a core partner by many permittees.

3.4.1.6 Other citizen groups

Many citizen groups are also interested in Wisconsin's nutrient credit markets. These groups tend to focus on environment protection, land conservation, and farmland preservation. Some, such as lake associations, hunting and fishing groups, and various watershed protection organizations, are likely to work with the permittees in order to improve the local water environment. They provide local knowledge on the watershed, funding, and channels for advocacy. In an AM case, a local watershed protection NGO ran a project that monitors the quantity and quality of the local waters. The historical data were instrumental in the decision-making of the point source permittee. The informant with the permittee stated that many other permittees started with little or no data, but due to involvement of the local group, they were fortunate to have the data. The existing data facilitated their decision on participation of AM. Other groups, e.g., farmland preservation groups and land trust, work with farmers to preserve working lands for farming. Though less focused on water quality improvement practices, they maintained long-term relationships with the producers and could facilitate connections with point source permittees. By working with the point sources, the land trust groups could expand their platforms for collaboration with farmers. More importantly, there has been a trend that the land trust groups are gradually expanding their missions to the field of watershed protection. Nutrient credit trading opens the window for them to accomplish the transition.

3.4.1.7 Other government agencies

Other government agencies, such as Natural Resources Conservation Service (NRCS), Farm Service Agency, and U.S. Fish and Wildlife Service were also identified by the permittees for providing funding and in-kind technical services. Along with providing funding and support through other farm bill conservation programs, NRCS operates the Regional Conservation Partnership Program (RCPP). The program awards funds to partners who work with NRCS to solve natural sources problems on farm, watershed, and regional level. The RCPP grants are used to co-invest the innovative projects implemented by the partners. An AM participant became the recipient of this fund. Although the majority of the program expense still came from the permittee, the additional financial support from the grant was not trivial either. The greater benefit resides in the in-kind services from NRCS, whose staff worked closely with the permittee in search and implementation of the best management practices. This collaboration is also meaningful for NRCS as other research has found that producers are skeptical about collaborating with federal agencies. The involvement of local partner, i.e., the point source permittee in the neighboring community, can make the conservation projects more acceptable to these producers. Also, as the NRCS cost share grants cannot completely cover the cost of the conservation projects, the matched payment from the permittee can bridge the gap, making the projects more affordable and attractive to the producers.

3.4.2 Approaches to connect with the producers

The first question about the trading network is how the point source permittees manage to connect with producers. Through interviews, seven networking methods are recognized. The methods are summarized in Table 3.5.

Existing relationship

In some cases, the permittees did have preexisting relationships with the owners of lands used for nutrient credits. Some municipal permittees provide sludge, the byproducts of wastewater treatment, to producers for land application. Industrial sources of certain types have more opportunities to trade other raw materials or waste with farmers. These relationships could be a good starting point for the permittees to work with producers. However, as the permittees usually only had preexisting relationships with limited numbers of farmers, they may not be able to find interested trading partners from the small groups.

Cold call

Permittees may contact farmers via cold call. When they obtained the information of adjacent land parcels, they could reach out to the owners of the land to solicit for collaboration. This method was used more frequently in WQT cases that traded small amounts of phosphorus credits.

Outreach and education

Permittees could hold information sessions or community meetings to engage potential cooperating producers. In these events, they would introduce the nutrient credit market and their plans to work with local nonpoint sources. These activities were often organized with the help of other entities that were closer to farmers. Two permittees noted that there were not many farmers attending these activities initially, though one permittee was able to recruit some interested producers in this venue.

Representative

Permittees can hire people who know farming and farmers well to help them with trading solicitation. This is a classic brokerage mode defined as representative by sociologists (Gould & Fernandez 1989). The people directly working for the permittees were also trusted by producers. Therefore, they could represent the permittees and persuade the farmers to participate in trading.

Liaison

Liaison is the second brokerage mode utilized by the permittees. The permittees could seek help from independent third parties, i.e., liaisons, to connect with farmers. County land and water conservation departments and local NGOs trusted by the farmers are typical liaisons.

Producer partner

The permittees could also approach to producers through progressive farmers who are interested in watershed conservation projects. This approach was identified as the third type of brokerage mode, gatekeeper (Gould & Fernandez 1989). A gatekeeper connects outside agent A with agent B in its own community. It facilitates the transaction while controls the channel between A and B. Although the mode was found in Wisconsin’s nutrient credit markets, it deviates from the classic gatekeeping mode as the progressive farmers would not dictate the channel of communication to make profits. Instead, they voluntarily helped the permittees to contact more producers. For example, in an AM case, the permittee helped to develop a farmer-led group whose members actively participated in the conservation projects and advocated for the AM projects.

Neighboring effects

When it came to the mature phase of a project, the successful best management practices implemented by the early adopters would attract more producers. A consultant noted that famers could be skeptical about nutrient credit trading, but positive stories about the successful examples would spread in the community. As more farmers recognize potential benefits from nutrient credit trading, it may become easier to engage the producers.

Table 3.5 Networking Methods for Producer Engagement. Seven methods taken by point source permittees to engage producers for nutrient credit trading were identified by the case study

Method	Description
Existing relationship	Utilize existing relationship between point source permittees and producers
Cold call	Identify potential nonpoint source partners and directly reach out to them
Outreach and education	Host outreach and education events to recruit partners
Representative	Hire people who are familiar with producers to engage them on behalf of the point source permittee
Liaison	Connect with producers with the help of independent third parties
Producer partner	Engage more producers with the help of progressive producer partners
Neighboring effects	Use successful conservation projects to attract more producers

All seven methods were used by permittees in Wisconsin to accomplish phosphorus credit trading with agricultural producers. Although cold call is considered as a very inefficient way to network, it still worked in certain cases, especially for the WQT cases in which only minimal amounts of phosphorus credits were needed. In these cases, instead of establishing a sophisticated vehicle for outreach, finding individual farmers who were willing to sell small proportions of their lands can be more efficient. For example, in one WQT case, the permittee purchased a small farm from the retiring landowner and turned it into grassland. This trading opportunity presented itself to the permittee: the consultant spotted a small farm for sale from an ad by the roadside. However, for WQT projects with greater credit demands and all the AM projects which require collaboration with larger groups of dischargers, as the number of projects to implement increases, cold call becomes less and less useful. In the largest AM case, the permittee contracted with 37 producers on a variety of best management practices and 23 producers were connected through third-party partners, accounting for 62% of the nonpoint source partners. Each of the connection process follows at least one of the brokerage modes: representative, liaison, or producer partner. Meanwhile, there were only 4 producers (11%) connected by cold call and 10 producers (27%) attracted by outreach and education events.

3.4.3 Existing social network and trading practices

I also explore how the existing social network interacts with the nutrient credit markets. The most outstanding theme that influences the viability of nutrient credit trading is rural-urban relationship. Nutrient credit markets in Wisconsin are shaped largely by the existing rural-urban relationship in the watersheds.

The relationship between rural and urban areas has long been an important topic in the field of planning. Spatial planning, migration and flow of substances, and interactions between urban and rural economies are traditional focal points of this topic (Tacoli 1998). This dynamic also echoes with many of the recent political developments in the U.S. and thus receives rising scholarly and public attention (Cramer 2016). Recently, a group of researchers expanded the discussion of rural-urban relationship to the issue of water quality improvement. They claimed that water quality trading programs can facilitate the formation of political alliances, exchange of knowledge, interpersonal relationships, and shared sense of place among rural and urban partners (Church et. al. 2020). One environmental NGO in Wisconsin that advocates for the nutrient credit markets called the trading a "municipal-agricultural partnership," indicating the important background of rural-urban relationship in the nutrient credit markets (Sand County Foundation 2020).

Building on the previous studies, two adverse aspects of rural-urban relationship emerge from this study that could undermine trading validity. The first of these is challenges posed by geographical boundary. The most intuitive difference between rural and urban areas is probably that they do not locate at the same place. During the interviews, "city limit" was a recurring term mentioned by almost all informants with municipal permittees. Nutrient credit trading (WQT and AM specifically) is a bold concept to many municipalities as it requires them to pay people outside of their geographical boundaries for something that municipal dwellers might feel they should be doing anyway. Some council members of the municipalities claimed that the producers outside of the city limits were not part of the urban communities and should not receive subsidies from the municipalities. A city leader described the good relationship between the city and farmers from adjacent areas with the fact that the farmers would attend the council meetings of the city. The geographical boundary between rural and urban areas to some extent hindered the collaboration between the two communities.

The second challenge relates to distrust and uncertainty. Rural and urban communities usually have different forms of economies and host different sectors. The point source permittees usually do not know in detail how the agricultural production as well as the best management practices function. Almost all permittees interviewed expressed concerns about whether the farmers would continue working with them in the long run. Similarly, farmers are also unfamiliar with the permitting system, detailed requirements of water quality discharge requirements, and nutrient credit markets. The lack of understanding and distrust undermine the foundation for collaboration.

Despite the barriers embedded in the rural-urban relationships, there are three types of channels that connect urban and rural communities that facilitate nutrient credit trading. The channels include economic, farmland preservation, and conservation networks. First, some permittees have been trading materials with neighboring producers before the launch of nutrient credit markets. The existing economic network between rural and urban communities could be used as a channel to discuss nutrient credit trading. Second, the farmland preservation network, for example, long-term relationship between a land trust and producers, could be converted to the network for nutrient credit trading. Lastly, the networks that include producers and all entities dedicated to watershed conservation can immediately serve the purpose of trading, as they both target at best management practices implementation.

Among the three networks, the watershed conservation network proved to be more effective in supporting nutrient credit trading. The formation of the watershed conservation network needs the efforts of members in both communities. For urban communities, the persons who are willing to work with farmers on watershed conservation usually not only possess knowledge about the agriculture sector but also feel cultural proximity towards the agriculture communities. Among all the interviewees, the informants who provided brokerage or quasi-brokerage services to the permittees were more likely to talk about how difficult and subtle farming could be. For rural communities, the progressive farmers embrace conservation projects and are more likely to collaborate with government entities or environmental NGOs outside of their communities. These two groups of people developed bonding social capitals with members in their own communities while also created bridging social capitals between rural and urban communities. Their networks reach beyond the geographic boundary and cultivated trust among these small groups of people. When a network around point-nonpoint source nutrient credit trading needs to be built, the bridging social capital and existing ties, as a pivotal asset of the communities, greatly reduced the uncertainties in the collaborations and nurtured the new network.

3.4.4 Nutrient credit trading and the new social network

Nutrient credit markets in Wisconsin connect different types of partners, foster nutrient credit trading networks, and thus further influence the rural-urban relationships in watersheds. Trading improves the relationships by changing the original social networks. Three patterns of social network change were identified by the case study.

The first pattern is creation of new networks (new social capital). When there were no existing rural-urban social networks, the point source permittees may directly connect with producers under the help of other entities. Although it might be groundbreaking in the watershed, these individual transactional relationships may not be able to resonate with other social ties. This type of change is common to smaller WQT projects in which the permittees found single landowners and implemented small-scale best management practices.

The second pattern is addition to the existing networks (improved social bonding capital). For urban and rural communities which had already built strong ties, the point source permittees would just utilize the ties as the channel to purchase phosphorus credits. For example, in one WQT case studied, the county land and water conservation department had worked with many producers for watershed conservation projects, during which more possible improvements of the farms were identified. The payment from the point source permittee was considered as an extra funding source for the rural-urban partners to implement more projects. Trading improved the network by including within it an external funding source, the point source permittees.

The third pattern is connection of two or more existing networks (improved social bridging capital). There might be various rural-urban social networks developed parallelly in one watershed. Through nutrient credit trading, especially AM projects, these networks could be connected. In an AM project, a land trust previously focusing on farmland preservation successfully stepped into the field of watershed conservation by becoming a core partner of the point source permittee. While the existing farmland preservation network greatly helped the permittee, the land trust also gained more opportunities to solicit for preservation projects via the watershed conservation network. Trading empowered both networks.

3.5 Conclusions

Nine nutrient credit trading cases on AM and WQT are examined to understand key actors and their engagement through social networks. Through document analysis and interviews with 19 informants, I identified seven groups of key actors in Wisconsin's nutrient credit markets and analyzed their roles and motivations. The actors are point source permittees, producers and farmer-led groups, engineering consulting firms, WDNR, county land and water conservation departments, other citizen groups, and other governmental agencies.

In exploring the interactions between nutrient credit trading and social networks, I discussed three questions. First, I identify how permittees find their trading partners by recognizing seven approaches they use to connect with producers, which include preexisting relationship, cold call, outreach and education events, representative, liaison, producer partner, and neighboring effects. Simple networking methods such as existing relationship and cold call serve transaction with small volumes better. When the permittees need to connect with large numbers of producers, they tend to rely on more sophisticated approaches such as representative, liaison, and producer partner.

Second, I analyze how the existing social networks influence nutrient credit trading. Among all the social relationships in the local communities, I find that rural-urban relationships impose the most substantial influence on potential trading participation. Geographical boundary and distrust are the two barriers between rural and urban communities that both undermine trading validity. Supportive aspects of rural-urban relationships include three networks around good and service trading, farmland preservation, and watershed conservation can form the foundation of the new nutrient credit trading network. The watershed conservation network plays the most critical role as it engages producers for similar purposes with nutrient credit trading—implement watershed conservation projects. The bridging social capital accumulated in these networks is an important asset that greatly facilitates nutrient credit trading.

Lastly, the influence of nutrient credit trading on local social networks, especially around rural-urban relationships, is illustrated. I find that trading fosters formation of new networks. More importantly, the interactions associated with trading add point source permittees and the municipal governments overseeing them into existing rural-urban networks. These interactive planning and implementation processes also connect different networks such as those involved with farmland preservation and watershed conservation. Point source permittees' investment on nutrient credit trading brings capital and personnel to the existing networks and leverages other resources such as conservation funds and in-kind technical services from other governmental agencies.

Chapter 4. Uncertainty, Transaction Cost, and Accountability: A Study of Broker-driven Nutrient Credit Markets

4.1 Overview

Point-nonpoint source nutrient credit markets enable point source permittees to buy phosphorous discharge credits from nonpoint sources, oftentimes agricultural producers. Markets have potential to reduce the abatement cost of the point source permittees while also increasing the revenue of the nonpoint sources. However, these markets are troubled by high transaction cost and unstable supply and demand.

Researchers believe that brokers can address these two issues. A broker is an intermediary that earns commissions by arranging transactions between buyers and sellers. Broker is a critical actor in many markets for goods and services. However, the application of brokerage service in nutrient credit markets is limited to a few programs. For example, Ohio has one of the United States' largest phosphorus credit trading market in its Great Miami River Basin. The Miami Conservation District buys credits from farmers via reverse auction and then sells the credits to point source permittees. Meanwhile, the local soil and water conservation district agents help the farmers to bid in the auctions. The Miami Conservation District plays the role of broker in this setting (Newburn & Woodward 2012). In South Nation River Basin in Ontario, Canada, a community-based watershed organization also works as a broker (O'Grady 2011). Woodward et. al. (2002) defined a water quality market driven by brokers as a water quality clearing house. They argued that compared to markets with only buyers and sellers, the clearing house has lower transaction cost per trade but higher market initiation cost.

As a way to incentivize watershed management and to help point source permittees cope with the stringent phosphorus criteria enacted in 2010, Wisconsin Department of Natural Resources (WDNR) launched three nutrient credit trading programs: Water Quality Trading (WQT), Adaptive Management (AM), and Multi-Discharger Variance (MDV). The WQT and AM programs allow the point source permittees to work with brokers. Many point source permittees did seek help from third-party entities to facilitate transactions with farmers. Most of the third-party entities, such as county land and water conservation departments, land trusts, consultants, and local environmental NGOs, acted as quasi-brokers as they fostered transactions between phosphorus credit buyers and sellers but might neither buy and sell credits themselves nor charge the permittees for the services. Wisconsin legislators have also discussed the possibility of establishing a statewide clearing house for WQT (A.B. 113 2019).

The third program, MDV, officially includes brokers as the core part of its design. Per the MDV program setting, to offset the excessive amount of phosphorus discharged, a point source permittee could pay a third-party entity a specified amount of money for them to implement agricultural nonpoint source pollution control projects. The initial price was set at $50/lb in 2017 and increases annually in accordance with Consumer Price Index. County land and water conservation departments could register for this program to become the brokers. As a result, they would receive the payments from permittees located in their counties[2]. Their responsibilities are to implement watershed conservation projects with the payment and demonstrate phosphorus reduction. The MDV option is not available to permittees in relatively wealthier regions, and it is designed to be a temporary program (potentially up to 20 years) that helps permittees transit to

[2] The permittees actually make payments to counties in the same HUC 8 watersheds with them. If there are multiple counties in one watershed, the payment would be split according to proportions of the county areas in the watershed. If a county decided not to be a broker, the MDV participants in that county could instead make the payments directly to WDNR or other third-party entities who are willing to be the brokers.

other permanent phosphorus compliance options. Even so, it has attracted more than one hundred interested participants in Wisconsin, and 30 counties had registered as brokers by March 2020. Approximately $1.5 million was paid to the counties through the program by the end of 2019.

Unlike previous broker-driven nutrient credit markets, the MDV program has more than one broker. Instead of a single market, the MDV program set off tens of independent local markets centering around the county land and water conservation departments. This situation provides a better opportunity to examine the role of brokers in the nutrient credit markets by comparative study. Therefore, I conducted a case study on Wisconsin's nutrient credit markets based on the MDV program. Specifically, I focus on three questions: 1) how do the broker-driven markets function; 2) how can brokers influence the transaction cost in the nutrient credit markets; and 3) how can brokers reduce the uncertainty in nutrient credit markets? The next section reviews the literature on transaction cost and uncertainties of supply and demand in environmental markets. The following section describes the methods applied in this study. Findings are presented in the fourth section.

4.2 Literature Review

4.2.1 Literature on transaction cost in environmental markets

As described by classical economists, in a perfect market with a truly frictionless world where every piece of information is available to everyone, the command-and-control regulations would be cost effective, because the regulatory authorities would know who can reduce the discharge with the lowest cost and allocate the permits accordingly. In reality, firms' production functions are not available to the governments. By recognizing the reality of imperfect information (but keeping an assumption of no transaction costs), Montgomery (1972) suggested that a pollution permit trading market is better than a command-and-control regulations and will allow for an optimal distribution of discharge quota regardless of their initial allocation by governments. This research lays the theoretical foundation for the studies and practices of pollution permit trading. Nevertheless, in the air and water pollution trading programs developed later, transaction costs turn out to be non-trivial. High transaction costs not only absorb resources and suppress trades, but they also make the equilibrium subject to (and influenced by) the initial allocation and thus further distort the market (Stavins 1995; Montereo 1998). The problem of high transaction cost is of particular importance in the point-nonpoint source phosphorus trading markets because of the unique physical and institutional characteristics of the agriculture nonpoint source pollution. These two characteristics also link transaction cost with the issues of property rights and trading volume.

To begin with, the runoff paths between farms and water bodies are hard to delineate, which makes it costly and sometimes impossible to monitor actual phosphorus loads. Challenges also come from the spatial and temporal heterogeneity of nonpoint source pollution, which gives rise to high uncertainty in the implementation of the best management practices (BMPs) that reduces runoff (Shortle & Horan 2017). The stochastic nature of nonpoint source pollution makes it hard to define the property right of pollution discharge without an excessive amount of resources available for monitoring, modeling, and enforcement (Horan & Shortle 2011). Moreover, the institutional factors do not help to relieve the situation. Unlike the point source polluters, the farmers in the U.S. are rarely subject to any effluent regulations except for the Total Maximum Daily Loads (TMDLs) in some watersheds (Craig & Roberts 2015). They either feel no obligations to reduce the nutrient discharge (Shortle et al. 2012) or hesitate to join the trading programs due to the fear of cascading subsequent regulations and the inability to meet the trading thresholds (Ribaudo & Gottileb 2011). Further, the searching and negotiating cost for finding sufficient suppliers can also be very high. Consequently, the trading volume will be too low to allow arbitraging and discovering the optimal price level.

These conclusions align well with the observations from the case studies. Researchers from the U.S. and Europe find that the transaction cost in nonpoint source pollution control programs accounts for significant proportions of the total abatement costs. The transaction cost consists of the overhead research, information gathering, and enforcement cost borne by the regulatory authorities and the per transaction cost borne by the farmers and the permit buyers, (Falconer & Whitby 2000; McCann & Easter 1999, 2000). In some trading programs, the transaction cost was so high that few trades actually happened (Fisher & Olmstead 2015).

Almost all the major challenges in the point-nonpoint source phosphorus trading could be related to transaction cost. Lowering transaction cost is the main approach to facilitate the discovery of the optimal price. Fortunately, this problem is not insurmountable. Instead of using sequential and bilateral negotiations for trading, the brokers could be introduced to decrease the transaction cost (Atkinson & Tietenberg 1991; Woodward et al. 2002).

4.2.2 Literature on uncertainties of credit supply and demand

Credit generation in environmental market is not a continuous process. Instead, it is more likely to depend on one-time investments on structural practices such as streambank stabilization for nonpoint source pollution control. Even the managerial practices such as cover crops are planned and implemented on a seasonal or annual basis. However, the demand of credits may fluctuate at a higher frequency along with the variation of wastewater load, climate, and other technical factors. It is a common challenge that one credit buyer can generate a higher amount of credits than are needed with one small conservation project.

This phenomenon was first found in wetland mitigation banking. Through wetland mitigation banking, developers whose projects impact wetlands can restore or create wetlands at other locations to compensate for the ecological loss. Public or private agencies, as brokers in this market, could create and bank wetlands first and sell them to developers later (Robertson & Hayden 2008). However, when a developer only needs to compensate for a small area of wetland and there are no immediate wetland restoration projects available, it would be too costly for the developer to implement one full restoration project. Alternatively, some states allow the developer to pay in-lieu fee to the broker as the compensation, and the broker could proceed with a restoration projects when enough funds from different buyers have accumulated. Researchers found that the implementation could be substantially delayed after the collection of in-lieu fee (Stephenson & Tutko 2018). The flexibility brought about by the brokers can smooth the supply and demand of the wetland market. By the same logic, in their review of point-nonpoint source pollution trading markets around the world, Selman et. al. (2009) argued that brokers can build a pool of nonpoint source credits so that the risk of unstable supply could be controlled.

The literature on transaction cost and uncertainties in supply and demand shows promise of the broker-driven nutrient credit markets. Building on the existing literature, I examine whether and how these theories apply in Wisconsin’s case.

4.3 Methods

I conducted a case study on the MDV markets of Wisconsin with document content analysis and interviews. For this study, Wisconsin’s MDV program is considered as one case with multiple embedded units of analysis (Yin 2017), reflecting the individual counties and their clients. Each county is the central broker in its local market, and it connects the local point and nonpoint sources. The counties receive MDV payments on an annual basis. The counties receiving payments are required to submit watershed plans to describe how they are going to utilize the payments by March of the following year. I requested the watershed plans from WDNR throughout the year of 2020 and collected 18 plans by December 2020. These were the plans for the payment made in 2019. I reviewed all the plans along with WDNR's estimate of the amounts of MDV payments by county. It turned out that most of the counties received only small amounts of payments. Thus I selected two counties that received the largest amount of payments as analytical units and two other counties who did not participate in MDV for comparison. The counties receiving small amounts of payments had explicitly explained that they would pool the payments with their existing funds for established programs. Therefore, they were not included as units for analysis of brokerage.

Directors of land and water conservation departments of these four counties were asked about their experience with MDV. Three of them accepted the interview requests, and the other one conservationist responded my questions via email. The interviews were conducted via Zoom and recorded as consented by the conservationists. The interviews were transcribed with the Otter.ai program, and materials were coded and analyzed with NVivo 11.

4.4 Findings

4.4.1 Current status of MDV and how it functions

By March 2020, among the 199 point source permittees who determined their compliance options (see Chapter 2), 99 of them chose MDV. Eighty-five (85) of these permittees were municipal wastewater treatment plants, and the remaining 14 were industrial sources, and the permittees were distributed across 37 counties. Thirty (30) counties had submitted watershed plans by March of 2020 and for MDV payments received in 2019. During these transactions, the county land and water conservation departments work with point source permittees, nonpoint sources, and WDNR separately. The counties' relationships with these three entities provide insights on the mechanisms of this broker-driven market.

County – WDNR: reporting and enforcement

WDNR supervises the MDV program. It reviews and approves the permittees' applications for participating in MDV. It also established a system to manage the registered counties. The counties that receive MDV payments are required to submit watershed plans the next year and annual progress reports in the following years. The premise is that the counties are better able to utilize the fund than permittees since the county land and water conservation departments are more experienced in watershed conservation. In return, WDNR expects those counties to demonstrate phosphorus reductions to water bodies that (at least) offset the excessive amounts of phosphorus discharged by permittees. However, the reporting and enforcement policies have not been thoroughly developed. The watershed plans submitted by the counties vary in both format and content. Although the counties did provide specific types of information such as the conservation projects (as required by WDNR), not all counties were able to provide detailed plans. Moreover, WDNR has not specified the approaches to enforce compliance of this requirement.

County - Point source permittee: transaction

In most of the transactions, county land and water conservation departments do not directly work with the permittees. When permittees made the decision about whether to participate in MDV, they mainly worked with and reported to WDNR. The permittees do not need to meet with the county and just make the payments to WDNR. This is the key feature of MDV: by paying the brokers, i.e., the county land and water conservation departments, the permittees transfer their liability of phosphorus reduction to the brokers and need not take any further actions. There are exceptions: some point source permittees, especially municipal permittees who pay the counties with public funds, may examine the conservation activities as they would want to make sure the municipal money is put into good use.

County – Nonpoint source permittee: project implementation

The relationship between the counties and nonpoint sources has long existed before the MDV program. The relationship is still about implementation of best management practices and overall land and water conservation across farm operations. The nonpoint sources do not necessarily need to take extra efforts beyond the traditional conservation activities to participate in nutrient credit trading. As the counties are required to demonstrate phosphorus load reduction achieved by the MDV payments, the counties tend to distribute the payments to established or well-planned projects in which they have good relationships with the producers. In one MDV project example, the permittee planned to make payments to two counties as the watershed overlapped with both of them. One county declined the offer and suggested the permittee to pay all the money to the other county. The main reason was that the county land and water conservation department had no existing projects and did not have close ties to the producers in the watershed. The small fraction of the MDV payment would not be able to cover their cost initiating a new conservation project there.

4.4.2 How can brokers lower transaction cost?

In the MDV program, the existence of a broker substantially reduced the transaction costs of point source permittees. WQT participants who need to reach out to producers themselves took five extra actions besides implementing the conservation projects. They need to craft a trading plan, search for trading partners, negotiate with the partners, monitor the implementation, and report to the regulator. Meanwhile, for MDV participants, most of these actions are not needed except for calculating and specifying their credit demands. Instead, the county land and water conservation departments handle these actions for them. In MDV projects, the majority part of the transaction costs are borne by the counties.

However, measuring the counties' transaction costs poses challenges. First, although potentially significant, the concept of measuring transaction costs is largely academic and is rarely accounted for in budgeting or bookkeeping. When asked to estimate the cost of each activity, e.g., searching for trading partners and negotiating the conservation projects, the county conservationists were not able to respond as the expenses had never been calculated from this perspective. Indeed, tracking transaction costs could be expensive and has no practical benefits for practitioners. Second, the counties did not intend to profit from participation in the MDV program and thus did not keep track of their actual input. Due to the difficulties in measuring breakdowns of transaction costs, researchers propose a measurement method that defines transaction costs as "all cost but abatement cost" (Krutilla & Krause 2011). In other words, transaction cost could be calculated by subtracting the amount of fund directly paid for best management practices implementation from the total amount of money spent on the project. The MDV program allows the county to redistribute no more than 35 percent of the total MDV payment to other uses that contribute to watershed conservation. It means that the counties should spent at least 65 percent of the payment on the conservation projects while the rest of the fund may be used to facilitate the transaction. However, most of the counties decided to use all the MDV payments on the projects and to facilitate transaction with their own staff hours. Third, many counties directly put the funds into existing projects. The transaction costs have been covered in their earlier efforts to implement the projects. As a result, the quantitative value of transaction cost was not measured in this study.

It is worth noting that almost all counties chose to pay for the transaction costs themselves. Since the amount of MDV payments is not large, this practice has so far not imposed much pressure on the counties. By leveraging the counties' existing assets and projects, the MDV scheme creates a mutually beneficial situation, as it helps the permittees achieve compliance and contributes extra amount of money to the ongoing watershed conservation projects. However, one conservationist noted that if they received more payment than they had done, they would run out of personnel to use the money. If the counties were to start new conservation projects for the MDV programs, the transaction cost might no longer be manageable.

4.4.3 How can brokers reduce uncertainty in nutrient credit markets?

As predicted by previous researchers, the broker-driven nutrient credit markets also transferred the risk of uncertain supply and demand from the buyers and sellers to the brokers. However, the estimated credit pool that smooths the supply and demand overtime has not formed so far for these Wisconsin nutrient markets. The risk is passed to the brokers in the MDV program without being reduced. While the point source permittees paid fixed amounts of money and were certainly free from further regulation, the brokers were left to face three types of risks.

First, the total amount of payment a county could receive is hard to predict. A point source may initially choose MDV but turn to other options later. The amount of phosphorus load it would pay for can also change drastically if the permittees decided to combine MDV with other compliance options. Even after the permittee entered the payment cycle, the amount of money paid to the county can vary year by year with the change of point source effluent conditions. Currently, the counties find themselves in an extremely volatile market.

Second, comparing with the fluctuation of demand, a county land and water conservation department needs to maintain a relatively stable conservation crew. If a county received a large amount of MDV payment which enables and requires the recruitment of more staff, the county may decide against doing so knowing that MDV payments the next year could drop requiring reduction in staff for the team. This problem couples with the already fluid budgets of the conservation departments and substantially increases the risk for the counties. Third, the land and water conservation departments need strong support from the county governments to be able to implement more watershed conservation projects. The brokers also face constraints and risk from outside the MDV market.

One of the major consequences of this transferred risk is the lack of accountability in the current MDV program. Due to the uncertainties and risk, the brokers are not able to act proactively or immediately after receiving payments. They are also not able to start new projects near to the point source permittees. As a result, there is a significant lag between MDV payment and delivery of watershed conservation projects. The locations of the conservation projects may also not be ideal from the perspective of water quality protection. Although the phosphorus reduction activities take place in the same watershed, the scale of the watershed area allowable for offsets (very large river basins of Hydrologic Unit Code size HUC 8) could mean they occur elsewhere and may not reduce the local adverse impact of the effluent from the point sources permittee. Finally, the penalties for the brokers who are not able to achieve the promised phosphorus reduction, as well as the remedy strategy have not been clarified.

4.5 Conclusions

In this study, I research the broker-driven nutrient credit markets in Wisconsin—the MDV program—seeking insights on how the broker-driven markets function, how brokers influence the transaction costs, and if brokers reduce the uncertainty in those markets. The MDV markets are centered around Wisconsin's county land and water conservation departments, and the counties act as brokers between WDNR, point source permittees, and producers. They do this by utilizing their existing relationships and watershed projects to generate phosphorus credits. The nutrient credit markets deviate from the traditional markets for goods and services in that the buyers in nutrient credit markets (the waste-water permit holders) are less incentivized to assure the quality of the subject (actual reduction of phosphorus in surface water) resulting from the market transaction. Most of the point source permittees simply make payments to the counties and do not participate in the phosphorus reduction projects. As a result, the relationship between WDNR and the counties becomes the safeguard of the markets, which assures the reduction of phosphorus load.

Two propositions about the benefits of brokers are that they 1) reduce transaction cost, and 2) reduce uncertainty of trading and smooth supply and demand by creating credit pools.

These arguments are tested in this study. It finds that brokers do help reduce the transaction costs of the point source permittees. For counties, the majority part of the transaction cost is incurred in the form of staff hours; staff of county land and water conservation departments dedicate their times to search for projects, negotiate with producers, monitor the implementation, and report to WDNR. The counties usually distribute all the MDV payment to credit-generating watershed projects and subsidize the projects with their staff hours. So far, this arrangement has been considered mutually beneficial as the volume of phosphorus reduction demand in the markets (based on permit reduction targets) is lower than potential supply from the spin-off the existing conservation projects (generally on agricultural lands). Being brokers does not require the counties to take too much extra efforts while expands the income source of the counties.

It also finds that brokers reduce the uncertainty of trading for credit buyers and sellers, but the risk has not been completely controlled. Rather, risk is passed to the brokers. While the demand of phosphorus credits constantly changes, the county land and water conservation departments, as government agencies, prefer stable budget and staffing arrangements. The expectation of varying demand leads to accountability issues: the brokers are not able to implement conservation projects in a timely manner and at locations where the phosphorus discharge could effectively be offset for the local water body.

In spite of the uncertainties and accountability issues that emerged in the early phase of the MDV program, the effectiveness of the broker-driven nutrient credit markets should not be overlooked. The program does bring more funding to the county land and water conservation departments. Once the group of permittees participating in MDV in each becomes more consistent, the broker can expect a more stable cash flow and thus follow a more predictable long-term plan to achieve phosphorus reduction.

MDV also has the potential to become a catalyst for greater changes in the watersheds. It is just a temporary compliance option and the program will last for no longer than two decades starting from 2017. After the expiration of the program, the point source permittees can choose to use WQT, AM, or other options to achieve compliance permanently. During the MDV stage, the counties, as brokers, work with producers to implement best management practices. Afterwards, the point source permittees may be able to bypass the broker and continue or even expand the collaboration with the same nonpoint source partners. The MDV may be the first step towards a collaborative solution to the environmental challenges in the watersheds.

Chapter 5. Conclusions, Limitations, and Future Directions

5.1 Conclusions

In this dissertation, I examine the nutrient credit markets in Wisconsin created to help point and nonpoint sources work together to reduce phosphorus load in surface waters. Specifically, my research focuses on three broad questions: 1) how do point source permittees decide to participate in nutrient credit trading? 2) how do point source permittees find their trading partners? 3) how can brokers facilitate nutrient credit trading? It reviews the nutrient credit markets from three perspectives.

First, I discuss the markets from the perspectives of market and transaction and finds that compared with traditional markets for goods and services, the nutrient credit markets move in a slower manner. The credit buyers, constrained by lack of information and the permitting system, can take several years to make and update their trading plans. Moreover, the point source permittees do not completely act like rationale firms. Especially for municipal permittees, the socio-economic background of the municipalities can significantly influence their choices of compliance options. The rural-urban social network also plays a vital role in nutrient credit markets. To engage more producers, point source permittees tend to utilize existing ties between the rural and urban communities by taking a variety of networking approaches. As for brokers, the county land and water conservation departments do not consider profit maximization as their primary goal. As government agencies, they prioritize conservation project implementation and control of budget fluctuation. The market perspective is still critical to studies of nutrient credit trading, but the deviations from a traditional, more competitive market should be emphasized.

Second, I examine these nutrient credit markets from the perspective of environmental management. The nutrient credit markets in Wisconsin emerge from a policy instrument to help achieve the stringent phosphorus criteria. I find that the markets as an environmental management tool heavily rely on the existing policy landscape: stringent phosphorus rule is the primary driver of the markets; TMDL-base mass limit and WQBEL can have different implications for trading decision-making; and the design of the permitting system and capacity of the regulatory entity also impose significant influence on the markets. The design of the markets, especially the market form, is of special importance to the success of trading. For a clearing house market with brokers, a conceptual framework is established to examine how brokers can reduce transaction cost and control risk.

Third, the perspective of community development is also emphasized. Besides the policy landscape, the stakeholder landscape is also critical to these markets. The rural-urban relationship is the foundation of the nutrient credit markets which in return shape the relationship. Not one single trade was accomplished without engaging third-party entities, demonstrating how the community helps the markets to thrive. Looking to the future, I also talk about how point-nonpoint source nutrient credit trading can catalyze greater changes on watershed conservation and other community development issues.

Last but not least, this empirical investigation of Wisconsin’s nutrient credit markets greatly benefits from the remarkably large number of participants in the markets. This phenomenon itself is intriguing. Comparing with previous water pollution credit trading programs, Wisconsin’s nutrient credit markets enjoy many favorable conditions. They are built on a more stringent and comprehensive phosphorus regulation system. The early attempts of water pollution trading were made in the 1990s in Wisconsin to help point source permittees cope with TBL. However, facility upgrade turned out to be more cost efficient for achieving the loose phosphorus limit of 1 mg/L. Then TMDL-based mass limits became the new policy driver for many of the pollution credit markets as they were usually stricter than TBLs. These markets were irrelevant to the majority of the point sources who were not under TMDLs. In Wisconsin's current market options, the statewide WQBELs are even stricter than the TMDL-based limits. As a result, a significant proportion of the permittees in Wisconsin are forced to take actions and the abatement costs of using facility upgrade to meet the new criteria are unbearably high for many of them. Also, comparing with markets initiated decades ago, thanks to the more stringent phosphorus limits, the typical amount of phosphorus credit needed for achieving compliance through Wisconsin' nutrient credit trading is much lower, making nutrient credit trading less costly and thus more attractive.

Besides the rules, the regulatory authority—WDNR—takes a very proactive role in the markets. It designs three different programs, AM, WQT, and MDV, which engages as many potential participants as possible. After these markets were launched, WDNR keeps working with permittees and other stakeholders to modify and improve these three programs. WDNR itself has also facilitated some trading cases. For example, WDNR staff met and encouraged a permittee to participate in the market and the permittee became one of the early adopters of the AM program. It also introduced a point source permittee who needed credits to another permittee who had generated extra credits by WQT. Interestingly, though the core idea of nutrient credit trading is to alter command-and-control type of regulation with market transactions, many of the markets with large numbers of participants, such as the nitrogen credit exchange in Long Island Sound, Connecticut (Wallace 2007), phosphorus credit market in the Great Miami Basin, Ohio (Newburn & Woodward 2012), and Wisconsin's phosphorus credit markets, have regulatory authorities as active coordinators and facilitators. This phenomenon does not void the power of market. Instead, it highlights the importance of market infrastructure in boosting transactions.

Another important issue is the continuity of the policy. The concepts of WQBEL and nutrient credit trading are so fresh that many permittees have to consider the risk of policy change. One of the reasons against trading participation identified in the case study is that the new phosphorus rule could be abolished at any point and the best strategy would be waiting it out. Though only speculatory, this suggestion reflects the permittees' concern about swaying political will and policy. Actually, many previous markets were able to generate a few transactions but failed to sustain the momentum due to lack of political support. Indeed, community agreement and legislative backing of the policy itself are critical to the success of the markets (O'Grady 2011). Besides stabilization of the markets, the continuity of policy has another benefit—the transaction cost could be reduced over time and smaller permittees would be able to participate in the markets given more years. The transaction cost for early adopters of the market-like policy could be extremely high. When there are more transactions, streamlined policies, stronger partners, and accumulated intellectual and social capitals can empower more permittees and move the markets into a positive feedback loop.

In summary, Wisconsin's nutrient credit markets set a relatively successful model for utilizing market-like environmental policy to handle water pollution problems. However, the influence on the long-term environmental outcome has yet to be tested. To assure the improvement of the water quality, WDNR and other stakeholders should continue addressing the issues of accountability and transparency to make sure that nutrient credit trading does not cause net increase of phosphorus load in the waters of Wisconsin. Unfortunately, when I conducted this study, requesting data and documents from WDNR was one of the major challenges: it was time consuming and the quality of the data was far from ideal. This was not because of WDNR's reluctance to disclose permittee information. Rather, resource constraints prohibit WDNR from compiling more accurate and comprehensive information regarding nutrient credit trading (and in general, point source permittees). This has been a recurring theme in many of the water quality compliance conversations. If not addressed properly, it may jeopardize the effectiveness of any nutrient credit markets.

5.2 Limitations

Despite its contribution to environmental planning literature, this study has several limitations due to resource constraints, timing, and privacy concerns. To begin with, the nonpoint source side of the markets is not thoroughly investigated. Many of the nonpoint sources, i.e., agricultural producers, prefer not to be identified due to privacy considerations. As a result, most of the publicly available trading documents do not disclose the producers' names, and many informants interviewed in the case study also confirmed that the producers were not willing to be revealed. Besides, there are many more producers in the markets than the number of point source permittees. The group of potential credit sellers that have not participated in trading is even larger. Without much public information, it can be extremely costly to collect relevant details about the producers.

Therefore, I decided to examine the markets from the perspectives of the credit buyers. Besides the privacy and resource issues, this decision was made due to three other reasons. First, the markets are created by point source effluent control policy and thus the point source permittees play a more important role in the markets than the producers do. If the point source permittees decided not to participate in the markets, the producers would never create any credits. Thus, as an early study on Wisconsin's markets, it is more reasonable to start with the credit buyers. Second, in the study on point source decision-making, the upstream watershed area and the ratio of point and nonpoint source phosphorus loads in the watershed are included as independent variables of the model. They collectively depict the potential supply of phosphorus credits and serve as the proxy of the nonpoint source's perspective. The third reason is that in the case studies, questions regarding nonpoint sources were asked without letting the informants identify specific producers. These questions could shed light on the producers' perspective.

A second limitation is that Wisconsin's nutrient credit markets, especially the MDV program, is still evolving, and the final equilibrium of those markets has yet to be captured. For example, there are still hundreds of point source permittees who may participate in the markets in the future, but the timeframe of this research does not enable modeling of their trading decisions. It could be argued that the timing of the compliance schedules is not related to the characteristics of the permittees and thus the current dataset is a random sample from the whole population of point source permittees. But for independent variables, such as the number of years after 2010, the trend might be clearer if a larger time span had been available. For the study on the broker-driven markets, most of the county land and water conservation departments have not provided detailed plans of conservation projects after receiving the MDV payments. This finding itself is meaningful as it reveals the concerns on accountability of the brokers. Detailed plans and annual progress reports from the counties could provide more materials for the MDV program.

Third, the differences between AM and WQT are not fully highlighted. Economists have long differentiated the permitting systems for pollution load and for ambient environmental quality, as well as their implications for pollution trading markets (Atkinson & Tietenberg 1982; Hahn 1986). The AM-based markets focus on ambient environment quality while the WQT-based markets trade pollution load. It is a good opportunity to examine the difference of these two types of markets on empirical level. However, rather than moving forward to implement AM for their permit, many of the participants admitted in their initial plans that they may turn to other compliance options, especially WQT, in the following permit terms. The features of the current AM participants captured may not represent the behaviors of typical participants of the markets for ambient environment quality. Thus, the difference between AM and WQT is only discussed in part of the qualitative sections of this study.

5.3 Future Directions

In the future, my dissertation could be updated from the three aforementioned perspectives. First, researchers could re-examine the nutrient credit markets from the perspective of producers. The current study indicates that economic incentive, progressive thinking, and trust cultivated from existing collaborations are the important factors that influence producers' participation. Qualitative and quantitative studies could be used to test and further develop these findings. This study can provide a more comprehensive view of the issue. Second, the trading dataset could be updated in three to five years to capture the latest developments of the markets. It is especially important to keep monitoring the progress of the MDV markets as they may provide invaluable lessons on broker-driven pollution trading markets. Third, the difference between AM and WQT could be studied when more permittees have determined to use AM as their final compliance options. The characteristics of participants of these two programs, as well as their different implications to abatement cost and environmental outcome, will all benefit future policy making.

Besides updating the current study, two new directions could also be explored. First, the environmental outcome of nutrient credit trading could be researched. As a study on environmental planning, I explore the behaviors of market participants. In the future, findings of my dissertation could be combined with hydrological and water quality modeling to analyze the environmental outcomes of trading, and environmental outcomes of different trading scenarios could be compared. Climate change could also be factored in the analysis to examine how nutrient credit trading resonate with long-term climate trends. This direction is particularly meaningful because the goal of nutrient credit trading is to protect the water environment.

A second direction for future study could build upon the finding that trading could greatly benefit from the existing watershed conservation networks. It is intriguing that in some trading cases in this study, the point source permittees leverage funds from other programs. Future researchers could take a close look at how nutrient credit markets interact with other policy instruments such as cost share and land use planning. Overlapping policies could on one hand, cause competition for watershed projects, crowd out certain programs, and thus waste resources. On the other hand, if coordinated properly, they could together foster innovative watershed conservation. In the end, I have sought to help advance that goal with this work.

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Appendix I. Correlation Matrix of Independent Variables in the Point Source Permittee Decision-making Model

Variable	Co	PC	LR	T	A	PL
Co	1					
PC	-0.15	1				
LR	0.09	-0.09	1			
T	-0.05	-0.09	0.08	1		
A	-0.03	0.08	-0.13	0.03	1	
PL	0.11	-0.03	0.02	0.05	0.07	1

Note:
Co = number of conservation staff
PC = average phosphorus concentration in effluent
LR = PS:NPS Phosphorus load ratio
T = number of years before decision-making
A = area of upstream watershed
PL = facility phosphorus load

Appendix II. Interview Question List

Question List for Semi-structured Interview with Wastewater Treatment Facility Staff

[Background Information]
First, some general background questions:
Q1 Please tell us a little bit about yourself? For example, what roles have you had with the organization name, how long have you been doing this work, and what is your current connection?
Q2 Is the status of the facility a factor in your compliance decision-making?
[follow up if age of the facility is not mentioned: is the age of the facility a concern? In other words, if the standard was not changed, when do you think the facility would be upgraded?]

[Trading experience]
Next, we'll ask about the overall "Trading" Experience"
Q3 Please tell us (more) about your experience with the compliance method?
[follow up if not mentioned: How do you describe your role in this?]
Q4 What surprised you about this process or the way it played out for organization name?
Q5 What are the most challenging problems? How did you overcome them?
[follow up if not mentioned: What resources and information or other resources do you wish you would have had but did not?]
Q6 What do you think are the biggest uncertainties in adopting compliance method?
[follow up if not mentioned: Do you worry about the long-term commitment of the farmers? Do you worry about whether this will actually improve the water quality?]
Q7 How could the policy be tailored to fit organization name better?
Q8 What can you tell us about the current status? Do you know if there has been progress and what BMPs have been implemented? Anything else you hope to do there?

[Decision-making Process]
Next, we are shifting our questions to the Decision-making Process
Q9 What is the relationship between the overseeing entity and the facility? For big decisions like pursuing this compliance option, what is the usual process within the facility and with the overseeing entity?
Q10 In this case, how did you decide to do compliance method? Who was involved in this process?
Q11 We would like to dig deeper here: what do you think is the key information for this decision? How did you get it?
[follow up if not mentioned: Can you recall the key events in this decision, for example, meetings, pilot studies, etc.]
Q12 In the plan, several reasons were listed as motivations for using compliance method, for example, reasons. What do you think are the most important ones when you made the decision?
Q13 Did you see any downside of compliance method while making the decision? What are they?

[Social network]
Now we are going to ask about the partnership of this program. You have a table that shows all the partners in the plan. We are curious about what this partnership looks like and how you managed to get everybody together.
Q14 Can you tell me who are the core partners in compliance method?
[follow up: How was working with them? Can you describe how they helped you?]
Q15 Did you know the farmers in the watershed before the compliance method? How did you approach to them to discuss potential collaboration? How many farmers are involved?
[follow up if a small number of farms are involved: why did you choose them as your partners]

Do you mind if us go over the partnership list with you one by one?
Q16 What is [partner name]'s role in the compliance method? What have they done? **Q17** How did you get to know them? Is it before or after you decided to do trading?

Q18 Are there any organizations that you wish to approach in the future?

[Resources]
OK, we have last a few questions.
Q19 Have you try to seek external funding for compliance method?
Q20 We are interested in the cost used to facilitate or validate the actual phosphorus reduction through adaptive management, such as cost of outreach, monitoring, reporting, and etc. In other words, breaking out the portion of payment for phosphorus reduction credits and the portion going to administrative/transaction-related costs that are involved in allowing those direct payments to happen and monitoring the results. In the plan, you have a breakdown of cost. Introduce the cost in plan. After the exploration, do you find any major deviations from this initial estimation? Are you able to estimate for us what percentage of the total budget was payment for nonpoint source phosphorus reduction?
[Final note. Stakeholder]
Q21 We would like to talk with a few other key partners in this compliance method. Are there any people who can better represent these groups? Anyone else we should talk with?

[follow up if county LWCD not mentioned: Is county Land and Water Conservation Department a key partner?]

If we were unable to reach out to some of them, could you help us with the communication? Do you mind if we mention you in the emails sent to them? This will show them that we have talked with the key person in the plan.

[Conclusion]

Thank you for your time! Do you have any questions or concerns about our conversation and this study in general? Do you mind if we contact you via email if there are anything that need clarification?

Question List for Semi-structured Interview with Other Partners

[Background Information]
First, some general background questions:
Q1 Please tell us a little bit about yourself? For example, what roles have you had with organization, how long have you been doing this work, and what is your current connection?
PQ1 Why did you (or your organization) participate in compliance method? How does it serve your organization's goals?
PQ2 What role does it play?

[Trading experience]
Next, we'll ask about the overall "Trading" Experience"
Q4 What surprised you about this process or the way it played out for organization name?
Q5 What are the most challenging problems? How did you overcome them?
[follow up if not mentioned: What resources and information or other resources do you wish you would have had but did not?]
Q6 What do you think are the biggest uncertainties in adopting compliance method?
[follow up if not mentioned: Do you worry about the long-term commitment of the farmers? Do you worry about whether this will actually improve the water quality?]
Q8 What can you tell us about the current status? What activities have you (or your organization) participated? Anything else you hope to do there?
[follow up if not mentioned: What particular BMP projects have you participated in?]

[Decision-making Process] For people who are not key informant, consider whether to include this part case by case
Next, we are shifting our questions to the Decision-making Process
Q12 In the plan, several reasons were listed as motivations for using compliance method, for example, reasons. What do you think are the most important ones?
Q13 Did you see any downside of compliance method? What are they?

[Social network] For people who are not key informant, consider whether to include this part case by case

Now we are going to ask about the partnership of this program. You have a table that shows all the partners in the plan. We are curious about what this partnership looks like and how you managed to get everybody together.
Q14 Can you tell me who are the core partners in compliance method?
[follow up: How was working with them? Can you describe how they helped you?]
Q15 How well did the compliance method help you get to know farmers in the watershed? If you didn't know those farmers before the program, how did you approach them to discuss a potential collaboration? How many farmers are involved?

Do you mind if us go over the partnership list with you one by one?
PQ3 Have you worked with this partner for this project? What do you do together?
Q17 How did you get to know them? Is it before or after you decided to do trading?

[Conclusion]

Thank you for your time! Do you have any questions or concerns about our conversation and this study in general? Do you mind if we contact you via email if there are anything that need clarification?

Appendix III. Case Report Templates

Item	Source	Content
1.Summary	NA	Summary of this report. Site name, location, serving population, treatment technology, regulation, compliance option chosen, status of the program.
2.Methods	NA	Information sources of this report; research strategy for publicly available information; interview information
3.Background	NA	
3.1 Environment	Fact sheet; trading plan; DNR PRESTOL model	Receiving water; HUC12, 10, and 8 watersheds, Areas of HUC12 and HUC10 watersheds; Location in HUC12 or HUC10 watershed; Proportion of point source and nonpoint source phosphorus contribution; Other point sources in the watershed; Land use in the watershed
3.2 Socio economic	Fact sheet; trading plan; Wisconsin DOA and US census bureau dataset; County Land and Water Resources Plan	County and city of the site; Counties covered by the watershed; Serving population, municipalities, and major point sources; MHI of the city; Agriculture activities in the county.
3.3 Technology	Fact sheet; interview	Designed and actual effluent volumes of the site; Phosphorus concentration in influent and effluent; Treatment technology applied to remove phosphorus; The status and age of the facility
3.4 Regulation	Fact sheet; TMDL plan	The phosphorus standard of the site: for WQBEL, monthly average and six-month average; for TMDL, daily and annual allocation as well as concentration equivalent; The facility's status of compliance; Compliance schedule
3.5 Other	Interview	Other outstanding background information learned from interview
4. Alternative Compliance Options	Alternative compliance plan; interview	Evaluation of alternative compliance plan: specific plan and estimated cost
5. Compliance plan	NA	
5.1 Motivation	Trading plan; alternative compliance plan; interview	Motivation for pursuing the current compliance plan
5.2 Timeline	Public information; interview	Timeline of decision-making and plan implementation
5.3 Current status	Trading annual report; interview	Current status of BMP implementation
6. Experience	Interview	Experience with trading, including surprises, challenges, and perceived uncertainties, comments on current policy
7. Decision-making	Interview	The process of decision-making

8. Producer	Interview	The approach to work with producers
9. Partnership	Interview; trading plan	Partners of the program and their roles; The formation of partnership; Whether brokers are involved and if so, their roles; Partner’s contribution to the program implementation

Appendix IV. Codebook for Interview Transcript Analysis

Process and Coding Framework

1. Extract fact
   In the preliminary round of coding, extract the following fact and write narrative about the case.
   - Timeline of the program
   - Interviewee professional profile
   - Partner information
   - Whether status and age of the facility are key factors in decision-making
   - BMP list
   - Other potential interviewees

2. Code by questions
   For this part, see the question list in Appendix I. Code the transcripts as answers to the questions.

3. Code by themes

Themes of the Codebook

1. Decision-making

1.1 Decision-making process

- Actors (who are involved)
- Structure (what are the relationships among actors)
- Activities (what they have done)
  - Meeting with partners
  - Meeting with government agencies
  - Optimization
  - Monitoring
  - Modeling
  - Grant application
  - Change of plan (change of compliance plan in the decision-making process)
- Input (what are the input in decision-making)
  - Community support
  - Funding
  - Existing watershed plan
  - Information
- Output (what are the outcomes, either final or intermediary, of decision-making)
  - Community support
  - Funding
  - Plan
  - Information

1.2 Decision-making factors [Note: developed based on trading plans]

- Environmental factor (surrounding environment and the condition of the site)
  - Availability of NPS credits
  - Characteristics of receiving water
- Physical factor (economic calculations)
  - Cost saving

  - Close gap between target and current discharge (a site needs a small amount of reduction that does not justify facility upgrade)
  - Extra funding
  - Safety margin (A site is in compliance but need safety margin)
  - Future use (A site is planning on expanding its operations)
  - Internal trading (a site owns land which enables internal trading)
  - Temporal variation (a site is in good shape most of the time but cannot meet standard in certain months)
  - Construction cycle (age and status of facility)
- Organizational factor
  - Brokerage
  - Overseeing entity
- Institutional factor (regulatory environment)
  - Stringent phosphorus regulation
  - Overlap with other policy (e.g., TMDL restriction on MS4)
  - Flexibility (the AM/WQT allows change of plan later and a site choose it because of the flexibility)
  - Minimal compliance actions required
- Social and economic factor
  - Relationship with agriculture community
  - Relationship with local government (do not include city WWTP's relationship with the city)
  - Partnership
- Cultural factor
  - Key person (leadership, etc.)
  - Value environment (the local community values the environment benefit)

2. Social network

2.1 Outreach strategies

- Representative (brokerage pattern, the permittee finds someone closer to it to reach out to farmers)
- Producer Partner (brokerage pattern, the permittee finds someone closer to farmer to reach out to farmers).
- Liaison (brokerage pattern, the permittee finds someone independent from it and the farmer to facilitate trading. E.g., NRCS or county LWCD)
- Cold call (no brokerage, identify field and projects and contact whoever owns the property)
- Outreach (use social media, flyer, public meeting, etc. to reach out to farmers and get them on board)
- Existing tie (existing relationships among permittee and producer)
- Neighboring effect (influence neighboring producers by successful projects)

2.2 Partnership process

- Use existing network
- Join existing network
- Build new network

2.3 Partnership mode (Rather than coding, materials related to this should be rewritten to a narrative regarding the nature of each partner. To do this, all materials should be coded as partnership mode for later search)

- Description of the partnership
- What roles the partners play
  - Funding (get funding from partners)
  - Technical service (get technical service from partners)
  - Build network (get more partners via partners)
  - BMP implementation (facilitate BMP implementation with the help of partners)

  - Publicity (get publicity from partners)
- Partner benefit (diffused benefits, how partners benefit from the collaboration)
- How they work together

2.4 Benefit of Partnership

2.5 Urban-rural: the urban rural relationship and perspectives
- Geographic boundary
- Acknowledgement about agriculture activities and rural communities
- Lack of knowledge about agriculture activities and rural communities

3. Classic items in NPS markets
- Abatement cost: reduced abatement cost
- Science: the scientific elements (or lack of scientific elements) in decision-making and implementation
- Region restriction (a site can only buy credits in a restricted region)
- Spatial heterogeneity (NPS practices vary a lot across space)
- Temporal heterogeneity (lag between credits usage and generation)
- Rigid regulation (rigid regulation undermines trading viability). Update: any issues related to DNR, whether positive or negative should be coded under this topic, because rigid and flexible regulations are two opposite concepts and should be pool together to depict DNR's role in trading.
- Lack of supply: not enough farmers are willing to participate (farmers do not want to participate)
- Environmental outcome: the uncertainties in environmental outcome
- Regulatory outcome: transfer of liability; farmers' commitment (if farmers cannot deliver environmental service, the point source permittee faces the consequence)
- Transaction cost
- Trust: (lack of) trust from farmers
- Political pressure (people do not like the idea of right to pollute)
- Crowded out: farmers participating in cost sharing programs do not want to (or cannot) participate in trading
- Threshold: threshold to create credits can harm trading
- Policy uncertainty: uncertainties of policy
- BMP: other issues related to BMP
- Double dipping: receiving several funds for the same BMP projects

Other items (the items assumed to be important but not identified in
- Targeting: the program enables targeting of farms with highest reduction potential
- Covid19: the influence of covid19 on the implementation of AM or WQT or the entities in general
- TMDL Uncertainty: the uncertainties caused by TMDL development
- Initiating Cost: as a new program, jump starting it can be costly for both regulatory entity, i.e., DNR, and permittees
- Ambiguous model: inaccurate model or data
- Agriculture: narrative of agriculture community
- Local Fund: farmers prefer not to work with federal agency. Instead, they are more willing to work with local partners
- Industry: characteristics of the industry and the implication for water quality trading
- Farm size: trade with big farms to deal with fewer partners

Appendix V. Case Study Management Protocol

Preparation	
Time	Tasks and Steps
30 min	Prepare interviewee profile • Confirm interviewee and search interviewee information online • Prepare interviewee profile in interview worklog and interviewee tracking table in Box folder • Create a special code for the interviewee. The format is: three letter code for the site_first name last name.
30 min	Schedule meeting time • Contact o Customize recruitment email o Estimated time for key informant is 90 minutes; for other partner is 60 minutes o If the interviewee is other partner, mentioned that I have interviewed the key informants • Send the email o If the email is not responded, follow up by forwarding the previous email in one week o If follow up email is not responded, ask help from the key informant • Schedule meeting time o Ask if interviewee can do it via Zoom meeting. Create a Zoom Link. By Zoom's new rule, password is required to join the meeting. Provide the password as well. o Send calendar invitation including Zoom link once the meeting has been scheduled. The invitation title is "Interview on [plan name] with UW-Madison/Extension Researcher". o Send email reminder to the interviewee the day before interview o In case of bad internet connection, exchange phone number as back up plan. • If declined interview request Note "declined interview request) in interview worklog and interviewee tracking table
120 min	Prepare for meeting • Customize interview material o Update slides for meeting o Update printed question list for meeting. Keep all changes by using track changes. o Prepare special questions, if there are any, for the interviewee and update the question list and slides • Update aggregated questions list Add newly created questions to the aggregated question list • Create an interviewee folder. The name of the folder is the code of the interviewee_interview date. • Move the customized question list and slide to the folder
Interview	
Time	Tasks and Steps
60-90 min	Interview o Use recorder and Zoom Cloud record the same time for recording o Record will be synchronized to Otter.ai for transcription o Take notes on printed question list
Data Cleaning	
Time	Tasks and Steps
30 min	Update Material • Complete interview worklog and interviewee tracking table • Update aggregated question list Some special questions are prepared before the interview. During the interview, new questions may be added and some questions may be dropped according to information learned from the interview. Finalize the special question lists and update them in the question list.

210 min	Clean Material ○ Write meeting notes Part one: questions and answers Part two: key facts Part three: other outstanding issues and comments Part four: follow up questions ○ Archive in interview folder Create and clean transcript (time for this clean process is about twice as much as the record length) ○ Access transcript from Otter.ai, download the raw version ○ Access audio record from Zoom. Download the audio record ○ Listen to the record and correct transcription mistakes on Otter ○ Export transcription in Word and further edit it by adding speaker names. Speaker names include “interviewer” and the interviewee’s code Code by Question ○ Important transcript into NVivo ○ Code the answers by questions. In interview, questions can be answered by responses to other questions. This round of coding should classify any information that can answer a question as its answer.
45 min	Follow up ○ Write follow up email for additional questions ○ After follow up, take note on all email communications in interview worklog. Download and archive all emails.
Data Analysis	
Time	Tasks and Steps
120 min	Code ○ Conduct three rounds of coding: by Classic Topics + Other topics; by Decision-making; By Social Network. ○ Update codebook if new topics emerge
120 min	• Descriptive writing Write narrative about partnership: use materials under code “partnership mode” to write about the partnership of the trading case • Write case study report (time for this task is not factored in the time demand here) Write case study report after all interviews with a site are finished
Total 760 min	