Feasibility Assessment of a Nutrient Trading Market in the Big Bureau Creek Watershed

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EXECUTIVE SUMMARY

Through the U.S. Environmental Protection Agency Targeted Watershed Grant, the Wetlands Initiative (TWI) and its partners conducted a detailed feasibility analysis and proposal for water quality trading, focusing especially on the role of constructed wetlands. Wetlands specifically designed to treat cropland drainage at strategic locations can remove nutrients, especially nitrate-nitrogen, cost-effectively and efficiently. This study assessed whether the environmental, economic, and social factors could support a nitrogen and phosphorus credit trading market in the Big Bureau Creek (BBC) watershed, a sub-watershed of the priority Lower Illinois River–Lake Senachwine watershed. Our methodologies and results can be easily applied to other agricultural watersheds. The project comprised six major parts: (1) a literature review, (2) an assessment for wastewater treatment plant demand and potential wetland site supply, (3) an economic analysis of a market, (4) development of a “smart market” proposal and simulation, (5) an assessment of the social readiness of stakeholders, and (6) specific proposals for administration of the market. We then provide specific recommendations for action.

First, we conducted a thorough literature review on nutrient credit trading. We examined existing trading programs around the world with respect to flexibility and likelihood of success. We evaluated market structure, conditions, and performance of emissions trading programs. We found that all programs suffer from thin trading, and many suffer from poorly defined rights and environmental requirements. Further, we found that trading was hindered by the high transaction costs related to finding trading partners and obtaining regulatory approval. These high transaction costs are a result of the complex physics associated with nutrient runoff in a watershed.

Second, we examined suitability of a nutrient credit trading program in the Big Bureau Creek watershed. Given the lack of statewide numeric nutrient criteria, we used hypothetical effluent standards for the point sources as the driver for demand. The credit nutrient demand needed to meet the discharge limit was low in comparison to the potential supply in a rural, agricultural watershed. We used three different approaches to identify potential wetland sites and estimate nutrient removal based on the availability of the wetland identification model and the watershed model data. TWI developed a partially automated wetland siting methodology, based on the best available topographic data and specific wetland and drainage area criteria. This methodology located 80 individual wetland plus buffer sites in areas of higher nutrient loadings. An AnnAGNPS model developed specifically for the BBC watershed assessed the baseline nutrient conditions and the nitrogen and phosphorus credit supply provided by these 80 wetlands. The AnnAGNPS model analysis indicated a wetland-based trading program would have sufficient nitrogen and phosphorus supply, pollutant type and form, impact, and timing. The results indicated that constructed wetland practices can play an important role in a nutrient credit trading program, and strategically positioning the wetlands in areas of high nutrient loading can be significant in achieving watershed nutrient reduction strategies.

Third, we conducted an economic analysis of a hypothetical market that allows point sources to buy nutrient credits from landowners who install nutrient-removal wetlands in the BBC watershed. This economic analysis used the landscape wetland assessment method to identify potential wetland sites and nitrogen removal. The analysis modeled supply and demand of nutrient credits as lumpy, based on discrete decisions controlled by local hydrogeomorphic conditions and wastewater treatment plant nutrient removal technology. The analysis found that in a nitrogen permit market, wetlands would be less expensive than upgrading small- or medium-size treatment plants. Indeed, the wetlands could remove more nitrogen than needed to meet demand. The economic analysis found that wetlands would not be constructed solely for phosphorus, because wastewater treatment plants can inexpensively remove phosphorus. Credit stacking analysis found that ancillary credits could also be produced and sold, but these benefits are not valued highly enough in their markets to stimulate wetland installation in the absence of a nitrogen market.

Fourth, we developed a “smart market” design for nitrogen and phosphorus, allowing for the lumpiness of wetland investments. This market design could be implemented and would drastically lower the transaction costs of trading. It differs from previous nutrient market designs in its centralized clearing with an optimization, thereby avoiding the problem of high transaction costs. We simulated the smart market for the Lime Creek sub-watershed and for Big Bureau Creek under various scenarios. We found that the smart market would cost-effectively incentivize farmers to reduce their runoff and to construct nutrient-removal wetlands. It would achieve signification reduction in nutrient loads at the outlet of the Big Bureau Creek watershed beyond that required by the point source demand. The smart market confirmed many of the results from the economic analysis.

Fifth, we assessed stakeholders’ social readiness, their support of, and resistance to a potential nutrient credit trading market in the Big Bureau Creek watershed. We used a multiple-step strategy to map relevant stakeholders, interview selected stakeholders, and engage stakeholder groups. For community mobilization efforts on conservation practices that address both water quality and water quality trading, we found a range of challenges and barriers. Stakeholders expressed a need to see the wetland practice demonstrated locally in the watershed, and they saw insufficient proof of the ability of wetlands to remove nutrients and generate credits reliably. Farmers consider nutrient-removal wetlands to be an innovative practice compared to more widely accepted and utilized best management practices (BMPs). Farmers are not likely to adopt a practice until they see “proof” that it will perform as expected, whether a nutrient credit trading program provides incentives or not. Based on the lessons learned, we developed recommendations as to how stakeholders should be approached and involved in developing water quality trading.

Finally, we examined the program administration needed beyond active federal and state agencies in a water quality trading program. We proposed two third-party alternatives: a water quality trading district and an independent system operator (ISO) for water quality. Either alternative could perform the administrative activities, serve as market manager to coordinate sellers and buyers, monitor water quality to quantify wetland credit production, and optimize the credit production under a cost-minimization approach.

We identified several critical actions that need to occur to support a water quality trading program:

- Set statewide numeric nutrient standards for nitrogen and phosphorus. At this time, potential buyers and sellers have little motivation to trade. Without nutrient standards, point sources cannot make adequate plans to reduce their nitrogen pollution, nor can they know what reductions will be needed to meet future permit effluent limits. In addition, program designers cannot develop trading ratios until they know the limits on nutrients in the watershed.
- Develop basic state water quality trading guidelines and rules with stakeholder involvement. Actual water quality trading programs can be tailored to specific watershed goals and market characteristics.
- Establish a registry of credits, specifying initial credits for all relevant stakeholders. Recognize rights of wastewater treatment plants and farmers already participating prior to standards or a cap (e.g., Total Maximum Daily Load), and protect them from unreasonable liability for their early effort. As with the federal sulfur dioxide market, initial rights could start high and be reduced proportionally over time.
- Establish a program administrator or aggregator to operate a market, either with a state-wide ISO or water quality trading district, who would start a smart market and manage the credit registry. An aggregator will minimize transaction costs to allow an active market.
- Develop enforcement mechanisms, including monitoring protocols, compliance, and penalties. The regulator could rely on participants to self-report at the start, while holding stronger mechanisms in reserve.
- Encourage and support the implementation of constructed wetlands for cropland tile drainage treatment prior to market establishment. Government financial and technical support of this practice is needed to initiate the implementation and monitoring of a few demonstration wetlands to address stakeholder concerns about performance variability and future credit generation.

The findings of the environmental, economic, and social feasibility assessments indicate that a nutrient credit trading market using strategically placed constructed wetlands to treat nutrient runoff from cropland drainage has significant potential to cost-effectively reduce nutrient pollution, particularly nitrogen. Such a market system, adapted for local conditions, could incentivize reduction in nutrient runoff by farmers in similar agricultural watersheds throughout the Midwest and beyond. Efforts to further establish the foundation for wetland-based nutrient credit trading are crucial to successfully develop and implement these programs and achieve urgently needed nutrient reductions.

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ACRONYMS

ACGA	American Corn Growers Association
AnnAGNPS	Annualized Agricultural Nonpoint Source
AOI	Area of Interest
ARS	Agricultural Research Service
BBC	Big Bureau Creek
BMP	Best Management Practice
CAFO	Concentration Animal Feeding Operation
CCA	Certified Crop Advisor
CD	Conservation District
CREP	Conservation Reserve Enhancement Program
CRP	Conservation Reserve Program
DEM	Digital Elevation Model
FSA	Farm Service Agency
GIS	Geographic Information System
HLR	Hydraulic Loading Rate
HUC	Hydrologic Unit Code
IDALS	Iowa Department of Agriculture and Land Stewardship
IDNR	Illinois Department of Natural Resources
IEPA	Illinois Environmental Protection Agency
IPCB	Illinois Pollution Control Board
LiDAR	Light Detection and Ranging
LRS	Load Reduction Strategy
MADIC	Multi-Agent Decentralized Market
MGD	Million Gallons per Day
MRBI	Mississippi River Basin Healthy Watersheds Initiative
NHD	National Hydrography Dataset
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
NRCS	Natural Resources Conservation Service
O&M	Operation and Maintenance
POTW	Publicly Owned Treatment Works
PS	Point Source
RCD	River Conservancy District
STP	Sewage or Sanitary Treatment Plant
SWCD	Soil and Water Conservation District
TBEL	Technology Based Effluent Level
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TPI	Topographic Positioning Index
TSS	Total Suspended Solids
TWI	The Wetlands Initiative
UIUC	University of Illinois at Urbana-Champaign
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WBEL	Water Quality Based Effluent Level
WLA	Waste Load Allocation
WQT	Water Quality Trading
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant

GLOSSARY OF TERMS

Additionality:	Pollutant reductions from new practice or activity are considered additional if they were made in direct response to a payment; otherwise, they would not have occurred.
Attenuation:	Attenuation is the temporary storage and/or permanent removal of nutrients from surface runoff, groundwater flow, or stream flow.
Baseline:	The minimum level of performance or minimum set of best management practices that must be in place before credits can be generated for water quality trading.
Best management practices:	Management or structural practices determined to be the most efficient, practical, and cost-effective measures for addressing a particular problem, such as pollution prevention or reduction. Commonly referred to as water or soil conservation practices in the agricultural sector.
Credit stacking:	The creation and sale of multiple credits for the same conservation practice or activity in various environmental markets.
Emission:	Emission or load is the amount of pollutant discharged.
Leakage:	Leakage occurs when a trade results in unexpected and unaccounted for net increases in nutrient loads.
"Lumpy" costs:	Those costs which do not increase smoothly or continuously as the level of service provided (e.g., nutrient removal) increases. The costs behave in a "step function" manner as the costs exhibit an initial economy of scale, with unit costs declining rapidly with increases in volume, and then suddenly jump upward when some existing capacity limit is reached.
Nonpoint source:	Pollution that comes from many diffuse sources rather than a single defined point.
Nutrient credit:	A unit of nutrient reduction typically measured in kg or lbs that may be exchanged in a water quality trading program.
Point source:	Any defined point or discrete conveyance (e.g., pipe, ditch, channel, conduit, well, concentrated animal feeding operation, etc.) from which pollutants are discharged.
Pollution offset:	A credit generated by a party to compensate for the pollution or environmental impact elsewhere.
Receptor:	The location point for measuring a pollutant load or concentration.
Trading ratio:	The regulator uses the trading ratio in trades to ensure the amount of reduction resulting from the trade has the same effect as the reduction that would be required without the trade. It is used to account for location, delivery, uncertainty, equivalency, and insurance. A 3:1 trading ratio means that the buying entity needs to purchase 3 kg of pollution reduction for every 1 kg it discharges above its regulatory or permit limit.
Transaction cost:	Fixed costs associated with completing a transaction, including finding a trading partner, negotiating, arranging regulatory approval, and enforcing the contract.
Water quality trading:	A voluntary exchange of pollutant reduction credits to meet defined water quality goals within a watershed more efficiently.
Watershed:	The geographic region where all the water that is under or on it drains off to a single point. Also called a drainage basin.

1 INTRODUCTION

1.1 Project Purpose

The Wetlands Initiative (TWI) and its partners performed a three-dimensional evaluation to assess whether environmental, economic, and social factors in the Big Bureau Creek (BBC) watershed, a sub-watershed of the Lower Illinois-Lake Senachwine watershed (HUC 07130001), are aligned to sustain a water quality trading market focused on nitrogen and phosphorus. The proposed nitrogen and phosphorus (or nutrient) credit trading program between point and agricultural nonpoint sources in the BBC watershed focuses on using constructed wetlands to achieve water quality improvement. Unlike most agricultural BMPs, constructed wetlands, when properly sited and designed, can intercept surface and subsurface drainage, operate under a wide range of hydraulic loads, remove a variety of pollutants, and provide a direct means to quantify nutrient reduction. Restored or constructed wetlands are one of the most effective practices to remove nutrients from either municipal effluent or nonpoint source runoff and to improve water quality in downstream waters (US EPA 2007a).

Both nitrogen and phosphorus emissions were considered in this study, as these two nutrients have local and regional implications when present in excessive amounts. Currently, Illinois has no numeric water quality standards for nitrogen and phosphorus in rivers and streams; therefore, trading has no regulatory driver. Assuming hypothetical effluent limits, we explored the viability of a nutrient credit trading program in anticipation of future standards to demonstrate the potential opportunities and challenges in developing water quality trading programs.

Experience with U.S. emissions trading programs is mixed. Watershed-based nutrient trading has failed to be successfully implemented or to generate significant cost savings in a number of programs around the United States. Economic, environmental, social, and other factors have contributed to the success and failure of emissions trading programs. The success of emissions trading programs depends on many factors including the market driver, size of the trading area, trading ratios, emissions standards, and transaction costs. A nutrient trading program is more likely to be successful when it has fewer trading restrictions, when transaction costs are minimized, when the new emissions standard is sufficiently below the old standard, and when there is certainty of environmental improvement. Programs are likely to be less successful when they are poorly designed, administrative/transaction costs are high, the new emissions standard is only slightly below the current emissions standard, and environmental benefits are ambiguous or uncertain. We reviewed and analyzed existing emissions trading programs with respect to flexibility and likelihood of success. Market structure, conditions, and performance of these and other emissions trading programs are carefully evaluated in **Section 2** to determine the factors inhibiting nutrient credit trading.

The first step in determining the viability of a nutrient credit trading program is the pollutant suitability analysis. **Section 3** first details the nitrogen and phosphorus loadings within the watershed and then assesses the suitability of these nutrients for trading. This assessment details the potential drivers for market participation, identifies potential buyers (permitted facilities), estimates future credit demand from buyers, and identifies potential sellers (landowners with nutrient removal wetlands) through different wetland siting methodologies based on available data. Further, the assessment determines the spatial and temporal effects on wetland-derived credit supply through watershed modeling simulations.

The pollutant suitability analysis alone is not adequate assessment, because it does not consider how economic factors influence the viability of a market. We conducted an economic analysis to determine if it would be feasible and socially beneficial to establish a market in the BBC watershed that allows point sources to buy nutrient credits from landowners that install nutrient removal wetlands. Utilizing the best available data, **Section 4** describes the costs associated with implementing conventional treatment technology versus constructing nutrient removal wetlands, including opportunity costs, from which effective discrete aggregate supply and demand functions were derived. Since conditions in the watershed did not allow for a commodity-style market, an alternative modeling framework was developed. Market outcomes, based on the quantity and value of trades, were determined under different regulatory conditions and trading scenarios. Issues related to nutrient trading with lumpy investments and credit stacking are also addressed.

Nutrient credit trading requires the regulatory authority to establish trading arrangements. These arrangements include delineating the trading area, setting emissions standards (or caps), determining the types of emissions sources that are allowed to be traded, establishing trading ratios between point and nonpoint sources, and monitoring and verification for compliance. Further, the regulatory authority must overcome skepticism at the market's ability to prove real physical offsets due to the hydrological complexity involved in nonpoint source (NPS) to point source (PS) trading. The regulator must enable emitters to find trading partners, decide whether to buy nutrient credits via contracts or the open market, develop the contract, carry out the transaction, and, depending on how the program is designed, monitor compliance by the trading partner. The costs of accomplishing these tasks are transaction costs. Recently, researchers have proposed online model-based clearing mechanisms called smart markets to reduce these transaction costs and enable trading that follows the hydrology. This project sought to determine whether such an approach could work, and whether a smart market for nutrient emissions could incentivize construction of wetlands. **Section 5** describes the proposed smart market design and provides the results of market simulations, which include scenarios where farmers also participate as buyers to achieve hypothetical watershed nutrient reduction goals.

Expanding the scope of typical market feasibility assessments, which focus primarily on pollutant suitability or economic feasibility perspectives of trading, this study also assessed the social readiness of the watershed for a nutrient credit trading program. **Section 6** details our interactions with market stakeholders. We mapped relevant stakeholders, interviewed selected stakeholders, and engaged stakeholder groups about water quality trading and conservation practices that address water quality. This section lists our recommendations on how to address social barriers and harness community support for a market.

Section 7 presents key water quality trading program elements, such as enforcement and administration, performance monitoring and verification, inclusion in NPDES permits, and market management. **Section 8** presents a summary of all the feasibility study conclusions and outlines the next steps for the development of a nutrient credit trading program in the BBC watershed.

1.2 Project Location Description

The Big Bureau Creek (BBC) watershed lies in north-central Illinois in the counties of Bureau, Lee, and LaSalle (Figure 1-1). The BBC watershed drains approximately 129,000 ha (499 square miles) at its confluence with Goose and Senachwine Lakes, which in turn outflows to the Illinois River. The drainage area can be further delineated in 13 12-digit HUCs (Table 1-1 and Figure 1-2). The BBC basin provides agricultural production, drinking water for Princeton and Tiskilwa, and both passive and active recreational opportunities.

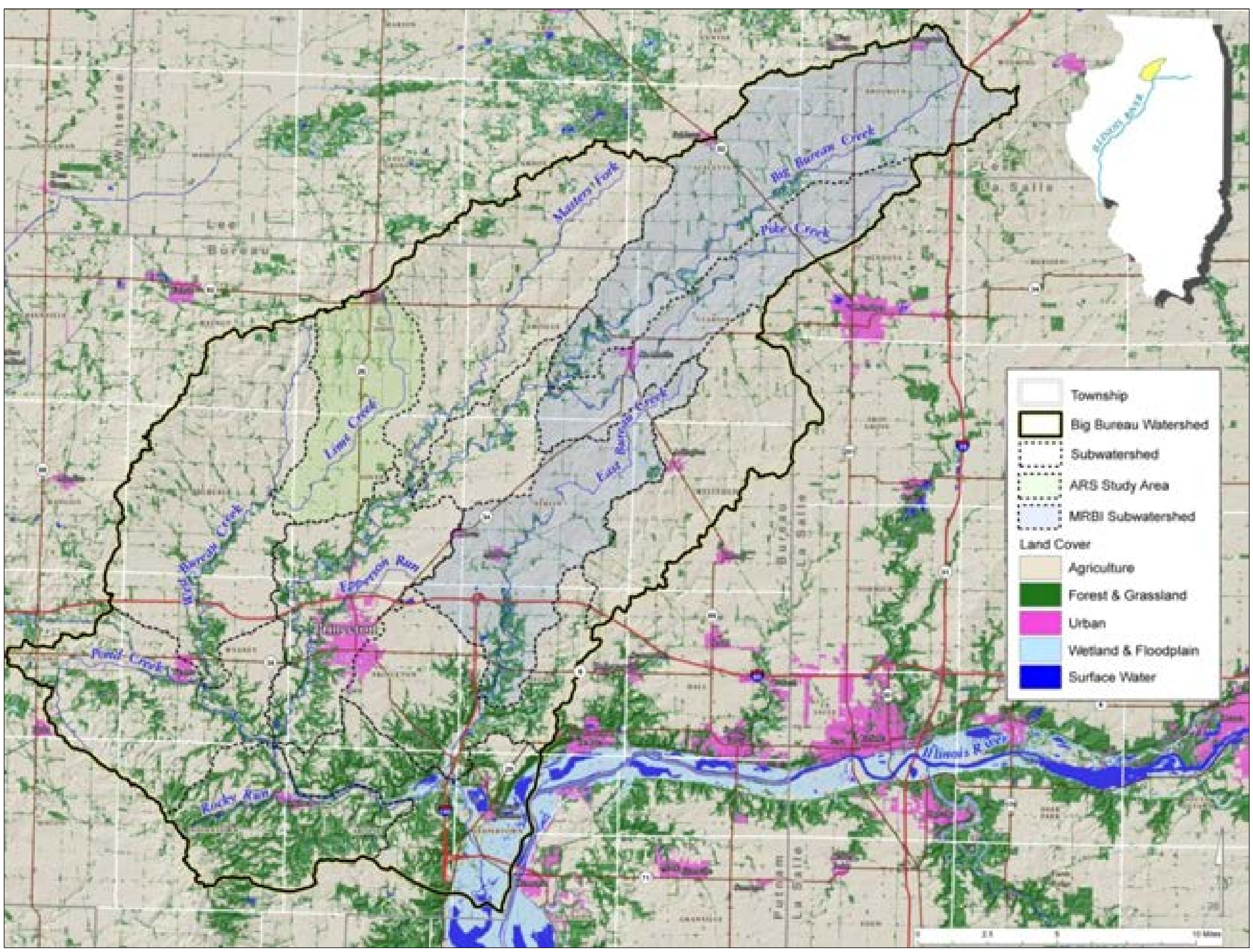

Figure 1-1. Land use in the Big Bureau Creek watershed (USDA NASS et al. 2000).

Table 1-1. The 12-digit HUC sub-watersheds in the Big Bureau Creek watershed cluster (Tetra Tech 2011).

10-DIGIT HUC	12-DIGIT HUC	12-DIGIT WATERSHED NAME	MAP ID NO.	SUB-WATERSHED AREA	
				(ha)	(acres)
0713000104	01	Lime Creek	1	6,953	17,180
	02	West Bureau Creek	2	15,786	39,007
0713000105	01	Pike Creek	4	8,356	20,649
	02	Town of Sublette – Big Bureau Creek	3	16,595	41,006
	03	Masters Fork	6	14,300	35,335
	04	Town of Greenoak - Big Bureau Creek	5	4,126	10,195
	05	Epperson Run – Big Bureau Creek	7	9,102	22,491
0713000106	01	Town of Arlington – Brush Creek	8	9,924	24,522
	02	Town of Malden – East Bureau Creek	9	10,440	25,799
	03	Brush Creek – Big Bureau Creek	10	8,564	21,162
0713000107	01	Pond Creek – Big Bureau Creek	11	10,272	25,382
	02	Rocky Run – Big Bureau Creek	12	7,077	17,487
	03	Old Channel – Big Bureau Creek	13	8,528	21,074
TOTAL				**129,930**	**321,074**

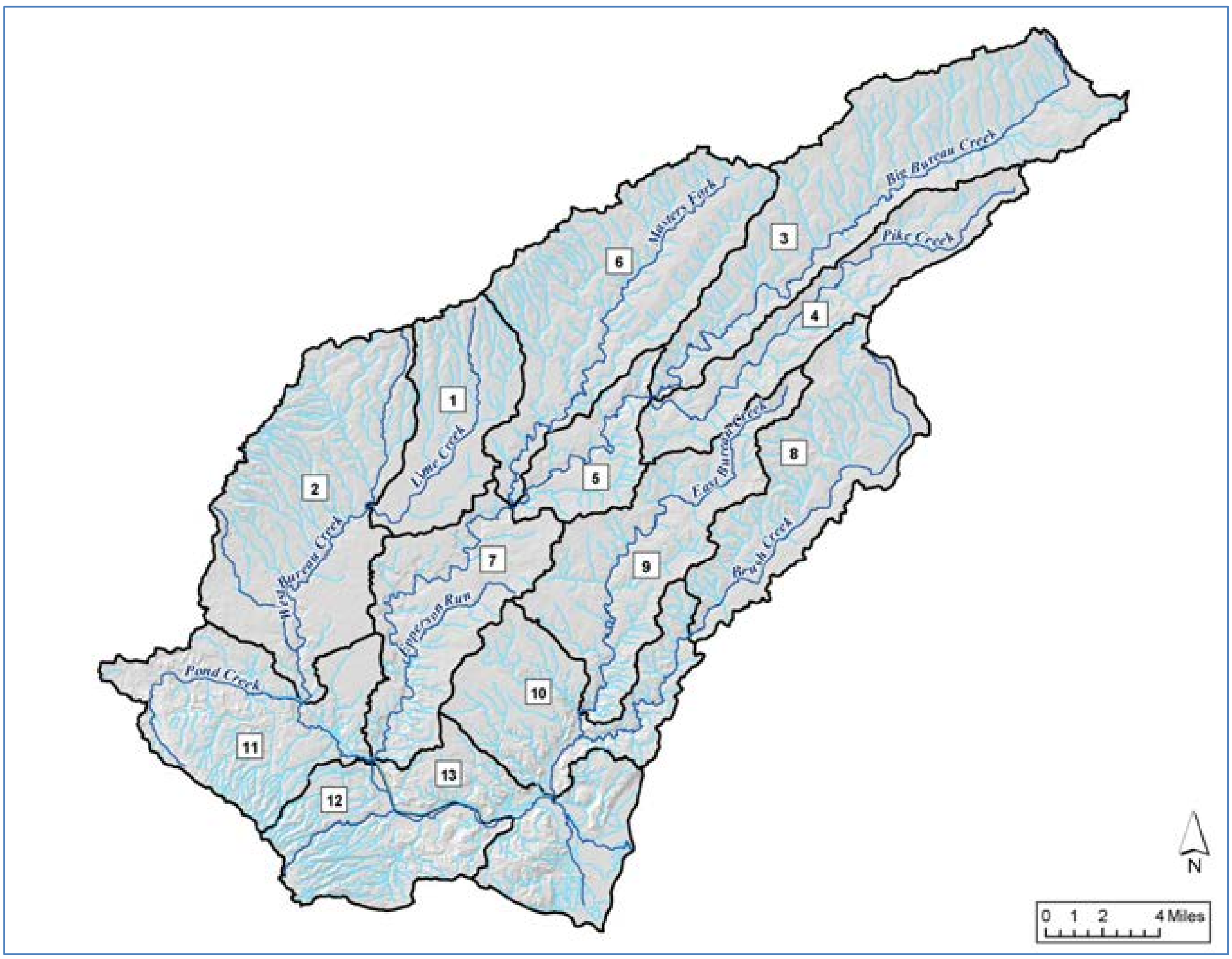

Figure 1-2. The 13 tributary sub-watersheds of Big Bureau Creek watershed (Tetra Tech 2011).

The watershed is representative of rural areas in the Midwest with a low population density of 40.9 persons per square mile (U.S. Census Bureau 2000), much land devoted to row-crop agriculture, and several wastewater treatment plants (WWTPs) present that may face stricter nutrient regulations in future years. The largest town in the county is Princeton, with a population of 7,641. Only four other towns in the area had a population greater than 1,000 in the 2009 Census estimates (U.S Census Bureau 2010a).

The BBC watershed is representative of the larger Lower Illinois-Lake Senachwine watershed, as the land cover is predominately agricultural (92%) and the watershed contains relatively little developed land within its drainage area (Figure 1-1). The dominant land use is cultivated crops (mainly in corn and soybean rotation) at 77%. Sugg (2007) estimated that approximately 60% of Bureau County, which covers the majority of the Big Bureau Creek watershed, is tile drained. In addition, the watershed has a significant amount of animal agricultural activity.

Other land cover types include woodland (6.1%), urban land (1.5%), and wetlands (0.1%) (USDA NASS et al. 2000). The Big Bureau Creek watershed has 445 ha (1,100 acres) designated as Illinois Natural Areas Inventory (INAI) sites, containing natural land features and biological communities of the highest quality (BBC Watershed Group 2008). Nine threatened and endangered species have been recorded within or near the watershed, eight of which were located within or directly adjacent to INAI sites.

According to the U.S. Fish and Wildlife Service (2011), National Wetland Inventory data classify 2.9% of the watershed as wetland habitat, mainly within the floodplain (Figure 1-3). Hydric soils, one of the characteristics of wetland areas, indicate that 18% of the watershed was potentially wetland prior to urban and agricultural development (NRCS 2010). The introduction of subsurface tile drains, dredging of drainage ditches, and channelization of tributaries has converted these former wetland areas into highly productive farmland.

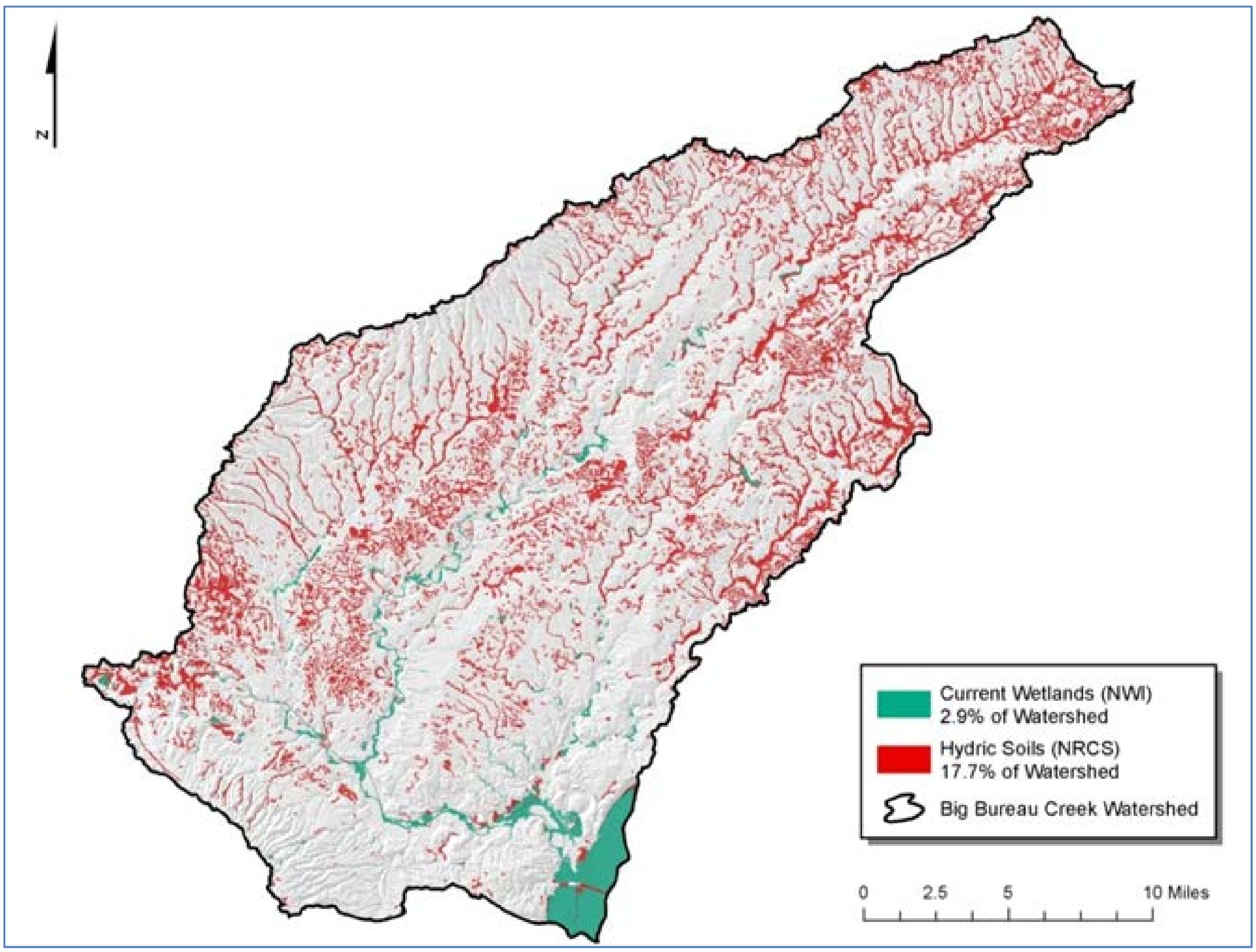

Figure 1-3. Potential former wetland areas based on hydric soils (in red) in comparison to current wetland areas (in green) (NRCS 2010; USFWS 2011).

1.3 Impact on Local Water Quality

Point and nonpoint source pollution has affected the water quality in the Big Bureau Creek watershed. Poor water quality has degraded the aquatic life within the main stem of Big Bureau Creek. However, overall habitat conditions improve downstream (IDNR and V3 2006). A 2004 macroinvertebrate biological integrity (MBI) study determined a very poor rating in the furthest upstream site, fair-to-good rating in the middle reach, and an exceptional rating in the furthest downstream sampling location. An Index of Biotic Integrity (IBI) based on multiple attributes of the resident fish assemblage followed a similar spatial trend, indicating improved water quality in the downstream reaches.

The U.S. Geological Survey (USGS) has monitored the water quality for the main stem of Big Bureau Creek at Princeton from 1978 to 2010 and, on a less frequent basis, at the outlet to Goose Lake. From 1984 to 2010, USGS monitored water quality for West Bureau Creek at Wyanet. Illinois EPA took monthly water quality samples in East Bureau Creek, Pike Creek, and Big Bureau Creek from 2010-2012 as part of the development of the Total Maximum Daily Load (TMDL) and Load Reduction Strategies (LRS) for the Middle Illinois River watershed and Tier 2 monitoring for the Mississippi River Basin Healthy Watersheds Initiative (MRBI) award within the BBC watershed. In addition, the USGS placed a nitrate-nitrogen monitoring probe near the outlet of East Bureau Creek for the MRBI award. Primary contact recreation and aquatic life designated uses are impaired in Big Bureau Creek and its tributary, West Bureau Creek, due to elevated concentrations of fecal coliform, total suspended solids (TSS), and nutrients.

The BBC watershed serves as an example of the water quality impairment that can occur in heavily agricultural areas. Existing data show that this watershed is contributing significant levels of sediment and nutrients, particularly nitrogen, to the Illinois River. Some of the most significant channel erosion in the state occurs in this watershed; approximately 1.1 million metric tons (1.2 million tons) of soil becomes detached annually, with 15% leaving the watershed (IDNR and V3 2006). This sediment load has led to the infill and sedimentation of Goose Lake and contributes sediment load to the Illinois River. Sheet and rill erosion accounts for the majority of the sediment. Stream bank and gully erosion account for 24% and 8% of the sediment leaving the watershed, respectively. Contributions from bank erosion are higher in this watershed compared to other watersheds in the region due to high banks, bluffs, gullies, and knick points.

The total suspended sediment load is naturally high within the watershed due to glacial geology, steep gradients, and flashy hydrology. However, soil erosion control and water management (e.g., grade control and wetlands) can prevent significant input. Total suspended sediment (TSS) concentrations are typically elevated and correlated with moist condition and high flow events (Tetra Tech 2011). This relationship indicates that high-flow runoff events are the primary cause of TSS loadings (specifically, bank erosion and in-stream sources) in the watershed.

The main stem of Big Bureau Creek accounts for 19% of the total nitrogen loadings in the watershed. One model estimates that 1,680 metric tons (1,850 tons) of nitrogen and 60 metric tons (66 tons) of phosphorus leave the watershed annually (BBC Watershed Group 2008). Nutrient loadings come from surface runoff, sheet and rill erosion from agricultural fields, subsurface tile drainage, livestock operations, urban runoff, septic fields, and point sources, such as municipal wastewater treatment facilities.

1.4 Impact on Gulf of Mexico Hypoxia

The BBC watershed cluster lies within the 8-digit HUC designated focus area of Lower Illinois River-Lake Senachwine (07130001). This watershed accounts for approximately 25% of the Lower Illinois-Lake Senachwine drainage area. The USGS ranked the Lower Illinois-Lake Senachwine watershed 23rd for total nitrogen delivered incremental yield to the Gulf of Mexico and 83rd for total phosphorus (Robertson et al. 2009). Previous watershed modeling has estimated that BBC provides 0.1% of the nitrogen in the entire Mississippi Basin, despite only encompassing 0.04% of the land area (IDNR and V3 2006).

2 WATER QUALITY TRADING

2.1 Challenges in Water Quality Trading

Pollution permit trading has an extensive literature dating back to the 1970s. Early theoretical literature covers both air and water pollution trading in general. Economists have argued for decades that society could benefit from emissions permit trading (e.g., Baumol and Oates 1988). Recent studies have confirmed that permit trading can improve water quality at lower cost than other regulatory approaches (Faeth 2000). The cost savings associated with trading are mostly due to lower marginal abatement costs for nonpoint sources (NPS) than for point sources (PS) (Stephenson et al. 1998; Butt and Brown 2000; Shabman and Stephenson 2007).

Nutrient trading, which falls under water pollution, is more complicated than other trading systems due to the complex nature of nutrient sources, transformations, and transport in waterways. Though the first water quality trading initiatives were introduced as early as the 1980s (Morgan and Wolverton 2005), it was not until 2003 that the United States Environmental Protection Agency introduced a national Water Quality Trading Policy (US EPA 2003). If such markets were in place, however, point sources such as wastewater treatment plants could potentially satisfy their nutrient reduction obligations at lower cost by paying landowners to engage in wetland remediation (See Hey et al. 2005). The resulting wetlands would have ancillary benefits such as waterfowl habitat improvement.

Despite the clear benefits from PS-NPS water quality trading, nutrient reductions from NPS are challenging in several ways. First, emissions from NPS are by nature stochastic and difficult to observe. Second, NPS reductions can be difficult to measure, which complicates comparing PS reductions to NPS reductions. Third, NPS reductions are difficult to enforce. These challenges potentially make NPS reductions more costly than PS reductions (Shortle and Horan 2001). Stephenson et al. (1998), however, claim that the problems inherent in NPS pollution are not much different from the problems associated with wastewater treatment plants (WWTPs) that occasionally overflow in response to unexpected and random weather events. As a result, they argue that the costs of pollution abatement can be similar for PS and NPS. In sum, whether NPS pollution abatement is a cost-effective mechanism is an empirical question that will depend on the specific pollutant and watershed considered, and especially on the design of the trading mechanism.

2.1.1 Market driver

Water quality objectives, whether expressed as nutrient standards, caps (TMDLs), step-down caps, or another limit, must be set and enforced. Buyers and sellers will not participate in a trading program if the program has no tradable commodity. Pollution caps must be set below key ecological thresholds to achieve environmental goals, and market caps must be set at a point that will drive demand for credits to achieve active market trading (King and Kuch 2003).

Since agricultural nonpoint sources do not generally face binding regulations on their environmental footprints, a tradable permit market that involves nonpoint sources needs to have a credible and stable source of demand for the environmental offsets provided by nonpoint sources. While the U.S. EPA does not have the authority under NPDES to regulate NPS, states can set TMDLs under the Clean Water Act for a range of surface water pollutants and have the authority to regulate, if they choose, NPS to achieve TMDLs.

Given a healthy institutional and regulatory environment, the presence of a TMDL can be important to stimulate demand for participation in nutrient credit trading markets. For example, the lack of a TMDL has held up the Kalamazoo and Lower Boise River trading systems. As described further in Section 3.1.2, the draft TMDL for the Middle Illinois River-Lake Senachwine watershed identifies the load reductions needed to meet the nutrient targets under various flow regimes for BBC. However, the draft TMDL cannot serve as the regulatory driver needed for a water quality trading program. Without individual waste load allocations (WLAs) for each permitted facility, specific effluent limits and the corresponding nutrient load reductions cannot be determined. Since point source users currently have no regulatory or financial incentives, they have no motivation to consider or invest into any pollution reduction technologies or alternative strategies such as nutrient credit trading. In addition, point source users are uncertain about the regulatory numeric nutrient criteria still under development. Both the point sources and agricultural nonpoint sources could be taking a risk by investing early in a trading program and wetland practice that may change based on the standards (and TMDLS) that are adopted in the future.

2.1.2 Market structure

It is important to specify clear goals and objectives for a trading program. Unfortunately, research into *designing* nutrient trading programs properly is rare. Nutrient trading programs have been implemented in the U.S. with little research and have experienced market failures as a consequence (King and Kuch 2003). Given the lack of research on designing effective and successful water quality trading systems, the requirements of a healthy trading system must be identified first and then used as measures of proper market design.

An “ideal” market for nutrient credits would have a number of specific characteristics. It would permit nonpoint sources to be paid for multiple services, achieving efficient incentives for land-use changes while avoiding perverse outcomes (Hansson et al. 2005; Jackson et al. 2005; Rodriguez et al. 2006). In a well-functioning market, agents buy and sell known, well-understood, environmentally verified, additional units of the service in question, accounting for spatial heterogeneity in service production. The program within which the market functions must have sufficiently stringent overall caps on permits to achieve the environmental goals at hand. A good market minimizes transaction costs given these constraints. Finally, an ecosystem-service market will not function if stakeholders do not view it as being fair, or if the legal and institutional environment exposes participants in such a market to risk.

Numerous types of markets exist for ecosystem services, and no one type of market is best in all situations. Woodward and Kaiser (2002) identify four types of markets for water quality trading: exchanges, bilateral negotiations, clearinghouses, and sole-source offsets. Along with these basic market types, additional features, institutions, or third parties can be introduced to potentially reduce transaction costs and improve program efficiency, equity, and success in meeting environmental goals (Table 2-1). Below we briefly discuss those four market structures and explore the potential for voluntary markets, “smart markets,” and reverse auctions to be useful in nutrient trading.

Table 2-1. Market structures, advantages, and disadvantages.

MARKET STRUCTURE	ADVANTAGES	DISADVANTAGES	APPROPRIATENESS FOR WATER QUALITY TRADING
Exchanges	Low transaction cost	Requires uniformity in commodity to be traded	Minimal
Bilateral negotiations	Provides latitude for buyer when commodities are not uniform	High transaction costs	Difficult with many constraints; requires simulation for approval
Clearinghouses	Reduced transaction costs, can enable greater monitoring by government agencies	Added responsibility for 3rd party running the clearinghouse: either government or another agreed-upon 3rd party	More formal trading structure approaching that of a more traditional market
Sole-source offsets	Can work in cases where no formal market exists, lower oversight costs than in more formal markets	High transaction costs, likely to occur only in obvious “win-win” situations	Appropriate where no formal market exists
Voluntary markets	Provide funding for offset projects, means for “early adopters” to reduce nutrient footprint, public education and constituency building for future mandatory markets	Allow free riding, unlikely to achieve environmental goals on their own	Potentially useful first step prior to developing mandatory markets
Smart markets	Low transaction costs, can optimize allocation of pollution rights given complex variation in transfer coefficients	Need some way to induce all sources to participate; most useful given currently non-existent constraints on water quality	Limited under current U.S. legal settings

EXCHANGES

Exchanges are the most traditional and easily recognized markets for trading goods or services (Woodward and Kaiser 2002). Exchanges provide a meeting place for buyers and sellers to exchange a well-defined commodity at a price determined by supply and demand. Exchanges provide clear prices and thus clear incentives to participants and involve the lowest transaction costs of any market structure.

However, a key requirement for exchanges is that the commodity being exchanged be uniform and well-defined; this is a serious drawback for water quality trading. In the widely praised U.S. program to use markets to reduce emissions of air pollutants responsible for causing acid rain, SO_2 allowances are assumed to be uniform, allowing these allowances to be traded using an exchange market. Though analysts always understood that SO_2 emissions from some parts of the country were more damaging than others (as was recently quantified by Muller and Mendelsohn

(2009)), program designers opted to neglect that variation in marginal damage to have a simple uniform market. The results do not seem to have been extremely spatially suboptimal (Burtraw et al. 2005). In contrast, water quality offset contracts give highly variable benefits across space given variation in the quantities of services yielded by the same activity on different plots of land. Furthermore, a given quantity of nutrient reduction from a nonpoint source has different benefits depending on the watershed to which it contributes and where the reduction is located relative to the point source with which the nonpoint source is trading. Thus, a commodity exchange is unlikely to be a useful market structure for nutrient credit trading (Woodward and Kaiser 2002).

BILATERAL NEGOTIATIONS

Bilateral negotiations arise when a commodity to be traded has little uniformity. Buyers and sellers must clearly communicate the nature of the commodity and its price, as in a conventional market for used cars, which has greater uncertainty about the commodity than the new car market. Unfortunately, these negotiations generate high transaction costs. Because of the lack of uniformity in nutrient credits, Woodward and Kaiser (2002) expect bilateral negotiations to be common in nutrient credit trading, despite their high transaction costs. Examples of bilateral trades include the Alpine Cheese Company/Sugar Creek (OH), Piasa Creek Watershed Project (IL), and the Dillon Reservoir Pollutant Trading Program (CO) (Breetz et al. 2004; Selman et al. 2009).

CLEARINGHOUSES

A clearinghouse model entails the participation of a local, state, or federal government agency, or another third party designated by the government and held responsible for the market, who acts as a buyer of credits from credit providers and a seller of credits to buyers. This agent is often referred to as an aggregator. In acting as a responsible third party, the aggregator provides several services that improve market function: (1) the aggregator can absorb risk in nutrient offset production for numerous small market participants; (2) the aggregator can take on legal responsibility for credit provision and meeting environmental mandates, increasing the willingness of buyers and sellers to participate; (3) the aggregator can exploit the acquired expertise and economies of scale associated with managing numerous pollution offset projects, thus reducing transaction costs for the market as a whole; and (4) the aggregator can facilitate purchases of multiple service flows by multiple buyers.

If a governmental entity acts as the third party, this can provide a means of improved monitoring of the market but at the cost of increased responsibility for the government entity. Alternatively, the regulatory entity might delegate responsibility for running a clearinghouse to a third party. Real-world examples of clearinghouses include state government involvement in North Carolina’s Tar-Pamlico Basin trading scheme; third-party clearinghouse operation supervised by a board including state, industry, and environmental representatives in Minnesota’s Rahr Malting Company’s program to reduce biological oxygen demand and nutrients; Long Island Sound’s Nitrogen Credit Advisory Board; the Miami Conservancy District’s involvement in the Greater Miami River (OH) trading program; and payments for environmental services in Costa Rica (Woodward and Kaiser 2002; Pagiola 2006; Ecosystem Marketplace 2009).

SOLE-SOURCE OFFSETS

Sole-source offsets are simply an action by a polluter to offset emissions by providing or purchasing an offset taking place elsewhere, in the absence of a defined water quality market. Sole-source offsets may have high transaction costs (as the buyer must effectively create their own trade); however, if the project is a true “win-win” situation, transaction costs may be low relative to the gains from trade. Oversight costs to government regulators are likely to be lower than in more formal markets due to the limited number of “trades” taking place. Examples of sole-source offsets include water quality improvements in the City of Boulder (Woodward and Kaiser 2002) and New York City (Chichilnisky and Heal 1998).

VOLUNTARY MARKETS

The Chesapeake Clean Water Fund (http://www.chesapeakefund.org/), developed from 2008-2009, is an example of a voluntary market, providing “voluntary nitrogen offsets” to businesses and residents of the Chesapeake Bay. Analogous to the voluntary carbon offset markets that have become popular in recent years (Hamilton et al. 2009), the Clean Water Fund includes: (1) an online calculator enabling the individual or business to calculate their “nitrogen footprint”; (2) recommendations to reduce the size of this footprint; (3) a mechanism to pay to offset the remaining nitrogen footprint; and (4) transfer of these funds to projects that actually reduce nitrogen loading in the Chesapeake Bay. Voluntary markets provide the means for “early adopters” to account for environmental costs that may later become mandatory, a way to begin funding “offset projects” that reduce a region’s collective environmental footprint, and a valuable educational service that may spur interest in eventual development of mandatory markets.

Despite these advantages, voluntary environmental offset programs have two major disadvantages. First, by being voluntary rather than mandatory, many polluters will act as “free riders,” enjoying the benefits of collective emissions reductions funded by others without having to pay these costs themselves. Even among firms interested in reducing their environmental footprint, the uncertainty associated with lack of full regulatory buy-in and with future credit price may limit participation. Second, because voluntary markets have no enforceable regulatory cap on pollutant levels, voluntary markets are unlikely to achieve environmental goals. Thus, while voluntary offset programs may be useful in the short term, they are unlikely to be a permanent or complete solution to environmental problems.

SMART MARKETS

A smart market approach (described further in Section 2.2.7) to trading nutrient credits works best when several things are true: (1) all pollutant emitters, point and nonpoint, must participate in buying and selling nutrient credits; (2) total emissions have a fixed cap; and (3) the program must satisfy well-defined environmental objectives. Unfortunately, these conditions often do not hold in the context of nutrient reduction in the U.S. Regulation of nonpoint sources of water pollution has been politically infeasible in the U.S.; therefore, those sources cannot be forced to participate in a smart market.

The Clean Water Act (CWA) does not specify total limits on pollution or set fixed ambient water quality targets; rather, it sets individual, technology-based or water quality-based effluent standards for point sources. The resulting emission “permit” environment sets the stage for individual point sources to want to purchase offsets from nonpoint sources that would be accepted by state and federal regulators in meeting the point sources’ permit obligations. However, the CWA does not put forth general pollution or water-quality objectives that can serve as constraints in a smart market. Regional or state laws and/or new water quality regulation might set a stage that is well suited to take advantage of the power of smart markets. Otherwise, adoption of smart markets for nutrient credit trading in the U.S. may be limited.

REVERSE AUCTIONS

In the absence of a perfectly competitive exchange for homogeneous ecosystem service credits, market power on the sellers’ side can yield transaction prices that are higher than the marginal cost of service provision to the sellers. This has been a source of concern in numerous programs where demand for ecosystem services comes from (or is funneled through) a single buyer who wants to maximize the service provision it can generate given the available funds. A useful procurement strategy is to use a reverse auction to identify the nonpoint sources that will be granted offset-credit contracts (Latacz-Lohmann and Schilizzi 2005). Examples include Australia’s BushTender (Stoneham et al. 2003), payment for environmental service programs in Costa Rica (Daniels et al. 2010), the Great Miami River Water Quality Trading Program (Newburn and Woodward 2012), and the Conservation Reserve Program in the U.S. Even with a reverse auction, buyers need to avoid collusion between sellers to bid up the price (Klemperer 2002; Claassen et al. 2008; Ferraro 2008).

2.1.3 Thin markets

A market comes closest to efficient outcomes when it has enough participants on both the supply and demand sides to approximate perfect competition. Several studies have suggested that few areas have enough potential trading partners for a tradable permit market to be beneficial (Roberts et al. 2008). The presence of “thin markets” has been observed in real permit trading systems where the number of trades has been small in most cases (Morgan and Wolverton 2005). This finding does not, however, imply that trading systems are not useful. As described by Woodward (2003), one single trade can be so valuable and result in such significant savings that it outweighs the implementation cost of the permit system. Based on the economic feasibility analysis, this scenario is potentially the case for the BBC watershed.

The market area could be expanded to the HUC8 Middle River-Lake Senachwine watershed, which would increase the number of major wastewater treatment facilities and buyers. However, program designers face a painful tradeoff between the goals of increasing market thickness and perfectly accounting for spatial heterogeneity in the effects of pollution from different sources. Pair-wise, or bilateral, trades in a wide geographic region can lead to problems like local hotspots in pollution (Salzman and Ruhl 2002). However, extensive rules requiring complex trading ratios or forbidding trades between sources that are not close together on the same body of water can thin the market to where it ceases to function, as in the famous case of the Wisconsin Fox River watershed (Hahn 1989). Without a smart market like MarshWren, which was developed for the BBC watershed (See Section 5), the balance between thin trading and cheating watershed dynamics must be struck carefully.

2.1.4 Trading units

The trading units must be well defined in a nutrient credit trading program. Unlike the buyers of well-understood physical market commodities, who can easily understand what they are purchasing, buyers of nutrient credits must have some assurance of the type and quality of offset they are purchasing. The trading unit is typically the amount (e.g., mass, kilocalorie, etc.) reduced over a specified time period (e.g., month, year, etc.).

Most trading programs in place rely on some type of trading ratio system to adjust for spatial differences and the high stochasticity of emission reductions from nonpoint sources (Stephenson et. al 1998; Morgan and Wolverton 2005). Trade ratios are typically used to address uncertainty over whether the nonpoint source (BMP) reduction has the same effect as a reduction at the point source. Ratios help ensure water quality in the watershed is protected and that trades between nonpoint sources and point sources, which are distributed throughout a watershed, positively impact the overall water condition in the watershed. Trade ratios account for practice performance uncertainty (or BMP efficiency), location or delivery, equivalency, insurance, and retirement. Some water quality trading programs do not attempt to determine the ratio scientifically based on assessments of practice performances, seasonal effects, or spatial consideration. Instead, they assign an agreed-upon value to account for uncertainty and insurance.

The literature has no consensus about the “right” trading ratio design. As demonstrated in Table 2-2, studies yield highly variable conclusions about the optimal ratio of pollution reduction from nonpoint sources traded for pollution increases from point sources. Many factors influence optimal trading ratios, including the variances of expected loadings and the nature of marginal enforcement and marginal abatement cost functions.

Table 2-2. Optimal trading ratios in economics literature.

TRADING RATIO $\left(\frac{NPS}{PS}\right)$	ASSUMPTIONS AND COMMENTS	CITATION
Less than or equal to one		
TR < 1	If planners focus on the mean of loadings rather than the variation, the result may be excessively high trading ratios.	Horan 2001
0.32-1	The trading ratio in this study is equal to simulated transfer coefficients based on the assumption that transfers are unidirectional.	Hung and Shaw 2005
Greater than one		
TR > 1	When permit levels are determined exogenously at inefficiently high levels, trading ratios above one are preferred. The objective of the social planner is to reduce abatement cost, society is assumed to be risk neutral, and trading has zero transaction costs.	Horan and Shortle 2005
TR > 1	If the damage curves of expected and certain emissions are convex, and the remaining structural assumptions are met, the trading ratio will be greater than one.	Hennessy and Feng 2008
TR > 1	Study of real world trading projects. All the projects use a ratio in excess of one.	Morgan and Wolverton 2005
Ambiguous		
Can be great or smaller than one	The ratio must take all costs (including enforcement costs) and uncertainty in technology and NPS loadings into consideration; otherwise, the water quality target may not be achieved.	Malik et al. 1993
TR for expected nonpoint source loadings ~ 0.9 (different for other programs)	This study finds that trading programs are more efficient when nonpoint permits are defined in terms of expected loadings rather than land use.	Horan et al. 2002
Numerically unspecified		
Defined mathematically	The ratio must take damage occurring at intermediate locations and degradation of the polluting compounds into account; thus it may vary with seasons.	Lankoski et al. 2008

2.1.5 Transaction costs

To make sense of environmental markets and management of the commons in general, it is critical to understand the key issue of transaction costs. Allocation of common resources usually requires the consent of many people, unlike allocation of private commodities. Considerable theory and experience in pollution permit trading have shown conclusively that transaction costs can cause market failures (McGartland 1988; Stavins 1995; Hoag and Hughes-Popp 1997; David 2003; Libecap 2005).

A successful nutrient credit or water quality trading program achieves environmental goals in an efficient manner. An efficient program implies that trading will only proceed when one source is able to reduce its pollutant load more cost-effectively as compared to another source (Fang and Easter 2003). High transaction costs can swamp the gains to participants of trading, leading to minimal market activity and preventing trades from improving cost-effectiveness relative to the command-and-control baseline (Crutchfield et al. 1994; Stavins 1995).

Because nonpoint sources are numerous, transaction costs pose one of the biggest challenges to designing a successful point–nonpoint source nutrient trading program. Transaction costs have several components (McCann et al. 2005). In the absence of a formal market, considerable time and money may be required for buyers and sellers to locate each other, negotiate and enforce a contract, and achieve approval of the appropriate environmental regulatory agency. These high opportunity costs may be at least part of the reason that markets for environmental goods and services seldom arise spontaneously.

Transaction costs are a function of the trading rules and institutions. Transaction costs include information costs (e.g., feasibility assessments, watershed modeling, BMP removal estimates, etc.), operation costs (e.g., monitoring and verification, site inspections, data management, etc.), and institutional or regulatory costs (e.g., program development, oversight, trade execution, legal and broker fees, etc.). Costs may be borne by legislatures and courts, agencies, and stakeholders, and at different times from program development to establishment (McCann et al. 2005).

Estimates of transaction costs from various studies range from 2 to 88% of total program costs and can consist of everything from environmental research to lobbying costs and administration (McCann and Easter 1999; Woodward and Kaiser 2002; Morgan and Wolverton 2005). A few market tools can help reduce transaction costs, including standardized credit calculators or other tools, online registries, and offset aggregators. Aggregators can be particularly useful when many small sources are involved, reducing transaction costs by bringing together and selling credits from multiple small sellers while providing technical expertise to involve the small landholders in emerging environmental markets.

2.1.6 Tradable rights

The need for water quality trading to mitigate water pollution stems from the well-established concept of markets in externalities. An externality is the impact of a transaction on a third party. For environmental issues, the externalities are widespread. When a farmer applies fertilizer for crop production, nutrient levels in the water are increased. These nutrients benefit some people, but are also detrimental to other people (e.g., contaminated drinking water) and the environment (e.g., hypoxic zones). The increased nutrient levels are externalities of the farmer's commercial operation. These externalities are priced at either zero (user can act freely) or, less often, infinity (users are prohibited from a given action).

Coase (1960) observed that if property rights are well-defined, then markets can overcome the externalities. If these rights are not specified, then the market may have trouble sorting out the externalities. Who has the initial right is irrelevant, because they would trade to the optimal solution. Coase (1960) could be interpreted to mean that the market will sort out the externalities, so the regulator only needs to help specify the initial rights. We will depend on this result from Coase in our market simulation.

The best science follows Coase's observations, suggesting the problem should be solved via rationed tradable rights (Tietenberg 2006). In Tietenberg's words, "Tradable permits address the commons problem by rationing access to the resource and privatizing the resulting access rights." The total quantity is rationed, but within that limit, users can trade. Carbon emissions trading and New Zealand's fishery quota system are cited as examples (Tietenberg 2006).

Unfortunately, simply defining the rights and allowing them to trade does not create a market. In his argument, Coase (1960) assumed perfect information and zero transaction costs. Of course, this is not the case. To trade, users need to be able to find each other, negotiate a price and a contract, close the deal, and enforce the contract with relative ease. Due to these transaction costs, "market failure" commonly occurs with thin markets as the limited number of buyers and sellers may have difficulty finding trading partners (Stavins 1995; Libecap 2005).

The current science shows clearly that people cannot always trade toward an efficient solution. McAfee (1997) and Baliga and Maskin (2003) show that allocation of a public good such as the quality of the environment requires government intervention. Business people are not responsible for the environmental flows; they are responsible only for adhering to the conditions of their own permits. Therefore, a water quality trading market (in any form, whether pair-wise, or the proposed smart market) probably should not be operated privately, such as by a users' cooperative. The government is responsible for rationing access to the commons, and due to hydrological complexity, simply limiting discharge is insufficient for guaranteeing water quality, or at least doing so efficiently. The government is also responsible for designing and implementing a proper market structure for trading, which accounts for the spatial and temporal variations among the dischargers.

The ability to allocate pollution rights efficiently determines the success of any pollution permit trading system. The distribution of permits to dischargers is efficient if the distribution satisfies environmental goals at minimum cost to society. To achieve efficiency, nutrient markets must incorporate specific factors (e.g., reliable nutrient transport parameters) in addition to the general factors that affect the success of any trading program (e.g., low transaction costs). The specific factors are associated with a given user's effect on water quality at one or more receptors. A receptor is a waterbody or a specific point on a waterbody where water quality is monitored. The target nutrient levels at the receptors serve as the basis for trading. Watershed managers or state authorities who struggle to control nutrient loading to a specific surface waterbody, may consider it as the only receptor concerned. If they want to control nutrient levels in both ground and surface water, or at different points in ground and surface waterbodies, the authorities must consider multiple receptors. The choice between single and multiple receptors has implications for the choice among different types of tradable permits and the complexity of market structures.

Due to the delayed and dispersed nature of nutrient transport in natural systems, nutrient trading requires significant information about the fate of nutrients released from sources. First, trading systems need knowledge of the relationship between emissions at sources and their effects at the receptors (O'Shea 2002). These linkages are usually described by transport coefficients. Transport coefficients measure the increase in pollutant concentration or mass pollutant discharge at each receptor over each time period of interest, caused by a unit pollutant loading or emission by each source. Reliable estimates of nutrient transport coefficients are required for a market to function properly.

Second, trading systems need reliable estimates of nutrient targets at the receptors. Targets may be defined as maximum acceptable mass pollutant discharge into a receptor or maximum acceptable pollutant concentration at a receptor. Tradable targets should be set taking into account the unmanageable sources such as stormwater.

Third, to achieve the optimal allocation of pure public goods, some kind of government intervention is required, and the regulator needs critical information about the users—mainly, the user benefits of pollution (Baliga and Maskin 2003). However, deriving user benefits of nutrient discharge is difficult. The market structure should be selected so that it incentivizes the users to divulge their true benefit functions to the regulator (Egteren and Weber 1999).

Fourth, availability of information about potential trading partners is needed to encourage trading (Fang et al. 2005). This requirement is significant for bilateral trading. A centrally controlled market, which operates as an exchange or a marketplace, does not require much interaction or direct exchange of information between buyers and sellers (Woodward et al. 2002). Therefore, in terms of both information requirements and transaction costs, a central nutrient trading market should have lower transaction costs compared to bilateral trading.

Some authors claim that the major reason for few trades taking place in U.S. water quality trading programs is insufficient supply and demand and that supply and demand are beyond the control of market designers (King and Kuch 2003). Other authors say that active trading requires a sufficient number of potential buyers and sellers (Hoag and Hughes-Popp 1997; David 2003). However, care is needed to tease out the various connected issues. Supply and demand depend on: (1) transaction costs; (2) initial distribution of discharge rights; (3) prevailing restrictions on nutrient discharge (in a non-market situation) and nutrient targets at the receptors; (4) scope of the trading system; (5) confidence in the market itself; and (6) the different abatement costs, discharge levels, and operations among the participants, and other factors.

In a water quality trading market, the cost of finding trading partners, negotiating prices and contracts, obtaining approvals (validating trades), and all related legal arrangements contribute to the overall transaction cost. Both supply and demand will be close to zero if the deal is too hard to arrange. With very high transaction costs, a given trade must be extremely valuable to be attempted, more valuable than the cost of making the deal. If transaction costs were close to zero, users could trade as often as they wished, even hourly. Thus, whatever the trading rules, however the rights are defined, the transaction costs have to be low enough that small trades are worthwhile.

Supply and demand depend also on the initial rights, which (theoretically) may be distributed in many different ways. First, the initial rights may be over-allocated, in which case government may seek to buy rights back from users, who would not be inclined to sell. Especially with high transaction costs, users will surrender rights only at a high price, so the market will be quite thinly traded. Second, the initial distribution may be zero, in which case users must purchase all rights (presumably from government), thus guaranteeing an active market. Third, users may be given reasonable initial allocations, but over time, those allocations will become less efficient due to changes in users' operations, supply and demand for production, and regulatory changes. High transaction costs will thwart trading; low transaction costs will enable trading, giving an impression of higher supply and demand. Various intermediate scenarios could be arranged or could occur naturally.

Prevailing and proposed restrictions or nutrient targets – that is, shortage – ultimately drive trade. If government does not restrict the resource in any way (whether at the individual, irrigation district, county state, or national level) then users will face no shortage and will not seek to trade, because the shortage price of the resource will be zero. On the other hand, given (almost any) enforceable restriction on discharge, the scope of the trading system can be chosen to improve demand and supply, within the limits of the physics. For example, trading within a whole catchment is likely to be more active than trading with respect to a particular waterbody.

David (2003) found that for a trading system to function properly, firms should be certain of the opportunity to buy back rights in the future. Users need to have confidence that the other users and government will respect their contracts, and that the market will continue to operate into the future. Government should ensure that the market operates fairly. If users have too much market power, the market will be inefficient. Empirically, market power depends on the number of participants (Deshel 2005; Montero 2008); as few as 10 can severely limit market power. A larger watershed would likely have hundreds of users, so market power is unlikely.

For a permit market to function properly, trading rules should be well established, understood, agreed, and adhered. The trading procedure should be simple enough to understand. Over-restrictive trading rules cause thin permit markets and market failures (Hoag and Hughes-Popp 1997; Faeth 2000). On the other hand, loosely defined trading rules may result in unfair trading and non-attainment of environmental goals. Some trading rules allow “free-rider” problems, which arise when some polluters benefit from the transactions of others and lead to thin markets (McGartland 1988).

A healthy market requires monitoring and enforcement. Discharge rights traded should be well defined. Firms should know that they would be penalized for violating permit limits (David 2003). Monitoring point source nutrient discharge is easy with the available technology, but monitoring nonpoint source nutrient loading is difficult. Since nutrient loading from agricultural nonpoint sources is related to the type of land use and land management practice, land use may be monitored in addition to the quantitative nutrient losses. Assuming low transaction costs, some kind of initial distribution, some kind of enforced resource constraint, and confidence in the market, users will trade, and will do so voluntarily, and those trades are likely to lead to efficient final allocations.

2.1.7 Liability

The NPDES permit held by point sources does not allow those sources to transfer regulatory liability for meeting their permit obligations to a non-permit holder. Efforts to generate pollution reductions from nonpoint sources could fail due to unexpected problems with the abatement activity (e.g., the wetland plants fail to grow) or uncontrollable external events (e.g., a terrible storm wipes out the wetland structures on private lands). The inability to transfer liability to an unregulated nonpoint source seller is a major risk to the point source buyer. Contractual agreement language can distribute financial liability between buyers and sellers for regulatory noncompliance (e.g., penalties and fees) due to practice performance failure or behavioral uncertainty (Shortle and Horan 2008; Morgan and Wolverton 2005). However, nonpoint emitters are unlikely to want to share financial liability in the case that trading fails to meet legally mandated environmental standards. Liability can be transferred to a third party or intermediaries, such as offset aggregators, who can manage risk by holding credits in reserve in case practices fail to deliver expected nutrient reductions (Selman et al. 2009) or by sharing financial liability for any noncompliance fines (Willamette Partnership et al. 2012a). The risk of liability can be a major factor in program failure, dampening enthusiasm on the part of regulated buyers and voluntary sellers to engage in offset trades (Woodward and Kaiser 2002).

2.1.8 Baselines, additionality, and leakage

Initial nutrient contributions or baselines for all actors must be established to determine the amount of credits each actor must buy or sell. Baselines are the nutrient reduction requirements that apply to buyers and sellers in the absence of water quality trading (US EPA 2007b). A WWTP should meet its technology-based effluent limit (TBEL) before buying credits, and then it can purchase credits to meet its water quality-based effluent limit (WQBEL).

Baselines, or thresholds, for nonpoint sources (i.e., farmers) are one of the key elements in a trading program, and they vary between water quality trading programs. To be eligible to sell credits, farmers must meet a minimum level of nutrient reduction or level of performance. The baseline may require farmers to comply with existing regulations, maintain current farm practices, install specific conservation practices, or achieve specific nutrient reductions (AFT 2013). The required level of performance that must be in place before a farmer can generate credits can affect the success of a trading program. A threshold based on current farm practices is the most cost-effective and allows for the most participants. A baseline established on a minimal level of performance (additional practices or nutrient reduction) can increase the number of practices implemented and the nutrient reductions in the watershed beyond the buyers’ demand. A baseline based on TMDL load allocations may require farmers to implement multiple BMPs just to meet their individual allocation, and the restrictive baseline may produce fewer credits with fewer qualified participants and at higher costs, if farmers need to implement more expensive BMPS before they can produce credits (See AFT 2013).

The credits produced preferably should be additional in that credit reductions should occur as a result of actual payment from buyers to sellers to reduce their nutrient contributions. In contrast, nutrient reductions that occurred as a result of management activities a farmer was planning in the absence of payments would not be additional, nor would changes brought about as a result of changing commodity prices or changes to other economic incentives (e.g., taxes or subsidies) on the farm.

Finally, total credits should ideally account for the possibility of leakage – that nutrient reductions in one location are offset by concurrent increasing emissions elsewhere. For example, a farmer might place one area under less intensive management but increase the intensity of agriculture elsewhere. Determining baselines, additionality, and leakage is often a difficult process, but should be done to the extent possible to provide proof to buyers and regulators that credits are real and resulting in environmental benefits.

2.1.9 Ancillary NPS ecosystem services

Activities that reduce nonpoint source nutrient loadings from private lands often yield ancillary benefits, such as wildlife habitat and carbon sequestration. Government agencies and environmental nonprofit groups might be willing to pay private landowners for providing those ancillary ecosystem services. Multiple-service markets that "stack" or "bundle" multiple types of credits to different types of buyers could increase funding for nonpoint source environmental improvements and provide positive ecological benefits. In theory, credit stacking can lead to implementation of higher-quality projects, such as wetland or stream restoration practices, that might not be cost-effective based on a payment from a single market or credit.

On the one hand, a market with stackable credits for multiple services may require greater up-front research, development, and legal or legislative costs, which may ultimately increase transaction costs. Environmental groups are also reluctant to let landowners engage in so-called "double-dipping," or being paid multiple times for the same activity. However, focusing on a single service such as nutrient reduction lowers incentives to credit providers, and risks maximizing the generation of a single ecosystem service at the expense of other services, given the tradeoffs often found between ecosystem services (Hansson et al. 2005; Jackson et al. 2005; Rodriguez et al. 2006).

The U.S. EPA's Water Quality Trading Policy (2003) "supports the creation of water quality credits in ways that achieve ancillary benefits beyond the required reductions in specific pollutant loads, such as the creation and restoration of wetlands, floodplains, and wildlife and/or waterfowl habitat." However, the policy does not take a position on whether the producer of water quality credits also retains the right to sell other ecosystem credits (Fox et al. 2011).

2.2 Types of Permits and Trading Systems

2.2.1 Emission (source) permits versus ambient (receptor) permits

The literature on air and water pollution permit trading discusses two general types of tradable pollution permits: emission permits and ambient permits (Montgomery 1972). An emission permit is defined based on the source. An ambient permit is defined based on one or more receptors ("ambient" refers to the atmosphere, which is the receptor for air pollution).

An emission permit allows the holder to discharge a pollutant at a specified rate at a specified location (Montgomery 1972; Tietenberg 2006). Theoretically, an emission permit is a bundle of ambient permits. As the sources and receptors are spatially distributed, the emission permits held at distinct sources have different pollution impacts on the receptors. Transfer of emission permits among sources can change the environmental quality positively or negatively. Therefore, emission permits cannot be freely traded one-to-one. Some trading rules are required to govern trade in emission permits. Different trading rules have been used and different types of emission trading systems have evolved as a consequence. The most commonly found emission permit trading systems are trading ratio systems, zonal permit systems, and pollution offset systems. Nutrient permits are commonly defined as emission permits, directly specifying the amount of some nutrient that the permit holder can discharge in kilograms. From a user's point of view, emission permits are easy to understand and achieve.

With emission permits, the cost of setting trading rules raises the cost of market design. Validating and authorizing trades according to the pre-determined rules may increase transaction costs. Market designers may ignore or over-simplify the physics to reduce the transaction costs.

An ambient permit is a right to increase the pollution level at a specific receptor. Ambient permits are issued separately for each receptor. They allow the permit holder to discharge so that the pollution effect at any receptor does not exceed the specified ambient limits. Since a pollution source generally affects multiple receptors, a source has to assemble a portfolio of permits to match the impacts on all receptors. When the catchment has multiple receptors, a separate market is created for each receptor, but in every market, permits are freely tradable on a one-to-one basis.

Nutrient permits may be defined as ambient permits. However, nutrient discharge, especially from a nonpoint source, has both spatial and temporal effects, as a given discharge may affect many receptors over different time scales in different intensities. Therefore, ambient-type nutrient permits should be issued separately for each receptor and each time period that may be affected, as rights to increase nutrient levels at a specified receptor in a specified time period. The major problem with ambient-type nutrient permits is the inevitable confusion for the users in assembling the right portfolio of permits to cover the operations in each period. The sources incur high transaction costs in purchasing a portfolio of permits.

A different way of specifying ambient permits is to define the permits as a proportion of the target nutrient load in a waterbody. In a watershed with multiple receptors with multiple time periods, a source that has effects on many receptors in different time scales will have to assemble a portfolio of proportional permits to match the effects of discharge in a single period. The advantage is the ability to adjust discharges relative to updated targets (Environmental Protection Authority 2003).

Since the U.S. Clean Water Act (CWA) does not regulate nonpoint sources, the agricultural nonpoint sources in the BBC watershed are not required to buy nutrient permits, but the point sources can buy nutrient reduction credits from nonpoint sources. Therefore, we consider possible market structures for both point source nutrient trading and point and nonpoint source nutrient trading.

2.2.2 Trading ratio systems for emission permits

Almost all the nutrient trading systems in the US are trading ratio systems (US EPA 2007c). Generally, trading ratio systems allow bilateral trade in emission permits based on pre-determined trading ratios (Hung and Shaw 2005; Tietenberg 2006). For example, a nitrogen emission trading ratio of 5:1 for the sources A and B means that A has to buy a 5 kg permit from B to increase A's emission by 1 kg.

The tradability and cost-effectiveness in trading ratio systems depend on how the bilateral trading ratios are calculated. A simple way to select trading ratios is the "non-degradation" criteria. Montgomery (1972) was the first to explain this criterion as a rule governing exchange of emission rights. A buyer may emit up to a level that causes no more pollution than would have been caused if the seller had emitted the maximum permitted level. Algebraically, if source i buys an emission permit of size e_k from source k, source i can emit up to a level e_i so that $h_{ij}e_i \le hk_jek$ for all j (where h_{ij} is the transport coefficient for source i and receptor j, ignoring the temporal dimension). Thus the trading ratio $\min_j(hk_j/h_{ij})$ applies to source i for the purchases from source k. This non-degradation trading ratio prevents additional pollution as the result of trading.

O'Neil et al. (1983) gave an example of non-degradation trading ratios for biochemical oxygen demand (BOD) discharge permits between point sources. Their paper discussed a transferable discharge permit system for the Fox River in Wisconsin to show the cost-effectiveness of trading, considering two receptors. They used a one-dimensional quality model (Qual-III) of the river to calculate the transport coefficients for varying river conditions of temperature and flow. They estimated bilateral trading ratios from transport coefficients, using Montgomery's method, so that quality standards would be met at all receptors, under any flow and temperature condition. They showed that tradable pollution permits are cost-effective and capable of maintaining water quality standards, even when the river conditions are uncertain and dischargers have different effects on river water quality.

In general, trading systems with non-degradation based trading ratios are more cost-effective than non-trading based approaches, such as command-and-control policy or tax policies. However, existing trading-ratio systems suffer from free-rider problems, high transaction costs, and thin trading, especially in multiple receptor and multiple time period situations. For example, assume that polluters *A*, *B*, and *C* affect receptors R1 and R2 by the transport coefficients shown in Table 2-3 below. If *B* wishes to buy from *A*, a non-degradation trading ratio would be min (1/5, 3/1) = 1/5, driven by receptor R1. Therefore, if *B* buys a 5 kg emission permit from *A*, then *B* may discharge only 1 more kg. This trade would decrease concentration at receptor R2 by $3{\cdot}5 - 1{\cdot}1 = 14$ mg/l, which allows source *C* a free ride to increase its emission. Non-degradation trading ratios increase the overall cost and discourage participation. However, downward adjustments of trading ratios to increase cost efficiency would violate water quality standards at some receptors.

Table 2-3. Transport coefficients (mg/l) for sources A, B, and C and receptors R1 and R2.

RECEPTOR	POLLUTER A	POLLUTER B	POLLUTER C
R1	1	5	0
R2	3	1	2

U.S. nutrient trading programs use a variety of methods to determine the trading ratios (See US EPA 2007c).The trading ratios used in the U.S., for point and nonpoint source trades in particular, are safety-oriented and sometimes stricter than the theoretical non-degradation based ratios (Hoag & Hughes-Popp 1997). Such trading ratios restrict the opportunities for trade and increase the cost for the buyers, but improve water quality or, at least, prevent any water quality deterioration because of trading. Some programs have a fixed trading ratio that applies for all trades, but other programs allow a series of pair-wise trading ratios that vary depending on the position of traders in the watershed (location), the nutrient transport in the watershed (delivery), the pollutant traded (equivalency), the level of variability in performance (uncertainty), and program goals (retirement) (US EPA 2007b). Below, we provide a brief overview of three trading programs and their trading ratios.

The Long Island Sound Nitrogen Credit Exchange Program (Connecticut) allows trades between point sources of nitrogen emissions. Seventy-nine municipal sewage treatment plants in Connecticut can participate in trading. The Connecticut Department of Environmental Protection (CDEP) oversees the trading system. The purpose is to control nitrogen loading to the Long Island Sound (LIS) estuary, a single receptor. CDEP used a water quality model of Long Island Sound and its major tributaries to determine the relationships between the discharge points and the actual delivery of nitrogen to the estuary. Since the PS discharged loads are highly certain, the trade ratios are based on the variability in delivery or attenuation among sources. A set of location-based delivery factors, which are calculated from a LIS water quality model, accounts for the variability between the discharge locations and the delivery of nitrogen to LIS. In 2005, 50 publicly owned treatment works (POTWs) had purchased nitrogen credits and 28 had sold credits.

The Red Cedar River Watershed Nutrient Trading Pilot Program (Wisconsin) allows trades between point and nonpoint sources of phosphorus. The only active participants are the city of Cumberland's POTW and the farmers in the Hay River sub-watershed. The treatment plant can buy phosphorus reduction credits from upstream farmers who implement nutrient management and no-tillage practices on land with high concentrations of phosphorus in the soil. The trading ratio applicable for all trades between the point and nonpoint sources was 2:1, meaning that the POTW must buy 2 kg of phosphorus reduction credits from qualified farmers for each 1 kg of phosphorus it needs to meet permit requirements. This fixed trading ratio was negotiated between the Wisconsin Department of Natural Resources and the city to account for uncertainty in NPS performance compared with PS removal. As of 2004, the treatment plant has funded the installation of more than 60 BMPs on local farms for the required load reductions.

The Lower Boise River Effluent Trading Demonstration Project (Idaho) allows trades between point and nonpoint sources of phosphorus. The TMDL for Lower Boise River serves as the basis for trading. Permitted point sources (e.g., wastewater treatment plants and industrial dischargers) and nonpoint sources (e.g., farmers and irrigation districts) can participate in the trading system. Trading ratios apply for trades between point and nonpoint sources. The Idaho Soil Conversion Commission who oversees the trading system approves the BMPs before credit purchase. For each approved BMP, it assigns a specific trading ratio, taking into account site location (delivery), phosphorus losses (attenuation) in the watershed, and losses due to irrigation withdrawals from the river. As of 2007, no trade had taken place.

Even with a range of trading ratios, these trading systems have thin trading and high transaction costs (Hoag and Hughes-Popp 1997; Faeth 2000; David 2003; King and Kuch 2003; Fang et al. 2005). An exception is the nutrient trading system in the Minnesota River Basin (Fang et al. 2005).

Another problem within U.S. nutrient trading programs is that the temporal impacts of nonpoint sources are not taken into consideration. All the trading systems discussed above are single receptor, single time period markets. In the calculation of trading ratios, none of the U.S. nutrient trading programs has taken into account the time lag between the implementation of nonpoint source BMPs and occurrence of nutrient loading reduction at a receiving surface waterbody. As a consequence, point source purchases of nonpoint source credits may increase pollutant loads in the short term.

The trading ratio could take into account credits generated from new structural practices before the practice has reached its maximum estimated pollutant reduction efficiency by prorating the credits based on the pollutant reduction the practice is achieving during the reconciliation period (US EPA 2007c). In Wisconsin, the practice must be in place, functioning, and effective before credits are available for trading, but there is flexibility regarding the timing of pollution credits for trades involving a point source purchase of nonpoint source offsets that are produced only under certain runoff or seasonal conditions (WDNR 2013). The credit user may “bank” credits generated the practice for the calendar year and use a portion of the banked credits to demonstrate compliance with permit levels that are based on averaging period less than one year.

Hung and Shaw (2005) presented a new type of trading ratio system for point source emission rights. In their proposed system, an environmental authority first sets environmental load standards for every discharge location along the river, and the effluent cap at each location is set equal to the location’s load standard, minus the effluent load transferred from upstream (sum of upstream caps). They assumed that upstream load standards are tighter than downstream ones, so that the caps are approximately uniform along the river. The cap is distributed among individual dischargers in the zone as the initial allocation. The trading ratios between sites are set equal to the relevant transport coefficients. Dischargers are allowed to trade with each other freely based on trading ratios. Hung and Shaw proved that this trading ratio system leads to efficient allocation of emission rights under both simultaneous trading and sequential bilateral trading. However, the major problem in their approach remains the transaction costs. In addition, setting load standards for every discharge location along the river can be difficult. This system may be suitable for trades between point sources located alone a river, but not for trades between point and nonpoint sources.

For nutrient trading, the appropriateness of trading ratio systems depends on the type of nutrients being traded. Bilateral trading ratio systems are not applicable to nitrogen trading, even when nonpoint sources are only sellers. Trading with nonpoint sources is always a multiple time period and thus a multiple constraint problem. A source may affect many constraints, so multilateral trades are needed to achieve the optimal outcome. There is no way to find bilateral trading ratios that lead to the realization of all possible gains from trade and environmental quality targets simultaneously. This was proven by Ermoliev et al. (2000), who showed that bilateral sequential trades converge to cost-efficient emission allocations only in the case of a single receptor (one constraint).

We conclude that trading ratio systems can lead to efficient distributions of nutrient discharge permits only in a single receptor and single time period situation. Point source-to-point source nutrient trading in general and point and nonpoint source trading for phosphorus specifically may be approximated as a single receptor and single time period trading problem. However, trading between point sources and nonpoint sources for nitrogen cannot be simplified in this manner.

2.2.3 Pollution offset systems for emission permits

In an attempt to reduce the high transaction costs of ambient permit systems, Krupnick et al. (1983) proposed a pollution offset system to trade emission permits. With a pollution offset system, emission sources are free to trade as long as the environmental quality standards are not violated at any receptor. This system needs an environmental quality model to simulate the impact of each proposed transaction and ensure that it does not violate quality standards at any receptor. Krupnick et al. (1983) showed that after all possible trades are exercised, then the outcome is the least cost distribution of permitted emissions. McGartland and Oates (1985) presented a “modified offset system” by introducing redefined quality standards to the original offset system designed by Krupnick et al. (1983). The standards were redefined so the environmental quality standard for every receptor equals a predetermined standard or the current (initial) level of environmental quality, whichever means less pollution.

Regardless of how the quality standards are defined, offset trading systems need environmental simulations to ensure that the proposed exchange of permitted emissions will not violate quality standards. Every transaction has to be approved by the regulatory authority initially. The work required to develop these simulations increases the overall transaction cost. In addition, they are pair-wise or bilateral trading systems, meaning that those who are willing to buy or sell have to find trading partners, and the search is costly. Offset trading systems also have free-rider problems (McGartland 1988). For example, assume that polluter *A* affects receptor R1, *B* affects receptor R2, and *C* affects both receptors. The relevant transport coefficients are as shown in Table 2-4. If *C* sells to *A*, then *B* gains a free chance to increase pollution at receptor R2.

Thin trading is another criticism about offset-based bilateral trading systems. A proposed pair-wise transaction may be infeasible if the environmental quality standard at any receptor is violated. In the above example (assuming only *A*, *B*, and *C* are in the region), *C* can sell to *A* or *B*, but any purchase by *C* and any trade between *A* and *B* are infeasible. Offset mechanisms may be suitable under some specific conditions, such as when multiple pollutants are considered.

Table 2-4. Transport coefficients (mg/l) for sources A, B, and C and receptors R_1 and R_2.

RECEPTOR	POLLUTER A	POLLUTER B	POLLUTER C
R1	1	0	1
R2	0	1	1

Leston (1992) performed a study of a two-pollutant and two-season pollution offset system for the Colorado River, Texas. The two pollutants considered were biochemical oxygen demand and ammonia nitrogen. Both pollutants influence the dissolved oxygen level of a stream, hence a pollution offset by either pollutant was allowed, and only the dissolved oxygen level was the environmental quality requirement. Leston's study indicated significant cost savings. Pollution offsets from the two different pollutants contributed to almost all the savings, whereas seasonal variation in the permit design had little effect on cost savings. In the case where nitrogen and phosphorus are traded to meet maximum loading standards and the standards are specified separately for each pollutant, the offset mechanism has high transaction costs and restricted trading opportunities. In contrast to Leston's case, which had only the dissolved oxygen level as the constraint, trading these two pollutants within the offset system requires a separate transaction for each pollutant.

2.2.4 Zonal permit systems for emission permits

Zonal permit systems group emission sources with similar spatial and temporal impacts into zones and allow for one-to-one bilateral trade in emission permits within the zones (Atkinson and Tietenberg 1982). Some zonal systems allow trade between zones based on pre-defined rules. Ambient permit trading systems may have zones to group those sources with similar effects together (e.g., Lock and Kerr 2008), but for the purpose of this work, we define zonal systems as those which allow trading in emission permits.

The Hunter River Salinity Trading Scheme in Australia is a good example of a real-world zonal trading system that succeeded in improving surface water quality (Environmental Protection Authority 2003). In this trading system, the river is divided into river blocks (zones), based on how many days the block will take to pass Singleton, a downstream location. Each point source located along the river belongs to one block. The Hunter River Scheme operates in real time. The scheme operators (representatives of New South Wales government) continuously monitor the river flow and salinity levels and determine how much more salt can be discharged into each block so standards are not violated. Emission permits are defined, not quantitatively, but as a percentage of the total allowed discharge. Initially, a total of 1000 discharge credits are allocated among the users. Credit holders can discharge salt into their river blocks only in proportion to the credits held; if a user has 30 credits, he or she can discharge only 3% of the total amount of salt allowed for the particular river block.

Under the Hunter River Scheme, both intra- and inter-block trading is possible on a one-to-one basis. Trades within a block require the buyer and seller to act accordingly on the same day, and trades between two blocks require the buyer and seller to act accordingly on different days. For example, if source *A* in the 160-day block sells 20 credits to source *B* in the same 160-day block today, then *A* has to reduce discharge by 2% of the total allowed in his block today and *B* can increase the discharge by 2% of the total allowed in the same block today. If *A* sells 90 credits to source *C* in the 155-day block (downstream) today, *A* has to reduce discharge by 9% of the total allowed in his block today, and *B* can increase the discharge by 9% of the total allowed in his block 5 days later (the 160-day river block today becomes the 155-day river block 5 days later). This trading scheme allows trades across time.

The prices are negotiated. A clever player would buy and sell based on river flow forecasts, because if the flow is high, the river can dilute more salt, and the total allowed discharge would be greater. An initial allocation of credits was made free at the commencement of the Hunter River Scheme in 2002, and 200 credits expire every two years from the commencement. New credits are sold in public auction so that the total number of credits is limited to 1000. All sold permits expire in 10 years. Therefore, there will be an auction for 10-year permits at 2-year intervals from the implementation of the project.

If nutrient targets are to be met on a daily basis (short-run targets), if only point sources are present, and if continuous monitoring and control is possible, a trading structure like the Hunter River Scheme is a good solution. However, this is not likely to be the case with nutrient trading in agricultural watersheds.

2.2.5 Ambient permit trading systems for receptor permits

Ambient permits are similar to any other freely tradable commodity. Once the permits are defined and initially allocated, an ambient permit trading system would operate as a "free" market (McGartland 1988; Montgomery 1972).

An ambient-type nutrient trading system is most suitable for point source nutrient trading because even if multiple receptors are considered, a source usually affects a receptor only in a single period and does not affect the upstream receptors. Therefore, the sources need only one of a few ambient permits to cover their operations in a specific time period.

Even with a single receptor, an ambient permit system is generally difficult to administer for point and nonpoint source nutrient trading, because nonpoint source nutrient loading in a single time period may have nutrient discharges into the receptor in many future time periods, requiring the user to assemble a portfolio of temporal permits to cover the loading in any single time period. Nonpoint sources may sell to multiple point sources simultaneously, but then some regulatory intermediation is required to coordinate and administer multilateral trading.

We will describe one proposed ambient-type nutrient trading system and show how it could be adapted for the Big Bureau Creek watershed as part of this feasibility study. Lock and Kerr (2008) proposed a nonpoint source nutrient trading system for the Lake Rotorua catchment in New Zealand. The purpose of this trading system is to control the nutrient discharge to the lake from catchment land uses. Lock and Kerr identified zones based on the time lag in years between loading in the zone and discharge to the lake. They assigned each nonpoint source (farmland) to one of the zones, assuming that all nutrients from that farmland reach the lake at the same time. They defined permits separately for each year, specifying the nutrient mass that the permit holder is allowed to discharge into the lake for each particular year. Loading from a farm in a T-years lag zone reaches the lake after T years, therefore, the farm owner must buy $T + t$ year permits to match the loading in year t. Lock and Kerr set temporal nutrient discharge targets (discharge goals for each year from current date). The lake nutrient target for each discharge year determines the total available number of permits.

The Lock and Kerr approach is a simplified ambient permit system, which assigns each farm to a single lag year or a block of a few lag years, and requires the farmer to buy a single permit for the particular year or block. This was done in an attempt to lower the transaction costs and to encourage participants to trade. However, nitrogen loaded into an aquifer from different sources usually does not reach a receiving waterbody at once, but reaches it gradually over a period of time. Therefore, no farm can be assigned to one specific lag zone. Secondly, Lock and Kerr (2008) ignored nutrient attenuation. The amount of attenuation varies depending on the location of the farm and the hydro-geological properties of the flow paths. The trading system should take into account the varying levels of attenuation from farms. As a result, some users are allowed to trade who should not be able to trade (Raffensperger and Milke 2008).

The above system could be adapted to include the dispersed nature of nonpoint source loads and any nutrient attenuation, and applied to the Big Bureau Creek watershed with or without zoning the nonpoint sources, but some regulatory intermediation is required to facilitate multilateral trade. If nutrient transport in the watershed is considerably dispersive, then the farms could sell credits to several point sources for different time periods simultaneously.

2.2.6 Centrally controlled multilateral permit trading

Ermoliev et al. (2000) proved that bilateral sequential trades converge to cost efficient emission allocations only in the case of a single constraint. In the case of multiple constraints, sources generally cannot increase their emissions without negotiating with several other sources, and multilateral emission permit trade is required. Ermoliev et al. presented a Multi-Agent Decentralized Market (MADIC), which requires an intermediate agency or a “broker,” who coordinates multilateral trade. This broker acts like a Walrasian auctioneer, a hypothetical market maker who matches buyers and sellers to get a single price, lowering the transaction cost. They showed that the proposed MADIC system leads to cost-efficient allocation of emission permits. They explained the system as follows.

The sources and the agency are connected through a computer network. The agency stores information such as the transport matrix, the environmental standards, and the current quality levels. The agency sets preliminary ambient prices and translates them into emission prices for each source using the transport matrix. Once the sources receive the proposed emission prices, they determine their individual demands or supplies and send the information to the agency. The agency adjusts the prices based on excess demand or supply, retransmits the new prices, and continues this process until equilibrium is achieved. Ermoliev et al. proved that this method leads to efficient allocation of permits, regardless of whether the permits are defined as ambient permits or emission permits.

Compared to conventional bilateral trading systems, the proposed centrally controlled market has lower transaction costs because the traders buy and sell from the auction without having to find a trading partner. Multilateral trading increases the opportunities for trade, because a polluter who impacts many receptors can buy from multiple sellers to offset the effects. For example, if there were a MADIC system for the case given in Table 2-4, polluter *C* can buy simultaneously from polluters *A* and *B*. However, the main problem of such a centrally controlled auction is that equilibrium may not be achieved quickly or converge monotonically. Ermoliev et al. (2000) mentioned that convergence to equilibrium may take a long time. The broker and the traders, even though they are decentralized, will have to play the game for long hours to end in equilibrium.

Morgan et al. (2000) proposed a similar trading system specifically for nitrate loading permits, equivalent to the general emission trading system proposed by Ermoliev et al. Both are centrally controlled multilateral trading systems in which the traders and the auctioneer are connected through electronic media. Morgan et al. discussed an ambient permit system for controlling nitrate concentration in one targeted groundwater well (a single receptor). Their trading system consist of three sub models: (1) a production model that estimates the profits from different production practices (crop rotation and nitrogen fertilizer application rate), (2) a soil model that estimates the water and nitrate leaching from each production practice, and (3) a groundwater model that simulates the nitrate movement from the farms to the well. They assumed that one practice is continued during the planning horizon. Each permit was defined as a right to cause a certain level of concentration at the receptor in the last year of simulation. An auction-type market was designed to operate as described below.

The auctioneer posts a price. Farms submit the optimal production practice and the number of permits to trade (buy or sell) based on the posted price. The auctioneer runs the soil model and groundwater model with submitted production practices and checks whether the water quality standards are met all the time during the planning horizon. If standards are met, the auctioneer checks whether supply and demand match. If both requirements are met, the price is finalized. Otherwise a different price is posted accordingly.

This nitrate trading system best suits when the market catchment has only one receptor. Even for a single receptor, many auction rounds may be needed to clear the market. Requiring permits to match the effects of loading in the last year of the simulation may increase nitrate concentration in the short run.

2.2.7 Smart markets

Negotiating and clearing trade agreements while meeting target nutrient levels is complicated by the dispersed and delayed nature of nutrient transport in watersheds. Bilateral trading systems have high transaction costs and free-rider problems; thin trading is inevitable. Trading ratio systems, unmanaged ambient permit systems, and conventional offset and zonal systems tend to fail. These observations suggest that water quality trading needs a multilateral trading framework, particularly when nonpoint sources are included.

A centrally controlled multilateral trading system as proposed by Ermoliev et al. (2000) is a plausible solution. However, their proposed Walrasian-type auction may not converge to equilibrium quickly or monotonically. A centralized multilateral trading framework needs some method to handle the hydrological complexity in nutrient transport and to set the prices accordingly. The only known trading system that addresses all of these issues is a smart market.

A smart market is a periodic auction that is cleared through the use of an optimization model. The market is “smart” because an optimization is used to choose the allocation under a set of constraints, where the allocation would be difficult to achieve with traditional trading mechanisms. An ordinary auction may use a computer for bidding, accounting, and clearing, but it does not require an optimization, because no special constraints need to be satisfied. Most auctions, such as the used car auctions or EBay, need no computer model to clear, because a single item is being traded one for one. In contrast, commodities such as electricity and water have complex flows, and the trades affect numerous constraints in the networks. Therefore, these commodities cannot be freely traded pair-wise.

A smart market has many advantages over an ordinary pair-wise market, where a buyer and a seller must find each other (McCabe et al. 1991). First, a smart market is centrally managed, so it serves as the marketplace where buyers and sellers can find each other. Second, the manager operating the market has responsibility to ensure good market operations, enforce contracts and guarantee payments, provide anonymity where appropriate, and enforce market rules. Third, a smart market is cleared by a constrained optimization model (e.g., a linear program). For nutrient trading, the linear program would incorporate the transport coefficients and the desired environmental targets directly, whether for a single receptor or many receptors. These constraints ensure market limits (total load in the stream) and protect against externalities. A smart market has all the beneficial features proposed by Ermoliev et al. (2000), combined with a direct method to find equilibrium prices and an ability to handle the complexity in water quality trading. The result is a multi-lateral trading platform that incorporates all available scientific information and users’ rights, which can clear immediately with very low transaction costs.

The smart market, while new to water quality trading, has been implemented for trading electricity, gas, transportation, and a variety of other commodities. The New Zealand Electricity Market (NZEM) is considered as a benchmark for electricity markets (Schweppe et al. 1988; Hogan et al. 1996; Alvey et al. 1998). More recently, Midwest American utilities began a similar market system (Carlson et al. 2012). These power markets run on agreed rules. Buying and selling is done through a common pool. Electricity generators offer electricity to the wholesale market for dispatch via the high voltage national grid. Electricity retailers bid online to buy electricity to supply their customers.

The electricity markets are cleared using a linear program. The linear program determines how much power is bought from each generator, how much power is sold to large commercial users, and at what prices so as to maximize the gains from trade and to satisfy a complex set of relevant constraints on line capacities, generator limits, and other factors. The optimal quantities cleared are determined by the primal variables of the linear program, and the prices are determined by the dual variables of the program. Linear programming duality theory proves that the dual prices are determined on the principles of marginal cost pricing. The online trading system processes the bids and offers and updates quantities and prices every five minutes, with high reliability and robustness requirements. The academic literature on electricity markets is extensive, and the industry is well supported by consultants, government, and continued research.

Besides electricity, smart markets are now in active use all over the world for a wide range of commodities and services. Depending on the initial rights, the markets may be one-way auctions, one-way procurements, or two-way trading. Many governments use smart markets to auction radio spectrum (Rothkopf et al. 1998). Australia uses a two-way smart market for its natural gas network, with complex constraints on gas flow and storage (VENCorp 2007). The University of Chicago has used a smart market for course registration; the complexity is in students' desires for sets of courses and in classroom capacities (Graves et al. 1992). The government of Chile uses a smart market to select contracts for school meals (Epstein et al. 2002); the complexity is in allowing a given contractor to offer bids for sets of schools rather than one school at a time, thus enabling economies of scale. Smart markets are also used for managing freight operations, airline take-off and landing slots, crude oil sales, pipeline capacity, and scheduling military leave.

Murphy et al. (2000) proposed a smart market for surface water. They created a simplified model of the south California water network, and they ran behavioral experiments with students in a lab setting. They found that their system produced fairly efficient outcomes, despite only having a half-dozen participants. They have gone further to address environmental flows, envisioning an agent that purchases water on behalf of the environment (Murphy et al. 2006).

Following the market design for electricity and to a much lesser extent the surface water market, Raffensperger and Milke (2005) and Raffensperger et al. (2008) designed a smart market for groundwater. In many ways, this smart market is similar to the NZEM; the auction is cleared using a linear program that maximizes gains from trade, bids and offers are accepted in step tranches, and prices are based on marginal cost pricing. However, the underlying interactions in water trading and electricity trading are different and the constraint structure is different. A groundwater hydrology model (MODFLOW) was used to obtain a response matrix. The response matrix coefficients measure the drawdown in groundwater head at each head control location due to a unit of groundwater withdrawal from each well. Using these coefficients, the groundwater head and drawdown response at each control location is stated as a linear function of extractions. The linear program determines the optimal abstraction rates for all the wells, which maximizes the gains from trade (consumer and producer surplus), subject to constraints on minimum and maximum acceptable groundwater head and drawdown at each control point. Both McCabe et al. (1991) and Murphy et al. (2000) suggested that smart markets could apply to trading pollution rights.

Prabodanie and Raffensperger (2007) proposed a smart market for trading nitrate between nonpoint sources, and later extended it for trade between point and nonpoint sources (Prabodanie et al. 2009, Prabodanie et al. 2010). They used a groundwater nitrate transport model (MODFLOW and MT3D) to obtain the transport coefficients (Prabodanie and Raffensperger 2007). The owner of each nonpoint source would estimate the nitrate loss from each land use option using a soil nitrogen model, and would bid to buy permits accordingly. A linear program finds the equilibrium price and quantities traded, maximizing the gains from trade subject to target nitrate levels at a set of receptors. The authors recommended that point and nonpoint source nitrate trading is most suitable when nitrate transport in the catchment is sufficiently fast and the point sources are willing to buy future permits, far into the future (Prabodanie et al. 2009). This work is only for trading nitrate (or nitrogen).

The same structure can be used for phosphorus trading, but transport coefficients must be defined and estimated in different ways. The important underlying assumption in the nitrogen markets is that the relationship between nitrogen loss from farms and effects at the receptors is linear, but this assumption is less likely to hold for phosphorus, because the transport medium of phosphorus is surface runoff and soil erosion. However, simplified delivery factors rather than transport coefficients may be sufficient for phosphorus trading. We developed a smart market trading platform, called MarshWren, for the Big Bureau Creek watershed, with the intention that it could actually be used to manage nutrient runoff with a market approach. We simulated different trading scenarios between point and nonpoint sources in the Big Bureau Creek watershed with MarshWren, under the hypothesis that wetlands can be a cost-effective way to reduce nitrogen and phosphorus loads in the watershed. A detailed description of the platform and simulation results is presented in Section 5.

2.3 Water Quality Trading in NPDES Permits

While water quality trading is not formally included in the Clean Water Act (CWA, 33 U.S.C. § 1251et seq.), the CWA does provide the legal basis and authority for water quality trading. The CWA provides for the U.S. EPA, states, and tribes to develop programs to control pollution. To achieve water quality standards through trading, permitting authorities have referred to the National Pollutant Discharge Elimination System (Section 402 CWA 33 U.S.C.§ 1342), State Certification of Water Quality (Section 401 CWA 33 U.S.C. §1341), and Water Quality Standards and Implementation Plans (Section 303(c) 33 U.S.C. §1313). Those regulations establish that a level of water quality must be attained and protected. The U.S. EPA Water Quality Trading Policy (2003) addresses how to align water quality trading programs with the CWA. Several state administration codes have specifically authorized water quality trading to achieve permit compliance (e.g., NR 217 Wis. Adm. Code; Minn. Stat. Chs.115 and 116, and Minn. R. Chs. 7001 and 7050; and Michigan CL 324.3103 and 324.3106 Part 30. Water Quality Trading).

2.3.1 Trading provisions in permits

The National Pollutant Discharge Elimination System (NPDES) system provides a well-tested legal framework for assigning and enforcing pollution control requirements on point sources. By modifying permit provisions with trading specifications, WQT programs may be integrated into the current permitting system. However, some conditions and constraints restrict how water quality trading can be incorporated into a permit and meet CWA requirements.

First, the NPDES permit held by point sources does not allow those sources to transfer liability for meeting their permit obligations to a non-permit holder. Since the buyers cannot transfer this liability, permit compliance is riskier due to the reliance on other parties to provide the necessary pollutant reductions, the stochastic nature of NPS nutrient reductions, and potential for practice performance failure. The inability to transfer liability is why most water quality trading programs are actually offset programs versus true trading programs.

Secondly, the U.S. EPA WQT Policy does not support trading to meet technology based effluent levels (TBELs), which are established based on what a particular treatment technology can reasonably achieve. A NPDES permittee can purchase credits to meet its WBEL, which is set based on water quality standards or a baseline that is derived from its TMDL waste load allocation. For trading under pre-TMDL impaired waters, the baseline would be determined by applicable WBELs, a target cap, or quantified performance requirement to attain water quality standards.

Finally, trading must comply with anti-backsliding and antidegradation provisions. Anti-backsliding refers to CWA Section 402(o) and 40 CFR § 122.44(l) that generally prohibits the renewal, reissuance, or modification of an existing NPDES permit that contains WBELs, effluent standards, or permit conditions that are less stringent than those established in the previous permit (US EPA 2010b).[1] To satisfy anti-backsliding provisions, the permit must describe how the reissued permit's discharge limits are at least as stringent as the previous permit's limits, after accounting for trading offsets. The U.S. EPA Water Quality Trading Policy does not consider using water quality trading to meet WBEL as a less stringent effluent limitation, provided the permittee is still responsible for the same level of pollutant reduction as in previous permits. Since trading provides a discharger an additional means of achieving its new limit, it is not subject to anti-backsliding prohibitions.

Antidegradation policies maintain and protect the level of water quality necessary to support beneficial uses. NPDES permits may not facilitate trades that result in the non-attainment of an applicable water quality standard (based on designated use). While the U.S. EPA Water Quality Trading Policy does not change how a state applies its anti-degradation policy, a state may decide to modify its policy to recognize trading. Section 302.105 in 35 Illinois Administrative Code contains the comprehensive set of regulations that establish the state's antidegradation policy "to protect existing uses of all waters of the State of Illinois, maintain the quality of waters with quality that is better than water quality standards, and prevent unnecessary deterioration of waters of the State." Outstanding Resource Waters (exceptional ecological or recreational significance) must not be lowered in quality with few exceptions. The Illinois EPA may provide exceptions for High Quality Waters (waters cleaner than required by water quality standards) if lowering the water quality is necessary to accommodate important economic or social development. Illinois EPA

[1] The anti-backsliding statutory provision provides exceptions in the cases of alterations to the facility, events beyond the permittee's control, and permit modifications. Section 303(d)(4) allows a less-stringent WBEL in a reissued permit when the facility is discharging to a waterbody attaining water quality standards as long as (1) the waterbody continues to attain the standards after the WBEL is relaxed, and (2) the revised limit is consistent with the state's antidegradation policy.

performs an antidegradation assessment to assure that all water quality standards will be met and all existing uses will be fully protected, that all reasonable measures to avoid or minimize the increased pollution will be taken, and that the activity causing the increased pollution will benefit the community at large.[2] For water quality trading, antidegradation provisions will be met if no net increases in the pollutant are be discharged into the waterbody and if trades do not result in any localized impairments or "hot spots."

The U.S. EPA's Water Quality Trading Toolkit for Permit Writers (2007b) provides NPDES permitting authorities with sample permit language and the information that they should incorporate about trading provisions into permits. In addition, some states with trading policies or programs have issued permits that could serve as templates for Illinois. How water quality trading language is incorporated in permits varies, as some permits provide limited details within the actual permit and reference a separate trading plan, and other states' permits provide all the details in the permit (see EPRI 2013). Prior to using credits to meet effluent limits, the permittee must submit a trade agreement to permitting authorities for approval. The general trading conditions that should be included in a trading agreement and/or permit are:

- the identification of the credit producers;
- the practice(s) that will be used to produce the credits, practice size, and site location;
- the date(s) when the practice will be installed and the date when the credit production will begin;
- the procedures to operate and maintain the practice;
- the contractual agreements between individual seller or third-party aggregator;
- the type, form, and amount of credits being generated for the specified time period, baseline conditions, credit calculation methodology, and trading ratios;
- the PS discharge (mass per defined time period), credits purchased, and the permitted effluent limit;
- the practice monitoring plan (e.g., who is responsible, measurement methodology, frequency, etc.);
- the inspection and verification procedures (e.g., who is the performing the inspection, frequency, etc.);
- the information related to accountability, certification, and data management (e.g., recordkeeping, reporting requirements, monitoring reports, registry information);
- conditions pertaining to the duration of credits and use in future permit cycles; and
- compliance assurances.

Regulators have incorporated compliance assurance into existing program structures and permits to address when practices fail, trades fail, or limits are exceeded. Mechanisms to ensure trade obligations (therefore, permit obligations) are met include developing reserve or insurance pools, extending the compliance period, and allowing correction or reconciliation periods. Current WQT programs provide examples of the different permit compliance mechanisms. The Miami Conservancy District (Great Miami River Watershed Water Quality Credit Trading Program) and the Pennsylvania Department of Environmental Protection provide for market stability by creating an insurance pool of reserved credits for BMP failure from natural or unexpected causes. The Wisconsin Department of Natural Resources and the Chesapeake Bay programs have extended the NPS averaging period to annual average credit results. The Pennsylvania Department of Environmental Protection has enforcement discretion when a permittee's credits are determined to be invalid, as long as the credit failure is not due to negligence or willfulness on the part of the permittee, and the permittee replaces the credits for future compliance.

2.3.2 Illinois permit provisions/variances

While Illinois has no WQT policy or guidelines established, Illinois does have precedent for market-based systems or trading to achieve or offset permit effluent limits. Under Illinois Complied Statutes 415 ILCS 5 Environmental Protection Act Section 13.4 (415 ILCS 5/13.4), the Illinois EPA was mandated by the Illinois General Assembly in 1998 to design a pretreatment market system that would give POTWs and their industrial discharge permittees the greatest flexibility in achieving cost-effective pollution reductions. The IEPA-designed pretreatment market would encourage innovative and cost-effective compliance options while resulting in, at a minimum, the total pollutant reduction as achieved by the current application of federal categorical standards, state pretreatment limits, and locally derived limits (State of Illinois 1998). The IEPA evaluation of pretreatment programs found that the federal categorical limits were more stringent than local limits. Therefore, the dischargers would have no incentive to trade, since U.S. EPA policy prohibits trading to meet the federal categorical limits, or the national, uniform technology-based standards for the industrial sector (US EPA 2003). The IEPA did not continue the development of a pretreatment program or trading initiative due to lack of interest from the stakeholders (i.e., POTWs, industrial dischargers, and IEPA) (Breetz et al. 2004).

[2] Prairie Rivers Network's "Practicing Antidegradation in Illinois – Protecting Existing Uses & Maintaining Quality of Waters" Guide Book.

On one occasion, Illinois allowed a variance in an NPDES permit for an offset trade. The Piasa Creek watershed Project is the only trade (point source to nonpoint source) in Illinois for total suspended solids discharged to the Mississippi River. The Illinois-American Water Company (IL-AWC) constructed a new water treatment plant in Alton, IL, which was subject to regulations that required the facility to treat their filter sediments on-site instead of directly discharging into the Mississippi River. To meet the technology-based effluent standards for total suspended solids, the plant would need to implement a sediment lagoon, dewatering equipment, and off-site landfilling to remove 3,300 tons/year (Cheng et al. 2001). The IL-AWC did not consider the $7.4 million capital investment economically reasonable, and there was public opposition to the plan (Gregory 2003).

As an alternative to the lagoon and landfill requirements, the Great Rivers Land Trust proposed a watershed project to reduce the flow of sediments into the Mississippi River upstream of the water treatment facility's discharge point. The IL-AWC petitioned for a variance that would allow them to provide $4.15 million for the implementation of conservation practices within the Piasa Creek watershed; the practices would reduce sedimentation by 6,600 tons/year at the end of the 10-year agreement. The IEPA determined this conservative 2:1 trading ratio based on federal guidance for TMDLs. The Great Rivers Land Trust served as the third-party broker and was responsible for generating the sediment reduction credits to fulfill the contractual agreement between the land trust and IL-AWC (Breetz et al. 2004).

The sediment offset agreement required an Adjusted Standard, AS 99-6, from the 35 Illinois Administrative Code sections 304.124, 304.106, and 302.203 (Breetz et al. 2004).[3] The IPCB found the adjusted standard request to be consistent with federal law in that the designated use status of the Mississippi River would not change as a result of the direct discharge from the new IL-AWC water treatment facility. The contractual agreement was approved by the Illinois Pollution Control Board (IPCB), and the IEPA granted a variance in 2001. The terms of the adjusted AS 99-6 and agreement terms between the land trust and I-AWC were written into special conditions of the facility's NPDES permit.

[3] Section 304.106 states no effluent shall contain "offensive discharges," such that no effluent contains "settleable solids, floating debris, visible oil, grease, scum, or sludge solids" and color, odor, and turbidity must be reduced below "obvious levels" (IPCB 2013). Section 304.124 delineates effluent standard concentrations for contaminants (IPCB 2013). Section 302.203 is the water quality standard that bans "offensive conditions" (IPCB 2013).

3 BBC POLLUTANT SUITABILITY

3.1 Water Quality Trading Drivers

As described in Section 2, water quality trading requires a "driver" or regulatory obligation that requires permitted facilities to reduce their pollutant discharges. The typical driver for a watershed is a Total Maximum Daily Load (TMDL), but not all trading programs operate under a TMDL. State nutrient criteria, wastewater treatment plant expansion, or other stringent water quality-based permit stipulations may trigger a demand for pollution reduction from another source at a lower cost.

3.1.1 Water quality standards in Illinois

Narrative water quality standards exist in Illinois Pollution Control Board (IPCB) regulations for General Use Waters and for Lake Michigan Basin Waters.[4] Narrative water quality standards allow the Illinois Environmental Protection Agency (IEPA) to derive numeric water quality criteria values for any substance that does not already have a numeric standard in the IPCB regulations (IEPA 2012). A few Illinois water-quality standards are exclusively narrative, i.e., having no explicit numeric component in the standard to apply them, including standards for total nitrogen, nitrate-nitrogen, and total phosphorus. The exclusively narrative standards apply only to the protection of aesthetic quality in Illinois waters.

Numeric nutrient criteria are a critical tool for protecting and restoring the designated uses of a waterbody with regard to nitrogen and phosphorus pollution. These criteria enable effective monitoring of a waterbody for attaining its designated uses; simplify the development of TMDLs for restoring impaired waters; and facilitate the formulation of NPDES discharge permit limits. Currently, only new, expanding, or upgraded "major" wastewater treatment facilities ($\geq$ 1MGD) have a 1.0 mg/L total phosphorus (TP) effluent standard. Numeric nutrient criteria approved by the U.S. EPA have been established in Illinois for lakes, reservoirs, and the open waters of Lake Michigan (Table 3-1) (US EPA 2012).

Table 3-1. The U.S. EPA approved numeric nutrient criteria for Illinois (US EPA 2012).

WATER TYPE	SUBTYPE	PARAMETER	VALUE
Lakes/Reservoirs	Any reservoir or lake with a surface area of 8.1 hectares (20 acres) or more, or in any stream at the point where it enters any such reservoir or lake	Total Phosphorus (TP)	0.05 mg/L
Lakes/Reservoirs	Open waters of Lake Michigan	Total Phosphorus	7.0 µg/L
Lakes/Reservoirs	Open waters of Lake Michigan	Nitrate-nitrogen (NO_3-N)	10.0 mg/L

In 2000, the U.S. EPA issued criteria for the concentration of total nitrogen (TN) and total phosphorus (TP) in streams and rivers of the United States (US EPA 2000). Using a statistical process based on the 25th percentile values from water quality databases, the U.S. EPA calculated a set of criteria for each ecoregion across the country. For the Midwestern states located in the Corn Belt and Northern Great Plains Ecoregion VI (i.e., Minnesota, Wisconsin, Iowa, Missouri, and Illinois), the recommended criteria are 2.18 mg/L for TN and 0.076 mg/L for TP. State agencies, authorized tribes, and territories are mandated by the U.S. EPA to write and enact water quality standards or to adopt the recommended water quality criteria for their relevant ecoregion.

Illinois decided that the statistical approach was inappropriate and has been working since 2000 on developing numeric water quality standards for nitrogen and phosphorus based on cause/effect relationships. Research studies have not been able to define the cause/effect relationships between nutrients and the impairment in Illinois streams. The Illinois EPA and Illinois Department of Agriculture initiated the process to develop an Illinois Nutrient Reduction Strategy in March 2013. This statewide strategy will be Illinois' plan to meet the goals established in the *Gulf Hypoxia Task Force Action Plan* (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force 2008). The strategy is a two-tiered process (scientific assessment and then policy development) that will likely result in statewide phosphorus and nitrogen standards for streams and rivers.

[4] General Use Waters cover all other waters of the state except those waters designated as Secondary Contact and Indigenous Aquatic Life Use Waters.

3.1.2 Total Maximum Daily Load (TMDL)

Section 303(d) of the Clean Water Act and the U.S. EPA regulations require that TMDLs be developed for waters that do not support their designated uses. A TMDL is a plan to attain and maintain water quality standards in waters that currently are not meeting the standards. A TMDL identifies the combined amount of pollution that a waterbody can assimilate (the loading capacity) without exceeding water quality standards. The loading capacity of a watershed is distributed through load allocations to nonpoint and background sources, Waste Load Allocations (WLAs) to point sources, and a margin of safety. TMDLs are required for waters impaired by both point and nonpoint sources as well as for water bodies impaired entirely by nonpoint sources.

A TMDL, however, does not necessarily ensure that the pollution reduction targets will be achieved. For point sources, states translate TMDLs into stricter permit effluent limits based on the WLA, but the CWA does not include similar mandatory controls for nonpoint sources. Instead, each state decides how best to control pollution from nonpoint sources. Illinois, similar to most states, continues to do so entirely through voluntary programs such as education and financial assistance/easement conservation programs.

IEPA applies TMDLs toward those impairments with numeric water quality standards that have been adopted by the Illinois Pollution Control Board. Load Reduction Strategies (LRS), included in TMDLs, focus on nonpoint source controls and address pollutants that do not have numeric water quality standards in place. The IEPA has drafted a TMDL and Load Reduction Strategy (LRS) for the Middle Illinois River watershed to address water quality impairments by fecal coliform, total suspended solids (TSS), and nutrients (Tetra Tech 2011). As part of the TMDL, the IEPA has proposed LRSs for TSS, TP, and nitrate plus nitrite-nitrogen (NO_3+NO_2-N) for West Bureau Creek and Big Bureau Creek, specifically the reach from Princeton to confluence with Goose Lake. Since Illinois has no numeric criteria for nutrients, the IEPA based the LRS targets on the reference conditions for Ecoregion 54. Therefore, the LRS targets are 1.798 mg/L NO_3-N and 0.072 mg/L TP across all flow conditions (US EPA 2000).

For the TMDL, Tetra Tech developed load duration curves using the available water quality and flow data to determine the existing and allowable loads for various flow intervals. While the load duration curve methodology does not attribute any impairment to any particular source, it can illustrate the flow conditions under which impairment occurs and the probable types of sources contributing to that impairment.

The mean annual NO_3-N concentrations have exceeded the water quality target of 1.798 mg/L NO_3-N in Big Bureau Creek in every year, and in West Bureau Creek in all but one year (Tetra Tech 2011). The highest NO_3-N concentrations are typically observed in April through June. Elevated median concentrations in the spring and early summer correspond to precipitation events paired with land management activities, such as agricultural fertilizer application. The median nitrogen concentration in BBC is 9.4 mg/L with concentrations increasing upstream, indicating that the primary sources are located in the headwaters and are related to land practices (IDNR and V3 2006). In addition, the elevated concentrations during high flow to mid-range flow events indicate that nonpoint sources are a significant source of NO_3-N.

The mean annual TP concentrations in Big Bureau Creek have exceeded the target concentration of 0.072 mg/L TP in all but two years over the sampling period (Tetra Tech 2011). While elevated all year, the highest TP levels are seen June through December in Big Bureau Creek. TP concentrations increase during lower flow periods, indicating that point sources are the most significant source of phosphorus in Big Bureau Creek. In comparison, the mean annual concentrations are lower in West Bureau Creek, and the higher concentrations have been measured in the spring, indicating that nonpoint source runoff from snowmelt and precipitation events are the more significant source of TP in this tributary. While phosphorus occurs naturally, it may be supplemented by fertilizers.

The LRS target load is the maximum load to a waterbody to maintain compliance based on the target concentrations, and varies with the stream discharge level. The IEPA recommended the highest nitrogen (Table 3-2) and phosphorus (Table 3-3) load reductions for higher flow conditions in West Bureau Creek. The total annual load reduction derived from the flow range, average pollutant concentration in the flow range, and the average number of days in the flow range was not determined. To achieve the LRS reduction, the IEPA recommended that urban and agricultural nonpoint sources should be the focus of best management practices (BMPs), and that untreated sewage sources should be eliminated (Tetra Tech 2011).

Table 3-2. Nitrate-nitrite Loading Reduction Strategy for West Bureau Creek at Wyanet (DQD-01) for various flow regimes based on a target of 1.798 mg/L NO_3+NO_2-N (Tetra Tech 2011).

STATION	LRS COMPONENT (NO_3+NO_2-N)	HIGH FLOWS 0-10%	MOIST CONDITIONS 10-40%	MID-RANGE 40-60%	DRY CONDITIONS 80-90%	LOW FLOWS 90-100%
Wyanet (DQD-01)	Current Load (lb/day)	15,919	4,917	1,066	52	1
	LRS Target (lb/day)	2,278	665	257	47	9
	LRS Reduction (lb/day) / %	13,641 / 86%	4,252 / 86%	809 / 76%	5 / 9%	

Table 3-3. Total phosphorus Loading Reduction Strategy for West Bureau Creek at Wyanet (DQD-01) for various flow regimes based on a target of 0.072 mg/L TP (Tetra Tech 2011).

STATION	LRS COMPONENT (TP)	HIGH FLOWS 0-10%	MOIST CONDITIONS 10-40%	MID-RANGE 40-60%	DRY CONDITIONS 80-90%	LOW FLOWS 90-100%
Wyanet (DQD-01)	Current Load (lb/day)	166	29	7	2	1
	LRS Target (lb/day)	91	27	10	2	0.4
	LRS Reduction (lb/day) / %	75 / 45%	2 / 8%			0.6 / 32%

Nutrient load reductions are needed across all flow conditions (high flow to low flows) in Big Bureau Creek, but the highest nitrogen load reductions of 57,900 lb/day (26,300 kg/day) and 20,000 lb/day (9,070 kg/day) are needed under higher and moist flow conditions, respectively (Table 3-4). The highest percent reductions for TP are needed under lower flow conditions (Table 3-5). To achieve these proposed loading reductions, the draft TMDL suggests a combination of agricultural and urban best management practices is needed to address the nonpoint source pollution (Tetra Tech 2011). Wastewater treatment plants (WWTPs) were determined to be significant contributors of phosphorus to the creek and the draft TMDL recommended that effluent limits be considered, but effluent monitoring is needed to determine the extent of point source contribution.

Table 3-4. Nitrate-nitrite Loading Reduction Strategy (LRS) for Big Bureau Creek at Princeton (DQ-03) and outlet to Goose Lake (DQ-04) for various flow regimes based on a target of 1.798 mg/L NO_3+NO_2-N (Tetra Tech 2011).

STATION	LRS COMPONENT (NO_3+NO_2-N)	HIGH FLOWS 0-10%	MOIST CONDITIONS 10-40%	MID-RANGE 40-60%	DRY CONDITIONS 80-90%	LOW FLOWS 90-100%
Princeton (DQ-03)	Current Load (lb/day)	34,855	8,670	2,679	139	34
	LRS Target (lb/day)	5,150	1,503	582	107	20
	LRS Reduction (lb/day) / %	29,735 / 85%	7,140 / 83%	2,097 / 78%	32 / 23%	14 / 41%
Outlet (DQ-04)	Current Load (lb/day)	71,126	23,824	3,280	127	N/A
	LRS Target (lb/day)	13,223	3,861	1,525	295	57
	LRS Reduction (lb/day) / %	57,903 / 81%	19,963 / 84%	1,755 / 54%		

Table 3-5. Total phosphorus Loading Reduction Strategy for Big Bureau Creek at Princeton (DQ-03) and outlet to Goose Lake (DQ-04) for various flow regimes based on a target of 0.072 mg/L TP (Tetra Tech 2011).

STATION	LRS COMPONENT (TP)	HIGH FLOWS 0-10%	MOIST CONDITIONS 10-40%	MID-RANGE 40-60%	DRY CONDITIONS 80-90%	LOW FLOWS 90-100%
Princeton (DQ-03)	Current Load (lb/day)	473	74	49	33	28
	LRS Target (lb/day)	206	60	23	4	1
	LRS Reduction (lb/day) / %	267 / 56%	6 / 18%	26 / 53%	29 / 87%	27 / 97%
Outlet (DQ-04)	Current Load (lb/day)	1,188	309	48	15	N/A
	LRS Target (lb/day)	529	155	61	12	2
	LRS Reduction (lb/day) / %	659 / 55%	154 / 50%		3 / 22%	

The draft TMDL regulation identifies the load reductions needed to meet the nutrient targets under various flow regimes; however, it does not serve as the regulatory driver needed for a water quality trading program. Without individual WLAs, specific effluent limits and the corresponding nutrient load reductions needed cannot be determined. Since the point source users have no regulatory or financial incentives, those users have little motivation to consider or invest into any pollution reduction technologies or alternative strategies such as water quality trading. On the other hand, we now have a window of opportunity to investigate and demonstrate that a wetland-based water quality trading program is both an economically efficient and environmentally effective means of meeting pollution reduction demands. Through this demonstration, the goal is for water quality trading to be a viable strategy accepted by all stakeholders by the time numeric criteria are enacted.

3.2 Nutrient Credit Demand: Emissions

The likely major sources of nutrient credit demand in the Big Bureau Creek watershed are wastewater treatment plants (WWTPs), since TMDLs do not have binding, mandatory pollution-reduction requirements for agriculture. Fifteen permitted facilities in the National Pollutant Discharge Elimination System (NPDES) discharge to streams within the Big Bureau Creek watershed (Table 3-6). This includes 13 publicly owned treatment works (POTWs) and 2 non-POTWs. The 13 POTWs are comprised of five water treatment plants (WTP) and eight municipal wastewater treatment facilities. Princeton Sanitary Treatment Plant (STP) is the largest wastewater treatment facility within the watershed at 2.15 MGD (million gallons per day), and the only STP classified as “major.” The remaining seven municipal wastewater facilities are either one- or two-stage lagoon systems, with four operating under individual NPDES permits and three operating under general NPDES permits. For this study, we assumed that none of the permitted treatment facilities, particularly the municipal sanitary plants, would be exempt from future nutrient standards.

Table 3-6. All NPDES permitted facilities within the Big Bureau Creek watershed with municipal wastewater treatment facilities area highlighted (US EPA 2010a).

PERMIT ID	NPDES FACILITY NAME	AVG. DESIGN FLOW (MGD)	RECEIVING STREAM	12-DIGIT HUC
IL0074721	Arlington WTP, Village of	0.002	Unnamed tributary to Brush Creek	071300010601
IL0033120	Bureau Junction STP, Village of	0.071	Unnamed tributary to Illinois River	071300010703
IL0042625	Lake Arispie Water Co STP	0.050	Little Bureau Creek	071300010703
IL0024791	Malden STP, Village of	0.050	Unnamed tributary to East Bureau Creek	071300010602
IL0067024	Prairie View Nursing Home STP	0.020	Unnamed tributary to West Bureau Creek	071300010701
IL0020575	Princeton STP, City of	2.150	Epperson Run to Big Bureau Creek	071300010505
IL0025160	Tiskilwa STP, Village of	0.120	Plow Hollow Creek to Big Bureau Creek	071300010702
ILG640034	Arlington WTP, Village of	0.002	Unnamed tributary to Brush Creek	071300010601
ILG640081	Dover WTP, Village of	0.004	East Bureau Creek	071300010602
ILG551091	IL DOT I-80 Bureau County STP	0.020	West Bureau Creek	071300010402
ILG580127	LaMoille STP, Village of	0.063	Pike Creek	071300010501
ILG551015	Maple Acres MHP	0.026	Epperson Run to Big Bureau Creek	071300010505
ILG580190	Ohio STP, Village of	0.077	Lime Creek to West Bureau Creek	071300010401
ILG640238	Princeton WTP, City of	0.065	Epperson Run to Big Bureau Creek	071300010505
ILG580245	Wyanet STP, Village of	0.250	Pond Creek to West Bureau Creek	071300010701

Because the wastewater treatment facilities in Bureau County are not regulated with respect to total nitrogen and total phosphorus emissions, they do not monitor their influent and effluent levels regularly. The Princeton STP, however, provided influent and effluent concentrations for both nitrogen and phosphorus for this study (Table 3-7). All six samples were taken in February and March 2011. While not representative of the entire year, the average of those emissions was used as an approximation of average annual concentrations at the Princeton plant. Emission data for the other 14 facilities in the watershed were not available. Because the water entering all of these WWTPs comes primarily from residential sources, we assumed that influent concentrations are similar for all plants in the area. The minor facilities are predominantly aerated lagoons that are less efficient in reducing total nitrogen and total phosphorus than an advanced facility such as the Princeton STP. According to the U.S. EPA (2002), aerated lagoons can remove 15-25% of phosphorus. For this study, the minor facilities emitted 75% of their phosphorus influent. We assumed that aerated lagoons remove approximately the same percent of total nitrogen (30%) as the Princeton STP (Table 3-8).

Table 3-7. Princeton STP mean influent and effluent concentrations based on 6 samples taken in February and March 2011.

PARAMETER	MEAN INFLUENT CONCENTRATION (mg/L)	MEAN EFFLUENT CONCENTRATION (mg/L)
Total phosphorus	2.97	1.01
Nitrate and nitrite	4.49	8.58
Total Kjeldahl nitrogen	11.07	2.32
Total nitrogen	15.62	10.78

Table 3-8. Influent and effluent concentrations assumed for the minor wastewater treatment facilities.

PARAMETER	INFLUENT CONCENTRATION (mg/L)	REMOVAL (%)	EFFLUENT CONCENTRATION (mg/L)
Total phosphorus	2.97	25	2.23
Nitrate and nitrite	4.5	N/A	N/A
Total Kjeldahl nitrogen	11.1	N/A	N/A
Total nitrogen	15.62	30	10.93

As previously described, the State of Illinois has not adopted numeric water quality standards for TN and TP; therefore, the State has not set emission limits for permitted facilities, and we had to assume reasonable emission requirements for the facilities. We defined two hypothetical effluent emission scenarios for the feasibility analysis: a minimum expected regulation and a diversified standard where major facilities would be more stringently regulated (Table 3-9). We also simulated a third scenario with emission standards based on best available technology (5.0 mg/L TN and 0.30 mg/L TP), but the results were not meaningfully different from the results for the diversified standards, particularly when the size and the number of major facilities were increased to expand the market.

Table 3-9. Hypothetical emission standard scenarios based on a minimum regulation and diversified standard (Chesapeake Bay Program 2002).

STANDARD	TOTAL NITROGEN (mg/L)	TOTAL PHOSPHORUS (mg/L)
Minimum regulation	All Facilities: 8.0	All Facilities: 1.0
Diversified standards	Major Facilities: 5.0 Minor Facilities: 8.0	Major Facilities: 0.5 Minor Facilities: 1.0

At the time of this report, none of the NPDES permitted facilities has implemented advanced nutrient removal processes. Consequently, our study assumes that the facilities will be required to abate emissions from their current discharge levels to those levels mandated by the new hypothetical regulation. The required abatement or credit demand is the amount of TN and TP that needs to be removed for a facility to meet the more stringent effluent limit.[5] We calculated the annual and seasonal nutrient demand for each permitted treatment facility.

Table 3-10 shows the credit demand based on the diversified effluent standard of 5.0 mg/L TN and 0.5 mg/L TP for the Princeton STP and 8.0 mg/L TN and 1.0 mg/L TP for all the minor facilities, as assumed in our study. The total estimated nitrogen credit demand was 20,500 kg/yr (45,200 lb/yr), with the Princeton STP accounting for over 80% of the demand. The phosphorus credit demand was 6,420 kg/yr (2,910 lb/yr) with Princeton STP generating 50% of the credit demand. The wastewater treatment facilities account for 93% of the nitrogen demand and 80% of the phosphorus demand.

[5] The load reduction was calculated by subtracting the mass load associated with the hypothetical standard from the existing effluent mass load. The mass load was determined by multiplying the assumed concentration by the daily flow and appropriate unit conversion factor.

Table 3-10. Estimated annual nutrient credit demand to achieve the diversified standard at each permitted treatment facility.

NPDES FACILITY NAME	AVG. DESIGN FLOW	TOTAL NITROGEN		TOTAL PHOSPHORUS	
	(MGD)	(lbs/yr)	(kg/yr)	(lbs/yr)	(kg/yr)
Arlington WTP, Village of	0.002	17.9	8.1	7.5	3.4
Wyanet STP, Village of	0.250	2,233	1,013	937.3	425.1
Arlington WTP, Village of	0.002	17.9	8.1	7.5	3.4
Prairie View Nursing Home STP	0.020	178.6	81	75	34
Dover WTP, Village of	0.004	35.7	16.2	15	6.8
LaMoille STP, Village of	0.063	562.6	255.2	236.2	107.1
Lake Arispie Water Co STP	0.050	446.5	202.5	187.5	85
Malden STP, Village of	0.050	446.5	202.5	187.5	85
IL DOT I-80 Bureau County STP	0.020	178.6	81	75	34
Ohio STP, Village of	0.077	687.7	311.9	288.7	130.9
Bureau Junction STP, Village of	0.071	634.1	287.6	266.2	120.7
Maple Acres MHP	0.026	232.2	105.3	97.5	44.2
Tiskilwa STP, Village of	0.120	1,072	486.1	449.9	204.1
Princeton WTP, City of	0.065	580.5	263.3	243.7	110.5
Princeton STP, City of	2.15	37,878	17,180	3,342	1,516
TOTAL		**45,202**	**20,502**	**6,416**	**2,910**

3.3 Nutrient Credit Supply: Wetlands

3.3.1 Wetland nutrient removal

Considerable research has shown that wetlands can be effective in removing a wide variety of water quality pollutants, including nitrogen and phosphorus (Reddy et al. 1999, 2005; Kadlec and Knight 1996; Crumpton et al. 2006; Kadlec and Wallace 2008;). Shallow wetlands or emergent marshes have been shown to be effective at reducing nutrient loads associated with point source discharge (Kadlec and Wallace 2008) and agricultural runoff (Crumpton 2005; Crumpton et al. 1995, 2008; Kovacic et al. 2000; Mitsch et al. 2005). For example, the Iowa Conservation Reserve Enhancement Program (CREP) has demonstrated that wetlands strategically positioned to intercept subsurface tile-drainage from cropland and designed to transform and sequester excessive nutrients are a promising technology in reducing nitrate loads transported to surface waters. Research at Iowa State University has demonstrated that the wetlands can remove 40–90% of nitrate-nitrogen from cropland drainage waters (Iovanna et al. 2008).

The ability of wetlands to remove or sequester nutrients, whether dissolved or associated with particulate matter, is due to a combination of biological, chemical, and physical processes (e.g., transformation, plant uptake, sequestration, settling, burial, etc.). These inherent processes are determined by the hydrologic conditions and catalyzed by the wetland soils and plant communities. If constructed wetlands are properly sited to intercept high nutrient loadings from agriculture subsurface flow and are designed with these processes taken into consideration, then they should provide an economically sustainable means for reducing nutrient loads and generating a nutrient credit supply for permitted dischargers who must comply with emission limits.

While wetlands can remove nitrogen by sedimentation and assimilation (plant and bacterial uptake), wetlands primarily reduce nitrogen through the microbial-mediated process of denitrification, which transforms nitrate (NO_3-N) to nitrogen gas (Kadlec and Wallace 2008). Studies have found that 90% of total nitrogen removal in wetlands occurs through denitrification (Crumpton et al. 1994; Xue et al. 1999). Denitrification efficiency depends primarily on temperature (i.e., plant growth cycles and peak microbial activity) and retention time.

Crumpton et al. (2006) found that nitrate removal can be explained by the hydraulic loading rate (HLR= Q/A, where Q is the water flow rate and A is the wetland area) and by the nitrogen concentration of influent waters. They found a nonlinear decreasing relationship between HLR and percent of nitrogen mass removed, as the retention time is negatively correlated with high HLR. Hence, as retention time increases, so does the percentage of nitrate removed

(Kadlec and Wallace 2008). Mitsch and Gosselink (2007) reported an optimal retention time of between 5 and 14 days for municipal treatment wetlands.

While researchers have developed process-based models for nitrogen removal from wetlands, phosphorus removal is less well understood from a theoretical basis. Unlike for nitrogen, phosphorus has no dissipation pathway. However, significant amounts of phosphorous are deposited, adsorbed, or used in natural and constructed wetlands (Richardson 1985; Johnston 1991; Walbridge and Struthers 1993). Orthophosphate (PO_4-P), the predominant inorganic form, accumulates readily in both sediments and vegetation by adsorption, precipitation reactions, or biological uptake (assimilation). Plant and microbial uptake processes contribute to the short-term uptake, but sediment accretion of bound inorganic and unmineralized organic phosphorus is the primary mechanism by which wetlands serves as long-term sinks (Richardson 1985; Walbridge and Struthers 1993). The accretion of new soil and organic material is necessary for the continual removal of phosphorus and serves as the only sustainable storage mechanism for phosphorus. However, we found no reliable scientific model to estimate wetland phosphorus retention ability based on watershed geomorphic, hydrologic, and climatic characteristics. Empirical studies have shown that annual phosphorus removal in wetlands receiving nonpoint source pollution in seasonal climates is highly variable ranging from 0.1 to 6 g P/m^2 (Mitsch and Gosselink 2007).

Vegetated shallow wetlands or marshes either with emergent or submerged plant communities are preferred for nutrient removal, particularly for nitrate-nitrogen.[6] While plant communities can incorporate a significant fraction of available nutrients through assimilation, assimilation is seasonal, as the nutrients can be released to the system during plant senescence. More importantly, emergent and submerged wetland vegetation enables the sedimentation of particulate nitrogen and phosphorus by slowing down the passage of water and providing friction, which increases retention time and produces the carbon necessary for denitrification (Johnston 1991; Kadlec and Knight 1996).

Shallow water wetlands provide maximum soil-water contact and the near-anaerobic (low dissolved oxygen) conditions at the sediment-water interface as well as in the microbial-algal biofilms developed on substrates (e.g., submerged plant parts, litter, etc.) that are conducive for efficient denitrification conditions (Mitsch and Gosselink 2007). Increasing water depth does not increase denitrification once all the anoxic sites in the sediments and litter have immersed (Kadlec and Wallace 2008). Some researchers suggested that wetlands should be designed with an optimal depth of 30–50 cm (Hansson et al. 2005; Mitsch and Gosselink 2007). However, a variety of water depths can provide low velocity areas for water redistribution and increase sediment retention capacity (Mitsch and Gosselink 2007).

3.3.2 Wetland positioning and size

Landscape position and wetland size affect a wetland's ability to improve water quality. Research has suggested that proper site selection of constructed wetlands within a watershed may be the most important determinant of whether a wetland will be successful in achieving its design objectives (Sonntag and Cole 2008). Certain wetlands may provide more nutrient removal than others based on their spatial setting relative to the surrounding landscape, land use, and watershed position. Wetlands sited in upper headwater areas may have limited opportunity to intercept significant tile flow and nutrients, whereas wetlands located downstream may experience higher flow rates that limit removal efficiency.

To achieve significant nonpoint source pollution reduction, wetlands must be appropriately positioned in the landscape where they can connect to the source and intercept high nutrient loads. The mass load reduction, particularly for nitrogen, will be more efficient if the wetland is located in higher nitrogen concentration areas. This suggests that wetlands should be located further upstream in agricultural watersheds where nitrate concentrations are highest. Nitrogen removal potential of wetlands can vary by a factor of 10 within a small sub-watershed (Tomer et al. 2013) suggesting that targeting wetland sites for their removal potential is important.

Extensive scientific literature combining ecological, hydrological, soil and agronomic research provides recommendations on site selection to reduce nonpoint source pollution from agriculture (e.g., Almendinger 1999; Trepel and Palmeri 2002; Tomer et al. 2003a; Newbold 2005; Dosskey et al. 2006; Diebel et al. 2009; Qiu 2009; Tomer et al. 2009). Water quality benefits substantially from careful targeting of wetlands, riparian buffers, and other best management practices at multiple landscape scales, such as within a small sub-watershed (Tomer et al. 2013),

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[6] Emergent plants are rooted in soil that is underwater and grow up through the water column so that stems, leaves, and flowers emerge above the water surface. Most emergent plants are tolerant of water depths of 30–60 cm (1–2 ft) with some species tolerant of water depths up to 90 cm (3 ft). Submerged plants are largely underwater with few floating or emergent leaves and are tolerant of water depths greater than 90 cm as long as there is light penetration.

within a larger watershed (Tomer et al. 2003a; Dosskey et al. 2006; Qiu 2009;), and at large landscape scale covering an entire state (Diebel et al. 2009).

Different methodologies have been applied for targeting wetland locations within watersheds. These include targeting areas suited for conservation, preservation, and restoration using a Geographical Information System (GIS) to find optimal locations. Some examples of the types of data used are digital elevation model (DEM) data (Trepel and Palmeri 2002; Tomer et al. 2009), soil survey databases (Dosskey et al. 2006; Diebel et al. 2009; Tomer et al. 2009), land-use/cover data (Russell et al. 1997; Newbold 2005; Qiu 2009), maps of the historical distribution of wetlands (Trepel and Palmeri 2002), water quality data (Diebel et al. 2009), and geomorphological maps (Moreno-Mateos et al. 2010). Most recently, Light Detection and Ranging (LiDAR) data have been applied for precision conservation (Tomer et al. 2013).

Wetlands must be sufficiently sized to allow adequate residence time to “treat” the nutrient loads. Empirical studies on the ability of wetlands to remove nitrogen often report the ratio of the constructed or restored wetland’s surface area to the size of its contributing watershed as a siting parameter. The wetland area-to-watershed area ratio is a simple indicator of retention time, and therefore, the wetlands’ ability to remove nitrogen (Woltemade 2000). However, the literature shows little consensus on what the right ratio should be, and suggested values vary from study to study. Under low flow conditions, wetlands that are small compared to the drainage area can be effective. Kovacic et al. (2000) suggest that the optimal ratio is between 1:15 and 1:20, based on a study of three wetlands in Champaign County, Illinois. In a study of four wetlands in Iowa, Illinois, and Maryland, Woltemade (2000) suggests that wetlands with a smaller ratio perform poorly with respect to nitrogen load reductions, due to short retention time in the wetlands, but Woltemade does not make recommendations for an optimal ratio for any specific geographical location.

The wetland-to-watershed ratio has been used in at least two statewide wetland policies. The Minnesota Board on Water and Soil Resources (2009) outlined a GIS approach to prioritizing potential wetland restoration sites for nutrient removal and stated that a one-hectare restored wetland should preferably have a drainage area of less than five hectares, or a wetland-to-watershed ratio of one to five. Wetlands with a drainage area of more than 20 times their own size were not recommended for nutrient removal; however, the report noted that use of a multiple-benefit ranking system (water quality, water quantity, and wildlife habitat) complicated the site selection process (Minnesota Board on Water and Soil Resources 2009). The State of Iowa requires that potential nitrogen-removing wetlands, which receive state funding from the CREP program, have a wetland-to-watershed ratio between 1:200 (0.5%) and 1:50 (2%), meaning that a one-hectare wetland needs to have a drainage area of between 50 and 200 hectares (USDA and IDALS 2009). Similarly, Tomer et al. (2011) used the size of the drainage area as a measure for prioritizing wetland sites for nitrogen removal, with a wetland-to-watershed ratio of 200 as the low cutoff limit.

Importantly, however, economic criteria are not usually applied for wetland site selection for nutrient removal. Targeting schemes based exclusively on environmental benefits are difficult to extend to economic analysis, because geospatial data on the costs of conservation easements, as well as wetland construction costs, are often unavailable. Restricting preservation and restoration to certain sites without carefully evaluating the cost and benefits may lead to suboptimal site selection (Newbold 2005). For example, if the most expensive wetland sites generate the largest environmental benefits, targeting based only on environmental performance will not result in the most cost-effective solution to nonpoint source pollution reduction.

3.4 Identification of Potential Wetland Locations

To treat agricultural tile drainage and surface flow, constructed wetlands are best located adjacent to or in-line with ditches, streams, or grassed waterways where subsurface tile drains can be day-lighted (or redirected to above ground surface) and the flow impounded for a period of time. Several approaches to constructing these “in-line” wetlands are possible, including low impoundments in drainage ditches or headwater streams, diversion to off-channel oxbows or abandoned channels, or retention in a bermed area between a sloping field and waterway. The alternative of building a low impoundment in a section of the ditch or channel takes advantage of the natural landscape while minimizing earthmoving requirements.

Depending on the height of the impoundment, the water would flood a length of the ditch and the low-lying land adjacent to the channel. A buffer would surround the wetland area to address the surface runoff entering the wetland and to ensure that the wetland would not exacerbate local flooding during extreme events. The wetland locations within the watershed are determined by siting and wetland criteria regarding wetland removal effectiveness. Potential wetland sites would be recommended only if they did not impact adjacent and upstream tile-drainage and infrastructure.

We used three different methods to identify potential or candidate wetland sites based on the availability of the wetland identification model and the watershed model data. Section 3.4.1 describes a landscape assessment of potential locations that the UIUC project partners used for the economic feasibility analysis. Sections 3.4.2 and 3.4.3 describe two different but related methodologies for the strategic positioning of potential wetland sites based on the level of topographic data available (LiDAR or DEM-10). The DEM-10 strategic positioning of potential wetland sites was used for the smart market design and simulations.

3.4.1 Landscape wetland assessment

We identified potential wetland sites using GIS and Public Land Survey data. For each square-mile section, we used three criteria to identify constructed wetland suitability (Lentz 2011a). First, a wetland should be located in a local depression with water flowing into it. Second, a wetland should be located close to a stream or a river. Third, a wetland should be located on a land-use class where no conflicting interests would prevent construction. To ensure that water flowed into a potential wetland site, we calculated the Topographical Positioning Index (TPI) with DEM-10 (Digital Elevation Model 10 meter) data in ArcMap (USDA 2010a). If a site (10 by 10 meters) had a negative TPI value, then adjacent sites would have higher elevations than the selected site and water would flow into it. We selected all sites located within 100 meters from any stream and river in the watershed. We excluded any sites on land-use classes that represented coniferous forests, low to high urban density, and open urban areas. Lastly, we summed the areas of all sites identified in each section and reclassified those areas as the maximum area that could be taken out of production and converted to wetlands in that section. In total, we identified 211 sections suitable for potential wetland sites for the part of the Big Bureau Creek watershed located in Bureau County.

To calculate the nitrogen removal potential for a candidate wetland site in each section, we used a model developed by Crumpton et al. (2006) and extended by Tomer et al. (2013). We estimated nitrogen removal potential as a function of both the Hydraulic Loading Ratio (HLR) and the flow-weighted average nitrate concentration. The model requires two GIS-based parameters: the size of the drainage area upstream of any potential wetland, which approximates the annual flow through the wetland; and the percentage of the upstream drainage area used for corn and soy production, which correlates with the expected concentration of nitrate. We calculated the drainage areas for the lowest point in each section using the ArcHydro extension to ArcMap, and we calculated the percentages of land in corn and soy production from land-use maps. Where 100% of upstream land was in a corn and soy rotation, we estimated the concentration at a potential wetland site to be 15 mg/L, with a proportional adjustment for lower crop coverage. The estimated inflow nitrate-nitrogen concentrations ranged from 2.44-14.71 mg/L with a mean concentration of 12.23 mg/L.

Of the 211 sections suited for wetlands, we estimated that 136 would be able to remove nitrate-nitrogen effectively (Figure 3-1). To have statistically significant estimates of a wetland's nitrate removal potential, we assumed the wetland area was 0.5% of the upstream drainage area. This percentage represents a conservative lower bound based on the previously described studies. The average wetland size was 37.6 ha (93.1 acres). The smallest identified wetland was only 0.73 ha (1.8 acres), while the largest was 74.8 ha (184.8 acres) (Figure 3-2). In addition to wetland area, a buffer area was placed around each wetland with a size equal to 10% of the wetland area. The buffer area was not considered in the nitrogen removal estimation, but it would provide phosphorus removal and benefits for wildlife.

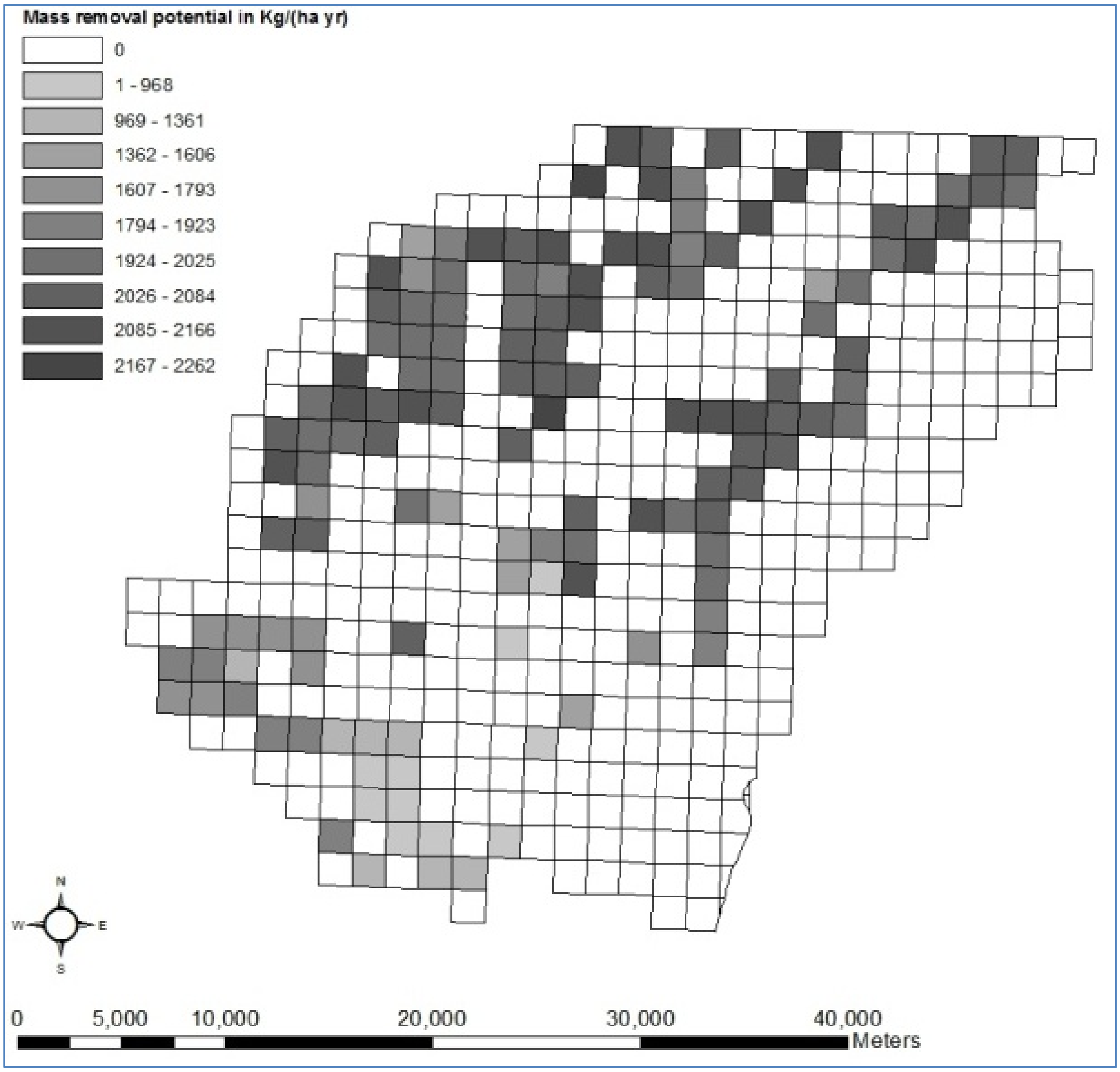

Figure 3-1. Estimated nitrate-nitrogen removal potential (kg/ha) within a section for the Bureau County portion of the BBC watershed.

To estimate phosphorus removal potential, we simulated two scenarios: one scenario with a conservative estimate of the ability of an Illinois wetland to remove phosphorus of 0.41 g $P/m^2/yr^1$, and one scenario with an upper bound of phosphorus removal potential 2.86 g $P/m^2/yr^1$. We obtained these estimates from a study of four constructed freshwater marshes along the Des Plaines River in Northeastern Illinois (Mitsch et al. 1995).

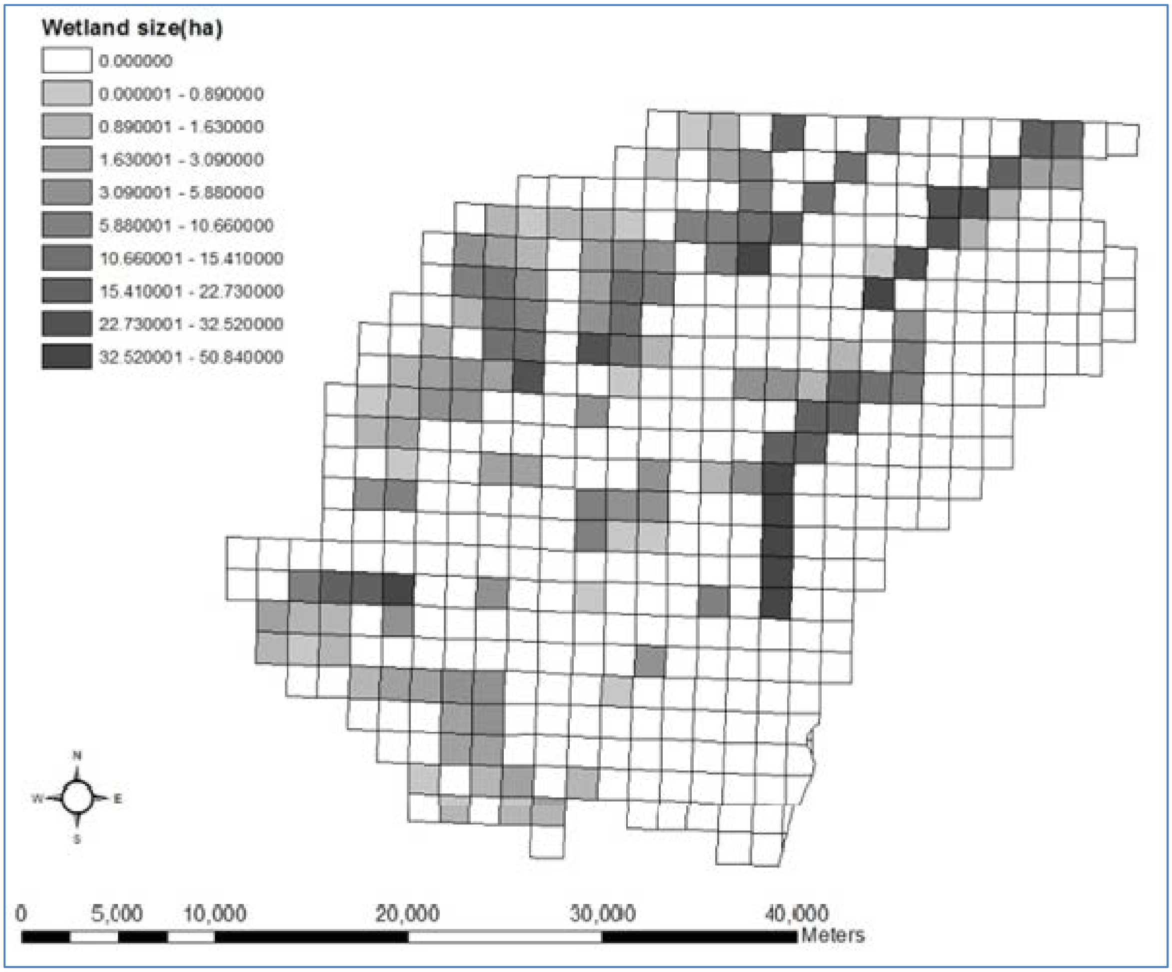

Figure 3-2. Estimated wetland size (ha) within a section for the Bureau County portion of the BBC watershed.

3.4.2 LiDAR-based methodology for Lime Creek basin

This section summarizes the identification of potential wetlands based on the LiDAR survey of Lime Creek, a 6500 ha (16,100 acre) sub-watershed of the Big Bureau Creek watershed. Agricultural Research Service (ARS) obtained LiDAR data by aircraft for this sub-watershed in December 2008. The 1-m grid digital elevation model (DEM) of the land surface was subjected to hydrologic modeling of overland flow and modified to enforce flow pathway convergence into drainage ditches and streams. (See Tomer et al. 2013 for a detailed description of this process.)

We screened potential wetland sites based on a predetermined set of criteria. The minimal contributing area, or drainage area, was set at 100 ha (250 acres) for wetland assessment, because the beginning of channelized ditches generally occurred near this threshold, and the flow paths contributing area < 100 ha (250 acres) in this sub-watershed were mainly ephemeral and non-channelized (grassed waterways). Sites at road crossings of drainage ways (grassed or ditched) and stream tributaries that had contributing areas greater than 100 ha (250 acres) were evaluated. This step identified 30-35 sites.

With the detail of LiDAR, the impoundment depth could be specified as the height of the ditch bank plus 0.9 m (3 ft) to provide for the flooded wetland area. The buffer associated with the wetland had a surface elevation within 1.5 m (5 ft) of the wetland water elevation. This buffer accounts for the need to maintain drainage through subsurface tile drains above the wetland, which are typically installed at a 1.2 m (4 ft) depth below the surface. The maximum wetland depth and wetland buffer were modified from the screening criteria used in Iowa’s Conservation Reserve Enhancement Program (CREP).

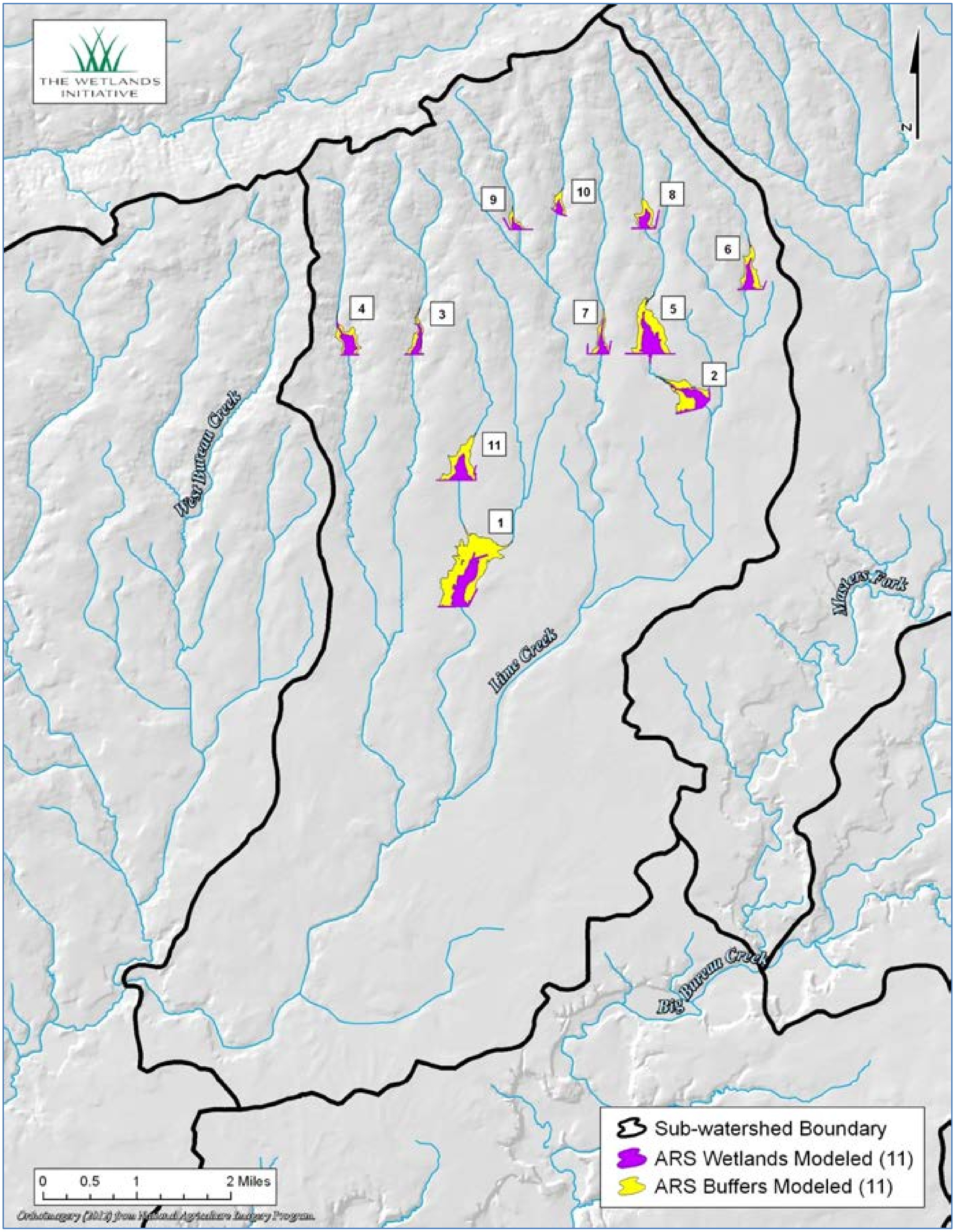

Figure 3-3. Location of 11 potential wetland sites (with buffers) in Lime Creek sub-watershed based on LiDAR DEM and specific siting criteria (Tomer et al. 2013).

ARS manually identified and digitized the impoundments 20 m (65 ft) up-gradient of each road-stream intersection. Locating these impoundments just above each road crossing provided the best chance to avoid impeding drainage at the next upstream road crossing. The simulated impoundment was 2.4 m (0.9 m plus 0.5 m) greater in height than the ditch bank elevations. The ditch bank elevation was estimated by adding the focal elevation (range in elevation with 20 m (65 ft) of the channel) to the channel elevation, which was estimated from the focal minimum elevation. If the focal minimum (or the bottom channel elevation) at the next up-gradient road-stream intersection was greater than the buffer impoundment, then that location was accepted as a potential wetland. We completed a final check using aerial photographic images to ensure that the wetlands and their buffers did not overlap or impede drainage from any farmsteads. Sites satisfying these criteria could be moved upstream as far as possible and still avoid impeding drainage at the next upstream crossing; however, we only explored such sites where there was a stream confluence between road crossings. We identified 11 potential sites in the Lime Creek sub-watershed (Figure 3-3).

3.4.3 DEM-10m methodology for Big Bureau Creek watershed

We could not obtain LiDAR data for the other 12 Big Bureau Creek sub-watersheds. Therefore, the Wetlands Initiative (TWI) had to develop a different wetland siting methodology based on the best available topographic data. In addition to the less refined contour data, it was not feasible to follow the manual screening procedures utilized by the ARS in the Lime Creek sub-watershed, given the size of the 129,240 ha (499 mi^2) Big Bureau Creek watershed. Therefore, TWI developed a GIS methodology for identifying potential wetland sites, based on the available 10m DEM (topographic) data and the ARS wetland design criteria. Our multiple-step process first located preliminary areas of interest (AOI); removed undesirable AOI based on watershed position; converted remaining AOI into impoundment points; removed sites servicing the same stream segment; calculated wetland areas and contributing area; and finally evaluated the suitability of each site based on criteria (e.g., minimum contributing area, ratio of wetland area to contributing area, etc.). The following sections describe these steps in detail.

3.4.1 Identification of preliminary AOI

The initial goal in determining preliminary AOI was to find wetted areas near perennial stream paths that were also on agricultural land. To find such locations, we combined three GIS datasets: soils (NRCS 2010), land cover (USDA NASS et al. 2000), and road proximity (IDNR/ISGS 2004) (Figure 3-4). The NRCS soil data contain several reports that indicate different aspects of soil wetness. For example, the hydric soils report is commonly used to find potential wetland locations. However, after analyzing hydric soils within the Big Bureau Creek watershed, we found that this dataset was inadequate. The hydric data highlighted numerous areas isolated from perennial streams but, more importantly, it failed to indicate areas along floodplains of major streams.

In contrast, the flood frequency report was better suited to the model objectives. This report classified all soil polygons into five flood frequency classes: “very frequent” (>50%), “frequent” (~50%), “occasional” (5-50%), “rare” (1-5%), and “very rare” (<1%). We chose the soil classes “very frequent”, “frequent”, and “occasional” to highlight all soil polygons near or directly adjacent to perennial flow paths and their floodplains. This dataset also correlated well with previous field observations of potential wetland sites in the watershed. The flood frequency dataset was converted to a raster surface, where a pixel value of “1” indicated the wetted areas (“very frequent”, “frequent”, and “occasional”) while a “0” indicated the remaining upland areas of the watershed (“rare” and “very rare”).

Locating agricultural land was a process of reclassifying land cover data. Any agricultural land cover (corn, soy, wheat, etc.) was reclassified as “1”, while urban cover types were classified as “0” to remove them from the analysis. Covers such as forested, marsh, and deep marsh were also left in the analysis (coded “1”), as we did not want to exclude these areas as potential wetlands. See Table 3-11 for a complete listing of how each cover type was reclassified.

The roads dataset was used to ensure that potential sites were not placed on top of roads. While we could identify some roads from the land cover dataset, many small rural roads were not visible. Consequently, we used the vector line road dataset and then buffered it by 10 meters on each side to convert into a polygon area exclusion zone. This polygon was then converted into a raster surface, where roads are coded a “0” and all other areas in the watershed are coded a “1”.

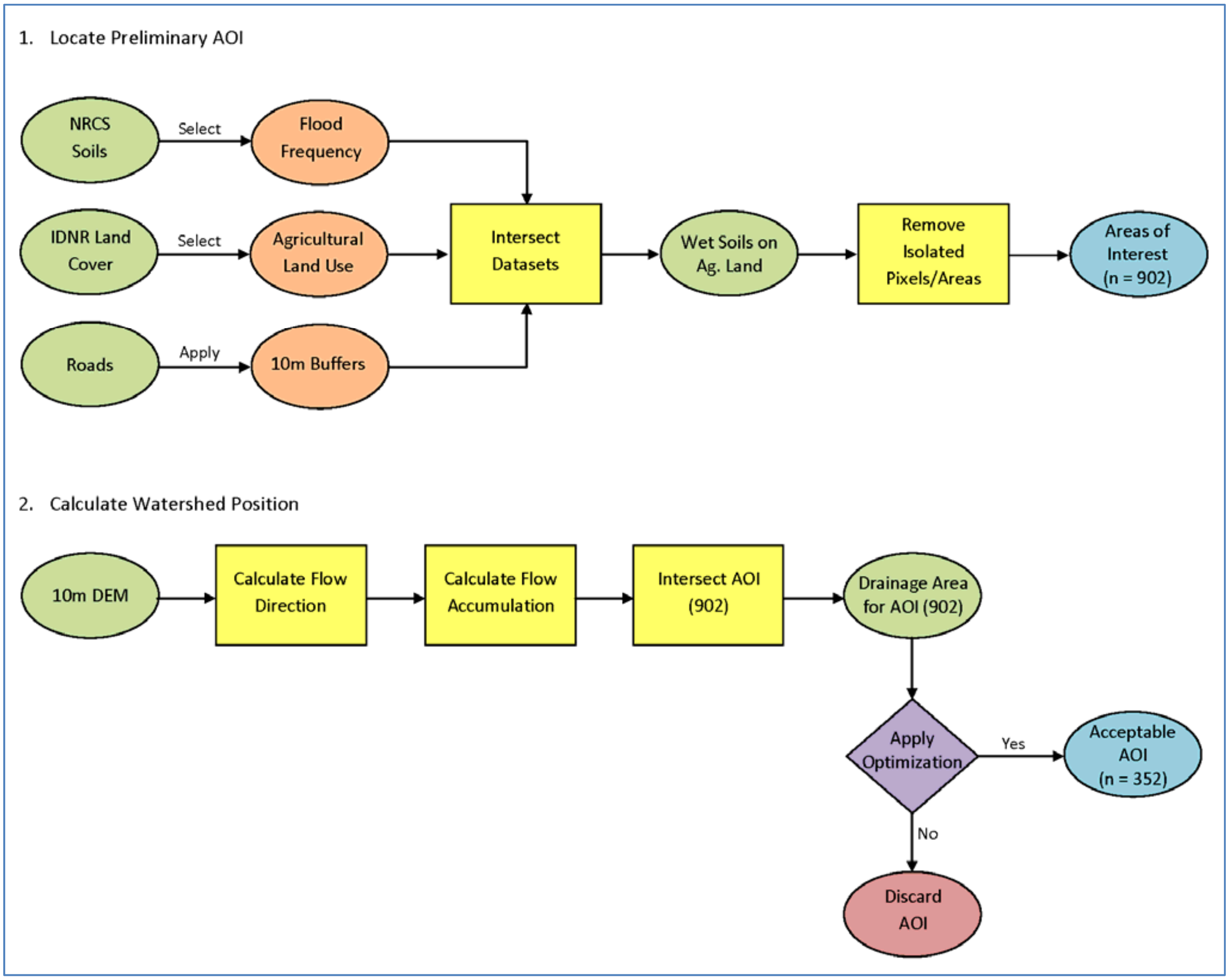

Figure 3-4. The first two steps of the DEM-10m GIS methodology for identifying potential wetland locations.

Table 3-11. Assigned weights to land cover classifications.

LAND COVER TYPE	WEIGHT	LAND COVER TYPE	WEIGHT
Background	0	**Partial canopy/savannah upland**	1
Barren & Exposed land	1	**Rural grassland**	1
Cloud shadows	0	**Seasonally/temporarily flooded**	1
Clouds	0	**Shallow marsh/wet meadow**	1
Coniferous	1	**Shallow water**	1
Corn	1	**Soybeans**	1
Deep marsh	1	**Surface water**	1
Floodplain forest	1	**Swamp**	1
High density	0	**Upland**	1
Low/Medium density	0	**Urban open space**	0
Other agriculture	1	**Winter wheat**	1
Other small grains & hay	1	**Winter wheat/soybeans**	1

We combined all three datasets (flood frequency, land cover, and roads) by summing the pixel values using the GIS Raster Calculator tool. All pixels with a summed value of 3 were kept in the analysis, while those with a “0”, “1”, or “2” were removed. This tool performed a geographic intersection of all desirable locations (pixels) within the three datasets. The resulting raster surface indicates the areas that contain soils that are within the three chosen flood frequency classes, are on agricultural land or wetlands, and are away from roads.

This raster surface had some small areas that effectively were noise in the raster surface. These were pixel values coded with a "1", which were isolated from other "1" pixels. This is a common effect when combining data from different sources with different raster resolutions and in areas where pixel values do not overlap perfectly. The software package Fragstats was used to eliminate isolated pixels by running the Patch Cohesion Tool, which filters out these isolated pixels by measuring the spatial connectedness of pixels. This tool creates a cohesion index that increases as the patch type becomes more clumped or aggregated in its distribution (hence, more connected). Once the isolated pixels (low cohesion index) were removed, the raster surface was converted to vector polygons. This process yielded 902 individual polygons or areas of interest (AOI).

3.4.2 Optimization of AOI watershed position

To optimize the drainage area each AOI was receiving, the flow accumulation (drainage area) for each AOI had to be calculated. Previous research in similar areas of the Midwest indicated that wetlands draining 100-2,020 ha (250-5,000 acres) of land are optimal for nutrient removal (Table 3-12). Therefore, any AOI that failed to meet this threshold was removed from subsequent analyses. This optimization was to ensure that potential sites did not take too much agricultural land out of production, receive too much drainage, or receive too little drainage, producing less efficient wetlands.

Table 3-12. Wetland criteria for the DEM-10m model.

PARAMETER	VALUE OR RANGE	DESCRIPTION
Land use/Land cover	Non-urban	Land cover data and visual inspection of satellite imagery to determine conflicts with roads, residences, structures.
Drainage area (Catchment size)	100-2,020 ha (250-5,000 ac)	Channelized ditches generally begin at this drainage area threshold.
Minimum elevation	Lowest point in drainage area	
Depth	Minimum depth = 0.3m (1')	These parameters are based on modification of Iowa CREP screening criteria and were used in the LiDAR-based methodology for the Lime Creek basin.
Wetland area	Minimum Elevation + 0.9m (3')	
Buffer area	Minimum Elevation + 1.8m (6')	
Wetland area: Drainage area	0.1-5.0%	While 1% is the target, the range was extended below 0.5% and above 2.5% to account for the lower resolution topographic data.

Flow accumulation (a raster-based tool in ArcHydro) is the sum of the number of cells/pixels that are upstream of each AOI. However, prior to running the flow accumulation tool, several terrain calculations in ArcHydro had to be performed. The following processes use raster digital elevation models (USGS DEM-10 meter) as inputs to create hydrologic models (Hydro-DEM) that show where and how water flows across the surface. The original DEM-10m (USGS) was initially processed by filling in sinks/pits, which is recommended for dendritic watersheds. This process "forces" drainage to accumulate along stream paths rather than getting trapped in small depressions. Next a flow direction surface was calculated using the pit-filled DEM to determine the direction (based on the eight cardinal directions) of the lowest adjacent cell/pixel for each pixel in the watershed. Once the flow direction raster was created, flow accumulation was calculated for each AOI. Because AOI are polygon areas, they have multiple flow accumulation points. We used the highest flow accumulation value to determine whether each AOI met the drainage area threshold criteria. After the flow accumulation threshold was applied, 352 AOIs remained for subsequent analyses.

3.4.3 Creation of wetland area polygons

Once the AOIs were limited to optimize locations within the watershed, these polygon areas were converted into impoundment points from which the wetland polygons would be created. The 352 polygons were intersected with the flow accumulation values, and the maximum flow accumulation value was extracted as a point. This maximum flow accumulation value became the impoundment point, which also coincided with the lowest elevation value within each AOI. Once the impoundment points were created, sites that serviced the same stream segment were removed to avoid overlapping wetland/buffer areas. We removed stream segment duplicates by spatial joining the impoundment points to each other via NHD (National Hydrography Dataset) streams. This process counts the number of points on each stream segment. Each segment with a count greater than "1" was selected and the points with the lowest flow accumulation value were removed. Visual inspection of the spatial join process revealed that a few (8) segment duplications were missed. Once all duplications were removed, 192 impoundment points remained.

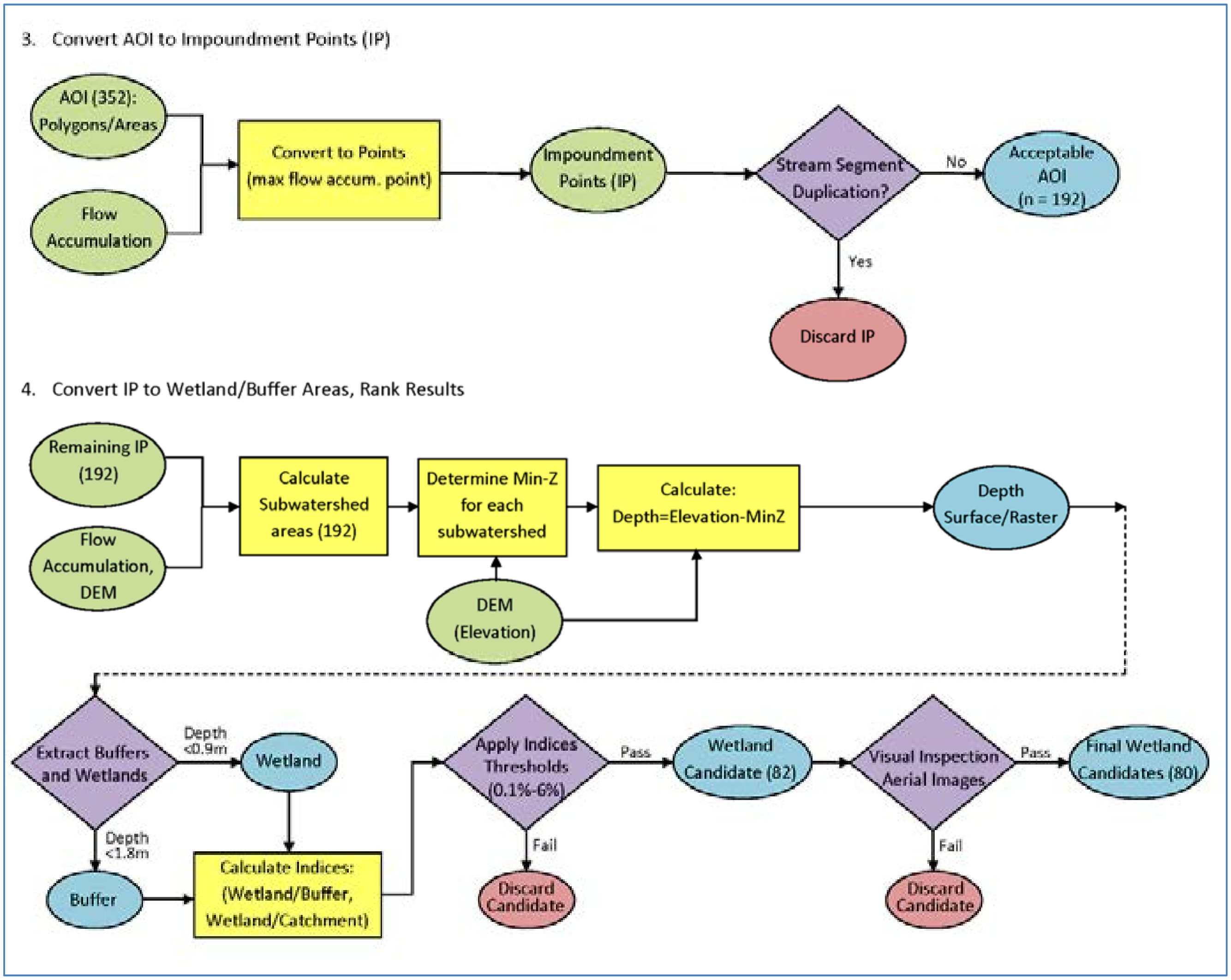

Figure 3-5. The first two steps of the DEM-10m GIS methodology for identifying potential wetland locations.

After the impoundment points were identified, the wetland and buffer areas were created using the DEM-10m. First, each impoundment point's sub-watershed area was calculated in ArcHydro (Figure 3-6A). This process is distinct from calculating the watershed or drainage area. The watershed tool creates overlapping polygons that represent the total flow accumulation at each point. However, the sub-watershed tool creates independent, non-overlapping polygons for each impoundment point. Consider a stream with two impoundment points: point A is near the headwaters and point B is much further downstream. The watershed for point B would include the watershed area of point A; however, the sub-watershed calculation for point B would only extend upstream as far as point A. The objective in calculating sub-watersheds was to use terrain features to control the areal extent of each wetland depth calculation (described below). This process also made the wetland depth calculation more flexible and efficient when using GIS geoprocessing tools.

The first step in creating wetland areas (polygons) from the impoundment points was to create a raster-based depth surface, as we did with the Lime Creek wetlands. The optimal depths utilized for wetlands and their corresponding buffers were 0.9 m (3 ft) and 1.8m (6 ft), respectively. The sub-watershed boundaries were used to extract the minimum z-value (or elevation) for each impoundment point, and then a raster surface was created with that value (minZ) assigned to each sub-watershed. The depth surface was derived by subtracting each sub-watershed's minZ from the original pit-filled DEM (Depth=DEM – minZ) (Figure 3-6B).

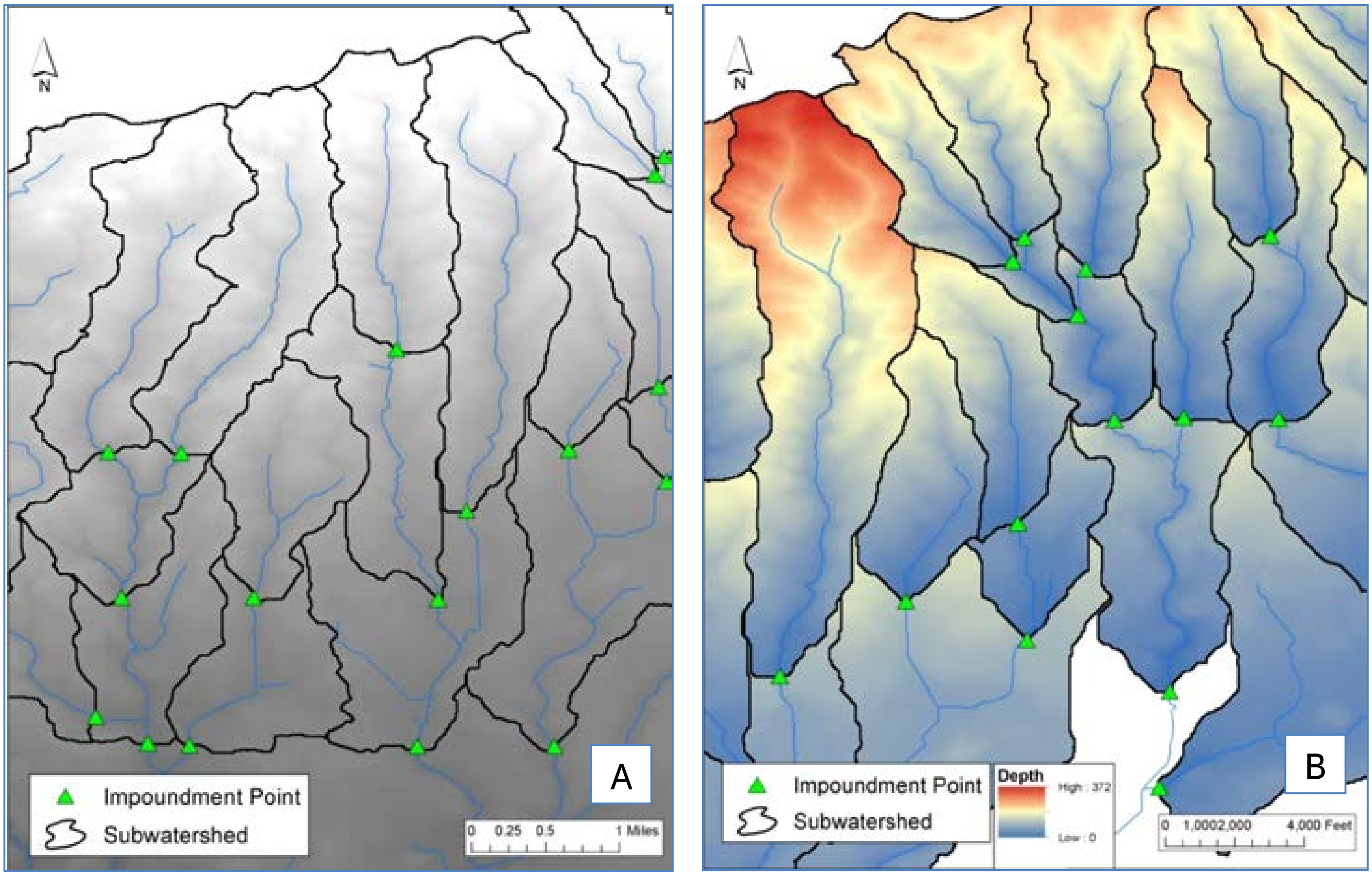

Figure 3-6. Examples of sub-watershed calculations for impoundment points (A) and sub-watershed depth surface (B).

The wetland and buffer areas were then extracted from the depth surface by using conditional statements in the Raster Calculator tool: Con(“depth” < 0.9, 1, 0) and Con(“depth” < 1.8, 1, 0). These statements select pixels with depth less than 0.9 meters, and the statements then reassign those values a “1”. All other pixels are assigned 0, and removed from subsequent analysis. The same statement is repeated for buffers where depths are less than 1.8 meters. All pixels with a “1” value were converted to polygons to create wetland and buffer layers (Figure 3-7).

These potential wetland areas were further optimized by calculating several indices: wetland area, buffer area, wetland-to-buffer ratio, and wetland-to-drainage ratio (Table 3-12). We did not use Illinois Conservation Reserve Program standards for selection criteria, because wetland implementation under a nutrient credit trading program is not expected to occur under a federal or state conservation (financial assistance or easement) program. The wetland area-to-watershed area ratio was extended beyond that used for the Lime Creek LiDAR methodology given the limitations working with the lower resolution10m DEM data. Since detailed tile drainage information was not available for this watershed, we assumed that the direct tile drainage area was the same as the surface watershed drainage area. Stricter criteria can be applied as more refined topographic data is obtained. Given the flexibility in the criteria, some candidate wetlands would have better nutrient removal ability and cost-effectiveness, but we did not predetermine the credit market opportunities or feasibility for the potential wetlands.

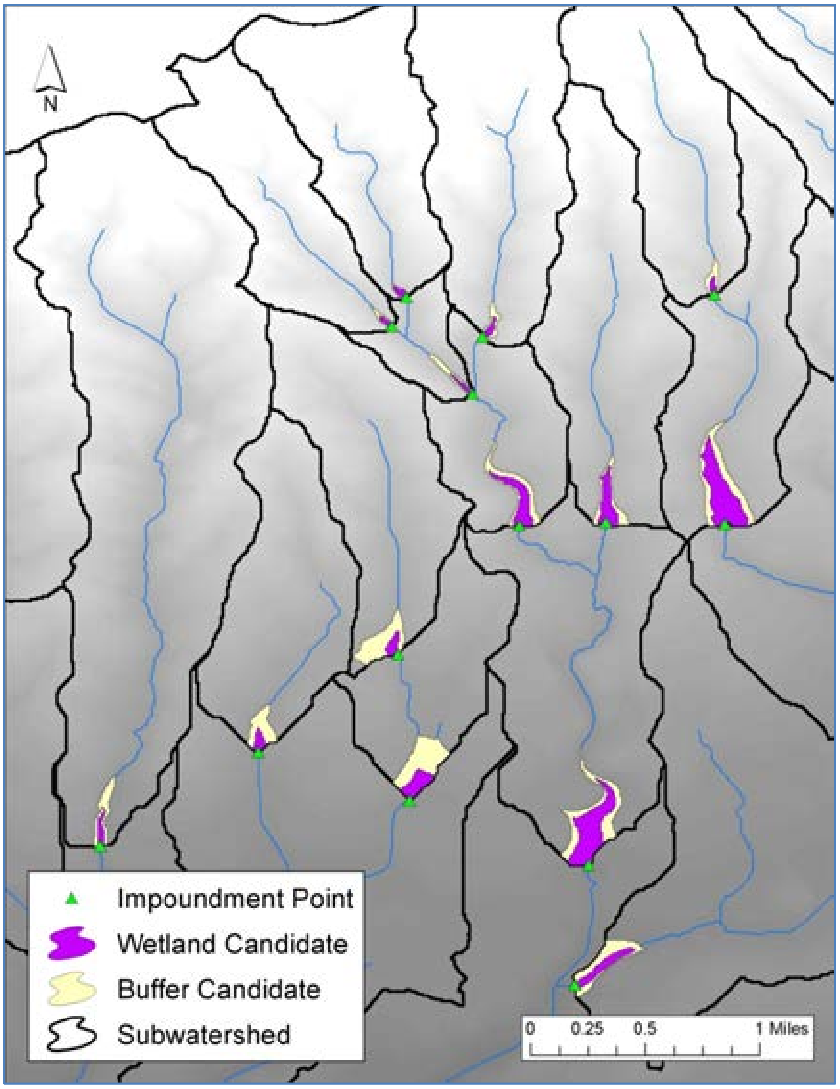

Figure 3-7. An example of the wetland and buffer calculations.

After applying these filters, 82 potential wetlands/buffers remained. After wetlands and buffers were created and optimized, recent (2010–2012) satellite imagery was used to verify that each wetland was on agricultural land, but also positioned to avoid holding water on road embankments and away from homesteads or other potentially valuable structures. Two potential sites were eliminated.

Consequently, the watershed model assessed 80 wetland potential sites to determine nutrient removal performance and ranking (Figure 3-8). Our study restricts the demonstration market to these selected sites. However, landowners could offer additional sites that did not meet this criteria and may be appropriate for a nutrient removal wetland.

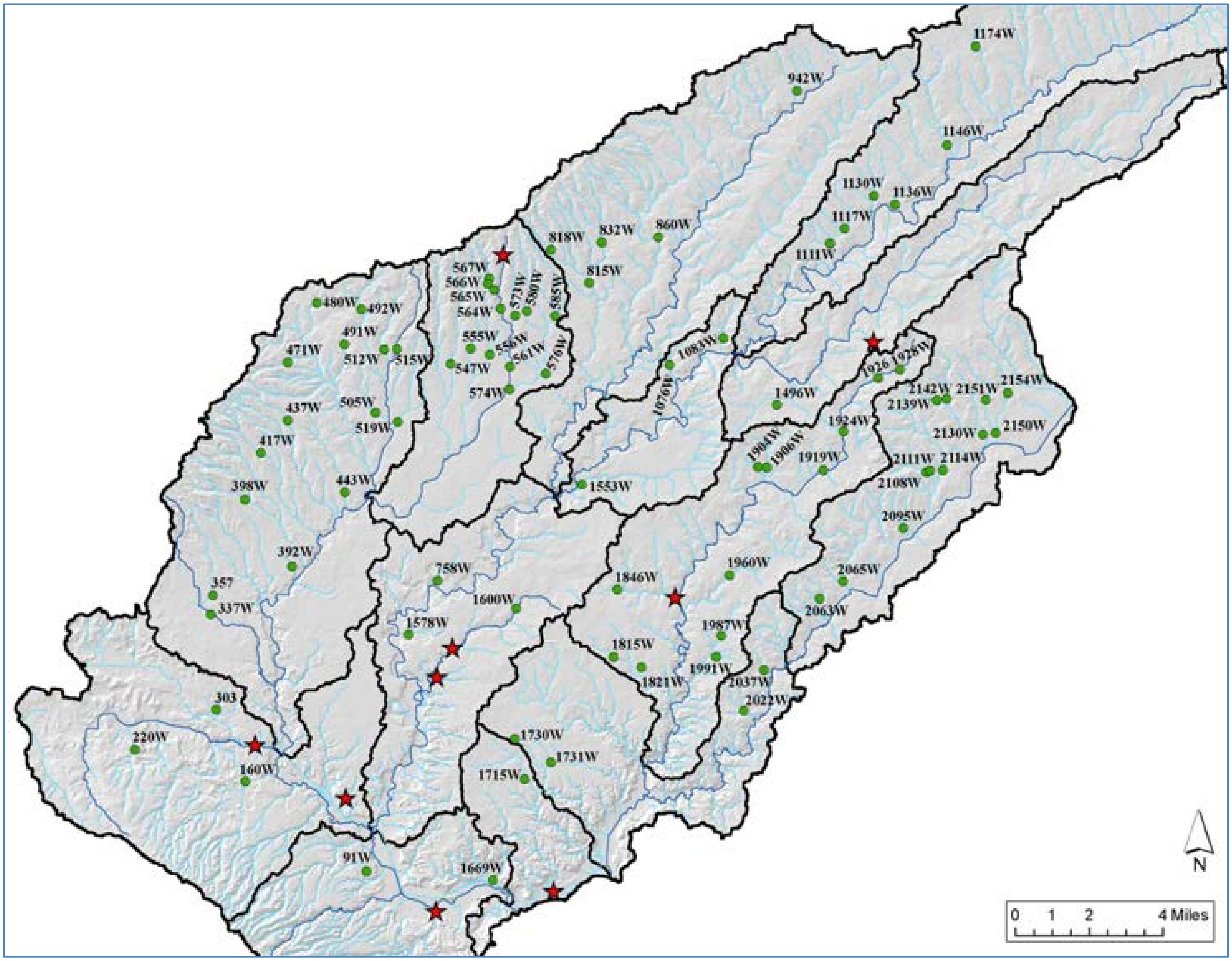

Figure 3-8. Location of the 80 potential wetland sites in Big Bureau Creek watershed based on DEM-10 m GIS methodology. Red stars represent the 9 main point sources.

3.5 Watershed Model Development

The USDA Agriculture Research Service (ARS) National Sedimentation Laboratory used the Annualized Agricultural Non-Point Source (AnnAGNPS) pollution model to determine the nutrient (nitrogen and phosphorus) loadings in the Big Bureau Creek watershed and at each identified wetland location (Bingner et al. 2001). AnnAGNPS is an advanced simulation model developed by the USDA ARS and the Natural Resources Conservation Service (NRCS) to help evaluate the watershed response to agricultural management and conservation practices. The model is a continuous simulation tool based on a daily time step and is designed to simulate runoff, sediment, and chemical movement from surface and subsurface flows from precipitation events (rainfall, snow, and irrigation) and as impacted by watershed characteristics and management. This model can identify the origin of pollutant loadings and can track the flow through the stream system to the watershed outlet. AnnAGNPS can be used to evaluate the water quality effects of implementing various conservation alternatives within a watershed (Yuan et al. 2006; Yuan et al. 2009; Bingner et al. 2010).

The AnnAGNPS model version 5.4, with enhanced wetland and buffer features, was used to account for the effectiveness of the potential wetland sites to trap water, sediment, and nutrients transported from agricultural fields into the watershed stream network. Bingner et al. (in preparation) describe the development of the wetland and buffer components within AnnAGNPS. The model utilizes current research on nutrient transformation and retention in a daily time step approach to simulate wetland nutrient retention and removal processes for individual precipitation events.

The impact of an individual wetland can be tracked to any downstream point in the watershed and eventually to the watershed outlet. The wetlands individually or in series can be evaluated for their effect on downstream pollutant loadings.

AnnAGNPS input relies on climate, topographic, management, and soil type data describing the watershed to simulate the hydrologic and nutrient loads discharged from the watershed. The software requires daily climate data to simulate watershed responses to precipitation and weather conditions. Our simulation used a 30-year period of weather data. Average annual precipitation in the simulated weather record was 966 mm (38.0 inch), consistent with the long-term averages recorded from the area (ISWS 2002, 2007). Average annual stream discharge simulated for the Lime Creek sub-watershed was 331 mm (13 in). This discharge was consistent with measured discharge data at the Princeton USGS gauge station (USGS 05556500), which drains a larger area (50,760 ha) of the same glacial landform (USGS 2011). The average annual stream discharge at Princeton was 332 mm from 1981–2011.

Since LiDAR data were not available for the entire watershed, the 10m DEM data was used as the topographic dataset. The watershed boundary near the Illinois River and Goose Lake was difficult to define, as the DEM resolution was not sufficient to capture the subtle elevation changes for that extremely flat floodplain area. The resulting Big Bureau Creek watershed boundary was determined to be 124,552 ha (481 mi^2), less than that previously defined in the BBC watershed plan. The 2009 land use data for the defined watershed was obtained from the Illinois Cropland Data Layer (USDA NASS 2009). We obtained soil information from the USDA Soil Survey Geographic (SSURGO) database as archived and distributed by the National Cartography and Geospatial Center.

ARS accounted for spatial variability of soils, land use, and topography by dividing the watershed into homogeneous cells from which the runoff and pollutants are routed downslope and then along simulated stream channels. Runoff (or discharge) was modeled from precipitation inputs (i.e., rainfall, snowmelt, and irrigation) at the field scale. To account for both surface and subsurface flow responses to a precipitation event, a daily soil-water balance can be maintained in the model that simulates tile drainage (Yuan et al. 2006). ARS calibrated the stream discharge to average the approximate long-term average discharge observed at the USGS gauge station near Princeton, IL, since 1981 on a depth equivalent basis. Point sources, such as wastewater treatment plant discharges, are accounted for in the model by inputting flow rates and concentrations of nutrients to the cell locations that receive the discharge. The model predicts sheet and rill erosion from each field based on the USDA Revised Universal Soil Erosion Model (RUSLE) (Renard et al. 1997), as well as ephemeral gully erosion (Bingner et al. 2010).

For the baseline scenario, the total pollutant loading and hydrologic discharge delivered to each potential wetland location and sub-watershed outlet was simulated by the model on a daily basis over the 30-year simulation period and tallied on an average monthly and annual basis. These loadings vary based on land use, wastewater treatment facilities, cropping patterns, soil type, and slope within the contributing area to each wetland.

Different topographic analysis approaches and tools were used for locating the “in-line” wetland potential sites and for the AnnAGNPS watershed development. The generated stream network was slightly different for each approach. Therefore, an initial effort was needed to position the GIS-located sites within the model’s simulation network. This was a new necessary step in the development of the model input parameters needed to locate and characterize each wetland. Issues arose with the use of the different topographic approaches when trying to match the downstream point of the potential wetlands with the downstream end of a channel reach generated by the approaches used by AnnAGNPS to ensure that flows from the downstream surrounding fields were not bypassing the wetland. Since the confluence of two reaches defines the upstream and downstream ends of a stream reach, locating a wetland between two confluences required considerable effort. In addition, we assumed that the simulations reflect any rerouting or modification of the subsurface tiles flowing into the wetland so that all tile drains operate the same with or without the wetlands present.

The transition of the GIS-located potential wetlands into the model raised the issue of the extent of the surrounding buffer associated with each individual wetland. ARS based the buffer areas for the GIS-wetland sites on the minimum elevation of the impoundment plus 1.8 m (6 ft). Given time constraints, it was not possible to directly implement the GIS shape file buffer locations dictated by the depth criteria in the model. Instead, a uniform width of 15 m (50 ft) was assigned to the vegetative buffers for the appropriate fields that contained wetlands. This width is in the middle range of what would normally be recommended.

ARS developed the model input datasets specifically for this watershed, and input parameters were continually updated. ARS incorporated improvements between simulation runs to better represent both the baseline conditions and the effect of the wetlands and buffers. For example, a series of simulation runs with point sources indicated that we needed to better account for out-of-bank flow in the channel system. The model required improved hydraulic geometry inputs with the expected channel characteristics. The detailed Lime Creek LiDAR data was utilized to determine the hydraulic geometry inputs, and these were applied to the entire watershed.

AnnAGNPS determines in-stream attenuation through a nutrient half-life in the stream channel for nitrogen, phosphorus, and organic carbon, which in these simulations was set to 730 days. From the farthest end of the watershed to the outlet, the travel time for water was only three days, so AnnAGNPS simulated only a little nutrient loss in the stream from all the degradation methods (e.g., chemical, biological, or photolysis).

3.5.1 AnnAGNPS baseline conditions

The AnnAGNPS model developed for the Big Bureau Creek watershed was used to estimate the nonpoint source loadings (i.e., flow, sediment by particle size class and source, nitrogen, and phosphorus) at certain reach locations. The selected reach locations were at the outlet of the 13 sub-watersheds and at the outlet of the 80 potential wetlands. The daily event output over the 30-year simulation period was summarized into average annual and average monthly totals for each pollutant of interest. The nine wastewater treatment plants within the defined watershed boundary were included as a special land use component to determine their contribution to the baseline pollutant loads.[7] The point source contributions are limited to constant loading rates for the entire simulation period.

The average annual precipitation (rainfall and snow melt) in the simulated weather record was 966 mm (38 in), which is consistent with the long-term averages recorded for the area (ISWS 2002, 2007). The average annual discharge or runoff out of the watershed was 316 mm (12.0 in) (Table 3-15). The USGS gauging station (05556500) located near Princeton, IL, in the Epperson Run basin averaged a 300 mm (11.8 in) discharge from 1981 to 2010 (USGS 2010).

NUTRIENT QUANTITY

The AnnAGNPS model nutrient estimates for BBC watershed indicate that a substantial load of TN and TP is generated within and delivered to each sub-watershed outlet and to the BBC watershed outlet (Table 3-13). The average annual TN and TP loads delivered to the defined BBC watershed outlet were 2,525,000 kg (5,605,000 lb) and 455,700 kg (1,005,000 lb), respectively. The loads correspond to average annual concentrations of 6.4 mg TN/L and 1.16 mg TP/L, which both exceed the U.S. EPA recommended criteria of 2.18 mg TN/L and 0.076 mg TP/L (US EPA 2000).

The AnnAGNPS predicted loadings are significantly higher than the estimates of 1,684,000 kg TN (3,712,000 lb) and 60,150 kg TP (132,600 lb) reported in the BBC Watershed Plan, which were calculated based on a mean detected stream concentration over a five-year period and the 2002 annual discharge water volume (BBC Watershed Group 2008). The higher AnnAGNPS estimates are likely attributed to the model accounting for both the dissolved and attached nutrient components and simulating the hydrologic and nutrient loads over a 30-year period, which is a different climatic series than that used in the watershed plan estimate.

The inclusion of the municipal and private point source loads only slightly increased the nutrient and suspended sediment pollutant loads delivered to the BBC outlet (Table 3-13). While the model simulation estimated that nonpoint source contributions are 99% of the average annual nutrient and sediment loads, the point source loads, which were assumed to discharge at a constant rate over all conditions, will have more impact on water quality during low and dry flow conditions within the basins.

Table 3-13. Comparison of average annual baseline pollutant loads (kg) with and without point source contributions at BBC watershed outlets.

BBC OUTLET	RUNOFF	TOTAL NITROGEN		TOTAL PHOSPHORUS		TOTAL SUSPENDED SOLIDS	
	(Mg)	(kg)	(kg/ha)	(kg)	(kg/ha)	(Mg)	(Mg/ha)
With point sources	393,672,045	2,542,387	20.41	458,689	3.683	100,446	0.806
Without point sources	391,589,663	2,524,796	20.27	455,686	3.659	100,415	0.806
Percent difference	0.53%	0.70%		0.66%		0.03%	

The point sources accounted for less than 1% of the average annual nitrogen and phosphorus throughout the entire BBC watershed, except for the Epperson Run basin, which receives the effluent from the largest point source in the watershed, the Princeton STP (Table 3-14). Several basins without direct point source discharges have an increase in loadings, as they are downstream of a basin with point sources.

[7] The location of the Bureau Junction STP was not within the AnnAGNPS defined watershed boundary; therefore, it was not included in the simulations.

Table 3-14. Comparison of the average annual baseline pollutant loads (kg) with and without point source contributions. Highlighted basins are downstream of another basin. Basins in bold receive direct point source discharge.

BASIN	ID	TOTAL NITROGEN (kg)			TOTAL PHOSPHORUS (kg)		
		WITH PS	WITHOUT PS	% DIFFERENCE	WITH PS	WITHOUT PS	% DIFFERENCE
Lime Creek	**1**	**138,719**	**138,224**	**0.36**	**23,222**	**23,100**	**0.53**
West Bureau	2	468,801	468,302	0.11	97,442	97,293	0.15
Pike Creek	**4**	**222,970**	**222,568**	**0.18**	**36,112**	**36,002**	**0.31**
Sublette	3	379,441	379,534	-0.02	50,093	50,091	0.00
Masters Fork	6	297,014	297,001	0.00	45,775	45,775	0.00
Green Oak	5	671,098	670,788	0.05	98,960	98,843	0.12
Epperson Run	**7**	**1,093,160**	**1,079,173**	**1.30**	**171,113**	**169,300**	**1.07**
Brush	8	240,152	240,152	0.00	42,483	42,483	0.00
East Bureau	**9**	**234,952**	**234,637**	**0.13**	**40,943**	**40,857**	**0.21**
Brush-BBC	10	607,092	606,774	0.05	106,892	106,801	0.09
Pond Creek	**11**	**741,624**	**739,403**	**0.30**	**157,530**	**156,995**	**0.34**
Rocky Run	**12**	**1,908,870**	**1,891,923**	**0.90**	**346,628**	**343,817**	**0.82**
Old Channel (OUTLET)	**13**	**2,542,387**	**2,524,796**	**0.70**	**458,689**	**455,686**	**0.66**

Nutrient loss is the load that has left the field and is delivered to the defined outlet. The average annual nitrogen and phosphorus loss at the outlet (Old Channel - BBC) was simulated to be 20.4 kg/ha and 3.7 kg/ha, respectively (Table 3-15). The Pike Creek basin had the highest total nitrogen loss at 26.8 kg/ha. Nitrate-nitrogen losses from tile-drained areas are typically > 20 kg/ha/yr (Gentry et al. 2009; Jha et al. 2010; Tomer et al. 2003b) but can exceed 60 kg/ha/yr during wet years (Jaynes et al.1999). In comparison, the phosphorus loss was only a fraction of the nitrogen loss. Typical phosphorus losses from agricultural fields have been reported to be < 1 kg/ha/yr (Helmers et al. 2007). The higher TP losses observed in the BBC sub-watersheds may be due to contributions from highly erodible soils, livestock areas, stream bank erosion, septic systems, and wastewater treatment facilities.

Table 3-15. Average annual baseline runoff (or flow) with nutrient load and loss at each sub-watershed outlet with point source impact included. The highlighted basins are downstream of another basin.

BASIN NAME	ID	RUNOFF	FLOW	AREA	TOTAL NITROGEN		TOTAL PHOSPHORUS	
		(1,000 Mg)	(mm)	(ha)	LOAD (kg)	LOSS (kg/ha)	LOAD (kg)	LOSS (kg/ha)
Lime Creek	1	23,198	331	7,011	138,720	19.8	23,220	3.3
West Bureau	2	71,258	316	22,558	468,800	20.8	97,440	4.3
Pike Creek	4	28,551	343	8,325	222,970	26.8	36,110	4.3
Sublette	3	55,355	340	16,260	379,440	23.3	50,090	3.1
Masters Fork	6	49,117	332	14,796	297,010	20.1	45,780	3.1
Green Oak	5	96,384	338	28,550	671,100	23.5	98,960	3.5
Epperson Run	7	172,895	329	52,492	1,093,160	20.8	171,110	3.3
Brush	8	31,188	334	9,336	240,150	25.7	42,480	4.6
East Bureau	9	33,016	322	10,259	234,950	22.9	40,940	4.0
Brush-BBC	10	85,212	315	27,038	607,090	22.5	106,890	4.0
Pond Creek	11	108,904	314	34,656	741,620	21.4	157,530	4.5
Rocky Run	12	301,231	318	94,701	1,908,870	20.2	346,630	3.7
Old Channel (OUTLET)	13	393,672	316	124,552	2,542,390	20.4	458,690	3.7

Table 3-16 presents each basin's estimated average annual load independent of the upstream watershed flow and nutrient loads that passes through it. The variation in nutrient loads delivered is due to the effects of cropping pattern and land cover included in the model simulations, with some influence of soil type and slope on the partitioning of surface and subsurface flows. TN loss is positively correlated with row crop land use, whereas the variation in TP loss between basins is likely from a combination of land use, soil type, and slope effects.

Table 3-16. Average annual baseline runoff (or flow) with nutrient load and loss within each sub-watershed with point source impact included.

BASIN NAME	ID	RUNOFF	FLOW	BASIN AREA	AREA IN ROW CROPS	TOTAL NITROGEN		TOTAL PHOSPHORUS	
		(1,000 MG)	(mm)	(ha)	(%)	LOAD (kg)	LOSS (kg/ha)	LOAD (kg)	LOSS (kg/ha)
Lime Creek	1	23,198	331	7,011	89.4	138,720	19.8	23,220	3.3
West Bureau	2	48,060	309	15,547	83.0	330,080	21.2	74,220	4.8
Pike Creek	4	28,551	343	8,325	87.0	222,970	26.8	36,110	4.3
Sublette	3	55,355	340	16,260	85.1	379,440	23.3	50,090	3.1
Masters Fork	6	49,117	332	14,796	86.8	297,010	20.1	45,780	3.1
Green Oak	5	12,478	315	3,965	76.7	68,690	17.3	12,760	3.2
Epperson Run	7	27,394	300	9,146	54.1	125,050	13.7	26,370	2.9
Brush	8	31,188	334	9,336	91.6	240,150	25.7	42,480	4.6
East Bureau	9	33,016	322	10,259	80.7	234,950	22.9	40,940	4.0
Brush-BBC	10	21,008	282	7,443	60.4	131,990	17.7	23,470	3.2
Pond Creek	11	37,646	311	12,098	70.40	272,820	22.6	60,090	5.0
Rocky Run	12	19,432	257	7,553	63.4	74,090	9.8	17,990	2.4
Old Channel	13	7,229	257	2,813	40.3	26,430	9.4	5,170	1.8
TOTAL AT OUTLET		393,672	316	124,552		2,542,390		458,690	

Since the AnnAGNPS model routes the runoff and nutrient loads from each drainage area (or cell) downstream into the stream network, the model has the unique ability to track pollutants as they are delivered through the watershed. Through this source accounting method, we can illustrate where the delivered nutrient load originated in the watershed (Figure 3-9). As expected, land in corn and soybean cultivation contributes higher nitrogen loads in comparison to non-row crop areas, such as forested land (See land cover map Figure B-1 in Appendix B). The headwater areas contribute the highest nitrogen loads. The areas with higher phosphorus delivered loads correspond to lands with more highly erodible soils or pasture (livestock) as the land use.

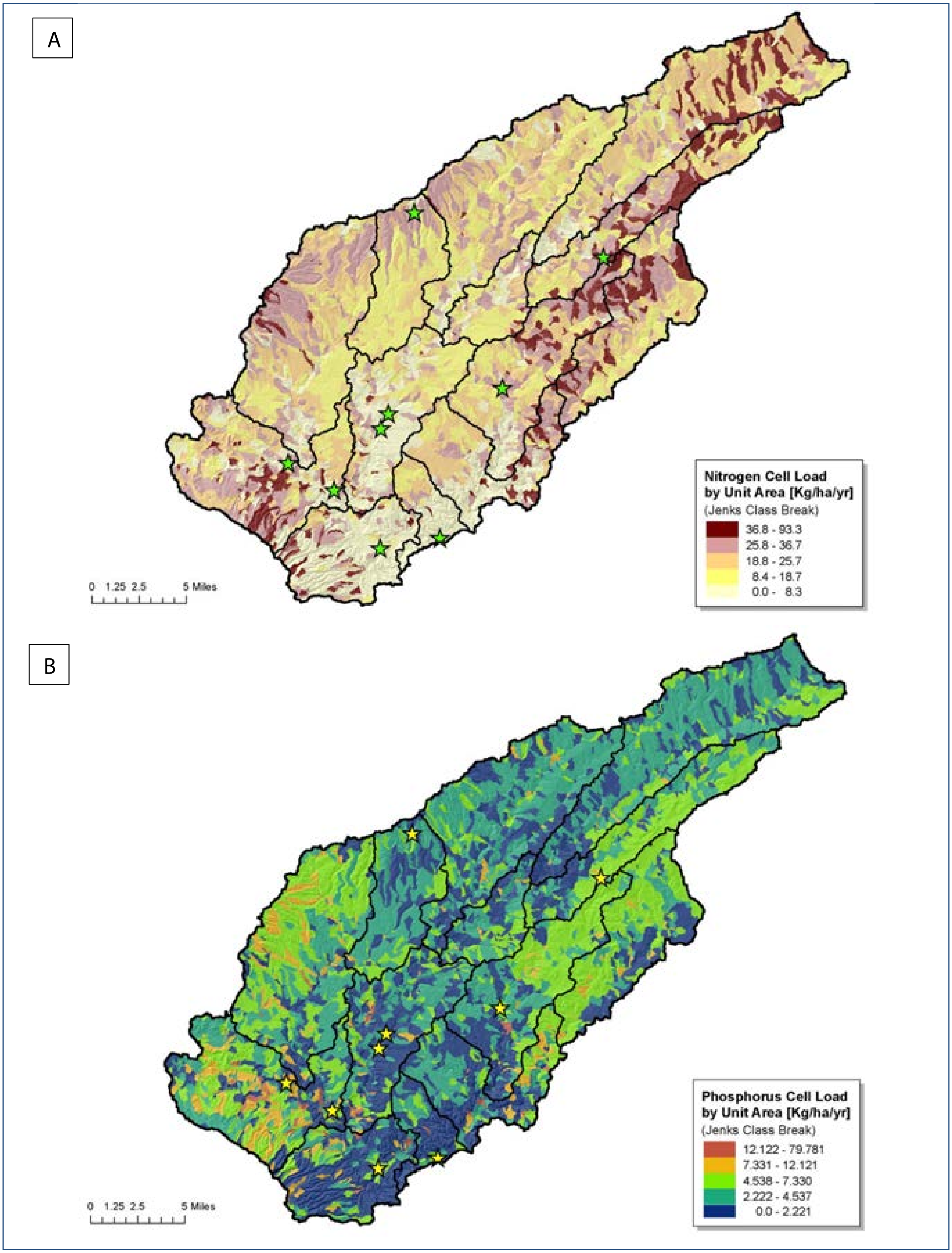

Figure 3-9. Average annual total nitrogen (A) and phosphorus (B) delivered cell load (kg/ha/yr) in the AnnAGNPS defined Big Bureau Creek watershed. The stars represent the nine permitted point sources.

NUTRIENT FORM

The composition of the baseline load reflects what is typically transported to waterbodies in agricultural areas (Table 3-17). Surface runoff is generally composed of attached organic nitrogen, while tile drainage consists primarily of dissolved inorganic nitrogen forms (i.e., NO_3, NO_2, and NH_4). The relatively flat landscape, intensive tile drainage, and land use practices that leave soil exposed (row crops versus pasture) are conducive for the infiltration and leaching of NO_3-N. The predominant form of nitrogen transported through the BBC watershed is the dissolved fraction (ranging from 64 to 81%). In the lower Illinois River, it was reported that 83% of the TN was discharged as NO_3-N (Goolsby and Battaglin 2001). Greater than 80% of tile drainage flux during precipitation events was NO_3, while NH_4 and dissolved organic nitrogen comprised 1-7% and 2-14%, respectively (Cuadra and Vidon 2011). The watershed characteristics are also conducive to dissolved P leaching through tiles (Gentry et al. 2007); however, attached P is the primary form of transport to waterbodies from overland (surface) runoff and subsequent soil erosion. The model estimated that attached P was 53-60% of the P load transported out of the basins.

Table 3-17. Composition of average annual nitrogen and phosphorus baseline loads at each basin outlet with the nine point sources included. The highlighted basins are downstream of another basin.

BASIN NAME	ID	NITROGEN					PHOSPHORUS						
		ATTACHED		DISSOLVED		TOTAL	ATTACHED		ORGANIC		DISSOLVED INORGANIC		TOTAL
		(kg)	(%)	(kg)	(%)	(kg)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)
Lime Creek	1	33,060	24	105,660	76	138,720	13,350	57	6,390	28	3,480	15	23,220
West Bureau	2	151,490	32	317,310	68	468,800	54,980	56	28,600	29	13,870	14	97,440
Pike Creek	4	48,170	22	174,800	78	222,970	21,510	60	9,140	25	5,470	15	36,110
Sublette	3	72,410	19	307,030	81	379,440	29,010	58	13,770	27	7,320	15	50,090
Masters Fork	6	80,530	27	216,490	73	297,010	24,280	53	15,320	33	6,180	13	45,780
Green Oak	5	138,510	21	532,590	79	671,100	57,990	59	26,410	27	14,560	15	98,960
Epperson Run	7	253,190	23	839,970	77	1,093,160	97,430	57	48,220	28	25,460	15	171,110
Brush	8	60,700	25	179,450	75	240,150	24,500	58	11,430	27	6,560	15	42,480
East Bureau	9	60,210	26	174,740	74	234,950	23,570	58	11,410	28	5,960	15	40,940
Brush-BBC	10	162,640	27	444,450	73	607,090	60,740	57	30,900	29	15,250	14	106,890
Pond Creek	11	265,870	36	475,750	64	741,620	85,140	54	50,700	32	21,680	14	157,530
Rocky Run	12	550,900	29	1,357,970	71	1,908,870	191,690	55	105,320	30	49,620	14	346,630
Old Channel (OUTLET)	13	720,260	28	1,822,130	72	2,542,390	255,590	56	137,530	30	65,560	14	458,690

TIMING

In agricultural watersheds, the window for greatest NO_3-N loss is February through July (Schilling and Zhang 2004). Nitrogen losses are most prevalent in the spring when the crops are not present or are too immature to effectively immobilize the available nitrate from the applied fertilizer (Helmers et al. 2007). In contrast, phosphorus in surface waters does not follow a consistent seasonal pattern. Instead, TP loads increase with higher precipitation events from overland runoff and tile discharge (Correll et al. 1999; Sharpley et al. 2000). The higher seasonal baseline loads for TN and TP are consistent with the timing of high precipitation or peak discharge events in the spring (March–May) and summer (June–August) (Table 3-18). Figure 3-10 and Figure 3-11 illustrate the variability in the nitrogen and phosphorus delivered load, respectively, between the winter and spring seasons throughout the BBC watershed.

Since we did not have specific effluent data for any of the point sources, we assumed that the discharged load would be consistent and would not vary over the course of the year beyond minor fluctuations. However, the watershed model demonstrated that the point source load has more impact on basin baseline nutrient loads during the fall (September–November) and winter (December–February) seasons when there are fewer precipitation events and less runoff (Table 3-19). The seasonal effect of point sources within each basin is presented in Appendix B, Table A-1.

Table 3-18. Seasonal comparison of nitrogen and phosphorus baseline loads (with point sources) at the basin outlets. Highlighted basins are downstream of another basin.

BASIN	ID	NITROGEN LOADS (kg)				PHOSPHORUS LOADS (kg)			
		WINTER	SPRING	SUMMER	AUTUMN	WINTER	SPRING	SUMMER	AUTUMN
Lime Creek	1	14,097	48,918	50,158	25,546	2,407	9,535	7,650	3,630
West Bureau	2	45,269	164,873	175,281	83,378	9,798	40,046	32,567	15,031
Pike Creek	4	25,059	102,104	61,031	34,777	3,975	14,474	11,718	5,944
Sublette	3	38,409	160,343	113,947	66,742	5,141	20,450	16,520	7,983
Masters Fork	6	28,887	104,237	109,378	54,512	4,011	19,164	16,038	6,561
Green Oak	5	70,451	287,819	198,570	114,258	10,471	40,159	32,298	16,031
Epperson Run	7	113,617	433,888	351,945	193,710	17,298	69,691	56,824	27,300
Brush	8	25,081	104,505	71,269	39,297	4,562	17,174	13,942	6,804
East Bureau	9	24,794	99,009	71,225	39,924	4,172	16,543	13,733	6,495
Brush-BBC	10	62,731	255,795	186,882	101,684	10,832	43,480	35,786	16,795
Pond Creek	11	37,863	272,650	274,593	126,518	14,742	65,249	54,090	23,448
Rocky Run	12	188,043	734,734	651,901	334,192	33,479	142,281	116,948	53,919
Old Channel (OUTLET)	13	254,322	999,089	847,498	441,477	44,841	187,753	154,228	71,867

Table 3-19. Seasonal percent increase in nitrogen and phosphorus baseline loads due to point source contribution. Highlighted basins are downstream of another basin. Basins in bold receive direct point source discharge.

BASIN	ID	TOTAL NITROGEN PERCENT INCREASE				TOTAL PHOSPHORUS PERCENT INCREASE			
		WINTER	SPRING	SUMMER	AUTUMN	WINTER	SPRING	SUMMER	AUTUMN
Lime Creek	**1**	**0.86**	**0.26**	**0.25**	**0.48**	**1.06**	**0.34**	**0.42**	**0.92**
West Bureau	2	0.27	0.08	0.07	0.15	0.27	0.10	0.13	0.27
Pike Creek	**4**	**0.00**	**-0.07**	**0.00**	**0.03**	**0.00**	**0.00**	**0.01**	**0.02**
Sublette	3	0.39	0.10	0.17	0.29	0.49	0.21	0.26	0.50
Masters Fork	6	0.14	0.00	0.05	0.11	0.21	0.08	0.10	0.21
Green Oak	5	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Epperson Run	**7**	**3.13**	**0.80**	**1.02**	**1.85**	**2.02**	**0.75**	**0.89**	**1.69**
Brush	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
East Bureau	**9**	**0.40**	**0.04**	**0.11**	**0.26**	**0.42**	**0.14**	**0.17**	**0.34**
Brush-BBC	10	0.16	0.02	0.04	0.10	0.16	0.06	0.07	0.15
Pond Creek	**11**	**0.81**	**0.21**	**0.21**	**0.44**	**0.75**	**0.22**	**0.26**	**0.59**
Rocky Run	**12**	**2.27**	**0.57**	**0.67**	**1.30**	**1.51**	**0.57**	**0.67**	**1.36**
Old Channel (OUTLET)	**13**	**1.74**	**0.43**	**0.53**	**1.02**	**1.20**	**0.46**	**0.54**	**1.09**

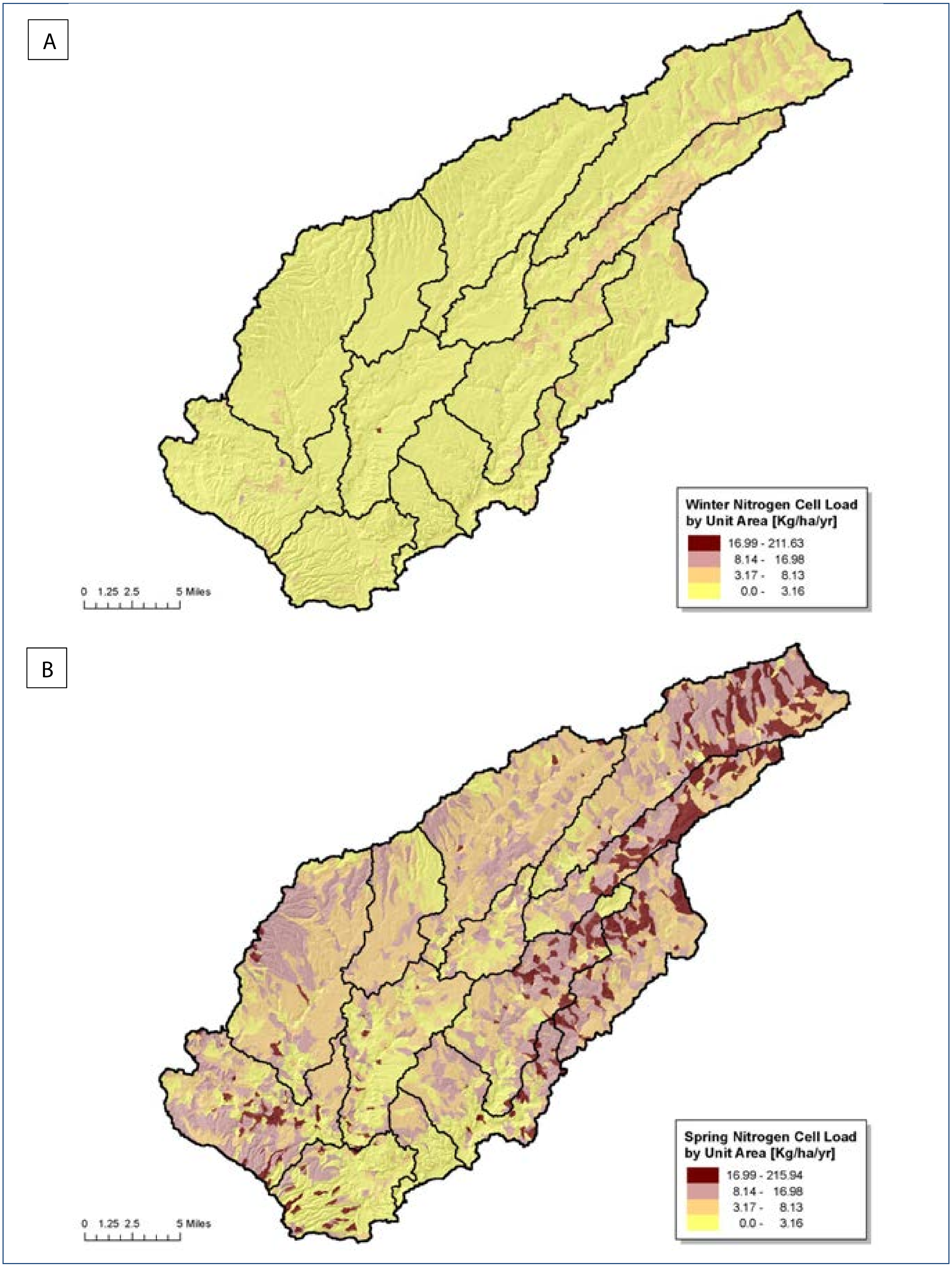

Figure 3-10. Comparison of total nitrogen contribution (kg/ha/yr) during winter (A) and spring (B) seasons.

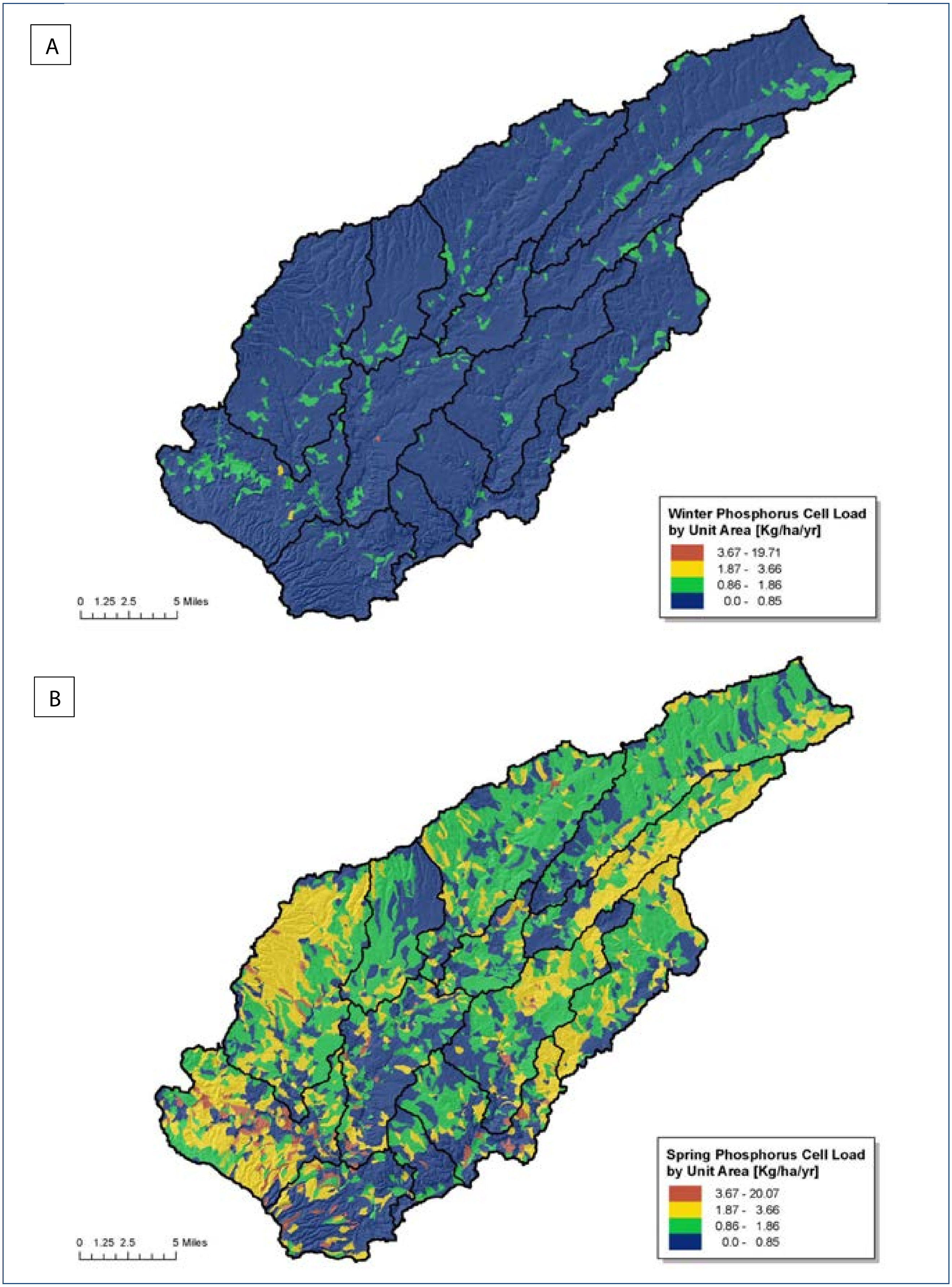

Figure 3-11. Comparison of phosphorus contribution (kg/ha/yr) during winter (A) and spring (B) seasons.

3.5.2 Wetland nutrient removal

Nutrient management and nutrient reduction practices can reduce nonpoint source loads. Understanding nutrient origin, transport, and composition can help assess how effective individual practices are and where practice implementation might result in more efficient load reduction. Since a significant amount of nitrogen in the BBC watershed is delivered in the form of NO_3-N via subsurface tiles to surface waters, practices that address surface runoff (e.g., cover crops, buffer strips, grassed waterways, etc.) will have little opportunity to intercept these loads. Wetlands sited to intercept tile and drainage flow have the potential to significantly reduce delivered loads by intercepting and “treating” the nutrients via transformation, assimilation, and sequestration of nitrogen and phosphorus and, to a lesser extent, trapping attached nutrients in the surrounding buffer.

The AnnAGNPS model with the wetland and buffer features was used to evaluate three “practice” scenarios: wetlands only, buffers only, and wetlands plus buffers. The nutrient removal capacity of these wetland plus buffer potential areas was calculated by subtracting the results of the “practice” scenarios from the baseline scenario at the outlet of each potential site. All the practice scenarios were simulated without the inclusion of the point sources. The wetland plus buffer scenario was also simulated with the impact of the nine wastewater treatment facilities.

The standard output of the AnnAGNPS model provided the integrated effect of all the 80 potential wetlands on nutrient load within the context of a system. However, there were nine instances where more than one wetland was located along the same stream reach or tributary. In these instances, the upstream wetland will have an impact on the hydraulic loading and nutrient reduction capacity of the downstream wetlands. To determine each wetland’s nutrient reduction capacity with the upstream wetlands present (individual wetland analysis) and without the upstream wetlands present (independent wetland analysis), the standard solve process and output had to be modified. Understanding the effect of each potential site was important, as the smart market-clearing model needed the nutrient removal ability of each potential wetland independent of other wetlands in the system.

Based on the selection criteria used, 80 potential wetlands were identified where runoff could be impounded in the basin’s upper reaches. In total, these potential wetlands could capture runoff and provide nutrient removal for 23% of the entire BBC watershed (Table 3-20). The potential wetlands plus buffer accounted for 351 ha (867 acres) of agricultural land, which is less than 0.3% of the total watershed area. Except for the Lime Creek basin (1.2%), the wetland plus buffer area was less than 0.6% of the total land area in each basin.

Table 3-20. The drainage area and area of the 80 wetland plus buffer sites in comparison to the total basin drainage area. Only the farthest downstream wetland’s drainage area was included for wetlands located on the same reach.

BASIN	ID	BASIN DRAINAGE AREA	WETLAND DRAINAGE AREA WITHIN BASIN	WETLAND DRAINAGE AREA : BASIN DRAINAGE AREA	WETLAND PLUS BUFFER AREA	WETLAND PLUS BUFFER AREA : BASIN AREA
		(ha)	(ha)	(%)	(ha)	(%)
Lime Creek	1	7,011	3,024	43	86.33	1.2
West Bureau	2	15,547	4,001	26	44.61	0.3
Pike Creek	4	8,325	435.5	5.0	16.67	0.2
Sublette	3	16,260	2,352	14	17.90	0.1
Masters Fork	6	14,796	3,616	24	13.56	0.1
Green Oak	5	3,965	1,718	43	13.07	0.3
Epperson Run	7	9,146	1,267	14	13.15	0.1
Brush	8	9,336	3,829	41	43.75	0.5
East Bureau	9	10,259	3,991	39	59.95	0.6
Brush-BBC	10	7,443	1,086	15	16.04	0.2
Pond Creek	11	12,098	1,939	16	12.19	0.1
Rocky Run	12	7,553	135.9	2.0	1.52	0.0
Old Channel	13	2,813	741.7	26	12.39	0.4
TOTAL AT OUTLET		124,552	28,135	23	351.13	0.3

NUTRIENT REDUCTION QUANTITY

The 351 ha of wetlands plus buffer (0.3% of the watershed area) would reduce the entire BBC watershed TN and TP load by an average annual of 14% and 11%, respectively (Table 3-21), while servicing only 23% of the watershed. With the AnnAGNPS model, we were able to estimate wetland nutrient load reductions spatially throughout the watershed. The percent nitrogen and phosphorus reduction within each basin is a factor of the total wetland and buffer area, the percent of drainage area intercepted by the sites, and the location of sites within high nutrient load areas. For example, the potential wetland sites are located in the Lime Creek basin where they intercept the upper headwater cells with the highest delivered loads for TN and TP (Appendix A, Figure A-2 and Figure A-3). (The effect of the wetlands plus buffer on the load delivered within each basin outlet is presented in Appendix A, Table A-2.).

Table 3-21. Average annual wetland runoff and nutrient load reduction at the basin outlets based on the combined effect of all 80 potential sites under the wetland plus buffer scenario. Highlighted basins are downstream of another basin.

BASIN	ID	BASIN DRAINAGE AREA	WETLAND PLUS BUFFER AREA	RUNOFF REDUCTION		TN REDUCTION		TP REDUCTION	
		(ha)	(ha)	(Mg)	(%)	(kg)	(%)	(kg)	(%)
Lime Creek	1	7,011	86.33	6,797,235	29	50,100	36	6,820	29
West Bureau	2	22,558	44.61	11,689,103	16	100,380	21	17,010	17
Pike Creek	4	8,325	16.67	1,240,403	4.3	7,996	3.6	1,498	4.1
Sublette	3	16,260	17.90	2,132,487	3.9	23,845	6.3	2,015	4.0
Masters Fork	6	14,796	13.56	1,709,899	3.5	26,838	9.0	1,904	4.2
Green Oak	5	28,550	13.07	5,242,108	5.4	48,892	7.3	6,033	6.1
Epperson Run	7	52,492	13.15	8,582,052	5.0	87,696	8.0	9,508	5.6
Brush	8	9,336	43.75	5,286,552	17	60,220	25	8,684	20
East Bureau	9	10,259	59.95	5,576,057	16	61,189	26	8,884	22
Brush-BBC	10	27,038	16.04	12,099,669	14	133,190	22	19,036	18
Pond Creek	11	34,656	12.19	13,206,606	12	123,727	17	19,877	13
Rocky Run	12	94,701	1.52	23,015,461	7.6	216,431	11	30,637	8.8
Old Channel (OUTLET)	13	124,552	12.39	35,360,511	9.0	352,645	14	49,778	11

NUTRIENT REDUCTION FOR THREE PRACTICE SCENARIOS

Under the buffer practice scenario, the model estimated that the buffers would remove only 1.2% (or 29,100 kg) TN and 1.8% (or 8,380 kg) TP at the basin level (Appendix B, Table A-3). Except for the Lime Creek basin with approximately 24 ha (59 acres) of potential buffer area removing 4.5% TN and 8.2% TP, the buffer practice in the individual basins is removing less than 2.2% and 3.7% of the TN and TP loads, respectively (Appendix B 0).

The permanent vegetative buffer surrounding the wetland traps the attached or particulate fraction of nitrogen and phosphorus, reducing the nutrient load that leaves the adjacent fields and is transported to the wetland. At the individual wetland level, TN and TP are trapped and deposited at nearly the same rate under the buffer-only scenario, but the effect of the buffer on nutrient reduction is highly variable (Appendix A, Table A-5). Figure A-4 in Appendix A compares the TN and TP loads at potential sites 505 (West Bureau Creek basin) and 573 (Lime Creek basin) under the three practice scenarios. Despite having buffers of relatively similar size, the buffer at site 505 reduces the nutrient load minimally. In comparison, the buffer at site 573, which has a smaller drainage area, has more effect on the TN load and reduces the TP load more than the wetland. Size, contributing drainage area, land use, and location of the buffer relative to the delivered load are factors that affect the performance of the buffer.

In comparison to the buffer scenario, the wetland-only practice scenario removes a higher fraction of the nutrients delivered via overland or subsurface runoff by transformation, sequestration, or assimilation. The 80 potential wetlands, comprising 225 ha (556 acres), would impound 9% of the total BBC watershed runoff and reduce the TN load by 332,100 kg (13.2%) and TP load by 43,690 kg (9.6%). The wetland-only reduction in the average annual nutrient load within each basin ranges over an order of magnitude for TN (3.5-35%) and TP (2.0-24.4%).

Under the combined scenario, the wetlands plus buffers reduced TN by 13.9% (352,170 kg) and TP by 10.9% (49,620 kg) at the watershed outlet. Wetlands vary in reducing TN and TP loads, as performance is influenced by hydraulic loading rates, retention time, and land use within the contributing drainage area (Appendix A, Table A-5). While individual site performance can be described by percent reduction (or efficiency), nutrient load reduction related only weakly to percent removal. The percent removal of the wetlands' intercepting small drainage areas (< 500 ha) varied widely, as percent removal depended on wetland size and nutrient loading (hydrology and land use) (Tomer et al. 2013). Percent removal increases with increasing wetland area to watershed area ratio (w:w) or decreasing hydraulic loading.

Individual site performance can be evaluated and compared through potential mass removal, or the load removed per wetland plus buffer area (kg/ha). Table 3-22 lists the top ranked wetlands plus buffers in terms of estimated total nitrogen mass removal. Table A-6 in Appendix B contains the complete list of 80 potential sites. Mass removal rates range from 318-7,455 kg TN/ha and 5-1,206 kg TP/ha. The potential wetland sites with the largest estimated mass removal rates are those with the largest annual hydraulic loading (AHL) rates (flow divided by w:w ratio); therefore, those wetlands received the higher TN and TP loading rates.

Table 3-22. The top ranked independent wetlands (plus buffer) based on total nitrogen mass removal (kg/ha). (Complete list of 80 potentials in Appendix A Table A-6).

WETLAND ID	WETLAND AREA	WATERSHED AREA	W:W RATIO	AHL	TOTAL NITROGEN REDUCTION			TOTAL PHOSPHORUS REDUCTION		
	(ha)	(ha)	(%)	(m/yr)	(kg)	(%)	(kg/ha)	(kg)	(%)	(kg/ha)
1919	2.11	1,642	0.13	272	30,159	59.1	7,455	5,096	54.6	1,260
566	0.23	238	0.10	385	3,699	54.5	5,183	613	67.4	859
555	0.75	398	0.19	187	5,720	67.7	3,769	512	61.4	338
574	2.10	1,350	0.16	213	13,802	50.8	3,626	1,518	32.5	399
1924	1.22	922	0.13	270	6,872	22.1	2,788	1,110	20.1	450
1136	0.48	450	0.11	339	3,325	33.8	2,784	322	0.1	270
815	1.95	1,545	0.13	282	10,019	23.8	2,483	607	10.0	151
160	3.33	1,365	0.24	144	15,598	30.9	2,462	1,585	17.5	250
1146	1.38	703	0.20	174	6,296	8.9	2,397	679	27.7	259
832	0.49	389	0.13	280	2,707	26.6	2,320	242	15.8	208
1730	0.33	131	0.25	138	1,803	60.5	2,272	250	62.3	315
1906	0.53	325	0.16	212	2,775	31.9	2,220	371	25.3	296
567	0.33	145	0.23	160	1,917	51.2	2,208	296	56.5	341
860	2.63	1,798	0.15	210	11,634	34.7	2,207	1,034	21.6	196
2142	0.64	271	0.24	157	3,037	31.9	2,050	427	26.4	288
1174	0.55	378	0.14	235	2,779	35.1	1,981	291	22.9	208
2114	3.27	619	0.53	70	9,814	48.5	1,975	1,013	35.0	204
491	0.71	491	0.15	218	3,893	42.7	1,921	747	36.9	369
2065	3.91	811	0.48	69	11,890	50.2	1,910	2,059	41.4	331
2130	5.83	899	0.65	55	15,573	51.4	1,818	2,063	39.5	241

Mass removal will generally increase with hydraulic loading as long as biogeochemical conditions are conducive for denitrification reactions (i.e., availability of nitrate and carbon). Measurements of nutrient removal wetlands in the Midwest suggest that these conditions are well supported in wetlands receiving hydraulic loading < 60 m/yr (Crumpton et al. 2006). The majority of the top-ranked wetlands, in terms of TN, have hydraulic loading rates two- to five-fold greater than 60 m/yr as they have w:w ratios < 0.5; therefore, the wetland size may not have adequate residence time to allow the wetlands' inherent functions to "treat" the nutrient loads. Both residence time and load reductions can be increased by increasing the wetland area relative to its contributing watershed area (the w:w ratio). Since detailed drainage information was not available for any BBC basin, we assumed that the direct tile drainage area was equal to the surface watershed areas. In reality, the direct tile drainage area may be smaller than the surface watershed drainage area. Therefore, the w:w ratio determined for this analysis may be less than a ratio based on the tile drainage area discharge to the wetland.

For a nutrient credit trading program, we are interested in the credits generated or the amount of nutrient reduced by the potential sites. The wetland practice plus buffer reduces the average annual TN and TP load delivered by 352,600 kg and 49,800 kg, respectively. This nutrient reduction provided by all 80 potential wetland sites far exceeds the local wastewater treatment facilities' credit demand based on the diversified effluent standard by nearly 20-fold. Therefore, only a fraction of the potential wetland sites would need to be implemented to provide the necessary load reduction required by the proposed permit limits. If we tighten the criteria to wetland sites that meet a 0.5-3.0% w:w ratio, then the estimated credit supply from 36 potential sites still would be 10 times greater than the credit demand.

The 10 wetland candidate sites located in the Green Oak, Pike Creek, and Sublette-BBC basin provide more than double the credit demand estimated for the "major" Princeton STP, which is located downstream in the Epperson Run basin. Nutrient reduction upstream of the facility lowers the potential for local water quality impacts or unacceptably high levels of pollutants downstream of the facility discharge point (i.e., hot spots).

Since AnnAGNPS is a continuous model that analyzes the long-term impacts of climate, hydrological changes, and land management practices, variability in the annual wetland removal data is expected over a 30-year period (Appendix A, Table A-7). Depending on the timing and magnitude of precipitation events, a wetland can have more impact on nutrient reduction in the years with high flows compared to the years with lower flows when the wetlands will receive less flow and nutrients. The potential wetland sites with larger drainage areas, and therefore higher runoff, have the higher standard deviations relative to nutrient reduction capacity, due to the higher fluctuations in flows and nutrient loadings. The average annual values for nutrient loads and reductions allows for comparison between scenarios and sites and provides a reasonable estimate of the potential credit production by a wetland over a longer period of time. To account for the random variability in weather, land management, and other factors that affect nutrient reduction during the year, an uncertainty ratio or a discount factor can be applied to the reduction to provide a more conservative estimate of removal.

NUTRIENT REDUCTION FORM

The pollutants discharged from the point sources—nitrogen and phosphorus—are the same or equivalent to the pollutants being removed by the potential wetland sites. However, certain forms of nitrogen and phosphorus have more environmental impact on water quality than others. The bioavailable fractions serve as fuel for algal primary production and growth, which can lead to eutrophic or hypoxic condition in local or downstream waterbodies. The nutrient forms removed by the individual wetland sites reflect the major proportion of TN (i.e., dissolved nitrogen) and TP (i.e., attached inorganic phosphorus) runoff that is delivered to the outlet of each basin and the watershed (Appendix A, Table A-8).

The Load Reduction Strategy within the draft Middle Illinois River TMDL (See Section 3.1.2) focuses on reducing nitrate-nitrogen (NO_3 -N) and TP loadings. The dissolved inorganic forms of TN (NO_3 –N, NO_2 –N) are 100% bioavailable, whereas both dissolved organic nitrogen and attached organic nitrogen are only partially bioavailable. A typical wastewater treatment plant's effluent load is predominantly composed of the dissolved fraction of nitrogen (NO_3-N). The NO_3-N fraction comprised approximately 80% of the Princeton STP discharge. With denitrification as the primary mechanism by which wetlands serve as nitrogen sinks, the dissolved nitrogen fraction (predominately NO_3-N) accounted for 84% of the TN removed by the candidate wetland sites at the outlet of the watershed and for 76-89% in each basin (Table 3-23). Since the composition of the wetland nitrogen load reduction is similar to the point source nitrogen effluent load, the wetlands can provide an equivalent reduction based on either a NO_3-N or TN limit.

A TP limit or load allocation allows a direct equivalent trading relationship between the WWTPs and the wetlands; however, these two entities contribute or remove different forms of phosphorus. A typical wastewater treatment plant's effluent load is predominantly composed of the dissolved inorganic phosphorus (PO_4-P). In comparison, dissolved inorganic P accounted for only 14-17% of TP removed by the wetlands and attached inorganic P accounted for 51-67% (Table 3-23).

The dissolved inorganic and organic phosphorus forms from both WTTP discharge and agricultural runoff are generally assumed to be 100% bioavailable. The particulate forms can exhibit a wide range of bioavailability. The bioavailable particulate (or attached) forms include phosphorus loosely bound to sediments, phosphorus bound to iron, and particulate organic phosphorus. The attached P in agricultural nonpoint source pollution tends to be less bioavailable than the attached P discharged from point sources. Machesky et al. (2005) found that only 10-30% of particulate or attached phosphorus was bioavailable in Illinois streams. The percent of TP that is bioavailable, on average, is 89% from a WWTP treating a rural population, 83% from an urban WWTP with biological treatments, and 31% from agricultural fields (Ekholm and Krogerus 2003).

Table 3-23. The composition of the nutrient load reduction for each individual BBC basin based on the combined effect of all 80 potential wetland sites. (ATT= attached, DISS. = dissolved).

BASIN	ID	TOTAL NITROGEN REDUCTION (kg)					TOTAL PHOSPHORUS REDUCTION (kg)						
		TOTAL	ATT.	%	DISS.	%	TOTAL	ATT. INORG.	%	ORGANIC	%	DISS. INORG.	%
Lime Creek	1	50,100	12,033	24	38,066	76	6,820	3,498	51	2,370	35	952	14
West Bureau	2	100,380	22,550	22	77,831	78	17,010	10,081	59	4,331	26	2,597	15
Pike Creek	4	7,996	1,552	19	6,444	81	1,498	971	65	285	19	243	16
Sublette	3	23,845	2,612	11	21,232	89	2,015	1,211	60	501	25	303	15
Masters Fork	6	26,838	3,165	13	23,673	88	1,904	1,037	54	607	32	259	14
Green Oak	5	48,892	5,340	11	43,552	89	6,033	4,025	67	1,002	17	1,006	17
Epperson Run	7	87,696	9,329	11	78,367	89	9,508	6,198	65	1,761	19	1,549	16
Brush	8	60,220	8,415	14	51,805	86	8,684	5,673	65	1,592	18	1,419	16
East Bureau	9	61,189	8,350	14	52,839	86	8,884	5,847	66	1,576	18	1,461	17
Brush-BBC	10	133,190	18,847	14	114,343	86	19,036	12,381	65	3,560	19	3,095	16
Pond Creek	11	123,727	28,431	23	95,296	77	19,877	11,473	58	5,458	28	2,946	15
Rocky Run	12	216,431	38,828	18	177,603	82	30,637	18,517	60	7,413	24	4,706	15
Old Channel (OUTLET)	13	352,645	57,670	16	294,975	84	49,778	30,985	62	10,973	22	7,819	16

Of the 80 potential wetland sites, one site is located directly downstream of a wastewater treatment facility. Wetland 564 was located approximately 2.4 km (1.5 miles) downstream from the Ohio STP, a lagoon treatment system, on the headwater reach of Lime Creek. This wetland alone on an average annual basis could treat the entire runoff, sediment, and nitrate (or total) nitrogen load discharged by the STP and could meet the estimated TP load reduction (110 kg) needed to achieve the diversified effluent standard (Table 3-24).

Table 3-24. The estimated baseline load and annual average load reduction for potential wetland site 564, located downstream of the discharge point of the Village of Ohio STP.

CONDITION	RUNOFF	SEDIMENT	NITROGEN LOAD (kg)			PHOSPHORUS LOAD (kg)			
	(Mg)	(Mg)	TOTAL	DISSOLVED	ATTACHED	TOTAL	ATTACHED INORG.	ORG.	DISSOLVED INORGANIC
Baseline	1,719,960	943.3	8,667	5,714	2,953	1,116	104.2	416.5	595.0
Baseline with PS	1,994,285	2,304	13,673	8,672	5,000	1,911	240.3	641.0	1,030
Load increase due to PS discharge	274,325	1,361	5,006	2,958	2,047	795	136.1	224.5	435
Wetland plus buffer	1,348,905	857	7,087	3,175	3,912	1,380	114.3	455.0	810.7
Load decrease due to wetland practice	645,380	1,447	6,586	5,497	1,088	561	126.0	186	219.3

NUTRIENT REDUCTION TIMING

Constructed wetlands have the ability to reduce pollutant levels throughout the year, but nutrient removal depends on weather and season. To ensure that the wetlands could offset point source emissions throughout the year, we determined the extent to which the temporal patterns in wetland performance match temporal patterns in point source demand. While the percent nutrient removal is consistent between seasons at the basin level, the mass nutrient reduction is higher in the spring and summer, corresponding to the higher delivered loads available for removal (Table 3-25). The winter months (December–February) have the least mass nutrient removal, but the nutrient reduction is ample to meet the estimated credit demand for nitrogen (1580 kg/month) and phosphorus (184 kg/month). The 80 potential wetlands plus buffer sites have sufficient nutrient reduction potential for each season to meet the point source demand. Individual wetland seasonal performance is listed in Appendix A, Table A-9.

Table 3-25. Season nutrient reduction (load and percent) at the outlet of each basin. Highlighted basins are downstream of another basin.

BASIN ID	ID	TOTAL NITROGEN REDUCTION								TOTAL PHOSPHORUS REDUCTION							
		WINTER		SPRING		SUMMER		AUTUMN		WINTER		SPRING		SUMMER		AUTUMN	
		(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)
Lime Creek	1	5,329	38	18,049	37	17,583	35	9,139	36	641	27	2,932	31	2,334	31	913	25
West Bureau	2	11,593	26	34,211	21	35,462	20	19,114	23	1,967	20	6,872	17	5,548	17	2,622	17
Pike Creek	4	859	3	3,174	3	2,629	4	1,334	4	195	5	597	4	449	4	257	4
Sublette	3	2,989	8	7,474	5	7,952	7	5,430	8	202	4	803	4	652	4	358	4
Masters Fork	6	3,338	12	8,196	8	9,272	8	6,032	11	166	4	769	4	671	4	298	5
Green Oak	5	6,300	9	16,228	6	15,836	8	10,528	9	797	8	2,320	6	1,758	5	1,158	7
Epperson Run	7	11,305	10	27,886	6	29,082	8	19,423	10	1,218	7	3,662	5	2,828	5	1,800	7
Brush	8	8,588	34	24,488	23	16,182	23	10,962	28	1,195	26	3,235	19	2,623	19	1,631	24
East Bureau	9	8,371	34	24,675	25	16,784	24	11,360	28	1,173	28	3,329	20	2,772	20	1,610	25
Brush-BBC	10	18,466	29	53,808	21	36,425	19	24,491	24	2,578	24	7,193	17	5,788	16	3,477	21
Pond Creek	11	14,248	21	43,063	16	43,228	16	23,188	18	2,247	15	8,138	12	6,592	12	2,900	12
Rocky Run	12	25,978	14	73,089	10	72,741	11	44,623	13	3,632	11	12,350	9	9,487	8	5,167	10
Old Channel	13	45,264	18	127,785	13	109,506	13	70,090	16	6,225	14	19,584	10	15,167	10	8,801	12

NUTRIENT REDUCTION LOCATION

For environmental efficacy, the improvement in the receiving waterbody must be equivalent if the nutrient loads were reduced at the wastewater treatment facility rather than at the potential wetland site. We evaluated the location of the load reductions to determine whether the water quality benefit at the wetland location was equivalent to any load reductions made by the wastewater treatment facility through enhanced nutrient removal upgrades.

Attenuation was evaluated by looking at the simulated nutrient attenuation ratios from the outlet of the potential sites to the outlet of the BBC watershed. The decay rate used in the model had a half-life of two years, and the travel time for water from the headwaters to the outlet was 83 hours. Therefore, the attenuation ratios were approximately 1.0, meaning the nitrogen loading losses were less than 1% from the headwater potential wetland locations to the BBC outlet, except for wetlands located upstream of another wetland in the same reach. Similarly, the nitrogen attenuation from the Princeton STP to the BBC outlet was 0.034%. Minimal loss through natural attenuation is expected as the majority of the TN is in the dissolved form and the other portion is attached to clay, which does not deposit easily.

3.6 BBC Pollutant Suitability Conclusions

We conducted an analysis to determine the pollutant suitability of a nutrient credit trading program for the BBC watershed. The analysis used a diversified effluent standard for the point sources as the hypothetical driver. Given the low number of permitted facilities and size of the facilities, the credit demand needed to meet the discharge limit was low in comparison to the potential supply in a rural, agricultural watershed. The landscape-assessment approach identified 136 potential wetland sites that were suitable to receive nutrient loadings from agricultural runoff. The nitrogen removal potential for each site was estimated as a function of the hydraulic loading ratio and flow-weighted average nitrate concentration. Phosphorus removal within the wetland area was estimated using two set removal rates. A partially automated wetland siting methodology, developed by TWI based on the best available topographic data and specific wetland and drainage area criteria, located 80 individual wetland plus buffer sites in areas of higher nutrient loadings. An AnnAGNPS model developed specifically for the BBC watershed assessed the baseline nutrient conditions and the nitrogen and phosphorus credit supply provided by these 80 wetlands.

Both model simulations indicate that potential wetland sites have more than sufficient supply of nitrogen to meet the demand set by the proposed effluent limits. Since only a fraction of the proposed potential sites are needed to meet the proposed nitrogen credit demand, more restrictive discharge standards or any imposed trading ratios to account for uncertainty could be accommodated. The AnnAGNPS model simulations show a sufficient phosphorus supply to meet the demand, particularly when the buffer surrounding the wetlands is included. The watershed model analysis indicates a wetland-based trading program is suitable in terms of nitrogen and phosphorus supply, pollutant type and form, impact, and timing. Finally, the constructed wetland practice can play an important role in a nutrient credit trading program, and strategically positioning the wetlands in areas of high nutrient loading can be significant in achieving watershed nutrient reduction strategies.

4 BBC ECONOMIC ANALYSIS

The economic analysis was performed by project partners at the University of Illinois at Urbana-Champaign. Their analysis and findings have been published in Lentz et al. (2011a, 2011b, 2013).

4.1 Credit Stacking and Lumpy Investments

Several studies have suggested that point source (PS) and nonpoint source (NPS) trading would rarely be of benefit, because potential markets are too “thin,” either because the market has too few buyers (PS) and sellers (NPS entities) (Roberts et al. 2008), or because the transaction costs associated with permit trading are too high (Crutchfield et al. 1994). The presence of “thin markets” has been confirmed in several real permit-trading systems (Morgan and Wolverton 2005). Thin markets are not necessarily always unsuccessful, however, because, as described by Woodward (2003), one single trade can be so valuable and result in such great savings that it outweighs the implementation costs of the permit system.

Crutchfield et al. (1994) established three criteria for successful water quality trading markets. The first criterion is that there needs to be significant PS and NPS loads. A second criterion is that a few PS of significant size must exist. The third criterion is that it should be feasible to reduce pollution from NPS. From our literature review, we added a fourth criterion that transaction costs be sufficiently low.

NPS pollution reductions often require changes in land use. Optimal environmental design is complicated when multiple environmental benefits can be associated with a single set of land use choices. While some land-use decisions yield multiple environmental benefits that are co-generated in tandem (Nelson et al. 2009), other management choices can improve one environmental benefit at the expense of others (Jackson et al. 2005). Research on targeting optimal sites for conservation has shown that when multiple benefits can be derived from the land, social welfare implications and the amount of benefits generated depend on the criteria used to select the sites (Babcock et al. 1996, 1997; Feng et al. 2007; De Laporte et al. 2010; Zhao et al. 2004). For example, a program could be established to allow farmers to sell nutrient credits associated with restoring or constructing wetlands on their property. However, targeting sites and selling a credit based on a single benefit (e.g., nitrogen removal) ignores the many other highly valued services that wetlands produce, such as phosphorus removal (Kovacic et al. 2006), carbon sequestration (Hansen 2009), wildlife/waterfowl habitats, and recreational benefits (Woodward and Wui 2001).

A system that restricts landowners to receiving payments only for a single benefit can yield less investment in an activity, such as wetland construction, than is socially optimal because landowners cannot internalize all the positive externalities of their actions (Horan et al. 2004; Nelson et al. 2008; Hansen 2009). For this reason, it might improve welfare to allow landowners to obtain payments for multiple ecosystem services associated with a single management action. For example, if a farmer were able to sell the different services provided by a wetland, then the farmer would be more incentivized to choose and implement this practice for producing nutrient credits in a water quality trading program. On the other hand, earning payments for the multiple benefits (or “credit stacking”) can violate the principle of “additionality” if landowners receive an extra payment for an action that they would have taken or performed in exchange for a single benefit program payment. Additionality requires that the activity have additional ecological benefits and that the activity would not have occurred without the credit payment (i.e., would the benefits or activity have happened anyway).

Woodward (2011) used a theoretical framework with continuous and differentiable cost and benefit functions to analyze the welfare effects of credit stacking across multiple pollutant markets. He found that credit stacking could be optimal if the emission caps for all pollutants are set at their optimal levels and if the programs are implemented in tandem. However, Woodward’s results do not directly apply to situations in which multiple markets are implemented sequentially, nor do they necessarily apply to markets with non-differentiable or non-continuous (i.e., lumpy) cost functions, which categorize most water quality trading programs. Investments in pollution abatement technology are lumpy as capital costs do not increase smoothly as level of removal increases, but rather behave as a step function based on discrete technology based effluent limits (Sado et al. 2010).

The primary objective of this economic analysis was to determine whether a water quality trading market is feasible and socially beneficial in the predominantly agricultural Big Bureau Creek watershed. The market would allow the local wastewater treatment plants (WWTPs) to buy nutrient credits from farmers that install constructed wetlands on a portion of their property. Within this analysis, important issues and questions about water quality trading with lumpy investments (which are common), multiple ecosystem benefits (which are nearly always present), and possible welfare effects of credit stacking (which is controversial) are addressed.

4.2 BBC Case-Specific Conceptual Framework

A credit market requires variation in either one or both of the costs and benefits of providing environmental services. In this study, the empirical example has spatial heterogeneity in both the construction costs and the opportunity cost of converting farmland to wetlands, as well as in wetlands' ability to remove nutrients. Economists commonly analyze tradable permit markets by equalizing marginal abatement costs for all pollution or offset sources (e.g., Hanley et al. 2007); the greater the initial heterogeneity in marginal abatement costs or marginal benefits, the greater the gains that can be realized through permit trading. Such analyses assume that underlying supply and demand for permits are smooth, differentiable functions or that the permit market is thick enough, such that abatement levels can be varied continuously.

The analysis of potential market conditions in the Big Bureau Creek watershed revealed only a relatively small number of potential trading partners, which makes commodity-style nutrient markets infeasible. Since the standard optimization approach is not applicable, an alternative modeling framework was developed. This does not mean that welfare-improving trades do not exist (Woodward 2003), but rather the standard first-order conditions that equate marginal abatement costs and marginal benefits are not relevant for this study. Wetland sizes are governed by specific design parameters such as optimal depth, hydraulic retention, contributing drainage area, and physical restrictions (e.g., cannot impact homesteads, farm structures, roads, etc.) (Kadlec and Wallace 2008); therefore, their ability to remove nutrients cannot easily be scaled. Consequently, a farmer will make a discrete choice about whether or not to construct or restore a wetland versus a continuous choice about wetland size. In addition, WWTPs' nutrient removal upgrades and wetland construction have high up-front fixed costs. The capital investment in either constructed wetlands or WWTP treatment technology can be justified only if it is considered a long-term investment. Therefore, potential trading partners are constrained to make discrete decisions whether to construct a wetland or upgrade a WWTP rather than continuous decisions about the exact quantity of nutrients each wetland or WWTP should remove. For these reasons, this trading model should analyze and compare the total cost of nutrient reductions from the different wetlands and WWTPs rather than the marginal abatement costs.

The specific spatial and seasonal information on the damage from nutrient pollution was not available at the time of this economic analysis; therefore, trading ratios could not be calculated to account for uncertainty and spatial heterogeneity in damages and benefits generated by the wetlands in different locations in the watershed. It was assumed the nitrogen credits were traded on a one-to-one basis. While the spatial and seasonal distribution of nutrient loads are not taken into consideration, it was assumed that the annual nitrogen reductions specified for each effluent standard are satisfied over a 20-year period. This assumption may not result in the optimal pollution level at all locations at all times. For total nitrogen, this is not a critical assumption as the main detrimental effect from nitrate-nitrogen occurs downstream in the Gulf of Mexico, not in local streams and rivers (with the exception of public water supply waterbodies). In contrast, high phosphorus levels can stimulate eutrophication (i.e., excessive algal blooms and aquatic plant growth) in local waters.

Environmental markets are commonly designed with an aggregator working as the "matchmaker" between the credit sellers (i.e., farmers) and the credit buyers (i.e., WTTPs). Some examples are the Delta Institute (2011) that aggregates carbon credits and the Environmental Banc and Exchange (2011) that sells wetland credits. For the purposes of this feasibility study, we assumed that one aggregator facilitates all credit sales and actively assembles the credit sales in a manner that minimizes the total cost of producing credits needed to meet the demand required to satisfy effluent limits. To account for transaction costs, a 35% addition to the abatement costs of nitrogen from wetlands was assumed (Fang et al., 2005).

We assumed a 20-year lifetime for WWTPs, and that wetland installations are carried out with 20-year contracts that prevent farmers from gaining income from the land from either farming or development sales during that time (US EPA 2008). A 5% discount rate was used. We also assumed no price inflation for inputs into a WWTP's removal process and easement payments for the wetlands.

The demand for nutrient credits comes from WWTPs that face higher nutrient removal costs than the costs farmers face from installing wetlands to remove nutrients. In this model, a WWTP is allowed to buy nitrate-nitrogen credits from other treatment plants as well as from wetlands. In the primary trading scenarios, the aggregator would minimize the total cost of meeting a nutrient standard through a combination of operating wastewater treatment facilities and constructing wetlands, a problem that can be described as follows:

(4-1) $$min\ TC = \sum_{i=1}^{I} c_i x_i$$

(4-2) $$s.t. \sum_{i=1}^{I} n_i\, x_i \geq N$$

(4-3) $$x_i \in \{0,1\}$$

where:

c_i represents the total cost of constructing and running wetland or wastewater treatment plant *i* for a period of 20 years;

n_i is the amount of nitrate removed by wetland or wastewater treatment plant *i* over the 20-year period; and

x_i is the binary decision variable which is set to 1 if facility *i* is built (either a wetland or a treatment plant), else 0.

The parameter *N* is the amount of nitrate-nitrogen that must be removed from the catchment.

When only nitrogen credits are sold, the market clears when the nitrogen constraint is satisfied (Equation 4-2). The total cost equals the cost of installing the wetlands or treatment plants that satisfy the constraint, where the number of facilities constructed is allowed to vary to find a least-cost solution.

In addition, we used the model to compare an ecosystem credit market where credit stacking is allowed with the nitrogen-only market. This same model is used to analyze the economic consequences of an uncoordinated (in time) implementation of multiple ecosystem credit markets. Three ecosystem services generated from constructed wetlands can be traded in our model: (1) total nitrogen, (2) total phosphorus, and (3) wildlife habitat. Nitrogen, phosphorus, and wildlife benefits are complements as in Woodward (2011), i.e., installing a wetland to remove nitrogen loads will also reduce phosphorus loads and deliver wildlife benefits. Though we did not use an explicit production function for wildlife benefits, it can be reasonably assumed that acres converted from agriculture to wetlands will improve the habitat conditions for wildlife in the converted areas. Conservation groups as well as governmental agencies are potential willing buyers of wildlife credits. Phosphorus and wildlife benefits per acre are assumed to be homogeneous across the study area and differ only in magnitude based on the variation in wetland size.

When nitrogen credits were sold first and wildlife credits afterwards, we assumed the market still cleared at the cost-minimizing solution for installed wetlands that satisfy the nitrogen constraint (Equation 4-2). The payment to farmers under this scenario differed from other scenarios; in this particular scenario, the payment to farmers was the sum of the wetland installation cost and the value of the wildlife credits.

When nitrogen credits were sold simultaneously with either phosphorus credit, wildlife credits, or with both the ancillary credits, the value of wetland *i*'s ancillary benefits was first subtracted from the cost of the wetland (c_i), and the cost minimization was then solved with the new cost matrix (Equation 4-1). The procedure implicitly puts a greater weight on larger wetlands and a reduced weight on WWTPs that do not provide any ancillary benefits (though WWTPs can remove phosphorus at little additional cost). For the markets where credit stacking was allowed, the market cleared at the cost-minimizing solution that satisfied the nitrogen constraint.

4.3 Conceptual Framework Data

The economic feasibility study was conducted in the part of the Big Bureau Creek watershed that lies within Bureau County, Illinois (Figure 4-1). We collected data from several sources, and the sources had no geographical unit in common nor were on the same geographical scale. Therefore, all data were aggregated and georeferenced to a single geographical unit. The Public Land Survey System (PLSS), which is a grid that subdivides much of the United States into one-mile by one-mile squares, was used as the common geographical source (National Atlas 2010). Each section (one square mile or 640 acres) represents one unit of observation in this trading feasibility analysis. The coordinates of the center of each section was calculated using ArcMap, with any sections that were separated into two polygons on the map merged. These coordinates were then used to join the data from all sources.

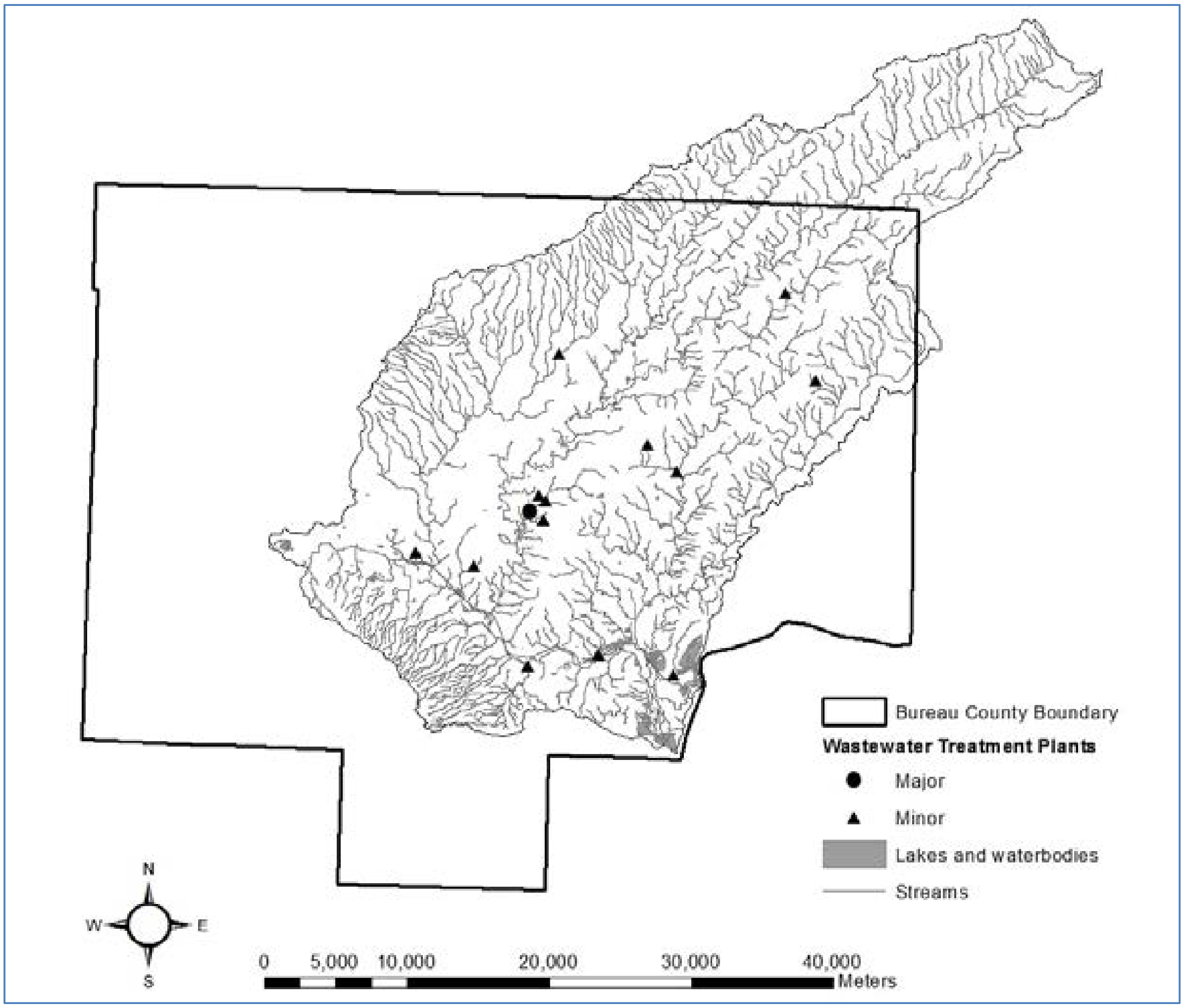

Figure 4-1. Map of the economic feasibility study area with locations of the permitted wastewater treatment facilities.

4.3.2 Wetland nutrient removal costs

The cost to farmers in supplying nutrient credits depends on two elements. First, the wetland must be constructed, entailing significant up-front investment. Second, the farmer forgoes a stream of agricultural profits (and agricultural policy payments) on any land that is converted into a wetland for the duration of the contract. Those values are capitalized in the value of agricultural land. Thus, we used a classic hedonic land price analysis to estimate the opportunity-cost component of nutrient supply costs in different parts of the watershed. Cost heterogeneity makes it important not just to choose lands on which to install wetlands based on nutrient removal potential, but rather to let a market mechanism determine the wetlands to be installed in areas with a high ratio of nutrient removal potential to cost (Ando et al. 1998).

Data used to estimate the construction cost of the wetlands were provided by the USDA Farm Service Agency (FSA). The dataset contained detailed information on wetland size, engineering cost, and construction cost from 20 wetlands constructed with Conservation Reserve Enhancement Program (CREP) support in Iowa (Table 4-1). Wetlands ranged in size from 3.4 to 18.44 acres (1.4 to 7.46 ha) and were similar in size to the proposed wetlands in Bureau County. Engineering costs, which included planning and design of the wetlands, did not vary much with size of the wetland in contrast to actual construction costs. Construction costs ranged from $37,784 to $184,929. This cost item varied largely with the topography and size of the wetlands (i.e., the costs associated with construction of levees and excavation of wetlands). Total construction costs in the data, equal to the sum of engineering and construction costs, ranged from $65,916 to $205,913. To estimate the average construction cost of a wetland of a given size, the data was used to calculate a simple linear regression of total construction cost as a function of wetland area (Table 4-2).

Table 4-1. Descriptive statistics for wetland design and construction costs for 20 Iowa CREP wetlands (provided by USDA FSA).

	OBSERVATIONS	MEAN	STD. DEV.	MIN	MAX
Wetland size (acre)	20	9.915	4.80	3.4	18.44
Construction cost ($/wetland)	20	96,624	43,228	37,784	184,929
Engineering cost ($/wetland)	20	30,486	8,365	16,451	52,532
Total cost ($/wetland)	20	127,111	42,273	65,916	205,913

Table 4-2. Regression results for construction, engineering, and total wetland costs based on Iowa CREP wetlands.

	CONSTRUCTION COST ($)	ENGINEERING COST ($)	TOTAL COST ($)
Wetland area (ac)	4,759.5** (1,800.1)	-429.6 (397.8)	4,329.9** (1,805.8)
Intercept	49,434.5** (19,738.0)	34,745.9*** (4,361.6)	84,180.5*** (19,800.3)
N	20	20	20
R-sq	0.280	0.061	0.242
adj. R-sq	0.240	0.009	0.200
Standard error in parentheses where *10% significance **5% significance ***1% significance			

The expected sale price of farmland represents the present discounted value of an indefinite stream of use values associated with that land, including farm profits and payments associated with commodity programs. The present discounted value for 20 years of use values (equal to the opportunity cost of a 20-year wetland contract) was calculated from the sale value of land in a section. As sale or rental prices are not available for all parcels in the Big Bureau Creek watershed, the average value per acre of land in each section was estimated. First, a hedonic price analysis on agricultural land sales in Bureau County was carried out. Then, the resulting regression equation was used to predict the values of all parcels in the watershed as functions of their characteristics. Finally, the average of all predicted land values in a given section was used to calculate the expected opportunity cost of a 20-year wetland contract in that section.

Hedonic analysis is frequently used to estimate the determinants of agricultural land prices, and hence the opportunity cost of installing wetlands on agricultural lands (e.g., Miranowski and Hammes 1984; Shultz and Taff 2004). This dataset includes agricultural parcels that sold in arm's-length transactions (transactions between independent, unrelated parties) in Bureau County between 1989 and 2010; details of the data can be found in Lentz (2011b). Following the literature, we specified price per acre as the dependent variable to reduce problems with heteroscedasticity, or where the variability of a variable was unequal across the values of the second variable that predicts it (Maddison 2009). Many explanatory variables come from information in the parcel sales records themselves. A measure of the area of the parcel was included (Shultz and Taff 2004). A dummy variable controls for whether or not the parcel is used for commercial crops. Several variables control for whether or not a residential home is on the parcel, and if so, how large the home is. The productivity index (PI) was used to control for variation in agricultural production potential (Olson et al. 2000). PI can range from 0 to 130, but land for agriculture normally has a PI between 70 and 130.

Other explanatory variables were added based on information from other spatial datasets. To capture development pressure, variables capturing the distance from the center of each section to the five largest towns in the study area (Princeton, Spring Valley, DePue, Ladd, and Walnut) were included (National Atlas 2010). A dummy variable for whether a section is at least partially covered by a reasonably large river or stream was included (the spatial data on streams with levels 0 through 3 comes from Detailed Streams (ESRI 2010) and Waterbodies (National Atlas 2010). Finally, the land value trends over time were controlled with a spline that has knots in farm-bill years: 1990, 1996, 2002 and 2008. Summary statistics for the data are in Table 4-3.

The results of the hedonic price analysis are presented in Table 4-4. Heteroscedasticity was corrected by estimating robust standard errors, and several functional form specifications commonly used in hedonic regressions were tried, including log-linear, linear, and semi-log. A log-linear form was found to fit the data better than a semi-log form with respect to both the adjusted R-squared value (0.61) and significance of variables. Hence, results from the log-linear model are reported and used for the opportunity cost estimates. The regression equation presented in Table 4-4 was then used to calculate estimated prices for the parcels used in the regression; as seen in Figure 4-2, the real and predicted prices are highly correlated.

Table 4-3. Descriptive statistics of the hedonic analysis.

VARIABLE	OBSERVATIONS	MEAN	STD. DEV.	MIN	MAX
Sale price per acre ($/acre)	696	9,876.8	16,138	80	155,340
Production Index	536	106.82	15.257	34	130
Cropland on parcel (dummy)	691	0.77569	0.41743	0	1
Distance to Walnut (meters)	694	24,423	10,066	712.82	45,280
Distance to Spring Valley (meters)	694	40,322	232,340	921.77	6,141,500
Distance to Princeton (meters)	694	19,050	8,565.0	1,285.6	39,762
Distance to Ladd (meters)	694	28,837	14,016	2,157.9	57,074
Distance to DePue (meters)	694	25,558	12,028	1,610.2	53,476
Water in section (dummy)	696	0.36494	0.48176	0	1
Home? (dummy)	696	0.32471	0.46860	0	1
Size of home site (acre)	696	0.31523	0.68786	0	6.76
Size of parcel (acres)	696	52.905	56.461	0.36	340.81
Year	696	2002.4	6.4191	1987	2010

Note: Production Index is a measure of an agricultural field's ability to produce crops; amongst other things, it captures soil quality, slope and erosion.

Table 4-4. Regression results for hedonic analysis. All dependent variables are in $/acre.

DEPENDENT VARIABLES	SIGNIFICANCE	STANDARD ERROR
Ln(Production Index)	1.353 ***	(0.231)
Cropland in section	-0.306 ***	(0.0954)
Ln(Distance to Walnut)	-0.004	(0.0471)
Ln(Distance to Spring Valley)	-0.416 ***	(0.133)
Ln(Distance to Princeton)	-0.186 ***	(0.0683)
Ln(Distance to Ladd)	0.105	(0.133)
Ln(Distance to DePue)	0.281 **	(0.135)
Water in section	-0.127 *	(0.0691)
Residential building on parcel	0.769 ***	(0.0907)
Ln(Size of residential building)	-0.051	(0.0758)
Ln(Size of parcel)	-0.328 ***	(0.0298)
Year(-1989)	0.0741	(0.0896)
Year(1990-1995)	0.0936 **	(0.0406)
Year(1996-2001)	0.0562	(0.0366)
Year(2002-2007)	0.0833 ***	(0.0145)
Year(2008-)	-0.134	(0.0856)
Intercept	-142.9	(178.2)
N		689
R-sq		0.623
adj. R-sq		0.614
*10% significance **5% significance ***1% significance		

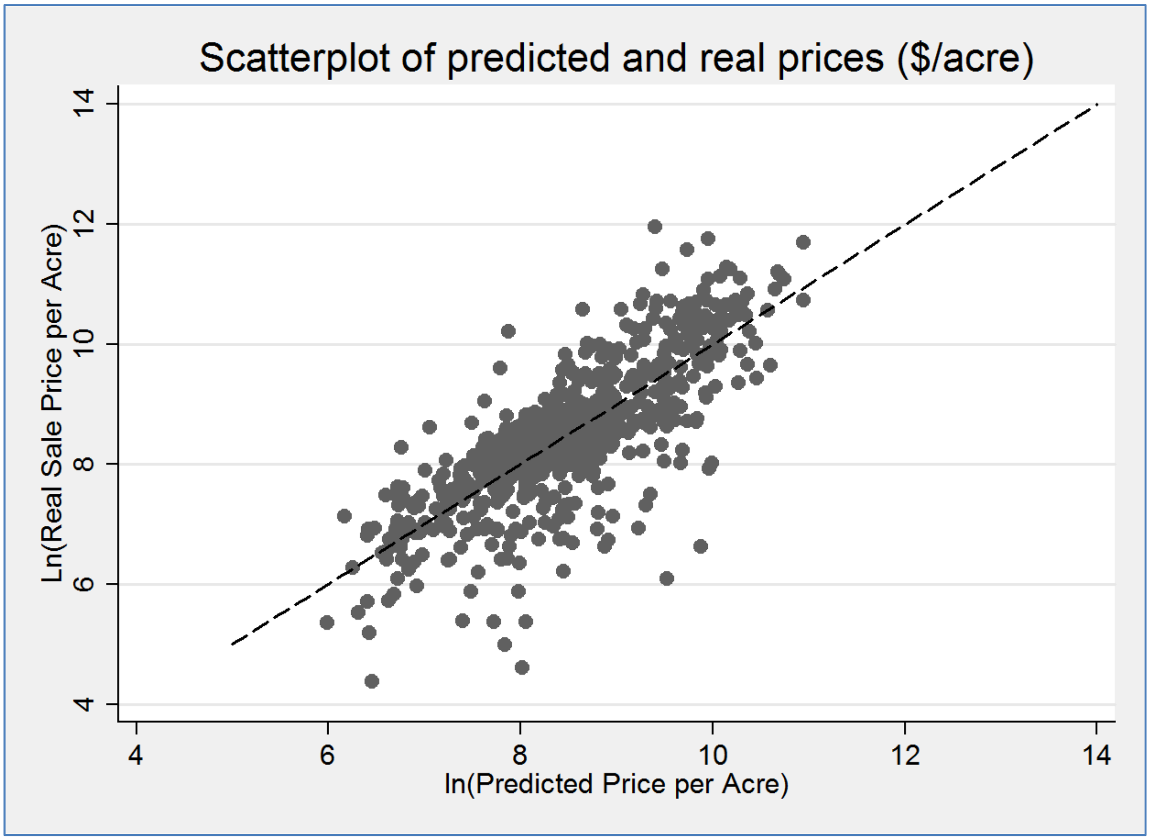

Figure 4-2. Scatter plot of predicted versus actual prices per acre (natural log scale).

The coefficients indicate that value per acre declines with the total size of the parcel. The production index is highly significant and has a positive impact on the price of agricultural land; more productive land is more valuable. The presence of a house has a positive impact on the price, though that effect does not depend significantly on the size of the house. Land value is negatively correlated with the presence of a stream or a lake in a section, perhaps suggesting that such areas require more drainage and have higher flood risks. The average predicted price in the county was $3,238/acre. Proximity to two towns (Spring Valley and Princeton) is associated with higher land values; the potential for urban development may be driving up land prices on those rural fringes. However, lands are less valuable if they are close to DePue; this probably captures the disamenity associated with the Superfund site located in that village.

The results in Table 4-4 were used to estimate the average 2011 agricultural land values for every section in Bureau County (Figure 4-3). Parcel values were then averaged at the section level, and corresponding costs of 20-year wetland contracts were derived. Table 4-5 summarizes the expected costs, which range from $21 to $773/acre. The average cost is $154/acre, which is similar to the 2010 average rental payments in Bureau County ($195 per acre) and the surrounding counties: $147/acre in Lee County and $140/acre in La Salle County (USDA 2010b). These findings are also consistent with previous work that found quasi-rents for land in the Court Creek watershed in nearby Knox County, Illinois, to range from $111 to $204/acre (Khanna *et al*. 2003).

Overall, we found that there can be a large variation in land values within a county. This variation is due to the heterogeneity in land quality, development, the presence of water, the presence of a homestead, and the size of the homestead and parcel. This variation in land value will affect a farmer’s willingness to accept payment for easements.

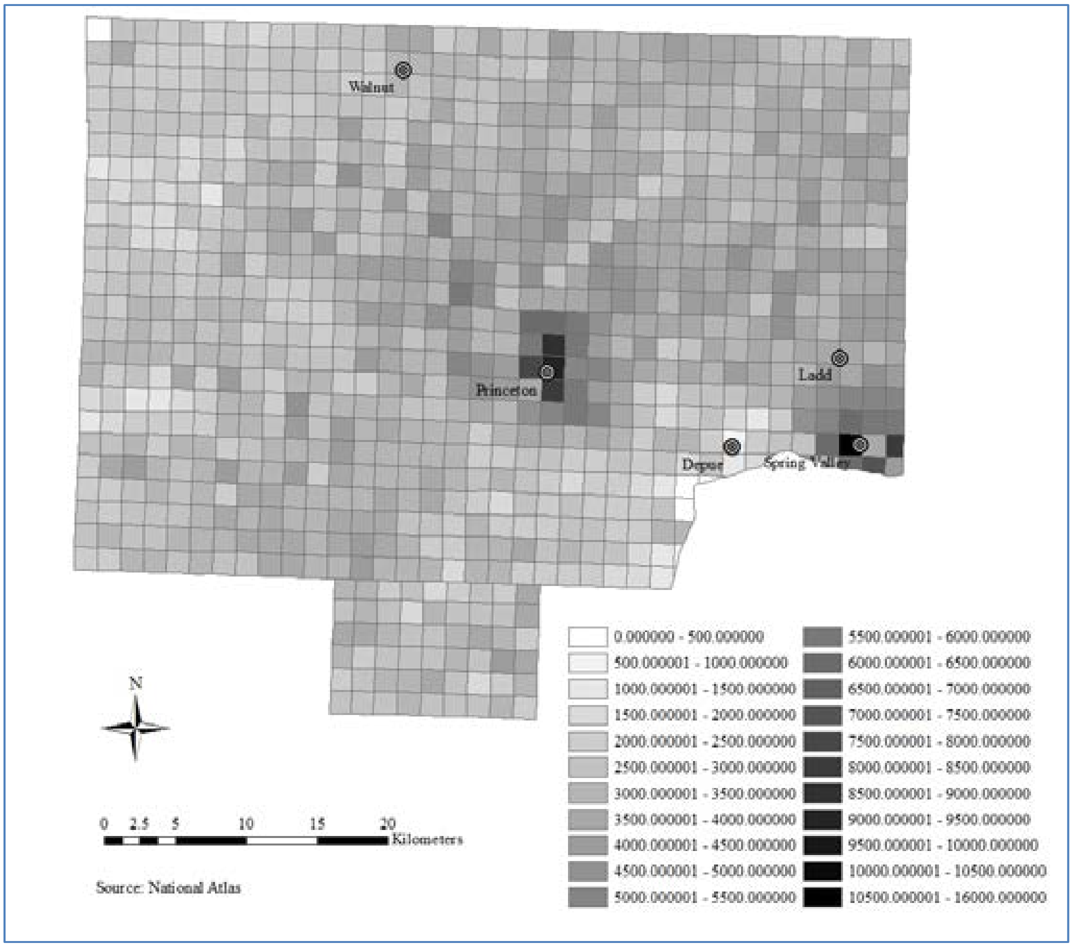

Figure 4-3. Spatial distribution of average predicted 2011 agricultural land prices ($/acre) for each Bureau County section.

Table 4-5. Predicted average land values and easements for sections in Bureau County.

	OBSERVATIONS	MEAN	STD. DEV.	MIN	MAX
Average predicted price ($/acre)	868	3,239	1,026	441.28	15,406
Annual easement ($/acre)	868	154.35	48.78	21.01	733.62
20-year easement ($/acre)	868	2,020	638.36	274.97	9,600

4.3.3 WWTP nutrient removal cost

We estimated the cost of emission reductions for each of the 15 NPDES facilities to achieve the diversified standard previously described in Section 3.2. Since specific nutrient abatement cost information was not available for any of the WWTPs, the abatement costs were estimated based on the limited information available for one WWTP and previously published research on nutrient removal technologies. Facility-specific analyses and design alternatives will have to be conducted to determine actual nutrient removal costs. Facility upgrade costs depend on permit effluent limits, flow and wastewater characteristics, and the facility's suitability for upgrade alternatives. These estimated WWTP abatement costs are intended to provide a basis for the comparison of enhanced nutrient removal through conventional treatment facility upgrades to constructed wetland nutrient removal in this feasibility study.

Nutrient removal costs were estimated following the methodology described in the *Nutrient Technology Cost Estimates for Point Sources in the Chesapeake Bay Watershed* (Chesapeake Bay Program 2002). This report has detailed information on capital upgrades cost and O&M costs for both significant (>0.5 MGD design flow) and non-significant (<0.5 MGD) facilities and specifies the incremental costs associated with different treatment levels that compare well with the effluent limits we assumed for the facilities as described in Section 3.2. The cost data are consistent with the literature on municipal nutrient removal technologies and was also used by Sado et al. (2010).

Sado et al. (2010) determined the costs of upgrades and additional O&M to achieve standards that are close to the standards we assumed in our scenarios. Their model uses the following explanatory variables: final phosphorus concentration (effluent), daily flow in millions of gallons per day (MGD), and whether the treatment plant uses biological or chemical treatment. They found that larger plants had economies of scale with respect to O&M cost and that capital costs increased based on the treatment level, though larger plants have higher construction costs (Sado et al. 2010). McConnell et al. (1988) specified discrete total cost functions for WWTPs; their cost function displayed intervals with increasing marginal costs and intervals with decreasing marginal costs. They argued that marginal cost functions are not necessarily continuous or concave and in reality, the costs may be “lumpy.”

The methodology in the Chesapeake Bay Program report was followed where possible, but in some cases simplifying assumptions had to be made because of data limitations. For example, it was not possible to follow the procedure for estimating O&M costs for nitrogen removal from major facilities upgraded to achieve an 8 mg/L TN effluent limit. Instead, the operation costs were assumed to be unchanged, and maintenance costs were 2% of the capital costs on an annual basis. Also, the report had little information about costs for minor facilities less than 0.1 MGD, which represent the majority of the facilities in this watershed. Thus, the capital and O&M costs of phosphorus removal in minor facilities were estimated from the equations for major facilities that had a size of 0.1-1.0 MGD. Similarly, the cost for minor facilities to remove nitrogen were estimated using the equations for plants greater than 0.1 MGD, which is slightly greater than the average of the minor facilities.

It was assumed that nitrogen and phosphorus removal would require different types of treatment upgrades and processes. The upgrade costs are much higher for minor facilities for nitrogen removal than for phosphorus removal due to the capital costs associated with facility upgrades (Table 4-6). Except for the smallest facilities (l<n 0.005 MGD), the average costs for TN removal were within the published estimate range of $1.20-$852/kg for major facilities (USEPA 2008). Princeton STP, the only major facility, has an estimated capital cost of $2.24/gal, which is at the higher end of capital costs for nitrogen removal ($0.63-$2.17/gal) (USEPA 2008). These costs are variable due to the type of nitrogen removal technology, target effluent limit, and type of facility upgrade (e.g., expansion or retrofit).

Table 4-6. Estimated total and average nutrient removal costs for permitted facilities (both water and sanitary plants) in the Big Bureau Creek watershed to meet the diversified standard.

FACILITY		TOTAL NITROGEN		TOTAL PHOSPHORUS	
NAME	DESIGN FLOW (MGD)	TOTAL UPGRADE COST ($)	AVERAGE COST ($/kg TN)	TOTAL UPGRADE COST ($)	AVERAGE COST ($/kg TP)
Arlington WTP, Village of	0.002	357,635	2,375	65,745	975.0
Bureau Junction STP, Village of	0.071	424,736	79.46	72,262	33.98
Lake Arispie Water Co STP	0.050	403,080	107.1	70,278	45.44
Malden STP, Village of	0.050	403,080	107.1	70,278	45.44
Prairie View Nursing Home STP	0.020	374,043	248.4	67,445	103.53
Princeton STP, City of	2.150	5,205,261	37.87	0	5.12
Tiskilwa STP, Village of	0.120	479,902	53.12	76,889	22.84
Arlington WTP, Village of	0.002	357,635	2,375	65,745	975.01
Dover WTP, Village of	0.004	359,422	1,193	65,934	490.86
IL DOT I-80 Bureau County STP	0.02	374,043	248.4	67,445	103.53
LaMoille STP, Village of	0.063	416,352	87.78	71,506	37.44
Maple Acres MHP	0.026	379,583	194.7	68,002	81.48
Ohio STP, Village of	0.077	430,705	74.68	72,790	31.99
Princeton WTP, City of	0.065	418,432	85.50	71,695	36.50
Wyanet STP, Village of	0.25	663,517	35.25	89,167	14.45

NOTE: Diversified standard = 5.0 mg/L TN, 0.5 mg/L TP for major facilities and 8.0 mg/L TN, 1.0 mg/L TP for minor facilities.

The data indicate that in this watershed, phosphorus reductions at the WWTPs are less expensive than from restored or created wetlands. For major facilities, like the Princeton STP, no capital upgrade would be required to meet the hypothetical phosphorus standard, but O&M costs associated with chemicals and labor would increase. The market price of phosphorus credits is assumed to be equal to the cost of removing one kilogram of phosphorus at the most cost-effective WWTP.

How a tradable permit market might work in areas with larger populations than that of Bureau County was analyzed in some of the scenarios. To scale emissions and costs for these scenarios, the watershed was allowed to include as many WWTPS as necessary to satisfy the demand for wastewater treatment for a given population size, and the largest plant was limited to a maximum of 30 MGD.

4.3.4 Wildlife habitat values

According to the United States Government Accountability Office (2007), the U.S. Fish and Wildlife Service paid between $283/acre (Mountain-Prairie Region) and $1,100/acre (Midwest Region) in annual easements, and between $68/acre (Mountain-Prairie Region) and $3,100/acre (Midwest Region) in fee simple acquisitions for protection of migratory bird habitat in the Prairie Pothole Region. These values can be interpreted as the willingness to pay for wildlife habitat. Since Big Bureau Creek is not located in the Prairie Pothole Region, and therefore has much lower production of wildlife, the highest wetland habitat values probably are not relevant to our study area. However, wetlands in the Big Bureau Creek watershed may still generate substantial wildlife benefits to hunters as well as bird-watchers. Thus, it was assumed that wildlife benefits could potentially have a value of $1,500/acre (3,700/ha) for a 20-year easement.

4.4 Model Scenarios and Results

4.4.1 Scenarios

We used the model for several scenarios with varied levels of total reductions required of the WWTPs and wetlands, easement costs, and wetland nutrient removal potential. For all market scenarios, both the total cost of installing the wetlands that satisfied the nitrogen constraint and the total transfer between the credit aggregator and the credit buyers was calculated. The total cost of meeting the standards when credit trading was allowed was compared to the total cost of meeting the standards by WWTP upgrades only. In addition to total cost, the quantity of the ancillary benefits generated from the wetlands was estimated (e.g., if a wastewater treatment plant needed to construct a 25-acre (10 ha) wetland to mitigate nitrogen emissions, how much total phosphorus the 25 acres (10 ha) would mitigate was estimated). To test if the benefits from credit stacking were different for a watershed that has a larger population and greater nitrogen emissions than the Big Bureau Creek watershed, the model was designed so that it could scale up the demand for nitrogen credits by adding more, and larger, WWTPs.

We found that wetland nutrient removal in a watershed such as Big Bureau Creek, which has large percentages of land in agricultural production and limited urban development, is a more cost-effective way of reducing nitrogen loads than upgrading small- or medium-size WWTPs (Table 4-7). Constructing a single wetland of sufficient size could satisfy the nitrogen reduction requirement for all 15 permitted facilities in the watershed and achieve substantial cost savings in comparison to upgrading all 15 facilities to meet the diversified standard of 5 mg/L of total nitrogen for major facilities and 8 mg/L of total nitrogen for minor facilities. This result is consistent with Woodward (2003), who observed that it may only be necessary to make one trade to justify a water quality trading market. The total cost of installing a wetland that satisfies the nitrogen reduction requirement is significantly less than upgrading the WWTPs in the study area.

This result did not change when the nitrogen credit demand was increased to simulate cities with larger populations. All three population scenarios are calculated under the assumption that the treatment plants had to meet the diversified standard with a mass nitrogen load removal that corresponds to the populations reported in Table 4-7. However, as the demand for nitrogen removal from wetlands was increased, the average cost per kilogram of nitrogen removed increased because a larger proportion of the nitrogen credits had to be produced by less cost-effective wetlands.[8]

The most cost-effective wetland was able to remove 1,904 tons of nitrogen over a 20-year period at a cost of $0.54/kg of nitrogen removed (Table 4-8). This corresponds to almost four times more than the total nitrogen removal needed for the study area under the most stringent effluent standard requirement. In general, the most cost-effective wetlands were the largest wetlands with above-average nitrogen removal potential. This result suggests that it was primarily the high construction and design costs of wetlands that were driving wetlands' nitrogen removal cost and that wetland construction has economies of scale. Most of the wetlands were able to reduce nitrogen for less than $5/kg, including construction costs and the opportunity cost of land (Figure 4-4 and Figure 4-5). David et al. (2008) found wetland

[8] The opposite was found for phosphorous removal. Not even when the highest phosphorus removal potential was used and the price of the land in the study area was reduced by 50 percent were wetlands close to being as cost-effective as wastewater treatment plants in reducing phosphorus.

nitrogen removal to cost between $4.09-$4.76/kg N in the Lake Bloomington watershed (Illinois) with easement costs assumed to be homogenous at $740/ha ($300/acre), which is a higher value than the average easements in this study.

Table 4-7. Cost and ancillary benefits of achieving the nitrogen removal requirement for the diversified standard scenario by: 1) upgrading wastewater treatment plants, 2) installing the cost-minimizing combination of wetlands that would result from a perfectly functioning decentralized nitrogen permit market, and 3) installing the wetlands in increasing order of cost per kilogram nitrogen removed.

SCENARIO	(1) UPGRADED TREATMENT PLANTS	(2) WETLANDS: NITROGEN PERMIT MARKET	(3) WETLANDS: BENEFIT-COST RANKING
BIG BUREAU CREEK STUDY AREA			
Number of wetlands	0	1	1
Number of upgraded WWTPs	15	0	0
Nitrate removed (kg)	409,989	433,055	1,904,466
Phosphorus removed (kg)	0[a]	5,943	29,080
Hectares for wildlife	0	11.40	55.92
Total cost nitrogen removal	13,035,709	331,135	1,046,573
STUDY AREA PLUS A CITY OF 105,000 PEOPLE			
Number of wetlands	0	3	3
Number of upgraded WWTPs	15 (1 large)	0	0
Nitrate removed (kg)	4,860,803	4,864,300	5,026,097
Phosphorus removed (kg)	0[a]	71,586	74,228
Hectares for wildlife	0	137.70	142.75
Total cost nitrogen removal	46,649,817	2,828,232	2,830,059
STUDY AREA PLUS A CITY OF 525,000 PEOPLE			
Number of wetlands	0	21	21
Number of upgraded WWTPs	19 (5 large)	0	0
Nitrate removed (kg)	24,038,456	24,058,450	24,058,442
Phosphorus removed (kg)	0[a]	343,967	343,966
Hectares for wildlife	0	661.5	661.47
Total cost nitrogen removal	208,103,809	15,159,540	15,159,544
STUDY AREA PLUS A CITY OF 840,000 PEOPLE			
Number of wetlands	0	57	58
Number of upgraded WWTPs	22 (8 large)	0	0
Nitrate removed (kg)	38,421,696	38,422,300	38,492,799
Phosphorus removed (kg)	0[a]	557,054	556,996
Hectares for wildlife	0	1071.257	1,071.15
Total cost nitrogen removal	369,557,800	27,464,860	27,540,527

[a] No phosphorus is actually removed from upgraded wastewater treatment plants because such removal would require additional money ($5.11/kg TP) to be spent on O&M.

Table 4-8. Potential wetland nutrient removal cost and efficiency.

	OBSERVATIONS	MEAN	STD. DEV.	MIN	MAX
Average nitrogen removal cost ($/kg)	124	2.70	3.68	0.55	26.50
Installation and easement cost wetlands ($)	124	304,714	235,217	116,724	1,145,200
Total nitrogen removal (kg over 20 year)	124	344,050	442,068	4,586	1,904,466
Easement size (ha)	124	9.72	12.35	0.165	55.92
Phosphorus removal (kg over 20 year)	124	5,057	6,424	85.8	29,080

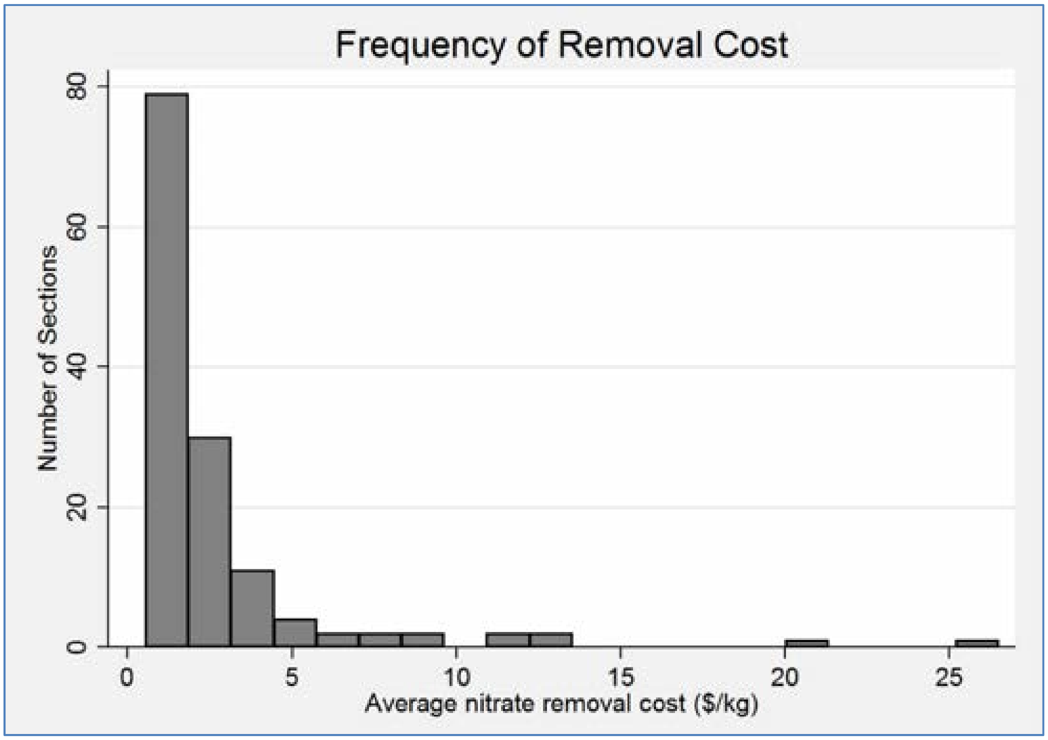

Figure 4-4. Frequency distribution of the average wetland nitrate removal cost ($/kg).

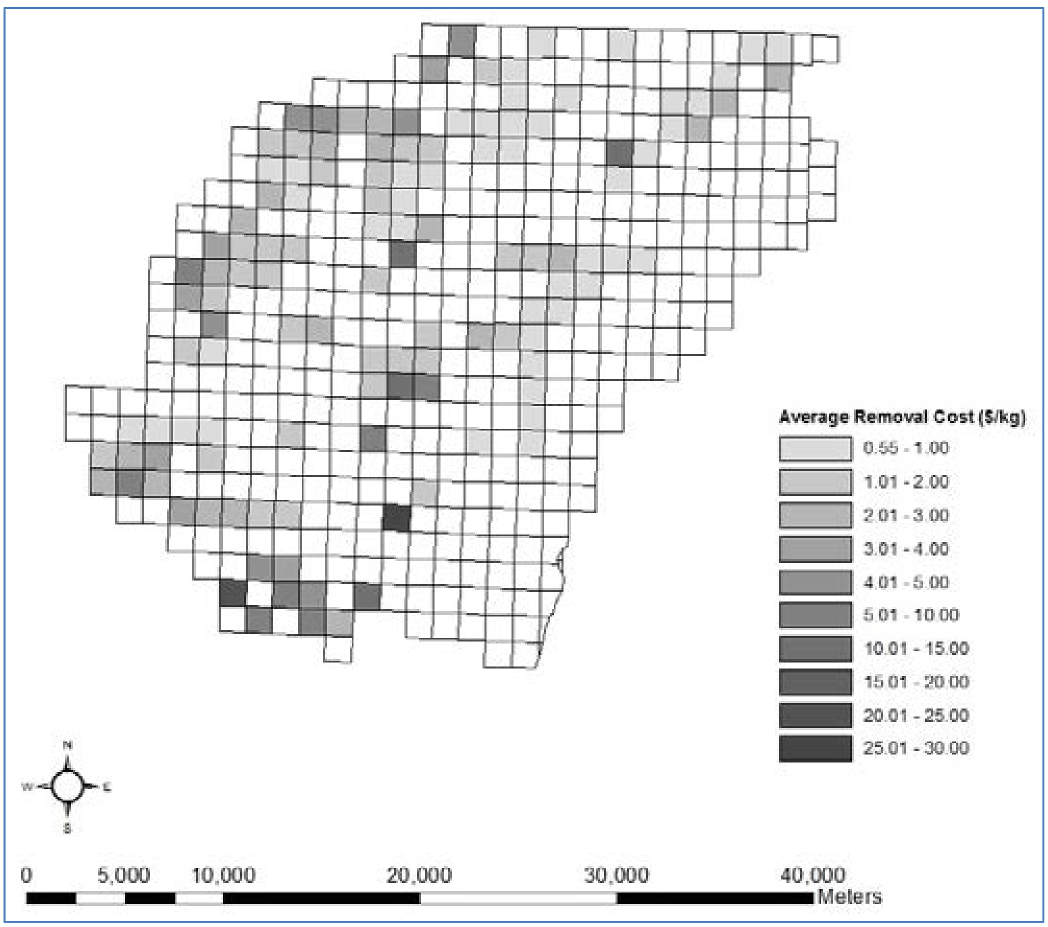

Figure 4-5. Spatial distribution of wetland average nitrogen removal cost ($/kg) in the Big Bureau Creek watershed. Each square represents a section that is 1 mile by 1mile.

4.4.2 Tradable permit market results: Single market

Previous research has suggested that conservation projects should be ranked and targeted based on benefit-cost ratios and that the most cost-effective projects should be undertaken (Babcock et al. 1996, 1997). Aggregators might use such an approach to identify which wetland construction projects generate credits in the most cost-effective manner. Therefore, one set of results were generated by ranking wetlands based on their nitrogen removal cost ($/kg), assuming wetlands were built in order of ranking until the nitrogen removal requirement was satisfied. Installing the most cost-effective wetlands achieved much greater nitrogen reductions than was needed to satisfy the nitrogen constraint in the study area. The total cost of satisfying the nitrogen constraint with the cost-effectiveness ranking approach was compared to the cost-minimizing solution that a perfectly functioning decentralized market might attain (Table 4-7).

The cost-minimizing solution had a lower total cost of satisfying the removal requirement in the study area than the scenario where wetlands were chosen by rank of cost-effectiveness. The greater the demand for nitrogen credits, the smaller the difference in total cost of meeting the nutrient requirement between the cost-minimizing solution and the benefit-cost ranking solution. Intuitively, this relationship can be explained by the fact that whether or not a wetland should be constructed is a binary decision and the wetlands with higher removal cost on average are smaller in size and therefore also remove less nitrogen than the ones with the lowest removal cost. The last wetlands to be installed—if they are targeted according to the benefit-cost ranking—are similar with respect to total cost and total nitrogen removal; therefore, the difference in total cost between the cost-minimizing combination and the wetlands targeted from benefit-cost ranking is small when demand for nitrogen removal is large.

Table 4-9 shows how sensitive the tradable permit market results are to changes in the determinants of credit supply (i.e., opportunity costs and wetland nitrogen removal efficiency). Increasing the land easement cost or opportunity to simulate areas with greater development pressure or rising crop prices did not change the result that wetlands are more cost-effective in nitrogen removal compared to WWTPs. A doubling in the opportunity cost did not increase the total removal cost by more than 26% in any of the scenarios. This result can be explained by the fact that the construction cost of the wetlands is a more significant component of the nitrogen removal cost than the easement cost.

To demonstrate the effects of wetland nitrogen removal efficiency on the market simulations, a wetland's ability to remove nitrogen was reduced by 50% and 90%, thereby increasing the cost per kg nitrogen. While this reduction in nutrient removal capacity increased the total cost of meeting the reduction requirement, it was still significantly cheaper to install wetlands than to upgrade the WWTPs in the study area and for the scenario with a city of 105,000 people. However, in the scenario where the cities had larger populations and nitrogen emissions, the wetlands were no longer a feasible solution because they could no longer meet the nitrogen demand. Under the 50% removal efficiency reduction scenario, the wetlands could only satisfy a small share of the nitrogen removal requirement, and the major WWTPs, at a size of 30 MGD, had to satisfy the rest of the requirement. The combination of WWTPs and wetlands did, however, reduce the total cost of nitrogen removal and provide more ancillary benefits than if all the WWTPs had been forced to upgrade instead of buying nitrogen credits. The minor WWTPs had high upgrade costs; therefore, the construction of less efficient wetlands was still a cost-effective way of reducing nitrogen emissions for those particular facilities.

In addition to the cost savings from constructing wetlands for nitrogen removal, wetlands generate substantial wildlife benefits and some phosphorus removal. While the wildlife benefits have not been quantified, a single wetland of 71 ha (29 acres) would have to be constructed to meet the new nitrogen standard in the study area and, all else equal, this would improve wildlife habitat in the watershed. The phosphorus benefits are harder to quantify and more uncertain, as the numbers reported in Table 4-7 and Table 4-9 are based on a retention rate of 2.86 g P/m^2/yr, which is optimistic. In general, the ancillary values generated by the wetlands will be higher than the nonexistent ancillary benefits created by upgrading the wastewater treatment plants exclusively to reduce total nitrogen pollution.

Table 4-9. Sensitivity analysis of meeting the nitrogen removal requirement for the diversified standard from the cost-minimizing combination of constructed wetlands or treatment plant upgrades under four scenarios: (1) wetlands' removal potential and easement costs are unchanged, (2) wetlands' nitrogen removal potential is reduced by 50%, (3) wetlands' nitrogen removal potential is reduced by 90%, and (4) the easement cost is doubled.

SCENARIO	WETLANDS NITROGEN PERMIT MARKET	WETLANDS 50% REDUCTION IN NITROGEN REMOVAL	WETLANDS 90% REDUCTION IN NITROGEN REMOVAL	WETLANDS DOUBLE EASEMENT COSTS
BIG BUREAU CREEK STUDY AREA				
Number of wetlands	1	1	3	1
Number of upgraded WWTPs	0	0	0	0
Nitrate removed (kg)	433,055	444,749	416,641	433,055
Phosphorus removed (kg)	5,943	12,613	61,341	5,943
Hectares for wildlife	11.40	24.26	117.96	11.43
Total cost nitrogen removal	331,135	573,257	2,404,132	398,551
STUDY AREA PLUS A CITY OF 105,000 PEOPLE				
Number of wetlands	3	7	1	3
Number of upgraded WWTPs	0	0	1[a]	0
Nitrate removed (kg)	4,864,300	4,863,747	4,864,454	5,026,097
Phosphorus removed (kg)	71,586	140,695	9,673	74,228
Hectares for wildlife	137.70	270.57	18.60	142.75
Total cost nitrogen removal	2,828,232	5,761,972	40,844,040	3,444,761
STUDY AREA PLUS A CITY OF 525,000 PEOPLE				
Number of wetlands	21	1	1	23
Number of upgraded WWTPs	0	5[a]	5[a]	0
Nitrate removed (kg)	24,058,450	24,040,650	24,042,110	24,040,500
Phosphorus removed (kg)	343,967	1,893	9,673	347,050
Hectares for wildlife	661.5	3.64	18.60	667.40
Total cost nitrogen removal	15,159,540	202,002,300	202,298,000	19,203,540
STUDY AREA PLUS A CITY OF 840,000 PEOPLE				
Number of wetlands	57	1	1	59
Number of upgraded WWTPs	0	8[a]	8[a]	0
Nitrate removed (kg)	38,422,300	38,423,890	38,425,350	38,426,740
Phosphorus removed (kg)	557,054	1,893	9,673	554,686
Hectares for wildlife	1071.257	3.64	18.60	1,066.70
Total cost nitrogen removal	27,464,860	323,092,800	323,388,500	34,291,350

[a] No phosphorus is actually removed from upgraded wastewater treatment plants because such removal would require additional money ($5.11/kg TP) to be spent on operations and management.

4.4.3 Tradable permit market results: Multiple credits

In some cases, the cost of a wetland is high enough that no single payment might be large enough to convince a farmer to construct one. However, if they could get paid for its value to society, then they might be incentivized to install a wetland through this additional income. A trading market was simulated where multiple benefits were sold either simultaneously or sequentially. As described in the previous section, nitrogen removal from wetlands is a more cost-effective method of meeting a given nitrogen standard for WWTPs. While the sale of nitrogen credits leads to some wetlands being built, neither wildlife credits nor phosphorus credits carry high enough prices to warrant wetland installation in the absence of a nitrogen market (Table 4-7 and Table 4-9). Indeed, the greater the demand for nitrogen credits, the more wetlands will be built and the greater the ancillary benefits (Table 4-10).[9] Therefore, nitrogen is referred to as the primary credit and phosphorus and wildlife credits as secondary credits.

In the study area, the demand for the primary credit (nitrogen) was limited. The lumpy nature of wetland installation means that credit stacking did not lead to more ancillary benefits, nor did stacking change the cost of meeting nitrogen reduction requirements (Table 4-10). The one wetland that had to be installed to satisfy the nitrogen removal constraint at the lowest cost in the study area was the same regardless of whether or not credit stacking was allowed. The wetland was not the most cost-effective per kg of nitrogen removed, but it was fairly large in area, and thus generated many wildlife and phosphorus credits. As a result of the wetland's many ancillary benefits, no other wetland generated the required amount of nitrogen credits at a lower cost after the wildlife and phosphorus credits had been included in the credit aggregator's decision of which wetland to install. Therefore, in this particular study area, an aggregator would not choose to contract with different landowners for different wetlands when credits could be stacked. The same holds true if the total demand was close to the maximum amount of the primary credit that could possibly be produced as seen in the maximum population scenario. The same credits would be demolished from the same 57 wetlands whether stacking was or was not allowed, since it was not possible to deliver large quantities of additional nitrogen credits as the supply was exhausted.

If demand for the primary credit was low or the credit supply was close to being exhausted, then the landowners' payments would increase if they were allowed to sell their primary credit first and then sell their secondary credits later. However, the total amount of environmental services produced would not increase, because the wetlands selected would not change. The construction decision was based on demand for the primary credit and not on retroactive implementation of additional credits (this result is similar to Horan et al. 2004). In the case where the primary credit was sold first and the secondary credits at a later stage, the decision to install a wetland was not motivated by the profitability of the secondary credits. Since the stacked payments would not lead to an increase in benefits relative to nitrogen alone, additionality criteria are not met.

The multiple benefit market analysis did demonstrate that the wetlands chosen (and therefore the total benefits) would change if the market had a substantial demand for the primary credit and, at the same time, the aggregator retained a choice of which wetlands to construct. Compared to the market outcome where it was only possible to sell nitrogen credits, simultaneously selling nitrogen credits with phosphorus and/or wildlife habitat credits resulted in larger wildlife areas, greater phosphorus removal, and either more (in the case with a city of 105,000 people) or less nitrogen removal (in the case with a city of 525,000 people).

Credit stacking may change the quantity and composition of the wetlands installed by the market and the benefits provided. Different collections of wetlands emerge in the solutions to the cost-minimization problem when stacking is allowed, but the market results can be unpredictable. In the scenario with 525,000 people, 21 wetlands were installed in the single nitrogen market but, when stacked with phosphorus and wildlife credits simultaneously, only 20 wetlands were installed (Figure 4-6). If wildlife and phosphorus credits are sold simultaneously with nitrogen, and if production of those credits increases linearly with wetland area, then the ranking of potential wetlands with respect to costs and benefits may change. The total wetland installation cost when all three credits were sold together was greater than the wetland costs for the simultaneous sale of wildlife and nitrogen credits or for the nitrogen credits sold in the single market.

[9] Combining wildlife easements of $1,500/acre ($3700/ha) with the least expensive cost for wastewater treatment plants to upgrade phosphorus treatment to meet the diversified and best available standard ($5.11/kg TP) did not yield sufficient demand to induce any wetland construction. Phosphorus removal from treatment plants is inexpensive because it requires very limited upgrades to meet the specified standard. The one major facility in the study area already has the technology in place to meet the most stringent requirement, requiring little additional processing. It is assumed that the same would also be the case when more and larger plants were added to simulate a larger demand for nitrogen and phosphorus credits.

Table 4-10. Comparison of the single and multiple markets with variable trading rules based on the cost and ancillary benefits of achieving the nitrogen removal requirement for the diversified standard scenario by minimizing the combination of constructed wetlands without stacking and with stacking. The numbers in parenthesis represents the sequence of the sale: (1) implies it is the first credit sold (if more than one credit is marked with (1) then the credits are sold simultaneously) and (2) means the credit is sold after the first credit (or sequentially).

CREDIT TYPES	NO STACKING	WITH STACKING			
	NITROGEN	WILDLIFE (1) & NITROGEN (1)	NITROGEN (1) & WILDLIFE (2)[B]	PHOSPHORUS (1) & NITROGEN (1)	PHOSPHORUS (1), WILDLIFE (1), & NITROGEN (1)
STUDY AREA					
Number of wetlands	1	1	1	1	1
Nitrate removed (kg)	433,055	433,055	433,055	433,055	433,055
Phosphorus removed (kg)	5,943	5,943	5,943	5,943	5,943
Avoided cost phosphorus ($)[a]	30,429	30,429	30,429	30,429	30,429
Hectares of wildlife	11.43	11.43	11.43	11.43	11.43
Wetland installation cost	331,135	331,135	331,135	331,135	331,135
Payment to farmers	331,135	331,135	373,502	331,135	331,135
STUDY AREA PLUS A CITY OF 105,000 PEOPLE					
Number of wetlands	3	3	3	3	3
Nitrate removed (kg)	4,864,303	5,026,097	4,864,303	5,026,097	5,026,097
Phosphorus removed (kg)	71,586	74,228	71,586	74,228	74,228
Avoided cost phosphorus ($)[a]	366,519	380,050	366,519	380,050	380,050
Hectares of wildlife	137.67	142.75	137.67	142.75	142.75
Wetland installation cost	2,828,235	2,830,059	2,828,235	2,830,059	2,830,059
Payment to farmers	2,828,235	2,830,059	3,338,559	2,830,059	2,830,059
STUDY AREA PLUS A CITY OF 315,000 PEOPLE					
Number of wetlands	10	10	10	10	10
Nitrate removed (kg)	14,466,280	14,466,280	14,466,280	14,466,280	14,466,280
Phosphorus removed (kg)	209,597	209,597	209,597	209,597	209,597
Avoided cost phosphorus ($)[a]	1,073,142	1,073,142	1,073,142	1,073,142	1,073,142
Hectares of wildlife	403.07	403.07	403.07	403.07	403.07
Wetland installation cost	8,673,384	8,673,384	8,673,384	8,673,384	8,673,384
Payment to farmers	8,673,384	8,673,384	10,167,576	8,673,384	8,673,384
STUDY AREA PLUS A CITY OF 525,000 PEOPLE					
Number of wetlands	21	20	21	20	20
Nitrate removed (kg)	24,058,440	24,050,480	24,058,440	24,050,480	24,047,150
Phosphorus removed (kg)	343,966	347,621	343,966	347,622	349,709
Avoided cost phosphorus ($)[a]	1,761,108	1,779,822	1,761,108	1,779,822	1,790,512
Hectares of wildlife	661.47	668.50	661.47	668.50	672.52
Wetland installation cost	15,159,540	15,176,541	15,159,540	15,176,542	15,194,266
Payment to farmers	15,159,540	15,176,541	17,611,624	15,176,542	15,194,266
STUDY AREA PLUS A CITY OF 840,000 PEOPLE					
Number of wetlands	57	57	57	57	57
Nitrate removed (kg)	38,422,300	38,422,300	38,422,300	38,422,300	38,422,300
Phosphorus removed (kg)	557,054	557,054	557,054	557,054	557,054
Avoided cost phosphorus ($)[a]	2,852,115	2,852,115	2,852,115	2,852,115	2,852,115
Hectares of wildlife	1,071.26	1,071.26	1,071.26	1,071.26	1,071.26
Wetland installation cost	27,464,860	27,464,860	27,464,860	27,464,865	27,464,864
Payment to farmers	27,464,860	27,464,860	31,436,010	27,464,865	27,464,864

[a] Avoided cost phosphorus is the minimum cost of using actions at WWTPs to remove the same amount of phosphorus as is removed by wetlands in the scenario.

[b] The payment to farmers is higher than the other columns. This is because the wildlife credits are sold after the installation costs for the cost-minimizing set of wetlands have been covered. Therefore, the payment is equal to the installation cost plus the wildlife credits.

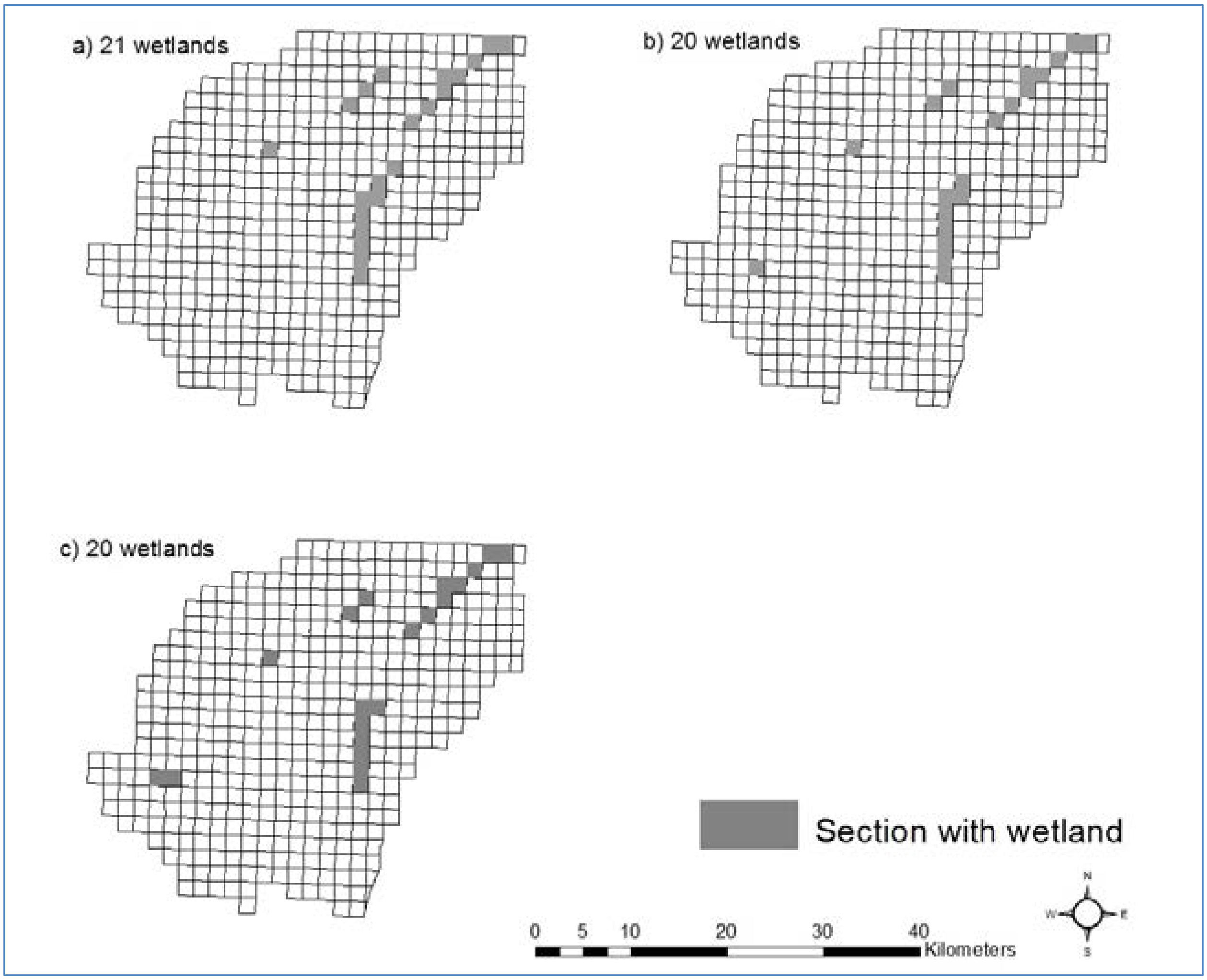

Figure 4-6. Effects of stacking on the spatial distribution of nutrient removal wetlands. The three figures show the distribution of the wetlands that needed to be constructed to satisfy the nitrogen removal constraint while minimizing the total cost under three scenarios: a) no credit stacking, b) wildlife and nitrogen (or phosphorus and nitrogen) credits sold simultaneously, and c) wildlife, phosphorus, and nitrogen credits sold simultaneously. Results are for a scenario of the study area plus a city of 525,000 people.

Woodward (2011) compared net benefits to society with and without stacking and assumed continuous benefit and cost functions; our results suggest this might not be the case when the investments underlying the supply and demand are lumpy or large and discrete in nature. Woodward (2011) found that credit stacking would achieve higher net benefits if the various markets were coordinated with respect to optimal caps, and also found that prohibiting credit stacking would achieve higher net benefits to society if the pollutants were substitutes. Our multiple benefit market scenarios showed that allowing credit stacking could lead to more of all three benefits being provided at little additional cost (e.g., nitrogen with simultaneous wildlife credits for the study areas plus a city of 105,000 people). However, in the scenario with a larger nitrogen credit demand (e.g., study areas plus a city of 525,000 people), the provision of the primary credits is less when stacking is allowed. It cannot be concluded that social welfare is improved by the extra benefits (rendering those payments “additional”) without better-monetized benefit values for the watershed.

The effect of allowing farmers to receive multiple payments from a single wetland depends on the specific situation. Stacking credits may improve social welfare while providing more ecosystem services, if (1) a substantial demand for the credit covers the majority of the cost of installing wetlands, and (2) the market for the primary credit is not exhausted. Finally, if the primary credit is sold first and secondary credits at a later point in time, no additional benefits will be generated, but the farmer producing the credits will receive extra payments.

4.5 Economic Feasibility Analysis Conclusions

Unlike many previous studies that assume continuous, differentiable supply and demand curves for water quality markets, this economic analysis modeled the supply and demand of nutrient reduction credits as lumpy and based on discrete decisions controlled by local hydrogeomorphic conditions as well as treatment plant nutrient removal technology. This empirical study focused on the economics of constructed wetlands' ability to provide ecosystem services, primarily nitrogen removal, in a rural agricultural watershed using a landscape wetland assessment to identify potential wetland sites and nitrogen removal (Section 3.4.1).

The results demonstrate that cost-minimizing wetland nitrogen removal in the Big Bureau Creek watershed, where agriculture is the predominant land use and urban development is limited, is a more cost-effective way of reducing nitrogen loads compared to upgrading small- or medium-size treatment plants. These results are based on a wetland design that is on the high end of construction costs (less expensive design alternative may be applicable with the smaller wetlands) and relatively conservative biological nutrient removal limits compared to limits of technology near 3.0 mg/L TN and 0.1 mg/L TP (US EPA 2007d). In addition, the constructed wetlands are a more cost-effective way to mitigate nitrogen pollution in watersheds with similar land use characteristics but with much larger urban centers and emission demands than that found in the studied watershed. In the nitrogen credit scenario (no stacking), the wetlands removed more nitrogen than needed to meet the demand, which is a benefit to the watershed.

In addition, this research is relevant to market settings where credit production is driven by demand for nitrogen credits. Ancillary credits can also be produced and sold, but these benefits are not valued highly enough in their markets to stimulate wetland installation in absence of a nitrogen market. For example, no wetland would be constructed for the sole purpose of selling phosphorus credits, and the phosphorus credit supply did not exceed the quantity of phosphorus that the facilities need to abate based on the assumed wetland removal rate of 2.86 g P/m^2/yr (wetland area only) in any of the simulations. Stacking did not change the outcomes of our market simulations, either if demand is so limited that only a single wetland is needed, or if demand is so high that the available nitrogen supply is nearly exhausted, as market conditions have little opportunity to alter the composition of the constructed wetlands.

These results lend positive support to the Wetlands Initiative's efforts to establish a wetland-based nutrient credit trading program. Wetland-based water quality trading markets have the potential to be a cost-effective "treatment alternative" for permitted facilities facing nutrient discharge limits in the near future and to incentivize farmers to construct tile-drainage treatment wetlands on their properties. The Big Bureau Creek watershed is representative of agricultural watersheds found throughout the Midwest. This system could be a model used to achieve nitrogen reductions throughout Illinois and the Midwest.

5 SMART MARKET DESIGN AND SIMULATION

The smart market design and simulations were performed by Drs. John Raffensperger and Ranga Prabodanie, both then at the University of Canterbury, New Zealand.

5.1 Introducing MarshWren

Based on recent work in allocating water resources, we designed a smart market trading platform called MarshWren. We developed MarshWren with the intention that it could actually be used to manage nutrient runoff (nonpoint source or point source) with a smart market approach. Lacking a live experiment with actual users (who are unlikely to report actual values for runoff contribution), we used MarshWren to simulate trading between point and nonpoint sources in the Big Bureau Creek (BBC) watershed under the hypothesis that wetlands can be a cost-effective way to reduce nitrogen and phosphorus loads in the watershed.

MarshWren resembles the economic analysis performed by the University of Illinois at Urbana-Champaign (UIUC) in Section 4, in that MarshWren uses an optimization model to choose allocations. However, rather than use the model to simulate how trading might evolve, the model is itself an integral part of the trading mechanism. A key feature of this market design is that the participants buy from or sell to a centralized market manager rather than from or to each other. The market manager aggregates all buyer and seller bids, which then become part of the optimization model; the optimization model chooses which bids to accept while ensuring that required load constraints are satisfied.

The system is a “smart market”—a periodic auction cleared with the help of mathematical optimization. The optimization can handle a range of complications, including different attenuation rates on stream segments and multiple environmental constraints, while taking advantage of relevant scientific data that affect nutrient loads (e.g., precipitation, temperature, catchment area, stream channel attenuation, etc.). Such a market design would drastically lower transaction costs, incentivizing market activity. The transaction costs of trading should be so low that participants could trade easily and often. While we recognize the political hurdles involved in implementation, users should find trading in the system to be transparent and simple. MarshWren demonstrates how the nutrient loads in the BBC watershed can be reduced by incentivizing farmers to build wetlands to reduce NPS nutrient runoff.

Our design follows that of Prabodanie et al. (2010) with a new feature to address the all-or-nothing nature of wetland construction (i.e., the entire wetland is built and operated if selected). The Prabodanie et al. (2010) market design is an online auction with an optimization model to facilitate multilateral trading. The traders can bid to buy from or sell to the auction manager rather than find trading partners on their own. The auction manager will enter the bids into the optimization model. The solution of the optimization indicates which bids should be accepted so as to minimize the cost. After solving the optimization, the auction manager informs the accepted quantities for trading, collects money from buyers, pays sellers, and clears the markets. Since the market design is quite general, it could work for other pollutants (e.g., biological oxygen demand, temperature, sediment, etc.) and for any segment-based configuration of streams, constructed wetlands, or other best management practices (BMPs).

We ran MarshWren to analyze different trading scenarios based on the wastewater treatment plant (WWTP) demand and AnnAGNPS wetland nutrient removal estimates described in Section 3. First, we simulated a “traditional” market for the whole Big Bureau Creek watershed with the trading participants being the farmers with potential wetland sites and the permitted point sources. Given that agricultural runoff is the primary source of nutrient loads, we explored two scenarios in which the nutrient load constraint was a 50% reduction in watershed load. This “watershed management approach” requires the field of potential buyers to be expanded beyond the permitted facilities; the permitted facilities are responsible only for their regulatory mandated reduction (based on the diversified standard described in Section 3.2). The buyers of these additional credits could be municipalities, the government through conservation programs or initiatives, conservation organizations, or farmers.[10] Since the modeled potential wetland sites did not have the capacity to achieve a 50% reduction themselves, we introduced other nutrient management practices to provide additional nutrient reduction capacity. We first studied the types of trades that could occur between farmers, WWTPs, and people willing to build wetlands in the Lime Creek sub-watershed, based on parcel-level farm data. Second, we simulated a similar market for the whole BBC watershed, but with estimates of farm data. In all cases, the platform took into account seasonal variation of the market. The simulations reported here correspond to solutions of the MarshWren optimization with our estimates of various participants’ bids.

[10] The inclusion of farmers as buyers is not implying that the farmers are regulated (or suggesting that farmers will be regulated), rather that the farmers are buying or selling nutrient loads under some watershed management approach to achieve a nutrient reduction goal.

5.2 MarshWren Market Design

The MarshWren market design consists of the identification of the participants, definition of the commodities being traded, description of the market operations, and formulation of the optimization model at the core of the market clearing. The word “market” refers to the whole design and its behavior. We will call an instance of market operation an *auction*, where participants bid through a web page, and the market manager solves the optimization and announces the results.

5.2.1 Market participants

The market players include the implementer/regulator responsible for setting up the market, the market manager who is responsible for operating the auctions, and the traders who use the market. Traders include municipal or privately owned permitted treatment facilities as point sources, farmers or landowners as nonpoint sources, and landowners who are willing to construct the nutrient removal wetlands.

Implementer. The regulator or the governmental oversight party is responsible for designing and implementing a proper market structure for trading, which accounts for the spatial and temporal variations among the dischargers.

Market manager. The key feature of this market design is that the participants implicitly buy from or sell to a market manager, the central player in the market. Participants trade through a common pool of nutrient credits managed by the market manager. The market manager is designated by the implementer and government regulator. The market manager could be an agent of the state EPA or a contracted agent who is overseen by the regulator. Many of the market manager’s tasks could be contracted to a private firm. However, due to the central regulatory nature of the nutrient allocation and the widespread externalities, a level of government oversight of the market will be required.

The market manager has significant responsibility in arranging and enforcing contracts, ensuring market operations, guaranteeing payments, and enforcing market rules. The market manager is responsible for ensuring smooth market operation (e.g., maintaining the auction website and its security), keeping the data in the market model current, enforcing regulations, and penalizing participants who do not meet their obligations. The market manager must keep records of nutrient credit ownership, maintain the hydrology data, and operate the auction website and clearing optimization. The market manager accepts payments from buyers and pays the sellers. While the market manager could authorize bilateral trading with specified criteria and trading ratios, we assume all trading occurs through the market manager.

The role of the market manager in MarshWren is similar to the role of the system operator in a modern electricity market. The system operator is responsible for clearing the market and for managing the physical stability of the power network. This centralized approach has many advantages. The smart market serves as the marketplace where participants go to trade; finding trading partners is easy. They can trade with greater anonymity, as only the market manager knows their bids. Participants are responsible only for their own obligations; they do not have to enforce contracts on other participants, as they would have to do with a bilateral trade.

Traders. The market participants include operators of point sources, owners of potential wetland sites, and owners of nonpoint sources, which are farms in this study but could be municipalities.

Point sources include municipal, private, and industrial facilities that discharge effluent directly into the stream. Concentrated animal feeding operations (CAFOs) can also be included in the trading program. Each point source must have a permit that specifies the limit or the maximum allowable total nitrogen or total phosphorus load discharged per day. We assumed that each point source discharges to a single stream segment. Demand arises when the point sources find it difficult and costly to meet their permitted discharge levels. Instead of making the costly upgrades to meet the permitted discharge level, the point source can buy nutrient credits from the market manager, as long as the market manager can match purchases to willing sellers. The sellers can be wetland owners, farmers, or other point sources that perform better than their own permitted discharge level.

As previously described (See Section 3.5), properly sited and designed wetlands can significantly reduce nutrient runoff from upstream sources. The owners of constructed or restored wetlands that are designed to capture and reduce nitrogen and phosphorus loads into the stream network can participate in the trading program as nutrient credit sellers. Wetland owners cannot easily control the load removed, as load is a function of upstream inputs and flow. However, the regulator can measure the amount of nitrogen or phosphorus by monitoring concentrations and flows at the inlet and outlet (which can be costly), or the regulator can license the wetland with a specific seasonal nutrient removal rate that takes into account potential variation over a 10 or 20-year period.

Nonpoint sources are the farms in the watershed. Farms that implement best management practices, such as nutrient management or cover crops, can generate nutrient credits and participate in the market as sellers. In our simulations, no baseline or threshold of nutrient reduction needs to be achieved prior to participation in the market, but we could trivially implement such a requirement within MarshWren. For simplicity of modeling, small farms could be grouped into square-mile sections, where each section or part of a section belongs to the drainage area of one stream segment. The model does not need this grouping as it can handle thousands of farmers. For the Lime Creek example, we intersected digital county parcel data with the AnnAGNPS loading data to determine the nitrogen and phosphorus contributed by each farm to the nearest downstream node. For some large farms, we divided the farm's contribution between two or more segments; a farm owner must bid separately for each segment, because different segments are likely to have different prices.

We assumed rather optimistically that all farmers would be interested in participating. Farmer participation would thicken the market considerably, and we wanted to demonstrate how large of a reduction in nutrient loading could be achieved. At first look, this assumption may appear optimistic. However, we think that farmers would be incentivized to participate by the prices from early rounds of market simulation and the low transaction costs. This problem is intertwined with the issue of initial rights, which we discuss in Section 5.3.

In general, sellers reduce the phosphorus or nitrogen load to their local node, while buyers increase the load to their local node. However, the market design also allows outside participants, such as a government entity or environmental organizations, to participate as a buyer to lower the total nitrogen or phosphorus discharge from the watershed.

5.2.2 What is traded?

In MarshWren, the commodity being traded is contracts. The contracts are based on kilograms of total nitrogen and total phosphorus discharged to at least one assessment point. Farmers and WWTPs can trade a contract directly based on kilograms by season, but people who offer to build wetlands will want to trade a somewhat different kind of contract. To trade these contracts, the market design has three key requirements, as with most other existing nutrient trading programs.

First, the market requires a pre-determined cap on the total nitrogen or total phosphorus load from the watershed, such as a total maximum daily load (TMDL) or quantitatively-specified load reduction strategy (LRS), possibly with caps on the load on each stream segment. A TMDL or LRS for total nitrogen or phosphorus specifies the maximum sustainable phosphorus or nitrogen load from the watershed as measured at a particular location. This location is typically the outlet of the watershed, identified as the "assessment point" in MarshWren. Alternatively, the regulator could choose a TMDL on each stream segment, rather than at a single point. MarshWren can include any number of assessment points.

Second, the market is driven by regulations that require that any discharge above the TMDL or LRS at each assessment point must be offset in some fashion. Third, the market requires an initial allocation of the TMDL or LRS among the sources that specifies the maximum allowed discharge levels. The market design does not require constant limits over time. The regulator could start with relatively high levels and reduce them over time, but implementing TMDLs in this manner requires some means of paying users for the reductions or for scaling down users' rights.

As described in Section 3, water quality standards for river and streams have not been established in Illinois, and a TMDL for nitrogen and/or phosphorus has not been approved for Big Bureau Creek or its sub-watersheds. Since the TMDL has not been specified, the initial rights cannot be specified (discussed further in Section 5.3). Currently, the catchments we are studying are badly over-allocated, i.e., users are discharging far more than any future TMDL would likely allow. Furthermore, in the unlikely event that some load were unallocated, the market manager would be in a position to sell the unallocated load.

From the point of view of the optimization, participants trade (buying or selling) the right to discharge, or they sell attenuation capacity in the form of a wetland. The trading occurs over some calendar cycle. We think that users would want to trade with a frequency related to their ability to control their discharge. For farmers, we assumed this would be once per season. WWTPs can control their discharge daily, but the rest of the market can trade less frequently, so we assumed once per season as well. However, participants who build wetlands are implementing a capital-intensive project. They would not want to change their wetland configuration each season; rather, they are likely to want to build the wetland with an assurance of payments for some number of years, 10 or 20.

We define a *nutrient credit* as a legal document conferring to its owner the right to discharge 1 kilogram of nutrient for one season. Each credit document specifies the season, year, and nutrient type (i.e., nitrogen or phosphorus); credits expire after one season. In the MarshWren market design, the market manager is responsible for recording ownership and trades of nutrient credits. The manager withdraws credits from sellers and issues credits to buyers. However, this arrangement of credits fails for wetland builders, because wetland builders cannot issue credits to buyers (since only the market manager can issue credits). Further, the wetland builders want payment for their land use that is sufficient for many years rather than only one season.

The smart market design allows the market manager to trade *contracts*, which are simply agreements. Farmers could agree to reduce their discharges, whether through changes in cropping or through implementation of best management practices. Having previously agreed to reduce discharge, a farmer may later wish to pay to increase discharge. The farmer can offer seasonal contracts. The farmer and WWTP contracts can be written in terms of nutrient credits.

In contrast, the wetland builder simply offers a contract to the market manager to build a wetland of a particular size and configuration at a particular place. The wetland must have some agreed-on configuration and attenuation ability, which is part of the contract. The market manager must be able to convert the wetland attenuation design to the same units as seasonal nutrient credits. The market manager then runs the optimization to determine whether to accept the offer. The wetland builder will likely wish to offer a relatively long-term 10-year or 20-year contract.

To take into account different users' different required contract lengths, each auction and the clearing optimization must match the trades to the contract lengths. Such requirements are generally known as "inter-temporal constraints." When each period is independent, each auction clearing is independent of future periods, and the auction can be cleared separately for each period. With inter-temporal constraints present, a multi-period market model cannot be replaced by a set of single period models. Fortunately, such constraints are easily included in the market clearing models. We therefore assumed and modeled a 10-year auction, in which farmers and WWTPs plan every season for the next 10 years. Clearing a futures auction in this way enables the market manager to write a 10-year contract with a wetland builder. In each following season, farmers and WWTPs can change their previously-traded positions, but the market manager will be assured that the TMDL at the assessment point can be satisfied.

A key purpose of this futures auction is to incentivize landowners to invest in wetland construction. A seasonal right would confer a specific load "curve" over the season for farmers, whereas the point sources would have a fixed load per day over the season. In fact, the regulator could operate a spot auction that runs weekly or even daily, allowing market participants with point sources to adjust discharges dynamically in response to short-term changes in their needs and environmental conditions. In any case, prices in the spot auction will provide useful information for participants in the futures auction.

5.2.3 Market data

We used a technology based effluent limit to determine the load reduction possible for the WWTPs in Big Bureau Creek (See Section 3.2). We used the AnnAGNPS watershed model to determine the seasonal baseline conditions and the seasonal effects of the potential wetlands at key node locations along the stream network. We assumed farmers could reduce up to two-thirds of their current runoff.

MarshWren calculates the total load from all catchment users, based on PS and NPS discharges in kilograms, wetland attenuation in kilograms, and any natural attenuation, through the stream network to the outlet. The model can easily take into account in-stream factors for each segment. As previously stated, the catchment has little natural attenuation of nutrients, particularly nitrogen, based on the decay rate used in the AnnAGNPS model simulations. As a conservative estimate, we randomly assigned a small seasonal attenuation factor (0%, 0.25%, 0.50%, or 1%) to the non-wetland flow path segments (e.g., stream tributaries, drainage ditches, grassed waterways, etc.).

We assumed a total seasonal constraint limit at the outlet, which is also the assessment point, and we solved our cases parametrically over a range of hypothetical reduction limits (e.g., 0%, 20%, 40%, 50%, 60%, 80%, and 100% or no limit). In each case, we assumed that both nitrogen and phosphorus would be reduced by the same amount in each season. However, MarshWren does not require this; it allows limits to vary by nutrient and season.

5.2.4 Market operation

At the beginning of each season, the market manager announces the date of the nutrient credit auction. On the auction web page, participants can bid to buy and offer to sell nutrient credits for each of the following 40 seasons (4 seasons over 10 years). Some trial auction rounds might provide price signals to the users so that they can adjust the bids accordingly. Once the auction is cleared, all payments (including payments for future credits) are settled immediately. Because participants make commitments for a reasonably long period, they will have reasonable certainty for their business operations.

Through a web page, potential wetland owners can submit an offer for each season or a single offer for multiple seasons over a specified time period. We assumed that they would be most likely to make a single offer for the full length of the futures auction, e.g., 40 seasons. A potential wetland owner would submit an offer to construct a wetland. The market manager would have to agree on the wetland's nutrient removal capacity (kg/season) for many sequential seasons; each season can have a separate nutrient removal rate. Following auction clearing, landowners with accepted offers to build wetlands could obtain immediate payment to build the wetland and would be obligated to operate the wetland for the full 10 years.[11] Alternatively, the market manager could hold some of the money due to the landowner to ensure contract completion. The contract would be enforced by the market manager, who would be empowered to penalize the landowner's noncompliance.

Point sources could bid to buy nutrient credits for each of the 40 future seasons separately. Bids ($/kg N or P) submitted by a point source for different seasons are considered as independent, and hence, different quantities can be accepted for different seasons.

Initially, farmers would usually offer to sell their nutrient credits ($/kg). They could submit separate offers for each season, or a single offer for multiple sequential seasons, possibly with the intention to invest in long-term nutrient reduction projects (e.g., buffer strips or grassed waterways). In our simulations, we assumed separate offers for each season. Following a sale, the farmer would be obligated to implement the BMPs as agreed, and the market manager must have the authority to penalize any farmer who does not abide by the agreed obligations. If a farmer changes her mind and wishes to increase discharge in a future season, she can bid to buy nutrient credits at the next auction.

In auction clearing, MarshWren does not discount the bids and offers made for future periods; participants should calculate their future values at their own discount rates. Hence, bids for future credits should already indicate each participant's discounted value of the future credit.

The spot auction works identically to the futures auction, except that only the current period is traded. The purpose of the spot auction is to allow short-term changes in load. The spot auction is likely to be active only if the regulator requires that the TMDL be met closely on a near real-time basis. These changes may be because of weather conditions or temporary changes in plans. Landowners are unlikely to bid in the spot auction for wetland development, as they would get payment for only one season.

Users who wish to trade bilaterally based on their own negotiations can do so. The trades would have to be authorized by a regulator, because different trading ratios may apply based on in-stream attenuation. More importantly, their associated transaction cost will be much higher, as the users must find each other, negotiate a fair price, write a contract, and enforce it. In general, pollution permit trading through a centralized auction will be much more convenient than bilateral trading.

5.2.5 Pricing

In this market, pricing for farmers and WWTPs must be somewhat different to pricing for wetland builders. The former will face standard marginal cost nodal or locational pricing, while the latter face "start-up" pricing. We could design the market to accept users' bids as given, in the same way that EBay works. However, the charged-as-bid approach tempts participants to shade their bids low to try to save money, in which case they could sometimes miss the amount they actually wanted. Further, participants are tempted to try to guess other people's bids.

Under a classical marginal price approach, farmers and WWTPs are not charged as bid. Rather, they are charged at the marginal cost. This is similar to a simple auction for a commodity, in which many bidders win, where the auctioneer charges all winners at the lowest price which clears the auction. Accepted buyers pay their bid or less; accepted sellers receive their bid or more. The advantage of this approach is that participants need not worry much about gaming their bids. They can bid truthfully, and would be charged at a fair "going rate."

The market requires a complicated "going rate," because the bids and offers are not directly comparable between different traders nor between traders of the same type, because traders have different impacts on the assessment points due to different attenuation. The clearing mechanism must manage these factors, while finding equilibrium prices that match supply to demand. A linear optimization model is well suited for this. The market manager reads the bids and offers, and then clears the auction by solving the optimization model. The model calculates the optimal quantities traded and the optimal prices at each stream node. The model ensures that the total load remains within the pre-determined limit or TMDL at the assessment point. Due to attenuation, total trades will not appear to balance

[11] The authors recognize that wetland construction and vegetation establishment (start-up period) can be 12-18 months. The market development and initial bidding can occur prior to NPDES permit issuance to ensure the credits are available when needed, or less credits can be offered during the period when the wetland is "coming online" during the 10-year auction period.

exactly. For example, an upstream increase of 100 with attenuation of 10% along the stream could be offset by a downstream decrease of only 90; this trade balances when attenuation is considered. Despite the complexity of the hydrology, MarshWren calculates the price correctly for each node in the catchment, based on the shadow (dual) prices, following standard optimization theory.

However, we face an even greater complication with pricing for wetlands, due to the nature of the wetland design and construction being essentially "all or nothing." The landowner offering to build a wetland may not be able to significantly change the offered configuration, size, or position of the wetland and, therefore, increase the nutrient removal capacity of the wetland. While wetland management or operation can impact nutrient removal, the physical design parameters are the main determining factors. We assume that the landowner has designed and plans to operate the proposed wetland for its best performance. In addition, the construction of a tile-drainage treatment wetland is a large capital investment relative to other BMPs. A landowner is unlikely to make that investment prior to his/her bid being accepted. This introduces discreteness to the decision, requiring binary decision variables in the MarshWren clearing model. Essentially, we would like the cost function to be smooth so we can find a slope for the marginal price, but the all-or-nothing nature of the wetlands introduces step changes.

We could therefore simply pay wetland builders as bid. However, they may be tempted to shade their prices, as with any first-price auction. Accepted bidders may further think that this kind of pricing is unfair, when they observe that sometimes the attenuation that their wetland provides is worth more than they bid. A fair "going rate" should be the value of their attenuation in the market. In fact, we could imagine a person willing to build a wetland without ever bidding for it as a whole, but instead seeking to be paid for the attenuation each year. Such a move could be viewed as unwise, but it should be possible at least theoretically. The point is that paying the price as bid does not always give a fair "going rate," and does not follow classical marginal cost pricing.

We can get the marginal cost pricing for a wetland by allowing fractional wetlands. Then the optimization is convex, and gives "good" prices. Wetland builders would be paid exactly the going rate for their attenuation, but a fractional wetland may be impractical. Yet another problem arises with all-or-nothing wetlands. Consider a case where the optimal fractional solution is to have 70% of a wetland, but the optimal integer solution is to have 100% of the wetland. Now the wetland is overbuilt from a true marginal price point of view, and so the nodal price is likely to be lower, possibly even zero. Thus, we have no good "going rate" to pay the builder, even though we know that the solution is optimal.

To address this lumpiness, we used the approach of O'Neill et al. (2005). They calculate prices for the binary assets in two steps. First, they solve the optimization as an integer program. Second, they convert the solved integer program into an augmented linear program with only continuous variables. The augmented linear program then provides the auction-clearing prices for all bids, both continuous and discrete. We therefore define the MarshWren optimization model as an integer program, with the understanding that it will be used in the manner of O'Neill et al. (2005).

Pricing for the wetlands, then, will be in two parts. First, the wetland builder with an accepted bid will be paid for the attenuation at the local prices. Second, the wetland builder will be paid a "start-up" cost. If the attenuation payment is equal to or greater than the bid, the start-up cost will be $0. If the attenuation payment is less than the bid, the start-up cost will be sufficient to raise the payment to the value of the bid. The O'Neill process has the unfortunate consequence that the market manager is unlikely to enjoy revenue neutrality. Buyers on the other side of the trade will face somewhat artificially low prices, a bit too low to ensure enough money to offset the startup payments to the wetland builders.

5.2.6 MarshWren optimization model

This section presents the MarshWren optimization model that was used for clearing each auction. We put the MarshWren data into a spreadsheet that serves as a front-end for the optimization software. We used open source optimization libraries, OpenSolver.xlsm and SolverStudio, both available at opensolver.org.

INDICES

u = user, either a farmer, an operator of a point source, or a potential wetland builders;

i, j = node in the stream network;

t = season;

n = nutrient type, 1 for nitrogen and 2 for phosphorus.

PARAMETERS

$A_{i,j,n}$ = attenuation of nutrient type n on segment(i, j).

α = fraction of total runoff allowed.

$D_{u,n,t}$ = user u's current kg load of nutrient n received at the nearest downstream node j in season t. The model takes this as a status quo, not necessarily as an initial right.

$SellPrice_{u,b,n,t}$, $BuyPrice_{u,b,n,t}$ = sell or buy bid price for user u, bid step b, nutrient n.

$SellQty_{u,b,n,t}$, $BuyQty_{u,b,n,t}$ = sell or buy bid quantity for user u, bid step b, nutrient n.

T = number of periods in the auction model, e.g., 40 seasons.

$WPrice_u$ = sell price for user u offering to build a wetland.

$WA_{u\ (i,j),n,t}$ = kg attenuation of nutrient n on segment (i, j) in season t if user u builds the agreed wetland at the beginning of season 1.

DECISION VARIABLES

$q_{u,n,t}$ = credits allocated to user u for nutrient n in season t.

$x_{i,j,n,t}$ = kg load of nutrient n on segment (i, j) in season t.

w_u = 1 if user u builds a wetland, assumed to be on a known segment (i, j), in season 1. Else 0. We will use the notation w_u* to indicate the optimal values of w_u in the integer program without constraint set 5-7 below.

$sell_{u,b,n,t}$, $buy_{u,b,n,t}$ = accepted sell and buy quantities respectively, for user u and bid step b of nutrient n in season t.

MODEL MARSHWREN

(5-1) Max$\sum_{\text{users } u}\sum_{\text{bids } b}\sum_{\text{nutrient } n}\sum_{\text{seasons } t}$ $(BuyPrice_{u,b,n,t}buy_{u,b.n,t}–SellPrice_{u,b.n,t}sell_{u,b.n,t})$ $– \sum_{\text{users } u}\text{WPrice}_u\text{w}_u$, subject to

(5-2) $q_{u,n,t} = D_{u.n,t} + \sum_{\text{bids } b}(buy_{u,b.n,t} – sell_{u,b.n,t})$, for each user u, nutrient n, and each season t.

(5-3) $\sum_{\text{nodes } i}(x_{i,j.n,t}– WA_{u(i,j),n,t}w_u) +\sum_{\text{users } u}q_{u,j.n,t} = x_{j,k,n,t}$ for each node j, except the assessment point node, each nutrient n, and each season t. Dual price $p_{j.n,t}$

(5-4) $\sum_{\text{nodes } i}(1–A_{i,last})x_{i,last.n,t} \leq \alpha\sum_u D_{u,n,t}$ for the assessment point node last, each nutrient n, and each season t. Dual price $p_{last.n,t}$

(5-5) $0 \leq buy_{u,b,n,}t \leq BuyQty_{u,b,n,t}$, $0\leq sell_{u,b,n,t} \leq SellQty_{u,b,n,t}$, for all users u, and bid steps b, each nutrient n, and each season t.

(5-6) $q_{u,n,t}$ free, $x_{i,j,n,t} \geq 0$.

(5-7a) In the first solution, w_u binary.

(5-7b) In the second solution, $w_u \leq w_u$* if w_u* = 0, and $w_u \geq w_u$* if w_u* = 1, for all u. Dual price ω_u.

(5-8) $0 \leq w_u \leq 1$, for all u.

EXPLANATION

(5-1) The objective maximizes the value of purchases minus the value of sales. This is how a broker would work, by accepting the highest buying bids and the lowest selling offers.

(5-2) This constraint set calculates the total quantity traded by each user as accepted, summing up the user's accepted bids. The dual price $p_{u,n,t}$ on this constraint equals the improvement in the objective if user u is allocated an additional kilogram of nutrient n. This value $p_{u,n,t}$ is the price that user u should face, whether user u is selling or buying nutrient n, in season t.

(5-3) This constraint set calculates the change in load of nutrient n into each node j in each season t. The dual prices $p_{j,n,t}$ give the nodal price of nutrient n at node j in season t. Due to in-stream attenuation, the nodal prices can vary along the stream. The adjusted prices of the stream nodes are given by the shadow prices of constraint 3. Users at this node face this price.

(5-4) This constraint ensures that the total load at the assessment point does not increase. The shadow price $p_{last,n,t}$ of this constraint is the increase in the objective if the load at the assessment point were increased by one unit (the marginal value). Hence, $p_{last,n,t}$ is the current market price per kg of credit at the assessment point. This price matches supply and demand, maximizing the benefits from trade. We used $\sum_u D_{u,n,t}$ as the total "worst case" runoff at the assessment point, which corresponds to the unattenuated maximum runoff from each user, a conservative value. When $\alpha = 1$, the seasonal load limit equals users' total load, with 0% reduction required. When $\alpha = 0.2$, the seasonal load limit corresponds to an 80% reduction.

(5-5) This constraint set corresponds to a piece-wise linear approximation of the users' demand curves for credit.

(5-6) We assume that farms and WWTPs cannot attenuate nutrient, so $q_{u,n,t} \geq 0$. However, we need $q_{u,n,t}$ to be free to avoid dual degeneracy. The decision variable associated with the wetland construction is binary, indicating that the landowner cannot build a partial wetland, and cannot build a wetland larger than offered. However, binary integrality is relaxed when solving the model as the augmented linear program, when constraint set 7 is added.

(5-7a, b) These constraints correspond to the augmented optimization O'Neill et al. (2005). First, the model is solved with 7a and without 7b. Second, the model is solved without 5-7a and with 5-7b. The dual price ω_u is the price faced by a user u for building a wetland.

(5-8) This constraint set implies that the wetland builder will not remove a wetland ($w_u \geq 0$), and the wetland builder cannot build a wetland larger than the one proposed ($w_u \leq 1$).

5.3 Initial Rights

Markets generally do not operate well without a clear specification of initial rights. Ours is no exception in this regard. Yet we had little ability to specify these initial rights, as government must first clarify them. Farmers' rights to runoff appear to be unlimited, while WWTPs are responsible for their allocation within a TMDL. Hence, farmers appear to have all the rights to discharge and WWTPs appear to have all the responsibilities. Since farmers are not regulated, they have no initial level from which to sell. But if they want to be paid to reduce, they would be incentivized to agree on some initial level in order to be paid to reduce from that level.

When the market manager accepts a farmer's freely offered bid, the farmer would have to adhere to the limit for the term of the bid (e.g., for season as in the market design here). At the end of the bid term, our market design specifies that the participant's initial right is restored. However, the government may be inclined to enforce the original initial level as the farmer's "initial right." After all, if the farmer was willing to be paid to reduce from a fixed initial level, the farmer would be implicitly agreeing that the initial level was the initial right. It may be that farmers' initial rights would be set when the state determines a TMDL allocation. If this is politically infeasible, we have to consider the farmers' load as non-tradable, i.e., the TMDL should be calculated after allocating for farmers' load. We assume that a TMDL will be determined and that farmers' fixed initial rights will eventually be established. Assuming this set of initial rights, the outcome to our market must be that farmers accept money to limit their right to discharge. The market manager would hold a contract with each farmer, which says that the farmer agrees to discharge no more than the quantity specified.

Fortunately, testing our market design does not require specification of initial rights. Further, we have strong evidence that the initial rights are unlikely to affect the final outcome. That is, assuming we have guessed users' costs correctly, the final outcome will be the same regardless of the initial rights, see Coase (1960).

We therefore assumed a simple market design, in which a market manager pays all traders. When we ran the model, we assumed that farmers, WWTPs, and potential wetland builders were only sellers. Thus, all "buy" variables were omitted in our models. The MarshWren optimization model as written above is more general than this, specifying buyers and sellers. A given trader could hold a net position other than zero, and thus offer bids to both buy and sell depending on the price. The trader would either buy or sell but not both in the solution.

To implement a net pool design, in which some traders buy and some sell, the market manager needs only to calculate the net trade after the market optimization. Therefore, users would put in bids based on their values for nutrient at their node, and the market manager can simply calculate the trade based on the difference between each trader's initial position and the final position. If the final is greater than the initial, the trade was a buy. If the final is less than the initial, the trade was a sell. Trader u located at node j thus receives $p_{j,n,t}\sum_{\text{bids } b}(buy_{u,b.n,t} - sell_{u,b.n,t})$ for each nutrient n and each season t. Remember that prices are negative. Alternatively, if trader u at node j has initial right Qu,n,t, we can calculate trader u's payment as $p_{j,n,t}(Q_{u,n,t} - q_{u,n,t})$ for nutrient n and season t. The total payment for the auction includes all nutrients and seasons in the auction: $\sum_{\text{nutrients } n} \sum_{\text{seasons } t} p_{j,n,t}\sum_{\text{bids } b}(\text{buy}_{u,b.n,}t - \text{sell}_{u,b.n,t})$, or equivalently, $\sum_{\text{nutrients } n} \sum_{\text{seasons } t} p_{j,n,t}(q_{u,n,t} - Q_{u,n,t})$.

We can further calculate the market manager's total revenue as the sum of the above terms over all traders: $V = -\sum_{\text{traders } u} \sum_{\text{nutrients } n} \sum_{\text{seasons } t} p_{j,n,t}(q_{u,n,t} - Q_{u,n,t})$. For an ongoing market, the market manager would probably want this to be nonnegative.

We assumed $Q_{u,n,t} = D_{u.n,t}$ for farmers and WWTPs, and we assumed wetland builders were purely sellers. Hence, we assumed the market manager pays out to all users whose bids are accepted. Again, MarshWren can handle any initial rights that government will specify, but the outcome of the auction does not depend on the initial rights.

5.4 Bid data

The auction accepts bids from WWTPs, potential wetland builders, and farmers. These bids, in a competitive market as this one is likely to be, should be close to users' marginal costs. Of course, we had no way to obtain accurate cost data from users, and many of them (especially farmers) would have incentive to disguise that data. Consequently, we estimated the costs based on considerable analysis. These estimates are of varying quality. As part of the estimation, we used two-part bids for the WWTPs and the farmers, with lower estimates for the first bid and higher estimates for the second bid in an attempt to bracket the true costs.

Table 3-10 and Table 4-6 contain the WWTP load and cost data, respectively, that we used in our simulation. We assumed that each WWTP could control nitrogen and phosphorus independently and by season. We assumed that a WWTP could reduce half of their nitrogen at a cost of $37.34/kg, and the remaining half at a cost of $74.68/kg. We assumed that a WWTP could reduce half of their phosphorus for $31.99/kg, and the remaining half at a cost of $63.98/kg.

After UIUC completed their economic analysis in Section 4.3.2, additional wetland cost data from the Iowa CREP program became available (IDALS 2012). We used these new data to calculate a new regression equation to estimate the total capital cost for each of the 80 wetland sites (Table 5-1). The total wetland cost included the opportunity cost derived in Section 4.3.2. We assumed that a potential builder could control only the general configuration of the wetland, and could not control the amount of nitrogen or phosphorus attenuated by season beyond that planned configuration. We consider these wetland cost estimates to be at the high end of the cost range, as they are conservative in certain design and construction aspects and are expected to have a 150-year design life. Because the bids varied for each wetland, we give detailed cost data below in each case description.

Table 5-1. Descriptive statistics for wetland design and construction costs for 54 Iowa CREP wetlands (IDALS 2012).

	MEAN	STD. DEV.	MIN	MAX
Wetland size (acre)	8.3	4.8	2.7	20.7
Total area (acre)	39.4	20.2	15.0	90.0
Construction cost ($ per wetland)	130,576	52,448	37,785	251,038
Engineering cost ($ per wetland)	29,742	12,570	3,561	56,157
Total cost ($ per wetland)	160,318	61,531	42,948	292,119
Capital cost regression equation:	Total Cost ($) = 817X (acres) + $128,125			

For farmers' bids, we have less assurance in our bid data, as agricultural BMPs have a range of nutrient removal efficiencies and costs. To achieve the proposed reductions in nutrient runoff, a combination of nutrient management (e.g., fertilizer management, cover crops, conservation tillage) and structural (e.g., grassed waterways, riparian buffers, etc.) best management practices will be needed, as these practices have different removal efficiencies for nitrogen and phosphorus. We determined a range of farmer bids based on estimated annualized costs derived from both NRCS payment rates and literature (US EPA 2007b; Talberth et al. 2010; Newburn and Woodward 2012) and on watershed model removal efficiencies (Waidler et al. 2009; Boeckler 2013).

We treated the Lime Creek and BBC cases somewhat differently, due to their different sizes. We will describe the BBC bids in that section. In the smaller Lime Creek case, for nitrogen, we used $2.98/kg for the first bid, and $4.04/kg for the second bid, identically for all seasons and all farmers. For phosphorus, we used $13.26/kg for the first bid, and $17.94/kg for the second bid. We assumed that a farmer could reduce total runoff by no more than two-thirds of their current runoff in each season as simulated by the AnnAGNPS baseline scenario. Thus, we assumed that a farmer could reduce one-third of the nitrogen runoff for $2.98/kg, and could reduce another one-third of the runoff for $4.04/kg, but could not reduce any more runoff; similarly for phosphorus.

If farmers' marginal costs for reducing nutrients are less than the values we estimated, then the nutrient reduction problem is easier overall than we have estimated. That would be good news in terms of considering an overall nutrient reduction strategy. On the other hand, if farmers' marginal costs are higher than our estimates, then we have a stronger case for our hypothesis that wetlands can be a more cost-effective solution.

5.5 Case 1: Lime Creek

This section describes the Lime Creek data and solution for a simulated auction. The market participants are one WWTP, 13 potential wetland sites, and 462 nonpoint source farm parcels.

5.5.1 Lime Creek data

The Lime Creek sub-watershed has only one permitted point source, the Ohio Sanitary Treatment Plant (STP), located at the top of the drainage basin. As described in previous sections, we identified 13 locations that could become wetlands, and we will assume that the landowners at those locations are offering to install a tile-drainage treatment wetland at those locations. Figure 5-1 shows a diagram of the stream network with potential wetland sites. Each segment is identified by an upstream and a downstream node.

The criteria used to site potential wetlands did not restrict a potential wetland site from being placed in the same drainage or stream reach as another potential wetland site. Throughout the BBC watershed, in nine cases a total of 14 wetlands were located downstream of another wetland. In the Lime Creek basin, several sites are located in the same stream reach or network flow path (Figure 5-1). The AnnAGNPS model standard output calculates each wetland's effect on the delivered nutrient load assuming all 80 potential sites were implemented (individual analysis). This individual analysis takes into account an upstream site's effect on the nutrient reduction capacity of a downstream wetland site on the same reach. The standard model output was modified to determine each potential site's nutrient reduction potential assuming no other wetland site was implemented on the same reach (independent analysis). As expected, the down-gradient wetland's nutrient reduction was higher without the presence of an upstream wetland (Appendix B, Figure A-5).

In the MarshWren model, we used the independent analysis results, since we do not know which wetlands would be implemented and the auction selects the optimal bids based on each wetland's estimated nutrient reduction and cost. We recognize that if two wetlands in a series are selected, then the downstream wetland's attenuation will be less than the nutrient reduction entered in the auction. Table 5-2 shows a summary of the input data for 13 potential wetland sites in the Lime Creek basin.

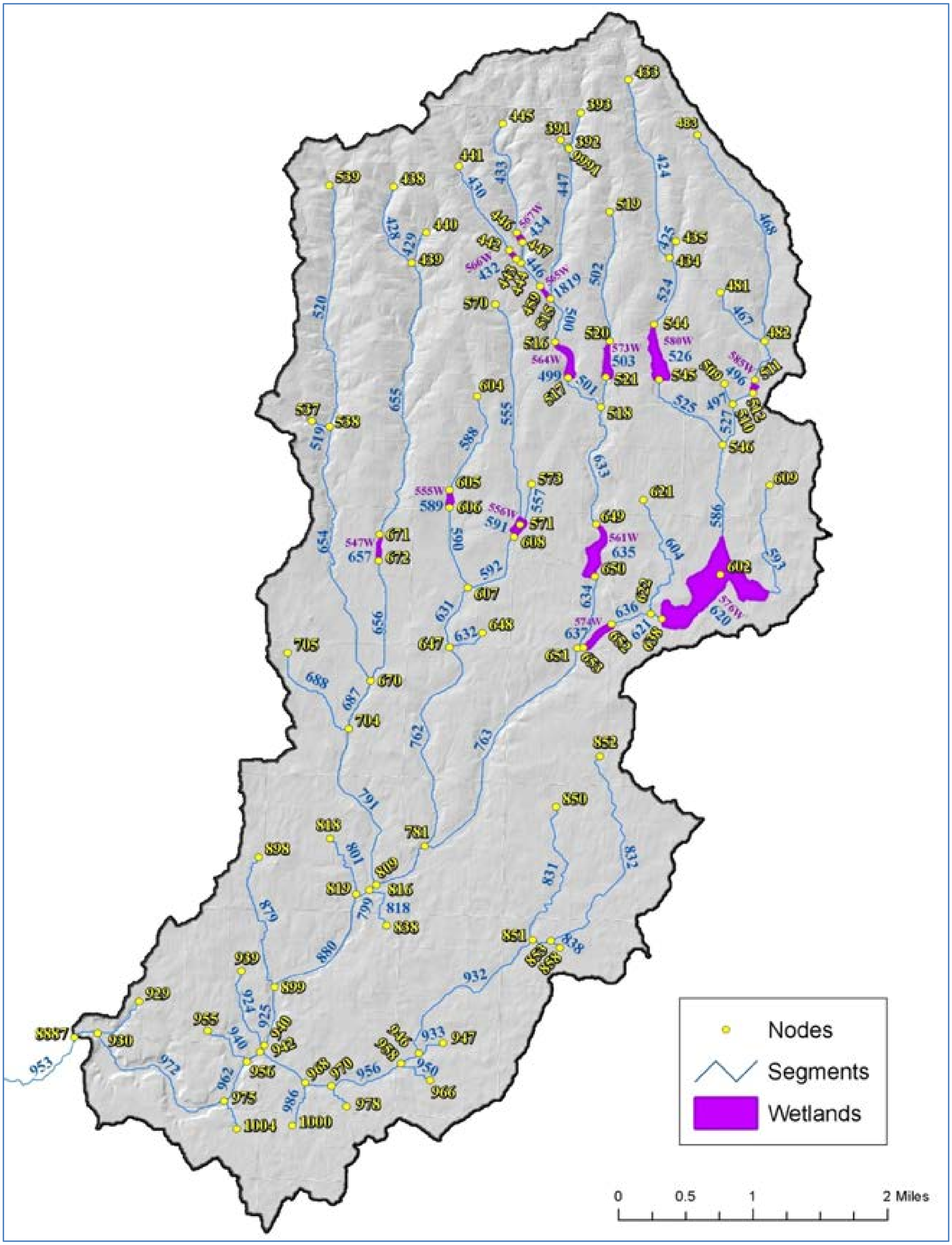

Figure 5-1. Lime Creek stream network configuration for MarshWren. Yellow numbers identify the nodes, blue numbers identify the segments, and the purple numbers identify the wetlands by the AnnAGNPS labeling system.

Table 5-2. Total cost and seasonal nutrient removal estimates for the 13 potential wetland sites in the Lime Creek basin.

WETLAND ID		COST ESTIMATE	NITROGEN ATTENUATION (kg)				PHOSPHORUS ATTENUATION (kg)			
MARSHWREN	AnnAGNPS		WINTER	SPRING	SUMMER	AUTUMN	WINTER	SPRING	SUMMER	AUTUMN
Wetland432	566	$131,662	286	1,376	1,454	583	10	289	269	45
Wetland434	567	$132,428	156	684	752	326	5	139	129	22
Wetland496	585	$133,452	231	566	694	432	9	51	46	18
Wetland1819	565	$133,473	206	591	707	403	4	66	59	11
Wetland499	564	$150,338	868	2,200	2,170	1,348	40	227	195	69
Wetland503	573	$147,363	255	1,021	1,012	470	9	144	131	26
Wetland526	580	$173,432	602	2,349	1,993	1,047	21	261	203	51
Wetland589	555	$135,647	685	1,915	1,984	1,137	33	225	191	63
Wetland591	556	$142,299	392	1,163	1,189	662	15	131	112	31
Wetland620	576	$358,397	2,251	8,194	7,912	4,056	416	1,641	1,200	601
Wetland635	561	$171,609	1,524	3,811	3,783	2,458	69	334	268	116
Wetland637	574	$146,994	1,648	4,636	4,621	2,897	157	615	490	255
Wetland657	547	$136,423	255	781	830	423	4	92	84	10

NOTE: The wetland IDs in MarshWren reflect the network segment in which the potential wetland site is located and do not correspond to the AnnAGNPS labels.

Since we have digital parcel information for this sub-watershed, we could estimate individual farm nitrogen and phosphorus contributions from the baseline scenario of the AnnAGNPS watershed model. A single farm parcel's nutrient loading may flow into two segments, and multiple parcels may contribute to a single segment. Therefore, we developed a GIS methodology to calculate which network node received each farm's load and that quantity of load. To do this, we ran a spatial intersection on three data sets: parcels (ownership), node-drainage area (land area draining to each node) and cell area (nutrient loading data). With this "intersected" dataset, we calculated the percentage of land in each cell occupied by each landowner. This percentage was then multiplied by the cell loading data to calculate N and P loads for each individual landowner. Lastly, the node-drainage area component indicated which node received the various N and P loads. Because different nodes are likely to have different prices, our market design requires farmers to enter separate bids for each segment contribution rather than a single bid for their whole farm parcel.

Since we did not consider initial rights, our simulation is a single-sided auction in which the market manager attempts to buy nutrient reductions at least cost. Farmers and the WWTPs are paid based on the nodal price per kg reduction. However, due to the all-or-nothing nature of building the wetlands, the market manager pays accepted wetland bidders a start-up payment plus an attenuation payment based on nodal prices. Thus the total payments for the wetlands are calculated using the formula $\sum q_{u,n,t}\, p_{j.n,t} + \omega_u$. We report dual prices as positive values for clarity of exposition.

5.5.2 Solutions for Lime Creek

We attempted to solve the Lime Creek case over a range of seasonal runoff constraints at the outlet of the basin, α = 0%, 20%, 40%, 50%, 60%, 80%, and 100% (with 100% being the limit equal to the current runoff). The model had no solution at the α = 0% and 20% limits, implying that 100% and 80% reductions are not likely to be feasible, since we assumed that farmers could not reduce their current runoff by more than two-thirds. The α = 100% case (no limit) costs nothing, so it is not reported.

Table 5-3 shows the wetlands in the solutions and their payments for the 40%, 50%, 60% and 80% constraint scenarios. Up to seven wetlands were required to be constructed depending on the nutrient runoff constraint. The greater the nutrient runoff reduction required, the greater the number of wetlands implemented. The final wetland payments are always at the bid or higher for the wetlands. The largest wetland (620) was present in each solution given its ability to remove larger quantities of nutrients; however, its payment was never higher than the initial bid price.

Table 5-3. The wetland sites implemented and the payments received for the four nutrient runoff constraint scenarios for the Lime Creek basin. The AnnAGNPS wetland identification label is in parenthesis.

SCENARIO	WETLAND 432 (556)	WETLAND 499 (564)	WETLAND 589 (555)	WETLAND 591 (556)	WETLAND 620 (576)	WETLAND 635 (561)	WETLAND 637 (574)
Bid	$131,662	$150,338	$135,647	$142,299	$358,397	$171,609	$146,994
40% constraint (60% reduction)	1	1	1	1	1	1	1
Attenuation payment	$0	$211,764	$0	$140,824	$0	$353,579	$0
Start-up payment	$131,662	$0	$135,647	$1,475	$358,397	$0	$146,994
Total payment	$131,662	$211,764	$135,647	$142,299	$358,397	$353,579	$146,994
50% constraint (50% reduction)	0	1	1	0	1	1	1
Attenuation payment	$0	$194,845	$0	$0	$0	$328,612	$0
Start-up payment	$0	$0	$135,647	$0	$358,397	$0	$146,994
Total payment	$0	$194,845	$135,647	$0	$358,397	$328,612	$146,994
60% constraint (40% reduction)	0	1	1	0	1	1	1
Attenuation payment	$0	$126,529	$0	$0	$0	$206,985	$0
Start-up payment	$0	$23,809	$135,647	$0	$358,397	$0	$146,994
Total payment	$0	$150,338	$135,647	$0	$358,397	$206,985	$146,994
80% constraint (20% reduction)	0	0	0	0	1	0	0
Attenuation payment	$0	$0	$0	$0	$0	$0	$0
Start-up payment	$0	$0	$0	$0	$358,397	$0	$0
Total payment	$0	$0	$0	$0	$358,397	$0	$0

Some wetlands seem to be uneconomical for any level of reductions required. For example, the bids for Wetland434, Wetland496, Wetland1819, Wetland503, Wetland526, and Wetland657 are not accepted in any of the scenarios. The Ohio STP does not need to reduce its discharge as its reductions were achieved by either the farmer-implemented BMPs or wetlands, given its estimated marginal cost is between 15 and 30 times the price for nitrogen and three to six times the price for phosphorus of the generic BMP or wetland price.[12]

The total nutrient reduction payments received by the three sectors (i.e., wetlands, farms, and STP) are presented in Table 5-4. To achieve a 60% reduction in nitrogen and phosphorus runoff, it would cost an estimated $3.5 million for the entire 10-year auction period. As the amount of runoff allowed is lessened, the distribution of payments between farmers implementing BMPs and landowners implementing wetlands switches as the less cost-effective wetlands have to be implemented.

Table 5-4. Total nutrient reduction payments to each sector in the Lime Creek basin for an entire 10-year auction period for the four nutrient runoff constraint scenarios.

LEVEL OF RUNOFF ALLOWED	PAYMENT FOR WETLANDS	PAYMENT FOR FARMS	PAYMENT FOR THE STP	TOTAL PAYMENT
40%	$1,480,342	$1,939,506	$0	$3,419,848
50%	$1,164,494	$1,127,256	$0	$2,291,749
60%	$998,361	$391,188	$0	$1,389,549
80%	$358,397	$55,443	$0	$413,840

Table 5-5 shows average prices by season and nutrient for the 40% limit (60% reduction). Winter has the highest nitrogen price, while spring and summer have the highest phosphorus prices. We think that prices in a real market are likely to differ by more than these prices over the different seasons. We assumed farmers' bids were the same each season, but they are likely to have different bids by season based on the selected BMP, crop rotation, fertilizer application and timing, etc.

[12] Individual wetland phosphorus removal was determined by the AnnAGNPS model; therefore, it is not the same removal rate used in the economic feasibility analysis in Section 4.

Table 5-5. Average user prices by season for the 40% limit (60% reduction scenario).

	WINTER	SPRING	SUMMER	AUTUMN
Total nitrogen ($/kg)	$2.45	$2.30	$2.30	$2.41
Total phosphorus ($/kg)	$12.79	$12.95	$12.95	$12.78

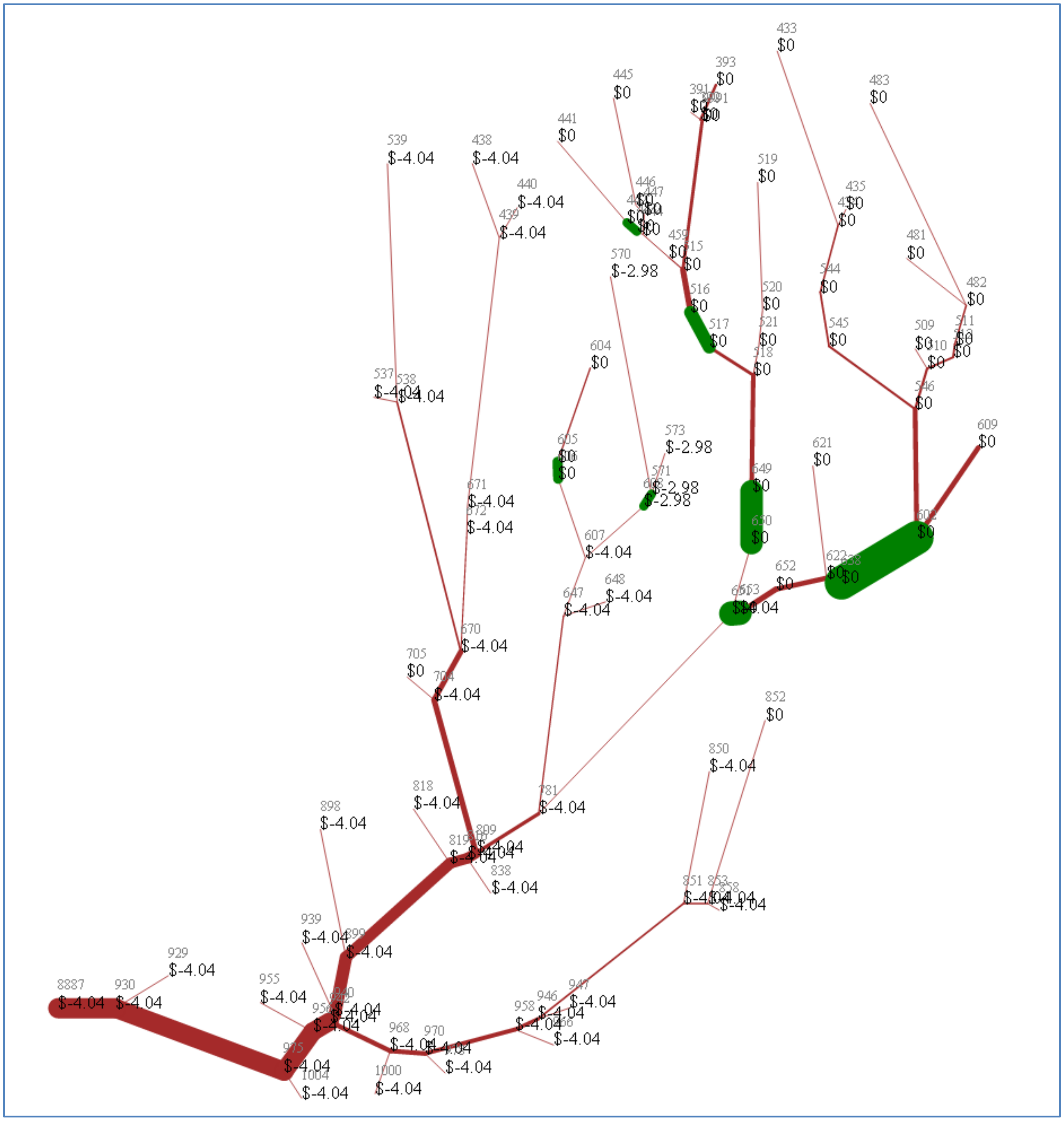

Figure 5-2. Lime Creek stream network with the node prices for the winter nitrogen in the 40% limit (60% runoff reduction). The segment widths indicate the amount of runoff, and the green segments are the implemented wetlands.

The prices can differ at each node in the stream network. While the implemented wetlands may have prices of $0 for a nutrient or season (winter nitrogen, Figure 5-2), they are installed to exploit high prices in other seasons (summer phosphorus, Figure 5-3). However, other wetlands still have prices of $0. In fact, four wetlands face a price of $0 for every season and nutrient. This is a case where the optimal solution is to include a wetland, but its all-or-nothing requirement causes it to be somewhat overbuilt for the nutrient removal allocated to it; therefore, it collapses the prices locally. In these cases, the builder would receive their price as bid based on a start-up payment but not an additional attenuation payment. The other three accepted wetlands received attenuation payments and, in two cases, they received more than their bid.

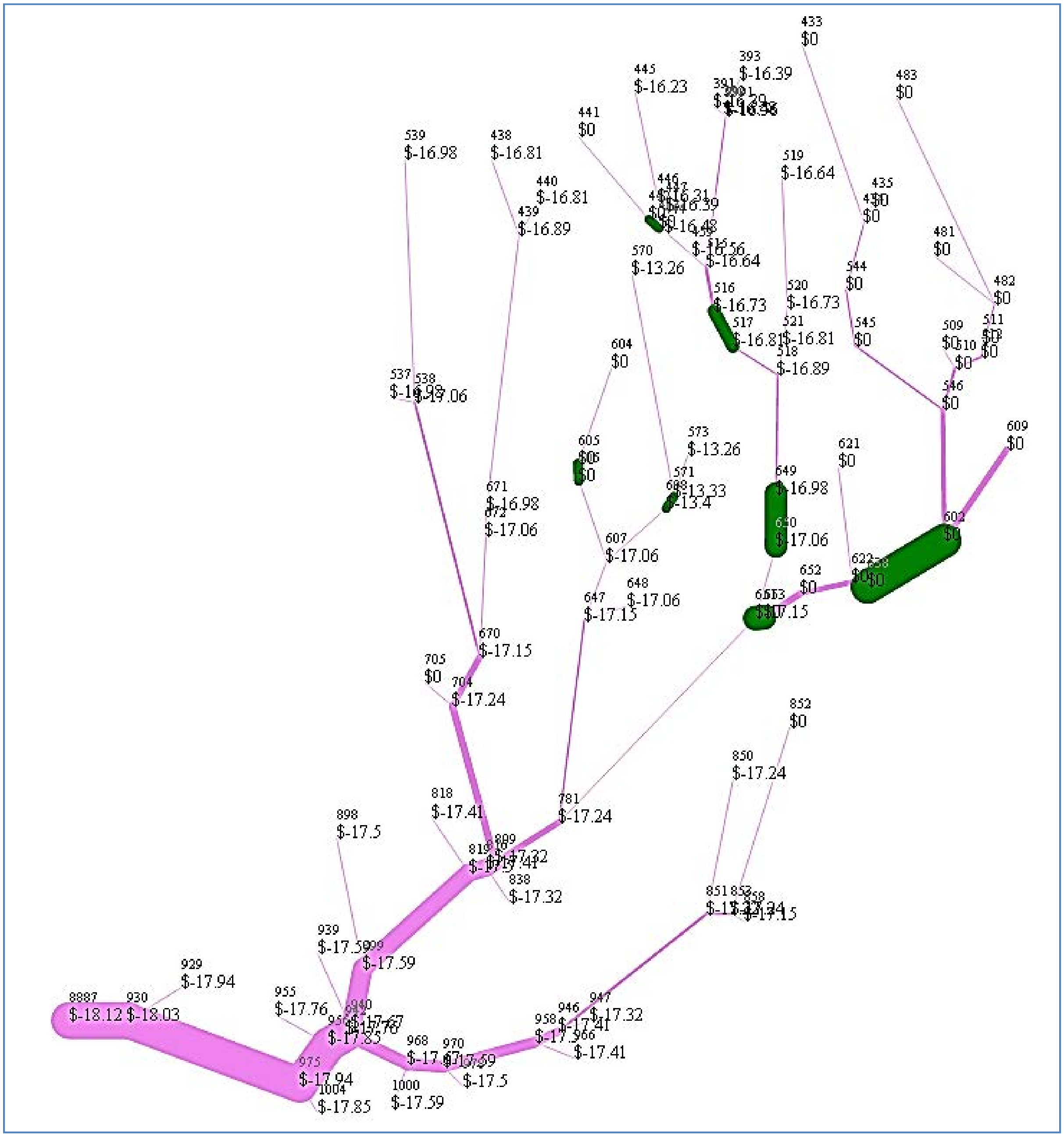

Figure 5-3. Lime Creek stream network with the node prices for the summer phosphorus in the 40% limit (60% runoff reduction). The segment widths indicate the amount of runoff, and the green segments are the implemented wetlands.

To understand this integrality problem, where the decision is only to build or not build a wetland, a bit better, consider the solution where we allow fractional wetlands. Figure 5-4 shows the schematic for summer phosphorus, where the solver allowed fractional wetlands. All wetlands are clearly driven by high prices. Every implemented wetland faces nonzero prices for some seasons and nutrients. Thus, the all-or-nothing requirement for wetlands can result in over-building that lowers prices, but including non-fractional wetland is still a correct solution.

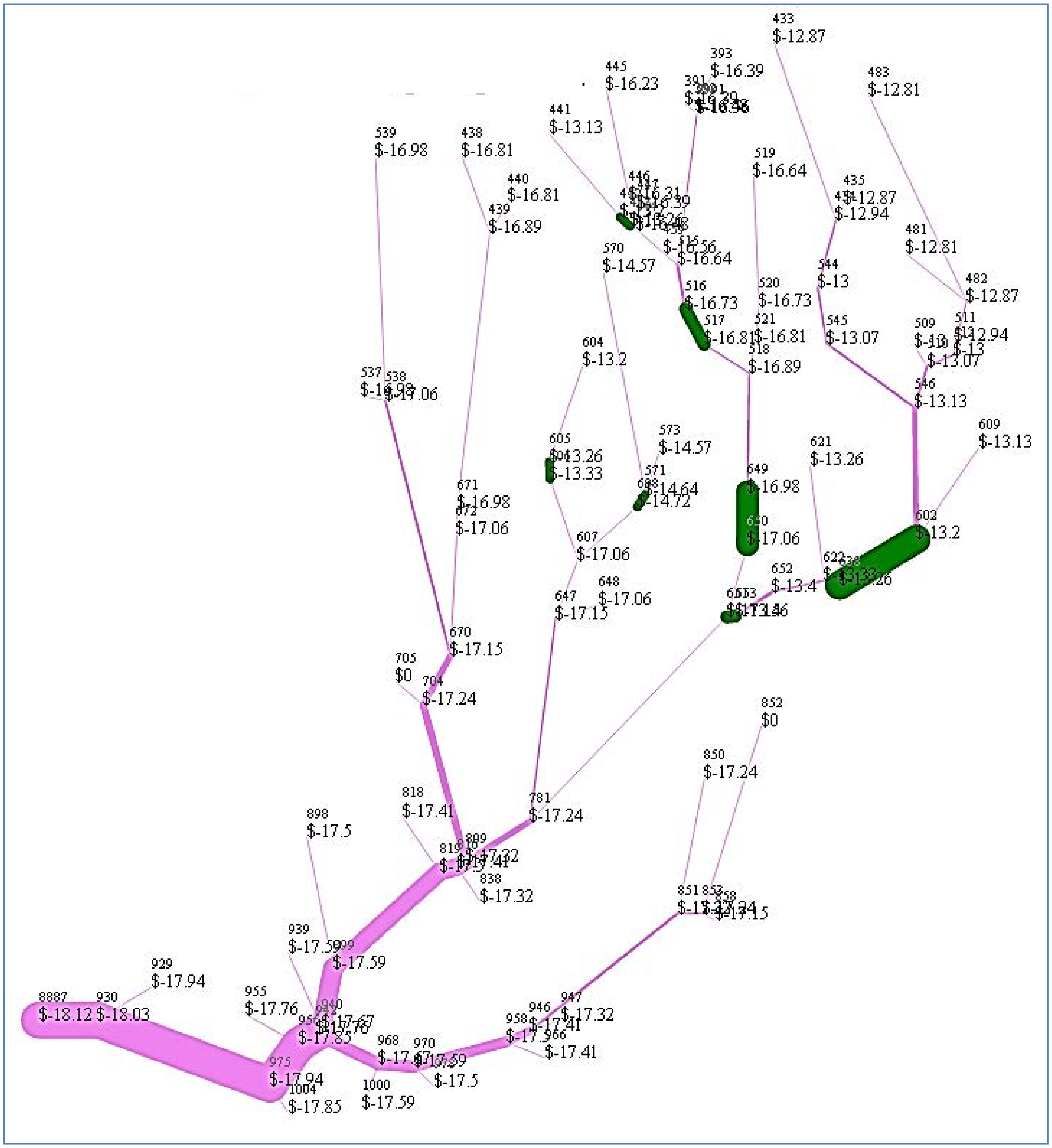

Figure 5-4. Lime Creek stream network with the node prices for the summer phosphorus but allowing for fractional wetlands in the 40% limit (60% runoff reduction). The segment widths indicate the amount of runoff, and the green segments are the implemented wetlands.

Total runoff in Lime Creek was 134,591 kg TN. In the 50% reduction scenario, the STP did not have to reduce its current nutrient discharge and the Lime Creek farmers had to reduce their nutrient runoff by only 15,686 kg TN (approximately 11%). Under the same scenario conditions, total phosphorus runoff was 22,306 kg phosphorus. The STP did not have to reduce its nutrient loading, whereas the Lime Creek farmers had to reduce their collective phosphorus runoff by only 4,814 kg. Of the 465 non-wetland participants, an average of 187 participants' nitrogen bids (over the four seasons) were accepted, and an average of 257 participants' phosphorus bids were accepted. Of course, these participants had to be appropriately located; the model could choose from all 465. The model indicates *which* farmers are most important for the market, so our model can advise which ones to approach first to ensure a successful market. We conclude that a market can incentivize wetlands in Lime Creek.

5.6 Big Bureau Creek case

This section examines several larger cases based on the entire Big Bureau Creek watershed. These cases have different assumptions about which participants are in the market and how runoff from different participants is considered, focusing on trades between WWTPs and wetlands.

Case 1: “Natural runoff” is the case where the model assumes no existing point source or agricultural and urban nonpoint source runoff, and the runoff is quite large and close to the limit at the assessment point. In this case, the WWTPs can discharge only a small amount within the limit. Since this case assumes no farming exists in the watershed, the WWTPs could pay an upstream wetland to provide attenuation below the “natural” level. We did not attempt to solve this particular case, because we do not have an estimate for “natural” runoff, and it seems overly artificial.

Case 2: “Natural runoff” (assuming it can be estimated) is effectively zero. All trades therefore occur between “zero” and the load limit. In this case, any tradable runoff into a wetland located upstream of a WWTP must come from some other source. If we omit farmer participation from the market, then the model assumes that runoff from non-participants is non-tradable. While this case is still an artificial example, it is more realistic than Case 1. We consider this case in section 5.6.2.

Case 3: “Natural runoff” plus agricultural nonpoint source runoff is large and close to the limit at the assessment point. Then the WWTP can discharge only a small amount within the limit. In this case, an upstream wetland could provide attenuation below the “natural” attenuation, to allow the WWTP to have higher discharge. This case is more realistic than Case 2 and is explored in section 5.6.3.

Case 4: Total runoff exceeds the limit. No “blame” can be assigned to one person or entity as we did not specify initial rights; the violation is a joint behavior. This is the analysis we did for Lime Creek previously. While we are conveniently ignoring the problem of initial rights, this is the most realistic case and is described in section 5.6.4.

5.6.1 BBC network description

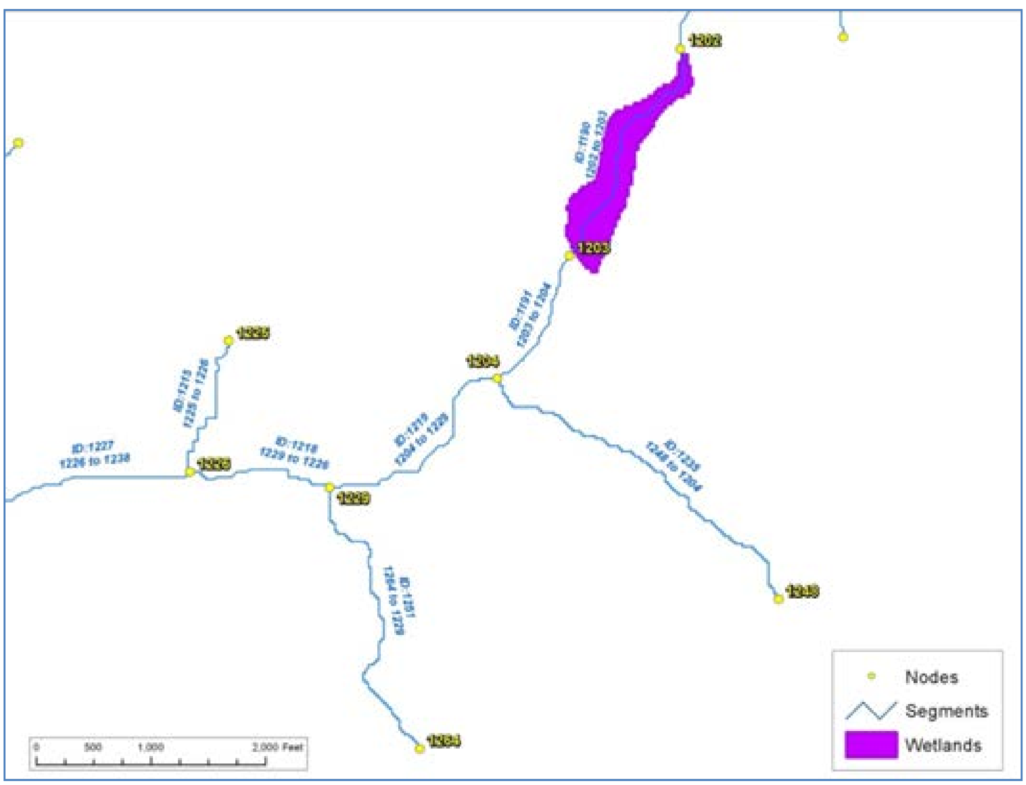

Figure 5-5. Example of the stream network generated with nodes and segments.

Figure 5-5 shows a representative part of the BBC stream network, which includes the Lime Creek basin. As with the Lime Creek case, each segment is identified by an upstream and a downstream node. We used the network generation tools in ArcHydro to create the stream network for the Big Bureau Creek watershed. These tools create nodes at each headwater segment and stream intersection. The entire watershed network has 1,838 nodes. The tools populate the “From_Node” and “To_Node” fields to indicate stream segment flow direction. We then manually edited the network to add nodes for the inlets and outlets of the potential wetland sites (Figure 5-6). Segments refer either to an ordinary stream segment or to a wetland, with the wetland segment having a much greater attenuation than an ordinary stream segment.

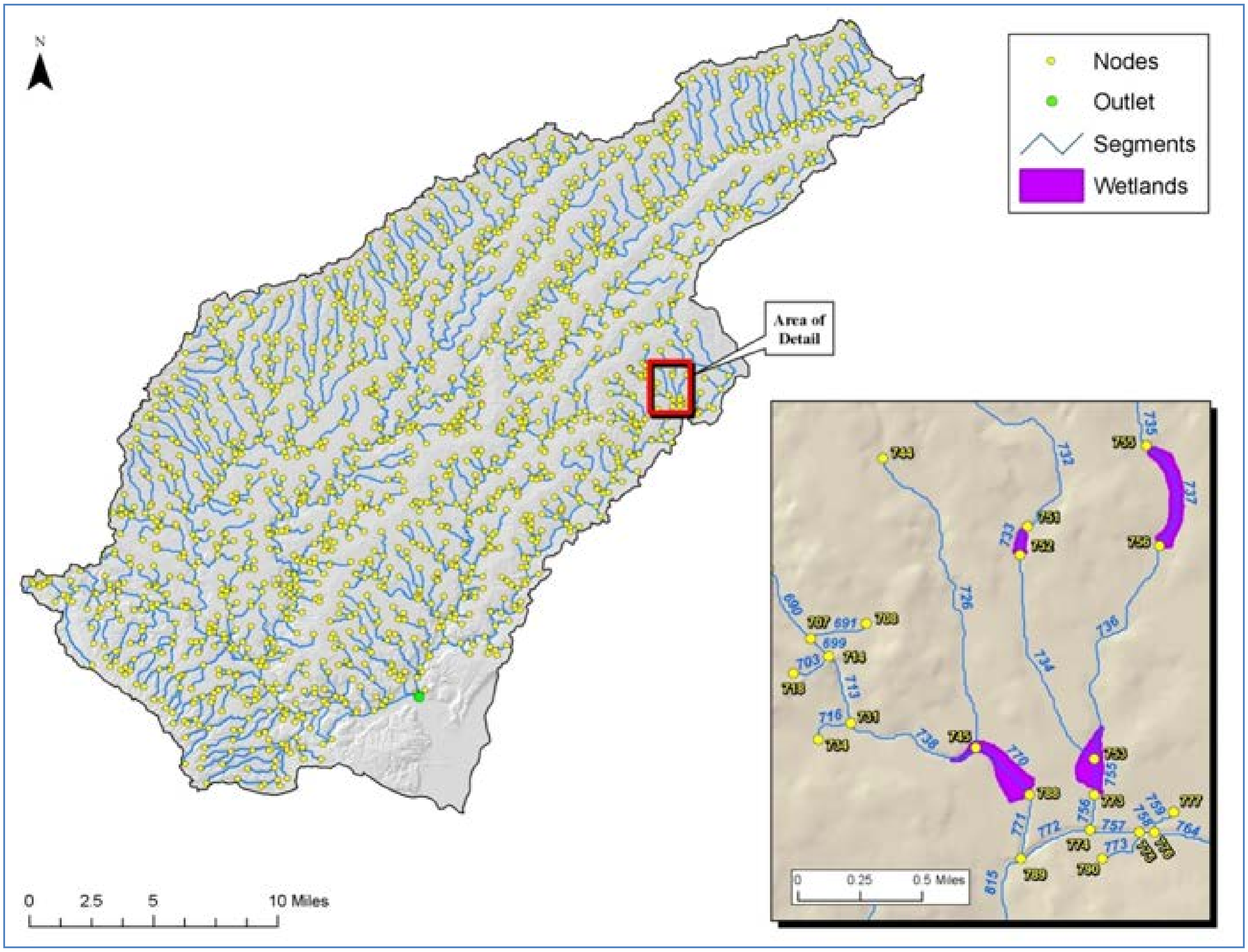

Figure 5-6. An example of the Big Bureau Creek stream network configuration.

The watershed has nine private and municipal wastewater treatment point sources (other permitted facilities were not included). Table 3-10 and Table 4-6 contain the WWTP load and cost data, respectively, that we used in our simulation. The 80 potential wetland locations identified are not currently wetlands, but could become wetlands. We used the AnnAGNPS watershed analysis results as described in Section 3.5.2 to determine the independent average seasonal nitrogen and phosphorus load removed by each potential wetland. These bid cost and season attenuation data are in Appendix B, Table A-10.

We wanted to include farmer participants in our BBC case, but digital parcel data were not available for the entire watershed. We therefore simulated farmers, in the relevant cases below, by treating each square-mile section as a unique farmer. To calculate which network node received each “farm” load and the load each “farmer” contributed to the nearest downstream node, we performed a spatial intersection on three data sets: township and range section (as a proxy for parcel data), node-drainage area (land area draining to each node), and cell area (nutrient loading data). With this intersected dataset, we calculated the percentage of land in each cell occupied by each landowner. This percentage was then multiplied by the cell loading data to calculate nitrogen and phosphorus loads for each simulated farmer. Lastly, the node-drainage area component indicated which node received the various nitrogen and phosphorus loads.

We found a total of 4,877 simulated farmers using this procedure. For convenience, we omitted 2,085 farmers (42% by count), each of which had runoff less than 164 total kg N for all four seasons (with an average of just 44.8 kg N); all 2,085 together contributed only 3.7% of total farmer runoff. Realistically, such small players are unlikely to participate in the market in any scenario. This left 2,792 “farmers” in the market. This simplified our simulation considerably, while introducing little loss from a market point of view.

As with the Lime Creek case, the market design requires that landowners or farmers enter a bid for each segment to which they contribute, rather than a single bid for their entire farm parcel. We used the same farmer bid values for BBC as we did in the Lime Creek case. Table 5-6 contains the estimated effluent discharge and bids for the nine WWTPs. Bids correspond to the cost of reduction at each WWTP.

Table 5-6. Estimated seasonal effluent discharges and bids for the 9 WWTPs.

	Ohio P1	LaMoille P2	Malden P3	Maple P4	Princeton P5	Wyanet P6	Prairie P7	Aspirie P8	Tiskilwa P9
Winter discharge TN (kg)	76.7	63.1	50.0	25.9	4245.0	250.2	20.0	50.0	120.1
Spring discharge TN (kg)	78.2	64.3	51.0	26.4	4327.3	255.1	20.4	51.0	122.4
Summer discharge TN (kg)	78.2	64.3	51.0	26.4	4327.3	255.1	20.4	51.0	122.4
Autumn discharge TN (kg)	77.3	63.6	50.5	26.1	4280.3	252.3	20.2	50.5	121.1
Winter Bid TN ($/kg)	$74.68	$87.78	$107.08	$194.66	$37.87	$35.25	$248.41	$107.08	$53.12
Spring Bid TN ($/kg)	$74.68	$87.78	$107.08	$194.66	$37.87	$35.25	$248.41	$107.08	$53.12
Summer Bid TN ($/kg)	$74.68	$87.78	$107.08	$194.66	$37.87	$35.25	$248.41	$107.08	$53.12
Autumn Bid TN ($/kg)	$74.68	$87.78	$107.08	$194.66	$37.87	$35.25	$248.41	$107.08	$53.12
Winter discharge TP (kg)	32.2	26.5	21.0	10.9	374.6	105.0	8.4	21.0	50.4
Spring discharge TP (kg)	32.8	27.0	21.4	11.1	381.8	107.1	8.6	21.4	51.4
Summer discharge TP (kg)	32.8	27.0	21.4	11.1	381.8	107.1	8.6	21.4	51.4
Autumn discharge TP (kg)	32.5	26.7	21.2	11.0	377.7	105.9	8.5	21.2	50.8
Winter Bid TP ($/kg)	$31.99	$37.44	$45.44	$81.48	$5.12	$14.45	$103.53	$45.44	$22.84
Spring Bid TP ($/kg)	$31.99	$37.44	$45.44	$81.48	$5.12	$14.45	$103.53	$45.44	$22.84
Summer Bid TP ($/kg)	$31.99	$37.44	$45.44	$81.48	$5.12	$14.45	$103.53	$45.44	$22.84
Autumn Bid TP ($/kg)	$31.99	$37.44	$45.44	$81.48	$5.12	$14.45	$103.53	$45.44	$22.84

5.6.2 Results for BBC case without farmer participation

In this section, we consider Case 2 described earlier. In this case, “natural runoff” and farmer runoff are ignored. This simulates trade between only the WWTPs and the potential wetland sites. Only the outflow from the WWTPs was considered, not any nonpoint source runoff from the farmers. The required reduction was, therefore, only for the outflow from the WWTPs, implying that we are testing whether wetlands can directly attenuate WWTP effluent. In this solution, the two largest WWTPs (Princeton and Wyanet) had to reduce their own nitrogen and phosphorus discharge. Even allowing fractional solutions, only two wetlands bids were accepted and only slightly, at 5% and 3.5% of each of the two wetlands.

The reason for the lack of accepted wetland bids is the location of the wetlands. Few of the 80 wetlands are located downstream between the WWTPs and the outlet, and none of the wetlands are between the largest WWTP and the outlet. Hence, the wetlands could only directly attenuate a little of the WWTP discharge. Practically speaking, the only way that the WWTPs could reduce the effect of their own outflow at the assessment point (outlet) is to reduce their own outflow. We conclude that a market for BBC will not work with nine WWTPs and 80 potential wetland sites, where the wetlands can attenuate runoff only from the WWTPs. Again, this case assessed only the possibility of wetlands directly attenuating WWTP effluent, as the case assumes that runoff from non-participants (i.e., farmers) is non-tradable.

5.6.3 Results for BBC case with farm runoff, but without farmer participation

In this section, we consider Case 3 as described earlier. In this case, “natural runoff” plus farm runoff is large and close to the limit at the assessment point (or BBC outlet). Then, in principle, the WWTP can discharge only a small amount within the limit. In this case, an upstream wetland could provide attenuation to allow the WWTP to have higher discharge. Farmers will not reduce their runoff, but wetlands could attenuate it, thus allowing downstream WWTPs to avoid having to reduce their own discharges. Thus, the wetlands are not required to attenuate WWTP effluent directly, but rather the wetlands can offset nutrient loads upstream from other sources. We note that this seems unfair to the WWTPs, but it does reflect the current law, where permitted sources are regulated.

We examined the case where the wetlands attenuated a quantity equal to 100% of the WWTP effluent, as measured at the outlet. Figure 5-7 shows a diagram of the result. Only two wetlands are needed, Wetland 851 and Wetland 796. Because of the all-or-nothing nature of the wetland bids, both were overbuilt relative to their continuous (fractional) solutions, so nodal prices are zero everywhere in the catchment.

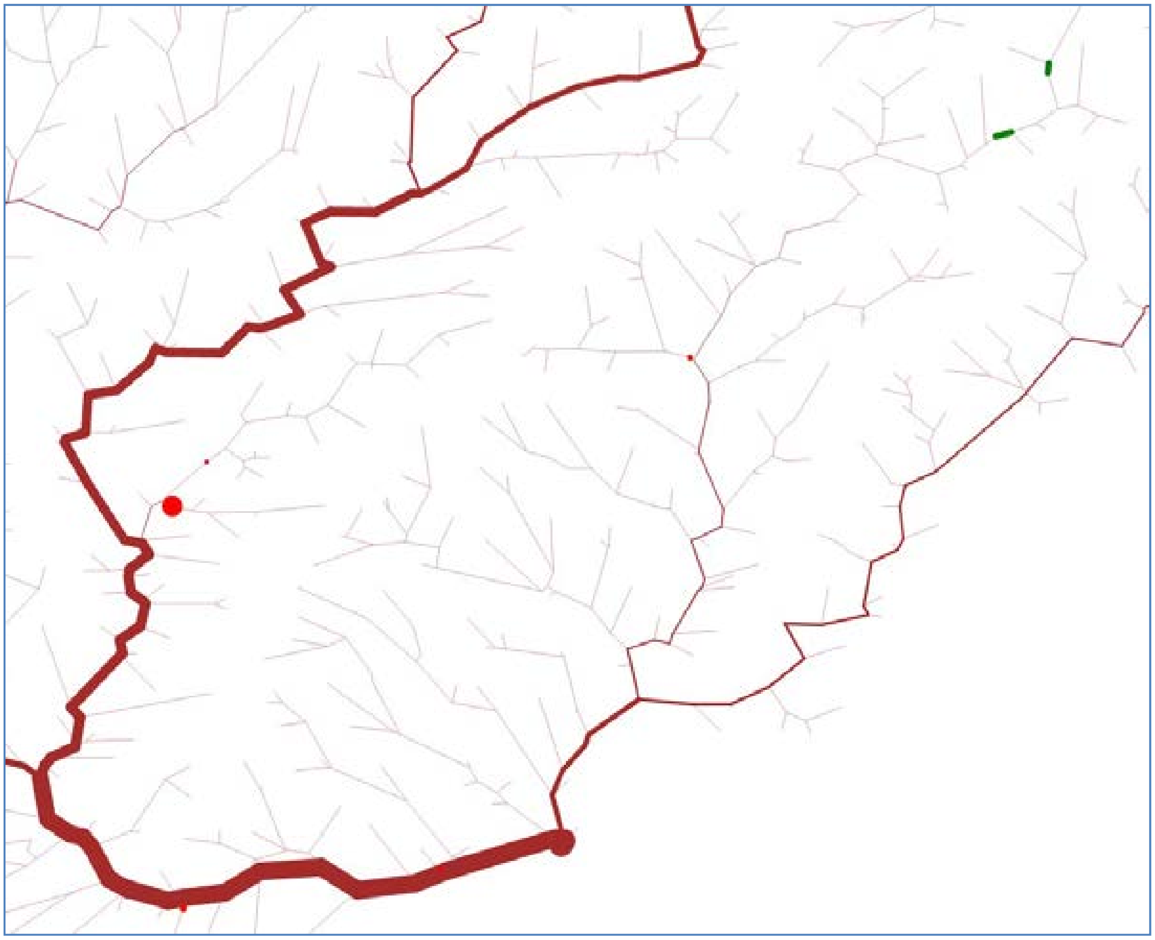

Figure 5-7. This diagram shows in the central part of the BBC catchment, for the solution when wetlands offset nutrient quantity equal to the total WWTP effluent. Segment width indicates nitrogen quantity. Wetlands are green. The orange dots are WWTPs. Prices are all zero.

The two wetlands were paid at their bid prices of $148,176 and $140,340 respectively, for a total cost of only $288,516, for a 10-year contract. This is only 32.7% of the total cost that the WWTPs together bid to reduce their own effluent; therefore, it is a huge savings. While this is excellent news from the point of view of the WWTP managers, this is insufficient to make a significant dent in the total runoff from the catchment. Note that even 100% of total WWTP effluent is a small reduction for the catchment as a whole, less than 1% of the total nutrient runoff.

5.6.4 Results for BBC case with simulated farmers participating

In this case, we assumed a full simultaneous multilateral market with all nine WWTPs, 80 potential wetland sites, and 2,792 simulated farmers. In the smaller Lime Creek case previously described, we used two-part bidding. In this case, we used a single bid for each farmer, as we felt that the large number of participants would still provide a good indication of market activity. For each farmer and each season, the bid for nitrogen reduction was randomly selected from a uniform distribution between $1.64/kg TN and $2.22/kg TN. The phosphorus bids were randomly selected from a uniform distribution between $8.73/kg TP and $11.81/kg TP. As in the Lime Creek case, we assumed that a farmer could reduce total runoff by no more than two-thirds of their current runoff in each season (as simulated by the AnnAGNPS baseline scenario). Table 5-7 shows the bid data for five simulated farmers.

Table 5-7. Market bid data for total nitrogen and total phosphorus for five example simulated farmers.

PARAMETER	S10	S11A	S12	S2	S11B
Winter TN current runoff (kg)	100.9	30.8	20.6	21.6	62.3
Spring TN current runoff (kg)	350.1	94.0	76.4	95.6	246.5
Summer TN current runoff (kg)	251.3	77.3	56.6	91.6	204.9
Autumn TN current runoff	163.9	55.6	37.2	51.1	125.4
Winter bid price TN ($/kg)	$1.80	$1.71	$2.10	$1.72	$1.68
Spring bid price TN ($/kg)	$1.83	$2.22	$1.82	$1.89	$2.06
Summer bid price TN ($/kg)	$1.64	$1.80	$1.92	$1.97	$1.72
Autumn bid price TN ($/kg)	$2.14	$2.17	$2.16	$2.18	$1.93
Winter bid quantity TN (kg)	67.3	20.5	13.7	14.4	41.5
Spring bid quantity TN (kg)	233.4	62.6	50.9	63.7	164.3
Summer bid quantity TN (kg)	167.6	51.5	37.7	61.0	136.6
Autumn bid quantity TN (kg)	109.2	37.1	24.8	34.1	83.6
Winter TP current runoff (kg)	9.6	8.9	2.3	2.2	6.8
Spring TP current runoff (kg)	37.8	24.3	8.1	15.0	31.2
Summer TP current runoff (kg)	30.9	19.7	6.4	13.3	26.3
Autumn TP current runoff (kg)	14.8	14.0	3.4	4.2	10.8
Winter bid price TP (kg)	$11.77	$10.50	$9.38	$9.04	$9.21
Spring bid price TP (kg)	$9.99	$9.70	$11.41	$10.73	$9.56
Summer bid price TP (kg)	$11.55	$11.58	$11.43	$11.21	$10.52
Autumn bid price TP (kg)	$9.71	$8.80	$10.63	$8.96	$9.71
Winter bid quantity TP (kg)	6.4	5.9	1.5	1.5	4.5
Spring bid quantity TP (kg)	25.2	16.2	5.4	10.0	20.8
Summer bid quantity TP (kg)	20.6	13.1	4.3	8.9	17.5
Autumn bid quantity TP (kg)	9.9	9.4	2.2	2.8	7.2

The results for this case are promising, indicating that a market could be highly effective and active for nitrogen and phosphorus. Figure 5-8 and Figure 5-9 show parts of the BBC catchment for winter nitrogen in the 50% reduction case, as the full image is too big to show in detail in this document. The example figures show wetlands being implemented, with generally low nutrient levels throughout the catchment.

For the 50% reduction case, we found that 23 wetlands would be built. Eighteen of these would be paid more than their bid, in some cases much more than their bid (Table 5-8). The total payment to these 18 landowners constructing wetlands was $7,561,500, more than double their total bid of $3,963,200. Why should the market manager pay these wetland builders more than their bid? The reason is the 10-year value of attenuation: The wetland builders deserve to be paid at least the going rate. Note that a start-up payment occurs only when the attenuation payment is insufficient to cover the winning bid. As with the Lime Creek case, the all-or-nothing nature of the wetland offer sometimes results in over-building, which then depresses prices.

The only WWTP reductions were for Princeton and only for phosphorus. Princeton had by far the lowest bid for phosphorus reduction of any farmer or WWTP. This agrees with the results found in the economic feasibility assessment (Section 4).

Nearly all farmers implementing BMPs participated in the market in some season. Only 95 of the 2,792 participating farmers (recall that we omitted 42% of the smaller farmers) had no nutrient bid accepted for any season. However, of the 11,168 bids for nitrogen, only 5,130 bids were accepted. Of the 11,168 bids for phosphorus, only 5,084 bids were accepted. As in the Lime Creek scenario, the watershed could achieve significant nutrient load reductions with most farmers making modest changes only in some seasons.

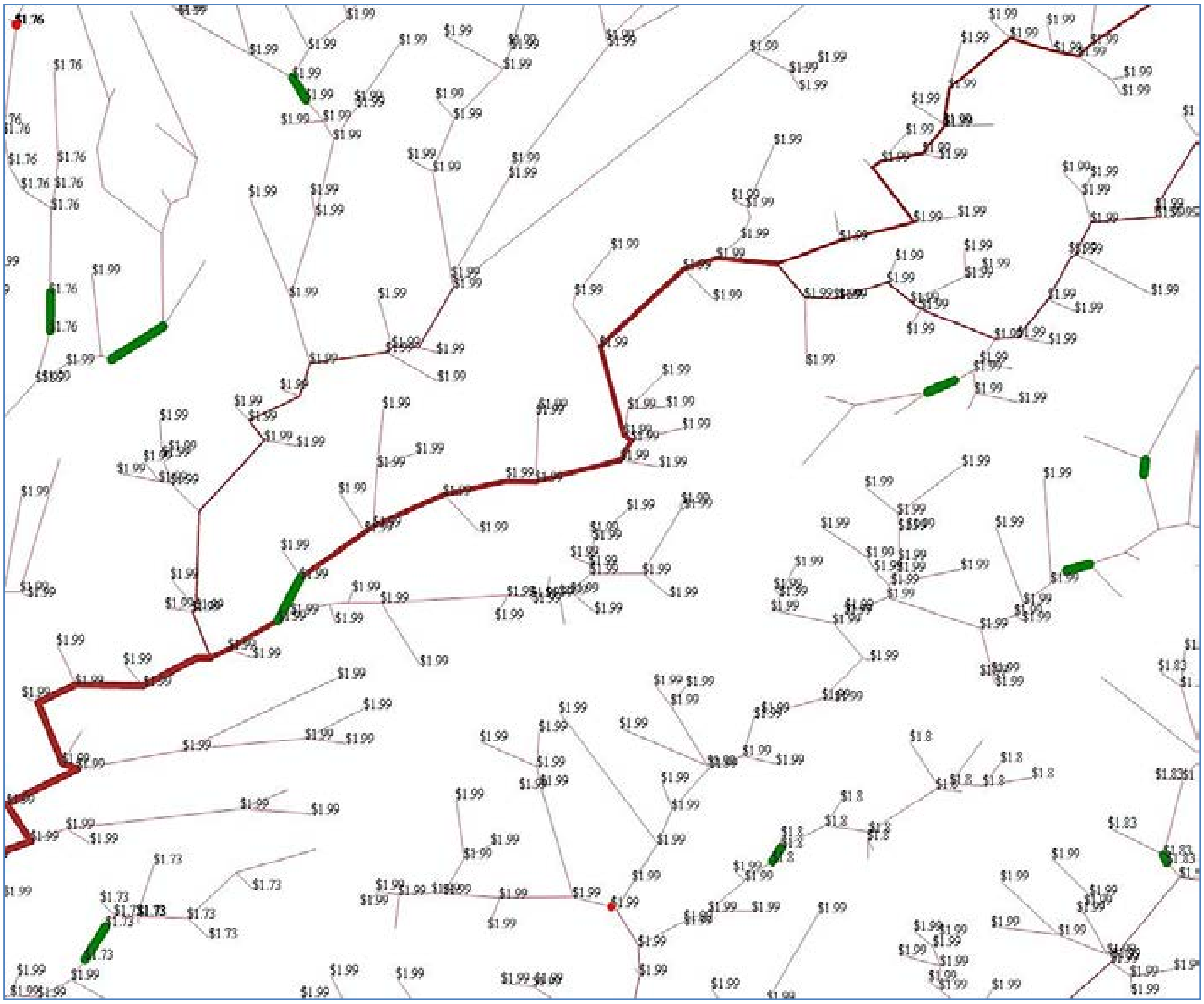

Figure 5-8. The nodal prices ($/ kg TN per season) in the upper central part of the BBC catchment for the 50% reduction case. Segment width indicates nitrogen quantity and the green segments are wetlands. Orange dots are WWTPs. The nodes with no prices shown have price zero.

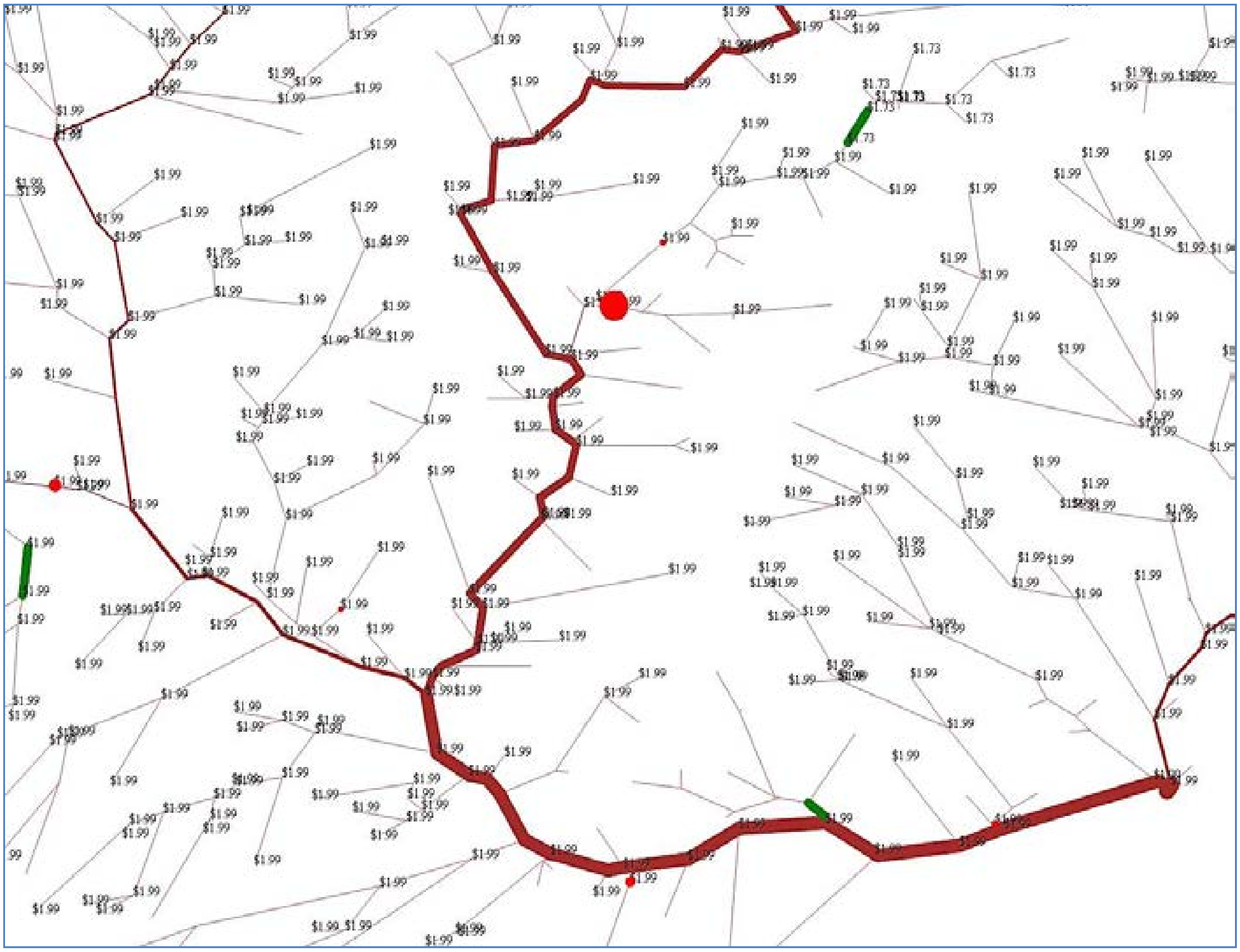

Figure 5-9. The nodal prices ($/ kg TN per season) in the central BBC catchment downstream of Princeton for the 50% reduction case. Segment width indicates nitrogen quantity and the green segments are wetlands. Orange dots are WWTPs. The nodes with no prices shown have price zero.

Table 5-8. Bids, 10-year prices, and final payments with profit for the accepted wetlands for the 50% allowed limit.

SITE	BID	NITROGEN BID PRICE ($/kg TN)				PHOSPHORUS BID PRICE ($/kg TP)				ATTEN. PYMT.	START-UP	FINAL PYMT.	PROFIT
	($)	WIN	SPR	SUM	AUT	WIN	SPR	SUM	AUT	($)	($)	($)	($)
W1561	159,530	19.94	19.57	19.56	19.99	106.23	106.69	105.54	106.59	475,476	0	475,476	315,946
W1201	177,379	17.75	19.38	19.36	18.65	105.14	104.57	103.45	104.72	608,071	0	608,071	430,692
W598	138,170	19.94	18.43	18.41	19.59	106.23	96.03	95.00	105.00	145,988	0	145,988	7,818
W695	154,020	16.90	18.17	18.41	7.72	101.59	97.00	95.95	100.64	183,460	0	183,460	29,440
W635	171,609	17.61	16.66	16.65	19.01	106.23	93.19	92.18	102.40	275,053	0	275,053	103,444
W620	358,397	0.00	16.17	16.16	0.00	0.00	0.00	90.81	87.44	421,872	0	421,872	63,475
W442	148,129	19.94	18.24	18.23	19.64	106.23	87.75	86.80	104.74	243,748	0	243,748	95,620
W396	154,251	9.94	17.35	17.34	19.30	106.23	85.57	84.65	103.43	302,981	0	302,981	148,730
W245	141,143	19.94	16.01	16.00	18.58	106.23	78.58	77.74	101.38	165,500	0	165,500	24,357
W660	210,718	0.00	15.53	0.00	0.00	0.00	0.00	81.73	0.00	86,678	124,040	210,718	0
W885	164,910	19.94	18.24	18.23	19.64	06.23	92.26	91.26	104.74	470,836	0	470,836	05,926
W1190	167,186	17.30	19.38	19.36	18.57	103.13	99.46	98.39	105.05	293,066	0	293,066	125,880
W1732	189,550	0.00	19.30	21.24	16.54	0.00	95.91	111.47	0.00	163,290	26,260	189,550	0
W851	148,176	0.00	17.59	17.89	16.55	91.32	95.02	95.10	0.00	848,921	0	848,921	700,745
W796	140,340	0.00	17.42	17.71	16.50	91.32	93.13	93.21	0.00	178,758	0	178,758	38,417
W607	195,215	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	195,215	195,215	0
W1120	172,102	17.98	19.52	20.16	19.11	106.23	109.95	108.76	107.39	451,748	0	451,748	279,646
W1389	163,133	16.62	20.62	19.55	17.40	90.91	99.53	105.33	100.56	202,997	0	202,997	39,864
W1124	158,979	18.30	20.31	20.57	19.39	106.23	111.06	109.86	107.93	461,841	0	461,841	302,863
W891	152,759	19.61	20.17	20.16	18.95	106.23	105.10	103.97	106.78	301,495	0	301,495	148,735
W770	170,578	18.00	19.97	19.96	18.88	101.15	103.01	101.90	104.28	514,920	0	514,920	344,342
W755	158,514	0.00	17.51	17.29	0.00	95.15	102.50	101.39	103.76	250,865	0	250,865	92,351
W737	168,414	0.00	17.51	16.81	0.00	93.28	92.63	90.32	103.69	154,900	13,513	168,414	0

Table 5-9 summarizes the solutions for allowed percent runoff of 80%, 60%, 50%, and 40%. As expected, the 100% solution has costs equal to $0 with all prices being $0/kg, and no bids were accepted. The 20% solution, at the extreme opposite, is infeasible. Figure 5-10 shows a graph of total cost (i.e., total payments from the market manager to all participants, assuming no buyers) versus percent of runoff allowed. Note that the cost is a 10-year cost, not a cost per year. A 40% reduction would cost approximately $20,000,000 over a 10-year period. As a comparison point, 408 farms in 2007 received federal conservation payments for mainly habitat-related programs (i.e., Wetland Reserve Program, Conservation Reserve Program, and Conservation Reserve Enhancement Program) totaling $1,148,000, or approximately the annual cost to achieve a 30% reduction in total phosphorus and total nitrogen (USDA 2009a). Targeted federal conservation funding on the purchase of nitrogen and phosphorus credits might incentivize farmers to implement practices that avoid or remove nutrients in surface and subsurface runoff, if farmers are willing to participate.

Table 5-9. Summary of solutions, showing accepted wetlands, total payments, and average seasonal prices.

WETLAND	80% SOLUTION	60% SOLUTION	50% SOLUTION	40% SOLUTION
Wetland 1561	0	1	1	1
Wetland 1201	1	1	1	1
Wetland 598	0	0	1	1
Wetland 695	0	1	1	1
Wetland 635	0	1	1	1
Wetland 620	0	1	1	1
Wetland 442	0	1	1	1
Wetland 396	0	1	1	1
Wetland 245	0	1	1	1
Wetland 660	0	1	1	1
Wetland 885	1	1	1	1
Wetland 1190	0	1	1	1
Wetland 1732	0	1	1	1
Wetland 851	1	1	1	1
Wetland 796	0	1	1	1
Wetland 607	0	1	1	1
Wetland 1120	0	1	1	1
Wetland 1389	0	1	1	1
Wetland 1124	0	1	1	1
Wetland 891	0	1	1	1
Wetland 770	0	1	1	1
Wetland 755	0	1	1	1
Wetland 737	0	1	1	1
Total payment	$3,410,795	$20,163,382	$30,972,055	$42,513,693
Avg price winter TN	$1.79	$1.83	$1.91	$2.00
Avg price spring TN	$0.00	$1.67	$1.83	$1.97
Avg price summer TN	$0.00	$1.68	$1.82	$1.96
Avg price autumn TN	$1.71	$1.81	$1.90	$2.00
Avg price winter TP	$9.40	$9.93	$10.39	$10.90
Avg price spring TP	$0.00	$8.69	$9.41	$10.20
Avg price summer TP	$0.00	$8.69	$9.43	$10.30
Avg price autumn TP	$9.27	$9.79	$10.24	$10.75

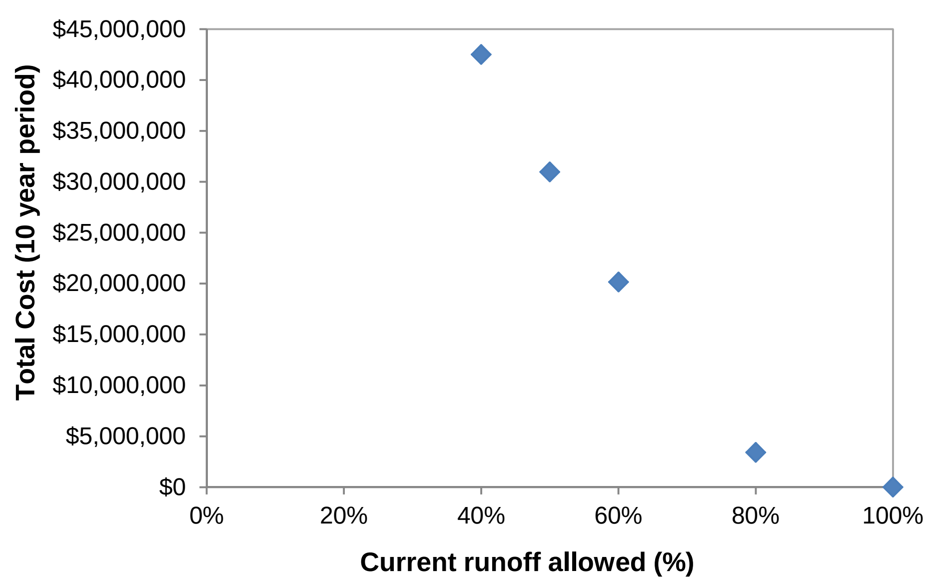

Figure 5-10. Graph of the total 10-year cost versus the percent of the current runoff allowed.

5.7 Further Work and Conclusions

We conclude that the smart market is an excellent way to incentivize the construction of wetlands and to incentivize farmers to reduce their runoff. The market could achieve cost-effective and significant reduction in nutrient loads at the outlet of the Big Bureau Creek watershed. While the Princeton STP can cost-effectively reduce its phosphorus discharge through treatment upgrades, limiting the WWTPs to reduce their nutrient loads, particularly nitrogen, through only technology-based controls does not appear to be the most cost-effective alternative.

The smart market model and simulations can be improved in several ways. First, the integrality requirement for wetland bids could be relaxed, if the wetland configurations could be assessed in more detail. This would eliminate the problem of side payments, and ensure that the market manager could have revenue neutrality, once the initial rights had been assigned. We think that the attenuation and cost estimates for the farmer practices could be made more accurate. We recognize that the market simulation may not be improved by trying to obtain better estimates of bids, as the farmers could reduce their runoff at lower cost than we have assumed in these models. However, farmers are unlikely to disclose their real costs without some incentive.

Perhaps most importantly, the market model should be stochastic, with different scenarios by season. This should be straightforward to implement, but would require distributions of runoff rather than averages. Finally, rather than bidding explicitly for changes in nitrogen or phosphorus, users could bid for changes in their land use or operations. To the extent that these changes affect both nitrogen and phosphorus, such a market for contracts would solve the problem of credit stacking.

6 THE SOCIAL FACTORS IN BIG BUREAU CREEK

The analysis of the social factors and forces were performed by Dr. Franz Wohlgezogen under the advisement of Dr. Edward Zajac at the Kellogg School of Management, Northwestern University, with contributions by Dr. Jill Kostel at the Wetlands Initiative and Pam Horwitz, then at the American Corn Growers Association.

6.1 Introduction

The apparent lack of interest or reluctance of community, regional, and statewide stakeholders to participate in water quality trading (WQT) has contributed significantly to program implementation delays or failures. A trading program needs to reflect the physical landscape characteristics and the economic assessment of the trading area (typically a specified watershed). Just as importantly, a trading program should consider the socio-cultural issues and concerns of potential trading partners and other key stakeholders within the watershed. The participation of trustworthy or embedded community stakeholders is vital in facilitating outreach efforts, promoting WQT, educating the public on the potential benefits of WQT, correcting any misunderstandings, and increasing farmer/landowner participation.

As part of this suitability and feasibility analysis, we worked to assess the social landscape as it relates to the support of and resistance to (e.g., lack of trust, areas of friction, etc.) a potential water quality trading market in the Big Bureau Creek watershed. A multiple-step strategy was used to map relevant stakeholders, perform interviews with select stakeholders, and engage stakeholder groups for outreach and community mobilization efforts on conservation practices that address both water quality and water quality trading. Based on the analysis of stakeholder perspectives, we developed recommendations to address the identified resistance or barriers and harness support for a potential market.

6.2 Socio-economic Landscape of the Big Bureau Creek watershed

The Big Bureau Creek watershed provides a typical example of the agricultural demographics and economics, as well as water quality issues, that can occur in a predominately agricultural watershed in Illinois and the Corn Belt region as a whole. The watershed has 11 villages and one city. These 12 community areas had a total population of 12,813 in 2009 (U.S. Census Bureau 2010a). Utilizing only the 2009 census block data completely contained within the watershed boundaries, the estimated total watershed population was 17,420 (U.S. Census Bureau 2010b). The City of Princeton, which is the seat of Bureau County, represents approximately half of the watershed's rural community population with 7,461 residents (U.S. Census Bureau 2010a). While the population of Princeton has only decreased by 1% between 2000 and 2009, the village populations, which had populations in 2009 ranging between 164 and 978, have decreased by 4–6% (U.S. Census Bureau 2010a).

Bureau County should provide a fair representation of the watershed as 48% of the county (418 out of 873 square miles) is within the watershed, whereas only 9.97% of Lee County (72.6 out of 729 square miles) and 0.92% of LaSalle County (10.5 out of 1,148 square miles) are within the watershed. The areas of LaSalle and Lee Counties within the watershed are approximately 99% in agriculture. The agriculture data follow similar status and trends in all three counties. The 2007 Census of Agriculture data (USDA 2009a) are not available at the watershed level for Big Bureau Creek, as these data are currently only reported at the major watershed level (Hydrological Unit Code 6). Since these data are available only at county level, Bureau County agricultural data will be presented here to describe the farm status and trends within the watershed (Table 6-1).

The average farm size in the county is 402 acres, which is greater than the statewide average of 348 acres. The average age of a Bureau County operator is 56.5 years (USDA 2009a). Farming was reported as the primary occupation for 65% of the principal operators. Only 10% of principal operators are female. Approximately 34% of the farms in Bureau County received payments through government conservation programs (e.g., Conservation Reserve Program, Conservation Reserve Enhancement Program (CREP), Wetland Reserve Program (WRP), etc.). This likely underestimates the amount of land stewardship performed in the watershed, as some farmers voluntarily implement conservation practices outside of government programs.

Table 6-1. A selected set of 2007 agricultural statistics for the counties in the Big Bureau Creek watershed (USDA 2009a).

PARAMETER	BUREAU COUNTY	LEE COUNTY	LASALLE COUNTY
County rank in total value of products sold	6	16	4
Rank in crop sales	7	12	3
Rank in livestock sales	18	42	39
Market value of products sold ($1000)	$303,358	$241,368	$328,997
Cropland ($1000)	$261,471	$195,871	$308,500
Livestock ($1000)	$41,887	$18,497	$20,497
Number of farms	1,189	898	1,622
Land in farms (acres)	478,389	395,624	643,291
Cropland	439,879	377,623	614,407
Other land	38,510	18,001	28,884
Average size of farms (acres)	402	441	397
Average operator age, years	56.5	55.3	56.2
Primary occupation – farming	660	522	871
Primary occupation – other	529	376	751
Farm production expenses ($ avg/farm)	$197,636	$172,631	$135,044
Net cash farm income ($ avg/farm)	$73,492	$81,436	$82,138
Operators reporting net gains	850	664	1,231
Operators reporting net losses	339	234	391
Government payments ($1000)	$10,029	$8,009	$11,943
Payments from CRP, CREP, WRP, etc. ($1,000)	$1,148	$518	$757
Acres	9,263	4,576	6,254
number of farms	408	257	450

The majority of the farmland (76%) and farm operations (85%) in Bureau County are classified as individual or family operations, which is reflective of the state of Illinois (Table 6-2) (USDA 2009b). Farmland in Bureau County has been in family ownership for multiple generations. Bureau County has 192 centennial farms (BCR 2009). While farm typology is predominately "small family" farms (851), the majority of the land is in "large family" farms (110,594 acres) and "very large family" farms (217,985 acres) (USDA 2009a).

Table 6-2. Operation and farm types for the counties in the Big Bureau Creek watershed (USDA 2009b).

PARAMETER (# / ACRES)	BUREAU COUNTY	LEE COUNTY	LASALLE COUNTY
Type of Operation			
Family/Individual	1,016 / 365,590	772 / 311,176	1,435 / 546,925
Partnership	124 / 78,211	90 / 70,573	122 / 64,237
Corporation – Family	25 / 30,261	22 / 11,047	41 / 27,718
Corporation – Other	6 / -	4 / -	8 / 1,483
Other (Coops, Trusts, Estate)	18 / -	10 / -	2 / -
Farm Typology			
Small Family Farms	851 / 128,225	631/ 97,407	1,155 / 178,626
Large Family Farms	151 / 110,594	124 / 86,905	236 / 197,230
Very Large Family Farms	133 / 217,985	106 / 195,580	155 / 247,280
Non-family Farms	54 / 21, 585	37/ 15,732	49 / 20,155

While Bureau County is ranked sixth in the state in terms of total value of agricultural products sold in 2007 (USDA 2009b), farming is becoming an increasingly rare way to earn a living. During the period of 1987 to 2002, Bureau County lost 940 farms (USDA 2004a) (Figure 6-1). While the land remained farmland, it was consolidated into larger farms that accrued larger profits and received larger government subsidies (Table 6-3). These trends are not specific to this county, as similar trends were seen across Illinois and much of the nation.

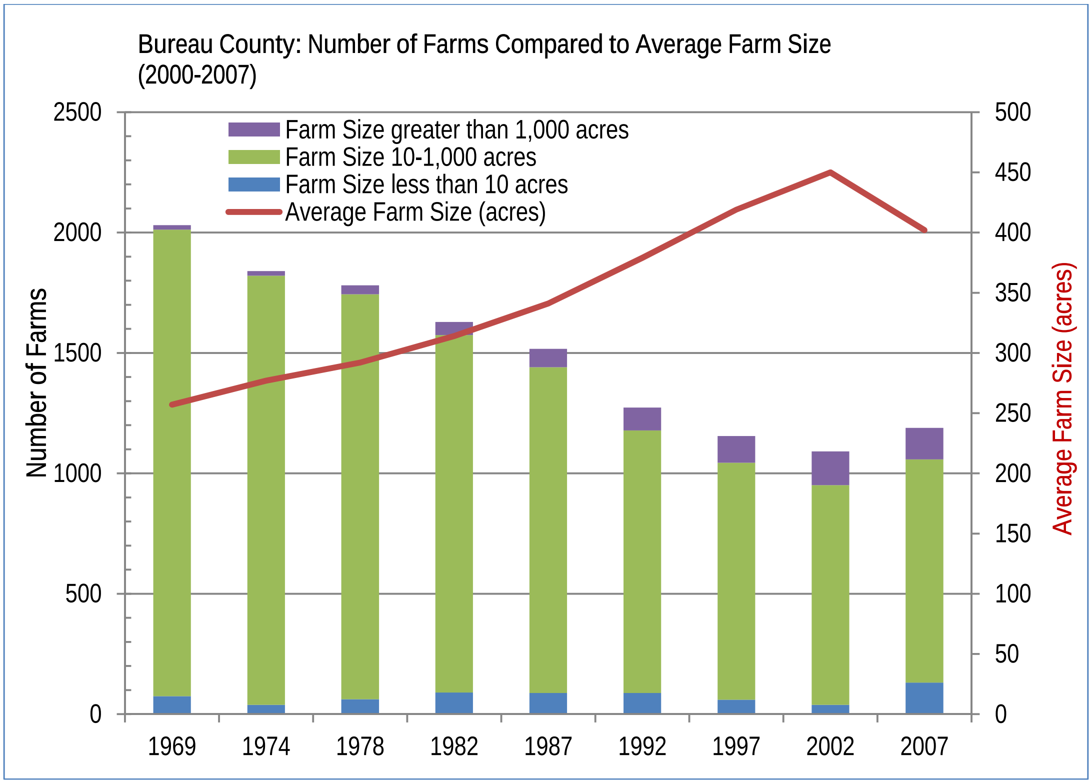

Figure 6-1. The number of farms, size of farms, and average size of farms for Bureau County (USDA 2004a; USDA 2009a).

Table 6-3. Farm statistics and market value of production for Bureau County 1997-2007 (USDA 2004b; USDA 2009b).

PARAMETER	1997	2002		2007	
	VALUE	VALUE	% CHANGE	VALUE	% CHANGE
Number of farms	1,217	1,091	-10	1,189	+9
Land in farms (acres)	494,887	491,180	-1	478,398	-3
Average size of farms (acres)	407	450	+11	402	-11
Market value of production ($1000)	202,518	203,923	+1	303,358	+49
Crop sales		173,210		261,471	+86
Livestock sales		30,713		41,887	+14
Market value of production ($ avg per farm)	166,407	186,914	+12	255,137	+36
Government payments ($1000)	8,475	9,463	+12	10,029	+6
Government payments (avg per farm receiving payments)	9,152	11,903	+30	10,340	-13

6.3 Social Structures in the Community

6.3.1 Existing social structure

Several civic groups concerned with issues of land stewardship existed in the Big Bureau Creek watershed when we began the project. The groups most relevant to us were the local watershed group and the local hunting clubs. The relevant environmental agencies (Illinois EPA, etc.) and non-governmental organizations (American Corn Growers, etc.) also played a more or less active role in shaping land stewardship attitudes and activities in the community. The local hunting clubs—Senachwine Hunt Club and the Princeton Game and Fish Club—also had an active interest in land stewardship initiatives, as water quality issues had negatively impacted their downstream hunting grounds over the last decade.

At the time of this project, the local watershed group had a membership of 8–12 local landowners and operators with representatives from the local USDA Natural Resources Conservation Service (NRCS) and the county Soil and Water Conservation District (SWCD). (These two agencies hosted the meetings at their local field office.) The group met regularly about once a month to discuss land stewardship issues, agricultural news and policy developments, and available government programs and funding opportunities for conservation practices. Group members shared best practices and lessons learned with conservation practices and occasionally invited representatives from the county or (Princeton) government to talk about issues of land use, conservation, water quality, stormwater runoff, etc.

In 2007, 35 watershed citizens were actively volunteering in the Big Bureau Creek Watershed Planning Group, which provided local input and feedback on the Watershed Based Plan. After the plan was completed and the associated funding for a watershed coordinator ended, the group lacked sufficient guidance or a strategic plan to implement the proposed watershed projects. Many members of the group originally became involved as protectionists of farm landowners and operators' rights and activities rather than as activists to address the natural resource concerns in the watershed as a community. Due to the absence of a reason to move the watershed plan actions forward as well as negative association with a local environmental clean-up situation, the number of participants in monthly watershed meetings had gradually declined to a core group. Therefore, they had become more and more reliant on SWCD and participants from outside of the watershed to provide technical support and guidance.

6.3.2 Social structural problems

Beyond knowledge-sharing and discussion of current farming-related events and local urban stormwater issues, the watershed group had little experience with initiating and organizing activities for its members or the local community. The group had not independently taken on any new projects or initiatives other than the organization of a field conservation tour after the completion of the Watershed Based Plan in 2008. As a result, the group had little opportunity to establish and cultivate strong ties to political or social leaders within the county, or a reputation for outreach or action.

The Bureau County SWCD had previously hosted the watershed group meeting on its premises and was regularly involved in the meetings, but during the time of the project, the Bureau County SWCD broke ties with the group, severing one of the few standing ties the group had to relevant local players in the conservation space. The "break-up" was triggered when SWCD dropped the sponsorship of the first MRBI proposal due to a lack of financial and administrative resources.

6.3.3 Significance of local social structure

Existing social structures—connections among and clusters of individuals within the community (Martin 2009)—are an important determinant for land stewardship programs' success. Our examination of social structures goes beyond the identification of stakeholders and their relative importance and/or influence within a community (Mitchell et al. 1997). It draws attention to the typology and nature of connections among stakeholders, and thus contributes to a better understanding of affiliations and (often informal) coalitions among stakeholders, patterns of communication and information sharing, and fault-lines and conflicts within a community (in the case of contentious connections among stakeholders).

Sociological research has shown that social structures influence individual attitudes and practice (Kilduff and Krackhardt 2008). Connections between individuals within a community often follow a homophily principle (Monge and Contractor 2003), causing individuals with similar beliefs, interests, or concerns to form and maintain connection with each other. Frequently, strong normative pressures operate within social clusters, which cause individuals' observable behaviors and their attitudes and implicit assumptions (e.g., about the relative importance of particular problems, and/or the legitimacy and effectiveness of particular practices) to converge. Normative pressures can have positive repercussions, as they can lead to disciplined (internally and externally reinforced) adherence to community values. However, these pressures can also lead to rigidities and groupthink (Janis 1972), which can reduce likelihood that new ideas or practices are introduced to or considered by the social group.

When new ideas or practices are introduced into a social cluster, they can often diffuse and become adopted quickly within that cluster. This is because individuals usually trust those they consider self-similar and like-minded, and are more easily influenced and persuaded by them (Cialdini 2001).

We could witness these normative tendencies and diffusion patterns within the local watershed group. A select few members of the group virulently and forcefully expressed views, based on anecdote, not data, that urban runoff had a more significant negative impact on local water quality compared to farming practices. These views quickly became a widely shared contention within the group. Similarly, some farmers' past responses to stormwater problems were accepted as a *de facto* standard response—even when the effectiveness of the practices in question relative to other available and feasible practices could not be verified.

6.4 Community Mobilization Strategy

The Wetlands Initiative (TWI) and the American Corn Growers Association (ACGA) developed a step-by-step mobilization strategy that involved (1) a systematic mapping of relevant stakeholders for a water quality trading program in the county, (2) preliminary interviews with select stakeholders to assess openness and readiness for a water quality trading program, (3) deeper engagement with key stakeholders groups to enlist them as active supporters of outreach and community mobilization efforts, and (4) broader outreach and mobilization efforts in the local community.

6.4.1 Stakeholder mapping (Q3 – Q4 2009)

The systematic stakeholder mapping included the following stakeholder groups:

farmers – representing the supply side of the water quality trading market;

permitted industries – representing the demand side of the water quality trading market;

conservation groups – who could serve as allies in the promotion of the water quality trading market;

agencies and government – who could help facilitate and eventually provide oversight over the water quality trading market.

We made efforts to record recent communication and outreach activities that had already been undertaken with stakeholders (which could potentially serve as point of reference of subsequent engagements), to classify their likely support of the water quality trading program, to empathically describe stakeholders' values and priorities, and to make note of known positive social ties (i.e., friends, alliances, etc.) and negative social ties (i.e., relationships characterized by mistrust, animosity, or rivalry) in the local community. We also made a preliminary determination of when during the outreach process individual stakeholders should be addressed and involved directly. All in all, views of 60 stakeholders were analyzed.

6.4.2 Preliminary interviews (Q4 2009 – Q2 2011)

On the basis of the identified stakeholders, an initial round of interviews with select members of the four groups was conducted. TWI and ACGA decided to approach both individuals they expected to be open to the water quality trading concept and those they expected to be strongly critical of the concept. This would allow us to identify issues that stakeholders react positively to and are particularly interested in, and those issues about which they have concerns, reservations, and objections. In addition to supporting a better understanding of stakeholder attitudes, these preliminary interviews had the benefit of keeping representatives from all groups in the loop and informed about the project. Such early communication about planned initiatives has been shown to be beneficial in a variety of change management contexts (Armenakis and Bedeian 1999; Kotter and Cohen 2002; Brashers 2006).

TWI and ACGA decided not to approach those members of the local community that we assessed as having most social and political capital in the local community. These key social leaders were to be approached later in the project, when the project, specifically the particular outreach and mobilization issues and plans, gained more definition. The rationale for this timing was that the key social leaders were likely expecting concrete proposals—a concrete business case—that they could decide to support. Research for the organizational context has shown that leaders want to be associated with successful initiatives (Bower 1970). Thus, when presented with a new initiative, they often demand comprehensive and convincing information that allows them to reduce the uncertainty of whether their support for the initiative would likely strengthen or harm their "batting average."

The preliminary interviews provided leads as to which individuals may be willing and able to assist the outreach and mobilization effort. The interviews revealed the relatively low level of organization and visibility of conservation initiatives or interests in the community. Farm visits with local farmers showed that while some landowners or operators had implemented conservation practices, they did so in private and did not promote these practices publicly.

The interviews revealed that the local SWCD organization did not actively or effectively play the role of social network broker (a social actor who connects other social actors who are themselves not connected to each other) among farmers who were potentially interested in conservation practices and those who already practice them. Network brokers play a key role in facilitating the spread and adoption of new ideas across otherwise disconnected social clusters (Burt 2004). Due to limited resources, the local SWCD is performing only its essential functions and duties (e.g., administration of the Conservation Reserve Enhancement Program; equipment rentals; county conservation newsletter; and rain barrel, fish, and tree sales) rather than actively reaching out and engaging landowners or the community in conservation.

The SWCD Board, comprised of elected directors, directs the activities and duties of the Resource Conservationist (RC), based on the funding they receive from the state or other sources. If they are not interested in developing or promoting initiatives, then the RC cannot participate. In the past, the local SWCD has turned down two grants due to lack of resources or interest in the offered programs.[13] On the other hand, the Board may not be aware of initiatives or opportunities unless the RC brings it to their attention. Several years ago, the SWCD did not support a concept for installing demonstration rain gardens in a few key urban centers in the watershed, as it did not see the value or importance in addressing urban nonpoint source runoff.

Indeed, the only social forums for conservation and water quality issues in the community seemed to be the two local hunt clubs and the watershed group.

6.4.3 Deeper engagement (Q4 2010 – Q2 2011)

Based on the insights from the preliminary interviews, TWI and ACGA decided to become more involved in the local watershed group. They regularly attended meetings, invited guest speakers to the group, and also connected the group to other conservation groups.

Given the low visibility and lack of social capital of the watershed group, and the limited role of the SWCD in promoting and raising awareness for conservation, TWI and ACGA decided to galvanize the conservation efforts by establishing a formal alliance of conservation partners that share an interest in addressing water quality issues and natural resource concerns. The alliance was formed by identifying and enlisting local stakeholders, agricultural groups, not-for-profit conservation organizations, consulting engineering companies, and local and state government agencies that can leverage financial and technical resources to build an outreach and education network. The goal was to increase public awareness of local natural resource concerns and the conservation practices that can address the concerns. The “Friends of the Big Bureau Creek Watershed” alliance was announced in the local newspaper and became the voice and face of the local outreach efforts.

6.4.4 Outreach and mobilization (Q3 2011 – Q4 2012)

The “Friends of the Big Bureau Creek Watershed” (FBBCW) performed outreach and communication activities, which included a combination of broad messaging (e.g., direct mailings, newspaper ads and articles) and direct personal communications (e.g., meetings, workshops/field tours, and 1-on-1 outreach). The coalition members developed, organized, and implemented a half-day workshop in March titled “2012 Economics of Land Stewardship & Nutrient Management Workshop.” In addition to a direct mailing to promote this workshop, flyers were posted at local NRCS/SWCD offices, an announcement was posted on electronic calendars or emailed to memberships of various agricultural groups, a news release was developed and published by local papers, and a radio ad was developed and broadcast on the local station.

The workshop increased the awareness of watershed natural resource concerns, introduced the Illinois MRBI-awarded programs, provided basic program and practice information, shared local farmer testimonials about implementing the promoted practices, and created a sense of NRCS and FBBCW commitment to providing the agricultural community with technical assistance. Farmers are not typically willing to adopt conservation practices that reduce profits or impede production, due to the return on the practice cost and the effect on normal operation activities (Hoag et al. 2012). Consequently, the workshop focused on the economic aspect of practices and land use. The topics included financial planning, nutrient/water quality issues, ecosystem markets, nutrient management, strip-till, cover crops, and the Conservation Stewardship Program.

Fourteen workshop attendees completed a custom outreach survey adapted from the Social Indicators Data Management and Analysis Tool (SIDMA) (Genskow and Prokopy 2011; http://www.iwr.msu.edu/sidma/). This tool organizes, analyzes, and visualizes social indicators (awareness, attitudes, constraints) related to nonpoint source

[13] In comparison, neighboring SWCDs appeared to have taken on initiatives in recent years. For example, Marshall-Putnam SWCD developed a Conservation Education Initiative, though it was not implemented due to lack of final project funding, and LaSalle County SWCD did a storm sewer stenciling project in conjunction with the Little Vermillion Watershed Committee.

management efforts to determine baseline and progress towards targeted behavioral change. The purpose of the survey is to identify or confirm which factors are preventing implementation of conservation practices. One discovery from the survey was that the most trusted sources of information about soil and water quality are SWCD, University Extension, Crop Consultants, and NRCS.

Feedback from the workshop participants and local coalition members suggested that local producers would be interested in seeing on-the-ground demonstrations of the various conservation practices being promoted. A conservation field tour was planned in August 2012. The half-day tour had four stops. The stops included a local fertilizer and seed company discussing nutrient management and application techniques, a local grazer with a cover crop specialist discussing the implementation of cover crops on grazing and row crop lands, and two local land managers who discussed their personal experience with enrolling in conservation programs and showed how they implemented practices such as wetlands, riparian buffers, and field borders. Despite farmers expressing a need to see practices “in action” and promotion that included a direct mailing to over 400 producers, press articles, and radio announcement, attendance was surprisingly low compared with the workshop. However, those farmers who attended found it to be informative.

Recognizing a growing segment of agricultural landowners are women who historically have been underserved and has traditionally low enrollment in USDA programs, a “Women Caring for the Land” meeting was held in August 2012. This was one of two “Women’s Circle” meetings held in Illinois. It was hosted by American Farmland Trust, Prairie Rivers Network, and the Women, Food and Agricultural Network, an Iowa-based organization that developed this women-outreach program and its format. The program offers a peer-to-peer informal discussion where women can talk about their operations and land stewardship goals. The FBBCW assisted in the promotion of the event and development of materials related to the MRBI program. The workshop was advertised through an NRCS press release printed in several local papers, electronic newsletters, and direct invitations (via the NRCS landowner database) to women who own or manage farmland in Bureau, Lee, and LaSalle counties.

The workshop included a morning “women-only” discussion about current land stewardship practices, sustainability in leases, USDA cost-share programs and practices, and the MRBI program. We provided the women with hard-copy information about the NRCS program and practices we are promoting, as well as new contacts should they want additional information. An optional two-hour tour of conservation practices was held after lunch. The event was successful as it hit the target participant goal, received excellent ratings by the women who completed surveys, and motivated two of the participants to discuss conservation practices with the outreach workers and NRCS in more detail.

6.5 Mobilization Challenges and Barriers

When promoting and attempting to diffuse innovative water quality improvement practices, we encountered challenges pertaining to all four stakeholder groups: (a) farmers, (b) permitted industries, (c) conservation groups, and (d) agencies and local government. We focused primarily on the perspectives of the farmers and WWTPs in the following discussion of challenges and barriers. The conservation groups felt that they did not have sufficient information about water quality trading at this moment to address the potential water quality issues, such as anti-degradation, hot spots, etc. The agencies have a significant role in the “perceptions of support and readiness.”

6.5.1 Strong positions and confusion

Farmers we encountered had a strong point of view about who they are and what they do. Many had firm convictions that they were responsible “stewards of the land,” and that they would never willfully engage in farming practices that were detrimental to the land and would endanger the success of their operation in the future. Many of them are relatively well-informed about current debates about environmental sustainability in farming, though often selective and somewhat idiosyncratic about the particular issues and positions they emphasize, choose to believe in, and subsequently fervently defend.

Farmers want to be viewed as responsible caretakers of the land who are providing the necessary food, fiber, and fuel for the world. During the 2012 workshop, the participating farmers expressed they often feel conflicted about issues affecting land stewardship. The land is how they make a living, and good management of the land will ensure long-term productivity. However, the current high commodity prices are pushing them to optimize crop yield and preventing them from taking additional steps that would improve land stewardship (e.g., taking land out of production for a grassed waterway or a riparian buffer). The advice and recommendations farmers are receiving on agronomy management and maximizing productivity are from individuals or companies with whom they have long-term trusted relationships (e.g., certified crop advisors, seed and fertilizer dealers, banks, etc.). Often farmers perceive that outsiders are providing the outreach and education on the value of conservation practices or management plans to address resource concerns, so the farmers are less likely to trust their information.

At the same time, farmers—even though they seldom confess it—are often confused by the various conservation/restoration programs available and those programs' administrative and implementation requirements. Rumor and hearsay often form the basis of their evaluation of a program's attractiveness or feasibility, and these initial evaluations were difficult to correct subsequently on occasion.

The ambiguities and uncertainties about various programs resulted in more difficulty choosing among different options for farmers and, in some cases, led them not to adopt practices at all. They seemed to rationalize non-adoption with "If I can't be sure about how this works/how effective it really is, I'm not going to do it," even when based on questionable information, as a reason retroactively selected to justify a decision made earlier.

The wastewater treatment industry has the same efficacy and feasibility concerns as the farmers about wetland practice implementation and water quality trading programs. Before they invest in an alternative technology to meet their permit requirements, they want to see it demonstrated. They are just as risk-adverse as farmers; however, they may be more accepting of the water quality trading concept, as regulating agencies (e.g., US EPA) and peer associations or networks (e.g., Water Environment Research Foundation, National Association of Clean Water Agencies, etc.) have been promoting the concept and have been providing their members information on existing programs and policy frameworks.[14] While the wastewater treatment sector may be more aware and accepting of the concept than the farming sector, a particular treatment district or facility may still not want to accept the risk of implementation, especially if it is the first one to participate in the development and implementation of a program in a given region and state.

6.5.2 Blame game

Discussion of water quality enhancing practices frequently and reliably triggered discussions about who is most responsible for water pollution in the local community. Farmers repeatedly voiced their frustration that they are doing a lot already to prevent/minimize water quality impact of their farm operations, but feel unjustly and disproportionately blamed by the public for much of the water quality problems. In their view, it is the urban population who acts irresponsibly, carelessly, and is "never" blamed, and it is urban point and nonpoint sources that are the cause of most of the water quality problem in the watershed.

Impervious surfaces (e.g., roads, roofs, parking lots, etc.) in urban areas increase stormwater runoff to storm drains and stream and rivers instead of allowing the water to infiltrate through the soils. In addition to the increase in water volume and velocity, the water moving off these surfaces picks up pollutants such as lawn fertilizers, heavy metals, salt, gasoline, oil, and trash, which can lower water quality. In watersheds with major metropolitan areas or high urban/suburban land use, urban nonpoint source runoff can be a leading source of water quality problems. While the city and villages in the Big Bureau Creek watershed do contribute to water quality impairments, the agriculture sector is the larger contributor of nonpoint source pollution, particularly excess nitrogen and phosphorus, due to its predominant land use and hydrology (ditches and tile drainage).

Discussion among farmers, however, often led to the conclusion that one should do something about the urban runoff first before undertaking any major initiatives with farmers. This represents a diffusion of responsibility for water quality issues in the urban community and a rationalization of delaying farming initiatives for water quality improvement ("there are bigger problems to solve first"). Worse, farmers may perceive implementing water quality enhancing practices as a symbolic surrender to the (perceived) accusations and public conceptions, as accepting of the role of "major culprit." It seemed to us that farmers in the local community we examined simply did not want to be the only ones (and the first) making an effort at addressing water quality problems. They want to see a sign of goodwill from other contributors that they make an effort to address water quality concerns, too.

The "finger pointing" is not limited to one direction; it goes the other way as well. The wastewater treatment facilities as defined point sources and visible "regulated" entities are often blamed as the source of water quality impairments whether through permitted discharges or occasional overflow events. Even with current and pending state nutrient discharge limits for these point sources, water quality standards or aquatic use goals may not be attained in all waters

[14] Note that the agricultural sector has promoted water quality trading and ecosystem markets. The US EPA and USDA have formed a partnership to establish water quality trading markets and have provided funding for the analysis and development of such markets. The Conservation Technology Information Center, a membership organization that provides information on technologies and sustainable agricultural systems, also produced "Getting Paid for Stewardship: An Agricultural Community Water Quality Trading Guide" in 2006.

unless the sources of nonpoint pollution are addressed. To achieve these goals, a watershed-wide collaborative approach to pollution reduction is needed that involves participation of all stakeholder groups.

6.5.3 Economics/financial considerations

As a general principle, farmers we interviewed were very hesitant to take land out of production, even if that land is only marginally productive, to implement water quality improving practices. Taking land out of production for conservation practices goes against their natural instincts to utilize their land in the most productive way to grow crops. Farmers' focus is often on optimizing yield (bushels/acre) instead of profitability or productivity (i.e., input/output relationship). Using land that could be used to grow crops for another purpose seemed counterintuitive to them at best.

Farmers were suspicious of our default argument that a water quality trading market would allow them to have a positive impact on the environment and earn a return on their investment in conservation practices, as we were suggesting a future and uncertain income as an alternative to a current, certain (albeit low) income. The lack of regulatory framework in place to support water quality trading exacerbated farmers' perception of high risk associated with committing land to wetlands or other water quality enhancing practices.

In addition to concerns about the payoff (financial and otherwise) of the wetlands implementation, farmers were concerned about process issues. Who would set prices for the market, and for how long would trading agreements be made? Who would potential trading partners be? Would they have a choice about who to trade with? These transactional concerns were particularly pressing since farmers had little experience with these types of contracts and trades. Because point source polluters are an unfamiliar business partner to them, these partners' behavior, reliability, etc. was uncertain. The wastewater treatment facilities, who will be the buyers of the nutrient credits, are asking the same questions, particularly in regards to whom they are signing contracts with, the contract structure needed to meet permit requirements, reliability, liability, and certainty.

6.5.4 Oversight and monitoring concerns

Beyond concerns about the relative effectiveness of practices and about the functioning of a water quality trading market, farmers often raised concerns about monitoring requirements, i.e., provisions and actions necessary to ensure the proper implementation and function of a given conservation practice. Farmers regarded less favorably practices that would require frequent and invasive monitoring regimes, e.g., verification and equipment readings by independent third parties or, worse, government agency representatives, or where the monitoring requirements were unclear. While they recognize that monitoring data and practice transparency are required for a program to be successful, they want to balance it with privacy protection, particularly in regards to who is holding the data and how it is going to be used.

Paradoxically, while we found farmers to have, on average, strong positions against strong or invasive government supervision and monitoring of conversation practices on their land, they also hesitated to support practices where legal frameworks were not yet established. Put differently, farmers were critical of conservation practices they perceived to strongly involve governmental regulation and oversight, but also were hesitant to create a self-governance/self-regulation solution by their own initiative that could help prevent restrictive governmental regulation or help shape such regulation to suit needs of farmers better. The primary concern about self-regulation initiatives for water quality practices and trading appeared to be that governmental agencies could end up not supporting those solutions.

As the entity regulated under the Clean Water Act, the wastewater treatment facility is ultimately the one with all the legal liability regarding permit compliance. Unless regulators have in place a solid practice performance and/or water quality monitoring program and oversight of practice operation, credit generation, and credit accounting, the WWTP may consider the purchase of nutrient credits from a nonpoint source (non-regulated entity) as too risky. The preference for a point source then may be costly nutrient control upgrades that the WWTP understands and can control instead of a credit market with less certainty and that involves outside entities voluntarily producing credits.

6.5.5 Perceptions of support and readiness

In our context, key local groups that could publicly support a water quality trading effort (e.g., the SWCD) were not actively engaged in supporting the project. Similarly, the Illinois Environmental Protection Agency (IEPA) was not actively participating in the analysis and feasibility study of a wetland-based water quality trading program. While the IEPA is involved (peripherally) in the Ohio River Basin interstate trading program, they are not leading an effort to develop state policy or guidance for water quality trading. Rather, they are taking a wait-and-see approach—in regards to what neighboring states are enacting and what third-party entities (such as TWI) are proposing to implement as on-the-ground demonstration—before they get involved and commit themselves to a position regarding the program.

While the lack of policy may allow stakeholders to develop simplified programs tailored to their specific watershed goals, IEPA sets the water quality standards and issues the NPDES permits. The involvement of the permitting agencies early and throughout program design and operation can ensure that the program meets their requirements and that they will approve its use (Willamette Partnership et al. 2012b). Having the IEPA as a “champion” of water quality trading could reassure interested wastewater treatment facilities that trading is an acceptable alternative to traditional nutrient control technologies and could encourage facilities to participate in the development of a trading program. The local wastewater treatment facility signaled its interest in a trading market, but remained guarded and cautious throughout the project period.[15]

All these factors contributed to farmers’ perception that major players in the field are not ready to engage in a water quality trading market, and that it would likely take a considerable amount of time and effort to bring stakeholders to support and implement the market. This naturally creates concerns about the potential failure of such mobilization efforts, and the inability to get a trading market off the ground. It also creates concerns that such efforts will considerably delay payback on up-front investments, or that regulations may change sometime during the protracted period of mobilization and thus may render initial plans for the market obsolete.

6.5.6 Problems inherent in the chosen mobilization approach

The “Friends of the BBC Watershed” successfully organized a workshop, conservation field tour, and women-only farm owner meeting and tour. However, the coalition had awkward dynamics that may have impeded the attainment of some of its stated goals, at least during the time period reported here.

The “Friends of the BBC Watershed” was constituted of a coalition of heterogeneous members attempting to advance a fairly radical innovation, and as such involved particularly high levels of relational and project-related risks (Tidd and Bessant 2011:304). Uneven commitment and contributions by members of the coalition and relative lack of feeling of shared ownership of the initiative proved problematic with respect to member buy-in and implementations of decisions made by the coalition. Despite the shared interest in improving water quality through implementation of conservation practices within three targeted sub-watersheds, notable differences between coalition members may have contributed to limited cohesion of the coalition. In retrospect, with regard to extant research on innovation partnerships, the risks and benefits of the project for individual members and the risks and benefits shared among members should have been made more explicit (Rothwell 1977).

We also found that outreach activities required more oversight, guidance, and support than we had anticipated, when those activities relied heavily on members of the local community for implementation. For example, we involved members of the local community to conduct interviews with local farmers about their knowledge about, attitudes toward, and implementation of conservation practices. The enlisted community members had lower capacity than we expected to conduct these structured interviews and to systematically document interview findings, and thus the interviews yielded few useable insights.

6.5.7 Comparison to Ohio River Basin project

The setting for this water quality trading program within the Illinois River Basin is similar to areas within the Electrical Power Research Institute’s (EPRI) interstate nutrient credit trading program for the Ohio River Basin (ORB), which encompasses portions of 14 states and an area of more than 200,000 square miles. Approximately 20% of the 548 counties completely or partially within the basin are classified as rural (EPRI 2011). ORB land use is 35% agricultural, and the farmland is located primarily in Kentucky, Ohio, Indiana, and Illinois. Approximately 20% of Illinois drains into the Ohio River.

In 2007, local farmers in the Sugar Creek watershed (Ohio) and Alpine Cheese implemented a bilateral trade program for the factory to meet its phosphorus discharge permit limit and to expand its facility. This community-based solution involved local county commissioners and congressional representatives, Ohio Department of Natural Resources, Ohio Environmental Protection Agency, Ohio State University, and the Holmes SWCD, which served as the broker in

[15] During the project period, the wastewater treatment facility was dealing with a violation notice filed against them by the IEPA for overflow problems during heavy rain and snow thaw events. Their response actions to bring the facility into compliance had to take priority and pushed exploratory projects such as a water quality trading market further down their agenda.

transactions between the company and participating farmers. The company provided funding to the SWCD for administrative costs for staff to do the necessary contact, planning, and design work.

The role SWCD played in the Sugar Creek watershed contrasts to the situation in Big Bureau Creek. While the Holmes SWCD also had limited resources, they were able to devise funding mechanisms and access grant programs that allowed them to play a central coordinating role in the project.

The Great Miami River Water Quality Credit Trading program is a much larger auction clearinghouse-based program covering a 4000-square-mile (10,360 square kilometer) watershed. It is centered on pre-compliance nitrogen and phosphorus credit purchases by participating wastewater treatment facilities. County SWCD staff work with local farmers who voluntarily implement best management practices, identify and submit the potential projects for funding based on bids to an advisory committee, perform any water quality monitoring, and certify and inspect project implementation. Any costs incurred by the SWCD were included in the nutrient bids. The counties with the highest participation in the program were generally the counties in which the county SWCD worked closely with farmers (Newburn, 2012).

When it reaches full-scale, the EPRI trading program could include up to eight states in the basin and create a credit market for 46 power plants, thousands of municipal wastewater treatment plants and other industries, and 230,000 farmers (AFT 2012). A key element of the program's success is the involvement of all crucial stakeholders in its development. The engagement of farmer and agricultural organizations to participate in an agricultural advisory committee and the development of the trading plan has been successful due to the influence of the Ohio Farm Bureau Federation and American Farmland Trust as project collaborators. In addition, two successful, on-the-ground water quality trading programs in Ohio, the Alpine Nutrient Trading Program (Sugar Creek Watershed) and Great Miami River programs, have been implemented with the involvement of local Soil and Water Conservation Districts (SWCDs). In addition, Ohio had established water quality trading rules in 2006 to assist in watershed-based program development; the rules have been revised as recently as 2012. In comparison, Illinois has no nutrient credit trading programs or trading rules.

6.6 Lessons Learned and Recommendations

6.6.1 Message framing

Our efforts to promote water quality trading can be regarded as an innovation diffusion challenge. Diffusion can be defined as "the process by which an innovation is communicated through certain channels over time among members of a social system. It is a special type of communication, in that the messages are concerned with new ideas." (Rogers 2003).

Diffusion success is influenced by economic considerations (e.g., personal costs and benefits, social benefits, access to information, incentives for adoption); behavioral factors (e.g., priorities, values, motivations, propensity for change or risk); organizational factors (e.g., goals, routines, organizational culture, inertia, stakeholders); and structural factors (e.g., available infrastructure and governance arrangements/institutions in the relevant field). While structural factors often have to be considered exogenous (not affected by any social actors) and not influenceable, economic considerations, behavioral issues, and organizational factors are—at least to some degree—malleable and manageable. For example, perceived personal benefits of an innovation, or its compatibility with an individual's values or an organization's goals, depend in part on how the innovation is communicated and presented to its intended audience, and not exclusively on inherent objective characteristics of the innovation. In other words, the relative attractiveness of any given innovation is socially constructed, the outcome of the communication processes among the members of the targeted social system.

Given the inertia and resistance we encountered from various stakeholder groups to the water quality trading concept, we recommend that organizations seeking to promote water quality trading models carefully and clearly craft how they communicate their proposed innovation to stakeholders, paying close attention to message framing. Rogers (2003) suggests five factors as important for the successful adoption and diffusion of innovations, that in retrospect we could have emphasized better: relative advantage/benefit (including perceptions of risk), compatibility, complexity, trialability, and observability. We elaborate below on these five aspects as they apply to communicating water quality trading as an innovation.

RELATIVE ADVANTAGE/BENEFIT (INCLUDING PERCEPTIONS OF RISK)

Landowners and operators want to know why they should adopt wetlands instead of other conservation practices. Often they do not have clear, objective information about the relative advantages and disadvantages of alternative practices and thus rely on social proof, i.e., peers' adoption of practices (see discussion of socio-structural issues below). One key differentiating feature of wetlands adoption that we emphasized to farmers is the potential to earn a return on the converted land through a water quality trading program. While this opportunity represents a significant upside of an investment in wetland restoration, the risk of a trading program not materializing and the risk of a market failure (similar to the failure of a carbon credits market) represents a significant downside risk. Both the upside and the downside of the proposal need to be managed in the communication with landowners and operators (Fliegel & Kivlin, 1966).

COMPATIBILITY

Landowners and operators want to know how wetlands and a water quality trading program fit into their current operation. Key concerns here are, for example, how the wetland might affect their existing productive land and whether participation in water quality trading programs would preclude them from participating in other conservation programs and grants, etc. Hence, we emphasized in our communication that we aim the program to involve only marginally-productive land.

COMPLEXITY

Water quality trading markets allow for a broad variety of practices and governance arrangements. However, we found that presenting the flexibility and range of choices to farmers may be overwhelming rather than encouraging. It suggests a significant level of complexity residing in the many degrees of freedom and the complex decision making that has to be undertaken by market participants—decisions that conceivably can go wrong or stall the process of market development. Hence organizations seeking to promote such a program may want to simplify their explanation of how the market can be set up, e.g., base it on a simple, exemplary, hypothetical case, and merely note that different setups to accommodate local preference and conditions are possible.

TRIALABILITY

Landowners and operators are often concerned about how much land they have to commit to a conservation program. To overcome the "all or nothing" attitude, which may lead farmers to fully reject the program because they are concerned about having to commit too many resources to it, we emphasized that participation can start with a relatively small acreage, e.g., "You can try this on 10 acres! We don't ask you to put in 400 acres."

OBSERVABILITY

Especially given concerns about downside risk, compatibility, and the complexity of wetlands and water quality trading, the visibility of benefits of the practice to farmers and their peers is important. Field demonstrations may be particularly suitable to communicate what the implementation looks like on the ground. Given stakeholders' relative unfamiliarity with the specific practice and uncertainties about implementation difficulties or risks, hands-on demonstration may be the most effective approach in generating interest and ultimately securing buy-in.

Message framing in communication with stakeholders can have a strong impact on how they judge these five criteria. It can help convince farmers of the benefits and the feasibility of a water quality trading program. Missteps in message framing, however, also can quickly create negative repercussions. Once wetlands and water quality trading is portrayed in a manner that is at odds with farmers' preferences, these negative associations and connections can take root and quickly become diffused in the local farming community. Once established, perceptions can be difficult to change.

6.6.2 Cultural resonance

While it is important to communicate clearly about water quality trading models' relative advantages, compatibility, complexity, trialability, and observability, such communication needs to take into account targeted stakeholders' values, beliefs, and concerns. The messaging needs to resonate culturally with stakeholders (Fiss and Zajac 2006; Burton et al. 2008). In our case, key issues that we needed to accommodate in our messaging were farmers' confusion about alternative practices, their concern about taking land out of production, the symbolic implications of water quality trading ("admitting" responsibility/culpability for water quality problems, etc.), and the external control/monitoring of wetland effectiveness. We had to find ways of communicating about these issues that resonated with held beliefs and assumptions.

Through initial conversations with farmers about water quality trading, for example, we learned they perceived that by participating in a trading program, farmers would be responsible for "cleaning up the city's problems" ("why can't they do it themselves, why should we do it for them?") or that they would be allowing the urban point sources to "get off the hook" in meeting permit requirements ("…because through trading they could discharge more pollution! We don't want that."). Given these perceptions, the partners changed how we presented the water quality trading concept by explaining that trading simply offers another means for point sources to meet future permit limits and by discussing the issues of antidegradation and anti-backsliding in non-technical terms.

If established institutional actors such as SWCD, or related agencies, are familiar with the water quality trading concept, and know just enough to be able to competently inform farmers about the basic requirements, benefits, risks, and prior implementations, they can lend institutional legitimacy to the concept (Zucker 1991). It ceases to be alien to the community, and instead becomes an objectified, legitimate option; in other words, it becomes concrete, rather than a vaguely defined idea. Thus, establishing legitimacy and a "tried-and-tested" perception of water quality trading concepts can be accomplished through workshops involving established local institutional actors who can help address farmers questions and concerns.

6.6.3 Socio-structural issues and "community readiness"

In addition to addressing stakeholders' cultural sensitivities, those who seek to promote water quality trading models also need to recognize and leverage social structures in the target community, the set of social relations among various stakeholders. An understanding of a community's social structure is particularly important when attempting to seed grassroots support for a practice. Research describes problems from outsider attempts at promoting innovations in existing social cliques (Katz and Allen 1982; Gladwell 2000). Outsiders have little social capital within a local community, and even when they commence establishing social ties to community members, those ties are often relatively weak and characterized by low trust. In short, outsiders have more difficulty persuading community members of the benefits of a particular practice than would an insider, a member of the community (Gladwell 2000; Cialdini 2001).

Hence, local farm leadership's openness to a particular conservation practice, and their active support and engagement in the promotion efforts for the practice, can significantly increase the likelihood of success of the practice and shorten the time needed to introduce it. In some communities, local farm leaders have already publicly supported, orchestrated, and successfully implemented conservation initiatives. They are recognized for supporting conservation efforts and have established governance platforms in the community that support and facilitate such efforts, e.g., steering committees and working groups. In some cases, they oversee field testing of practices and share experiences and tips for implementation. Such farm leaders are a visible and critical aspect of what is often referred to as "community readiness" (Donnermeyer et al. 1997), the degree to which a local community is aware of, interested in, and prepared to try and implement a given practice. Based on our interaction with the local farming community, we suggest the following important facets of community readiness for water quality trading programs:

- awareness of water quality issues with farmers and municipalities; farmers ideally have an appreciation of different perspectives and points-of-view on water quality issues;
- acceptance of conservation practices to address water quality issues;
- openness to new ideas and new practices that tackle water quality problems, willingness to depart from established practices and assess and try new methods (a helpful proxy for this could be farmers' participation in local technical committees);
- engage local farm leadership, ideally with substantial social capital in the form of strong and diverse ties to different stakeholder groups in the community, and the ability to develop new ties with relevant stakeholders;
- engage existing and effective social platforms for water quality issues, e.g., a watershed group or steering committee (independent of government agencies), ideally with well-established ties to the local community, with involvement of local farm leaders, and a track record with the community for successfully implemented initiatives.

Community readiness is not simply about the assessment of average individual local stakeholder openness/support, but it also considers the relations among stakeholders. For example, a community that has five outspoken proponents of water quality trading at the periphery of the community's social structure and where ties among community members are generally weak is less likely to successfully implement the program compared to a community with three outspoken central members with dense social ties among members.

Practical tactics for water quality trading projects include peer tutoring and peer-to-peer diffusion. We have generally received good feedback and responses to peer success stories. Persuasiveness of the story depends critically on who exactly the peer. Is it a landowner or operator? Farming crops or livestock? Is the operation commercially successful? Does he/she have local roots in the community? Also, having peers talk to and discuss with smaller groups or even pairing them one-on-one with farmers may prove more effective for outreach efforts than formal presentations or talks to a large audience. Our experience showed that individual farmers were more open to discussion and more comfortable asking questions in small groups or one-on-one.

The Iowa Conservation Reserve Enhancement Program (CREP) has successfully leveraged peer-to-peer diffusion to promote what is considered a difficult-to-implement practice.[16] The CREP is a partnership between the Iowa Department of Agriculture and Land Stewardship (IDALS), the USDA Farm Service Agency, and local soil and water conservation districts. Through this program, landowners voluntarily establish tile-drainage treatment wetlands in the heavily tile-drained regions of Iowa. Over the last 10 years, more than 70 wetlands have been restored, and there is a waiting list for additional wetland installations. This practice may have become popular beyond the federal and state financial incentive package due to farmer-landowner peer diffusion through formal and informal interactions. Through the Iowa Learning Farms program, IDALS has led individual county field tours. In addition to the CREP specialists and university water quality engineers and scientists, farmer-landowners who have installed the wetlands lead the tour and speak about the water quality (and ancillary) benefits, installation, and financial incentives for the practice. The implementation of the practice by local innovators provides neighboring farmers an opportunity to see the practice first-hand throughout the stages of installation to a fully functional wetland.

While local peers are likely to be most successful in kindling interest and mobilizing support for water quality trading, it may be worth experimenting with involving non-local U.S. farmers from states that have already implemented water quality trading. Such involvement could be in the form of testimonials, conference calls, or video conferences.

6.7 Conclusion on Social Factors in Big Bureau Creek

In summary, a key finding from the project was that site selection for water quality trading and other innovative agricultural practices requires a triple evaluation: one to assess the physical landscape characteristics and their suitability for the project; one to assess the economic feasibility; and one to assess the social landscape, the local social structure, and community readiness for the project. While TWI conducted extensive assessment of the first aspect prior to selecting this watershed, more substantial due diligence could have been undertaken for the third aspect. This would have uncovered social structural challenges that could potentially have influenced the watershed selection decision, or at the least would have allowed the project partners to better anticipate and address hurdles during the program outreach and future project implementation.

As TWI prepares for the next step toward implementation of the water quality trading program, the project team's effort will concentrate on two priority areas. First, the team aims to provide better observability of wetlands' benefits by implementing local small-scale demonstration wetlands. These demonstration wetlands will also help address concerns about risks and complexity of wetlands implementation. Second, the project team aims to help develop a more effective social platform for farmer engagement in water quality issues in the watershed. This could entail eliciting active involvement of local farm leadership and winning their support to reach out more effectively to other members of the farming community.

[16] Information about CREP is based on personal communication with IDALS staff.

7 PROGRAM ADMINISTRATION

7.1 Enforcement and Administration

The state and federal regulatory agencies play an important role in a trading program by participating in market structure development, providing legal protections, removing regulatory uncertainty, providing enforcement, overseeing program administration, and encouraging participation in the trading program. Participants' confidence will increase knowing that the modeling estimates, trading ratios, and program design can stand up to legal scrutiny and not be called into question in the permitting stage or in enforcement actions (US EPA 2008). The U.S. EPA retains authority oversight over all trading programs to ensure consistency and compliance with the Clean Water Act.

7.1.1 Program Enforcement

In addition to the development of numeric nutrient standards and specification of rights and responsibilities to generate the needed supply and demand, the Illinois EPA has a key role in the enforcement of water quality trading (WQT) rules or framework to ensure compliance anti-backsliding and antidegradation provisions and attainment of water quality goals. Illinois EPA will have to approve the inclusion of water quality trading into a point source's NPDES permit and the length of the trading contracts (e.g., one permit cycle, 10, or 20 years). In addition, the regulator will have to develop and implement mechanisms to ensure practice performance, credit production accountability, and both parties' compliance with trading requirements. The Illinois EPA may choose an enforcement protocol that relies on self-reporting for credit production with spot audits (as is currently done with permitted entities) or on more extensive verifications if self-reporting proves ineffective.

Compliance will improve if the permitted entities face penalties or other legal action (US EPA 2008). However, enforcement of environmental policies under command and control, environmental taxes, or tradable permit systems all carry different costs, which should be weighed against their ability to achieve environmental goals with maximum economic efficiency (McCann and Easter 1999). If enforcement is too expensive and burdensome, the program will not be successful. On the other hand, if important stakeholders do not have faith that enforcement yields meaningful pollution reductions when offsets are purchased from nonpoint sources, the program will not have the widespread stakeholder and political support necessary for its success.

7.1.2 Program Administration

The Illinois EPA, as the state regulatory agency, will need to approve the infrastructure elements needed for program operation and program administration as well as make official program improvement decisions on an annual basis (Willamette Partnership 2012a). Basic infrastructure elements include contract templates, verification documentation, transaction processes, and reporting and recordkeeping databases that facilitate compliance evaluations. In addition, the regulator needs to approve the methodology for determining nonpoint source credits production, whether through performance monitoring procedures (described in Section 7.2), dynamic watershed modeling, a credit calculator that pre-determines the number of credits based on implementation of best management practices (BMPs) at specific locations, or a combination of both.

Since the IEPA already oversees the credit buyers through their NPDES requirements and would oversee the credit production according to program rules, this agency could be responsible for ensuring that the market clears over some selected time interval. This time period would allow the producers and buyers of credits to adjust their operations, within their abilities, according to climatic, hydrologic, or other special conditions. The accounting period might be quarterly, semi-annually, or annually.

Many market structures can work more efficiently by employing an electronic system to estimate, register, and even sell offset credits. Registries can reduce the transaction costs associated with a trading program and increase credibility with regulators and stakeholders by making credit generation and trading more transparent. Such systems are available in the world of ecosystem service marketplaces, with several devoted to surface-water nutrient flows. For example, NutrientNet (http://www.nutrientnet.org/) applies accounting technology with a registry, marketplace, and credit estimation tool for alternative agricultural BMPs.

While IEPA can serve as the program administrator, a third party could also hold the role that is knowledgeable about the program's development, modelling, practices, and program functions and rules. Program administration includes oversight of the daily, monthly, or yearly functions (e.g., trade approval, practice verification, monitoring, credit reporting, data management, etc.) that ensure the trading program is operating both efficiently and in accordance with the approved program rules. The program should be managed adaptively to address new credit needs or issues and to resolve conflicts. In addition to administrators, third parties can serve as aggregators, verifiers, registrars, etc. Aggregators are sellers that create opportunities to produce credits by working with multiple landowners to pool credits. However, an aggregator can pay for, manage, design, and control BMP implementation construction that is being implemented, as is done with the Environmental Banc & Exchange (http://www.ebxusa.com/nutrients).

We propose two third-party alternatives that can perform the administrative activities previously described, serve as market manager in coordinating activities of multiple sellers and buyers, and monitor water quality to quantify wetland credit production and to optimize the credit production under a cost-minimization approach. First, a water quality trading district could focus on managing the market at the watershed level with the the advantage of local democratic control. Second, a water independent system operator (ISO), similar to those used in the electricity market, could handle market operations statewide.

7.1.3 Water Quality Trading District

The Water Quality Trading District Act was developed and proposed by Donald Hey of Wetland Research Inc., and George Covington, an attorney specializing in land use issues including conservation easements, and is proposed to govern the relationships among the multiple owners of land comprising a single trading unit.

The authors propose the establishment of the Water Quality Trading District Act through the endorsement of the Illinois State Legislature and the approval of the Illinois Pollution Control Board. As part of this feasibility study, we investigated several existing government districts and organizational structures that could be used to administer, operate, and represent a Water Quality Trading District (WQT District) in a trading program and to the regulatory agencies.

From the outset, we realized that an organization likely does not exist that would fully meet the needs of the WQT District. Consequently, we established the necessary conditions for the efficient and effective management of a WQT District. These conditions included the right to petition and negotiate with the various market and regulatory authorities on behalf of the WQT District, to oversee the operation and monitoring of the WQT District, and to maintain the financial records of the WQT District and those of the individual members in regards to the production and sale of nutrient credits (i.e., the organization would produce a monthly record of operating conditions, credit production, and credit sales). This record would be submitted to the regulatory authority as required and to each of the members of the trading district.

In addition to these administrative activities, the organizing structure would serve as the market manager or aggregator in coordinating the activities of the multiple sellers and buyers. It would administer the sales and proceeds and assist the regulatory agencies in identifying appropriate trade ratios. Further, the WQT District would monitor water quality to quantify wetland credit production and to optimize the credit production under a cost-minimization approach.

Before proceeding with the development of the WQT District, we did an extensive review of existing district structures in Illinois. We concluded that the organizational structure that would best suit our particular needs would be a Special Purpose District. Following the general format of other special districts in Illinois, the WQT District would be drafted to suit the needs of water quality trading programs.

Before proceeding with the discussion of this district and its application for our purposes, it is important to understand the use of special districts. Illinois is notable for the number of governments providing services, and has the largest number of special districts of any state aside from California. Illinois' special districts overlay the three general purpose governments: counties, townships, and municipalities. The proliferation of special districts is due in part to the general purpose governments not providing all of the needed services; therefore, special districts have been created to provide those specialized services. The benefit of special districts is that they localize the costs and benefits of the specialized service. Examples of special purpose districts include, but are not limited to, wastewater treatment, drinking water supply, flood protection, and airport authorities.

In Montana and Minnesota, Water Quality Districts have been formed to protect, preserve, and improve the quality of ground and surface waters. While these districts lack the authority to pass regulations to protect water quality, they can develop or implement local water quality programs, administer local ordinances, and construct and maintain facilities necessary to accomplish the purposes of the districts. This special district structure does not exist in Illinois.

We reviewed the special purpose districts that currently exist in Illinois and that have some relationship to water (e.g., drainage, levee, and sanitary districts). We focused specifically on their organizational structure and powers to determine whether one of these special districts can serve as the mechanism to institute an ecosystem service market in the Big Bureau Watershed. If none of the existing districts were appropriate, then we determined which structures and powers are necessary to adopt in creating an entirely new district.

Wastewater treatment and water supply districts do not envision or contemplate the treatment of water in terms of producing water quality credits, nor do such districts typically own sufficient land to produce credits through the use of constructed/restored wetlands or agricultural BMPs for water quality improvement. Both their district charter and operations would need to be changed substantially, which most likely would be financially infeasible. While levee districts have a completely different purpose, they would support the use of wetlands for credit production. If an existing levee district decided to convert to a WQT District, then they would be covered by the infrastructure conditions of the WQT District in terms of controlling wetland water levels.

In addition, we reviewed three conservation-related districts in detail: (1) Conservation Districts, (2) River Conservancy Districts, and (3) Soil and Water Conservation Districts (SWCDs). We concluded that none of these districts provided the supporting conditions necessary for the administration and operation of a water quality trading program. The closest district would be the SWCD. While this may be the district that we ultimately use, it would require substantial modification. Therefore, we drafted the Water Quality Trading District Act. If the producers and buyers of water quality credits would prefer to operate under the more well-known and understood district, the critical parts of the WQT District could be incorporated in the SWCD. For now, the conditions of the Water Quality Trading District Act need to be carefully scrutinized, and this scrutiny would be more difficult if the SWCD were modified. Further, while the purposes of both districts are similar, the strategies needed to achieve their purposes are very different.

Since most, if not all, of the other special purpose districts bear little or no relationship to the creation and management of a water quality trading program, we propose the establishment of the Water Quality Trading District Act. A WQT District, unlike most districts (except airports and trade authorities), produces income for its district members. The landowners in a water quality district will be paid for removing nitrogen and other water pollutants (e.g., phosphorus, suspended sediment, etc.). At the same time, the constructed or restored wetland can be used for flood control, for which the landowner would be paid for a flood easement without the loss of income from water quality treatment. Other sources of income that could be stacked include hunting, fishing, bird-watching, conservation, etc. Wetlands and BMPs have costs associated with them: operation and maintenance of any infrastructure, invasive species management, and monitoring and administration as required by the regulatory agencies. However, a WQT District benefits from economies of scale related to the maintenance, operation, negotiating credit sales, and administration, particularly when dealing with the regulatory agencies.

To establish this Act, political support from the Illinois legislature will be necessary. TWI and other supporters of water quality trading can, and will have to, petition the Illinois Pollution Control Board. Support from the potential credit buyers (e.g., wastewater treatment operators, municipalities, and, perhaps, water supply operators) and their associations will be needed. The draft terms and conditions structuring the Water Quality Trading District Act are given in Appendix B. The proposed language of the legislative act enabling the district covers the following topics: purpose; need; formation; governance; authority; contracts, acquisitions, and taxes; expansion and maintenance of infrastructure; water quality credits and other ecosystem service credits, including other fungible activities produced by the district; and state and federal overview.

7.1.4 Water ISO

Analogous to the independent system operator (ISO) in the electricity market, the water ISO would be responsible for the administration and operation of a water quality trading market in accordance to U.S. EPA Water Quality Trading Policy and state rules and regulations. The water ISO, as in the electricity market, is set up as a nonprofit corporation using approved governance models. Strict oversight and regulation by the federal and state government on the key components of the market can assure a strong market.

As a marketplace operator, the water ISO’s role is to maintain credit reserves (or insurance pools) to mitigate participants’ exposure to risk, coordinate trades through a combination of auctions and bilateral contracts, determine market price, and oversee the financial settlement of the market in a transparent manner (See Section 5.2.4 for smart market operator description). The objective of the water ISO is to serve the public’s interest by providing a reliable means to achieve water quality goals in the service area, ensuring no one market participant can control operating procedures, providing access to and pricing of services to any market participant without discrimination, and supporting an efficient, competitive market through its operating procedures and pricing.

7.2 Monitoring and Verification

The lack of a solid connection between nonpoint source BMPs and the delivery of measurable environmental benefits has been a key limiting factor in market development to date. Practice compliance and the production of credits that are quantifiable and verifiable are important factors that need to be considered in the development of a point source to nonpoint source (PS–NPS) nutrient credit trading program. Compliance with management BMPs can be hard to verify with contractual obligations. In contrast, practice compliance is straightforward for structural practices. Structural practices such as constructed wetlands are readily observable and unlikely to be removed once installed given the relatively large capital investment.

While compliance certifies that a BMP has been implemented, it does not necessarily mean that the expected nutrient reductions have occurred. Market designers face two alternatives in quantifying offset reductions: direct measurements or measurements based on changes in land use or practices. Clearly the former measure is a more accurate but costly option, while the latter is a proxy for actual environmental benefits delivered.

7.2.1 Monitoring methods

The credibility of a trading program depends on the accuracy of nutrient reduction measurements; however, most water quality trading programs do not directly monitor or quantify nutrient reductions. Many trading programs are based on the implementation of BMPs to create credits from nonpoint source runoff. It is a challenge to calculate nonpoint source pollution baselines and the subsequent nutrient reduction from BMPs, given the diffuse nature of the runoff, the influence of weather on nutrient loss and reduction, the differences in effectiveness based on location, and the difficulty or infeasibility of measuring actual pollutant reductions from field-based BMPs. While the level of monitoring needed for NPS has not been fully analyzed, direct measurements at the practice site or downstream can be prohibitively expensive, and a long-term monitoring period may be required to provide conclusive results.

In the absence of direct monitoring data, PS–NPS trading programs typically rely on predetermined nutrient reductions for individual practices, regardless of location or site-specific calculations, using established models or tools to estimate nutrient losses and BMP reductions (e.g., USDA's Nitrogen Trading Tool, US EPA Region 5 Load Estimation spreadsheet, World Resources Institute's NutrientNet). Most standard load reduction models do not reflect the stochastic nature of a watershed's climate, nutrient loading, hydrology, etc., which affect an individual practice's nutrient credit production.

These methods are inherently less certain than direct measurements, so program administrators use safety factors or uncertainty ratios to increase confidence in reduction levels. It is often assumed that as long as BMP practices are implemented and maintained, they will achieve the estimated nutrient or pollutant reduction. Therefore, the credits generated and environmental benefits provided by most BMPs are not easily validated. However, the regulator can regularly update and calibrate a load-estimating model based on direct measurements.

7.2.2 Monitoring wetland performance

A wetland-based trading market, however, can include the tracking and reporting of real environmental results through direct measurements. A baseline determination is not needed to measure practice performance, as the program operators and manager can determine nutrient reduction (or credit production) by measuring the flow and the difference in nutrient concentration at the inlet and outlet of the constructed wetland. Wetland monitoring includes measurements of flow velocity (manual and automated) and nutrient concentrations (e.g., TSS, turbidity, TP, TN, nitrate-nitrogen, ammonium, soluble reactive phosphorus) at the inlet and outlet locations, wetland water elevation, and water temperature. The direct monitoring can account for spatial and seasonal variability in nutrient removal efficiency. To increase credit certainty, the operator should measure wetland parameters (e.g., wetland area and depth) that affect performance (e.g., hydraulic loading rate, residence time, temperature, and inflow nutrient concentrations). The effectiveness of the surrounding vegetative buffer, particularly for phosphorus removal, is harder to assess through direct measurement and will require a site-specific model to estimate the reduction of surface runoff pollutants.

A review of wetland studies showed that the duration and frequency of samples and the nutrient forms analyzed influenced whether the wetland appeared to reduce (or increase) nutrient loading (Fisher and Acreman 2004). Therefore, a thorough monitoring program should include a combination of weekly grab samples and automated daily samples throughout the year to capture storm event effects and seasonal variation in nutrient reductions. Intensive and close-interval monitoring of high flow events is particularly important for phosphorus, as high phosphorus load days were found to correspond to high flow days (Crumpton et al. 2012).

The constructed wetland practice has an advantage over most other BMP in that nutrient reduction can be quantified and not simply presumed based on the number of wetland acres. However, the labor, equipment, supplies, laboratory analyses, and evaluation can make intensive monitoring expensive. For example, research support provided by Iowa State University for the intensive monitoring, analyses, and evaluation of seven wetlands within the Iowa CREP program was approximately $307,000 in FY2012 (IDALS 2012). In some cases, the monitoring of wetland performance in trading programs was prohibitively costly to the point that it was more cost-effective to grossly oversize the wetland to overcome uncertainty about performance (US EPA 2007a).

If buyers have no assurance that the nutrient reductions are real and acceptable to the regulatory agency, then buyers will not participate, as they could be charged with violating their allocated discharge limits or permits. However, if the monitoring program is too expensive, then buyers will have no economic incentive to trade, as the nutrient credit price will be too high. Establishing cost-effective and adaptable guidelines for the collection of monitoring data and measurement of wetland performance may reduce uncertainty and increase WQT program potential (US EPA 2007a). A combination of existing wetland monitoring research, specific watershed modeling information, and on-site demonstration will be needed to determine the minimum performance monitoring data required for a water quality trading program to assess the variability (annual and seasonal) in nutrient removal and credit production.

Since this program is focused within a HUC-10 watershed—versus a much larger watershed that has more geography, weather, and land use heterogeneity—it may be more feasible to collect the minimal monitoring data on the majority of the wetlands and more intensive data for a representative subset of the wetlands that reflects the range of wetland parameters (e.g., wetland area to watershed area ratio, watershed land cover, and nitrate-nitrogen concentrations). These data would help validate and refine the existing wetland mass balance models. A pilot program can be initiated with wetland performance based on conservative presumed load reductions derived from the developed watershed model, then adjusted once site monitoring data becomes available for the wetlands.

7.2.3 Practice verification and certification

Prior to acceptance, the regulatory agency or program administrator must verify and certify all credits. Verification of BMP implementation, maintenance, and monitoring is a necessary preliminary step to determine the value of a reduction credit. In this verification, the regulator or administrator checks that the sellers are complying with program rules and practice procedures and that the practice is achieving the performance standard or nutrient reduction established by the program contract. Certification is simply the final review step before credits are accepted or issued.

Consensus is needed between all participants during the design of the trading program, on the practice standards, operation and maintenance protocols, and monitoring schedule, and about who is responsible for ensuring credible and verifiable credits. Farmers are not interested in practice and performance monitoring by government agencies, particularly regulatory agencies, as they consider it intrusive, costly, and a possible precursor to regulation. On the other hand, the wastewater treatment facilities and regulatory agencies need assurances that the practice is being maintained and operated as designed and that nutrient reduction credits are being produced.

Many WQT programs use a third party to verify that a practice is implemented or constructed and maintained as designed. Farmer reluctance to on-site verifications may be overcome if done professionally and efficiently by someone with whom they already have a trusted working relationship, such as a crop consultant, certified crop advisor (CCA), or SWCD resource conservationist. For most structural practices, only the implementation or continued maintenance is inspected and verified during the credit period.

Constructed wetlands also require some level of direct measurement to monitor credit production. The water quality sampling needs to be performed by someone who is trained in the sampling protocols as outlined in the program's quality assurance project plan (QAPP). The QAPP is the document that outlines the procedures that those who conduct the monitoring will take to ensure that the data they collect and analyze meets project requirements. Field technicians, CCAs, or a local university can perform sample setup, collection, and delivery. Samples can be analyzed by a certified laboratory or a local university laboratory that meets a similar level of accreditation and follows standard analysis protocols. Any verifier must be accredited and trained in water quality program guidelines, conservation practice design and implementation, operation and maintenance standards, and water quality sampling protocols. Any incurred costs from third-party verification and certification need to be incorporated in the transaction costs.

8 CONCLUSIONS

8.1 Project Findings

The findings in this triple-evaluation study indicate that the environmental and economic conditions in the Big Bureau Creek watershed could support a water quality trading (WQT) program. If successfully demonstrated in the field, then these findings could represent the first step toward a significant and exciting impact across the entire tile-drained Midwestern agricultural region.

While other point source–nonpoint source WQT programs have included wetlands in their suite of nutrient management and reduction best management practices (BMPs), our project focuses primarily on wetlands positioned and designed to capture and remove nutrients from agriculture sub-surface and surface runoff. This practice allows for a more focused assessment of the potential impact of this particular BMP that is designed specifically to address the nitrogen delivered by agricultural tile drainage.

Given the low number of permitted facilities and the size of the facilities in this particular rural agricultural watershed, the credit demand needed to meet two different hypothetical effluent limits was quite low relative to the potential credit supply. Based on a general landscape assessment and an advanced simulation model, we found that potential wetlands sited through TWI's methodology could more than sufficiently meet the nitrogen and phosphorus demand in terms of pollutant type and form, impact, and timing. In terms of nutrient reduction strategies, the 80 potential wetlands (plus buffer) sites could reduce the annual nitrogen and phosphorus load by an average of 14% and 11%, respectively, despite capturing only 23% of the watershed runoff and representing less than 0.3% of the total watershed area.

Wetlands have a higher up-front cost than other conventional BMPs, but they provide a long-term, high-level nutrient removal solution. The economic analysis, using the landscape assessment results, concluded that wetlands are a more cost-effective way to reduce nutrient pollution, particularly nitrogen, than traditional wastewater treatment plant (WWTP) nutrient abatement technologies. Only a few wetlands were needed to meet the point sources' nitrogen demand in this particular local marketplace. This study serves as an example, however, of how a wetland-based nutrient trading program could be a more cost-effective alternative to WWTP nutrient abatement in other rural agricultural watersheds with larger city populations and emission demands. The economic analysis also determined that social welfare would not increase by including multiple payments for ancillary benefits, but additional income may encourage farmers to install wetlands and participate in a voluntary trading program.

MarshWren, the smart market trading platform designed to manage nutrient runoff in the Big Bureau Creek watershed, extended the economic analysis one step further. In a watershed where the land use is predominantly row-crop agriculture, trading alone will not significantly improve water quality. Rather, trading can decrease the cost of nutrient reduction for point sources. Taking a "watershed management approach" to achieve watershed nutrient reduction goals, the field of potential buyers was expanded in MarshWren beyond the permitted facilities to include conservation programs or initiatives, conservation organizations, or farmers. While it was still more cost-effective for the largest WWTP to reduce its phosphorus discharge through treatment upgrades, implementing nutrient removal wetlands and other agricultural BMPs was more cost-effective than WWTPs reducing their nutrient loads, particularly nitrogen, through technology-based controls. The inclusion of additional buyers and sellers would incentivize the construction of more wetlands and incentivize farmers to reduce their runoff cost-effectively. With this expanded market, significant nutrient load reductions at the outlet of the Big Bureau Creek watershed were predicted.

In addition to analyzing the pollutant and economic feasibility of a watershed, this study assessed the social landscape, the local social structure, and community readiness for a water quality trading project. The socio-cultural issues within the watershed and the concerns of potential trading partners and other key stakeholders were evaluated. A number of social structural challenges were uncovered that would have allowed the project partners to better anticipate and address hurdles during the initial program outreach and could influence future project implementation. Based on the analysis of stakeholder perspectives, we developed recommendations to address the identified resistance or barriers and harness support for a potential market.

8.2 Next Steps

The purpose of this study was to determine if the conditions in this typical Midwestern farm-belt watershed could support a trading program. This study is the starting point in the development of a water quality trading program in the Big Bureau Creek watershed that could then be replicated in other rural agricultural watersheds throughout the state and, ultimately, the Midwest. The feasibility study has provided insight on the potential social, economic, programmatic, and regulatory conditions that need to be considered or resolved during the program design phase. We identified several critical actions:

- Set quantitative nutrient standards for nitrogen and phosphorus. Currently, potential buyers and sellers have little motivation to trade. Without nutrient standards, point sources cannot make adequate plans to reduce their nitrogen pollution, nor can they know what reductions will be needed to meet future permit effluent limits. In addition, program designers cannot develop trading ratios until they know the limits on nutrients in the watershed.
- Establish a registry of credits, specifying initial credits for all relevant stakeholders. Recognize rights of WWTPs and farmers already participating prior to standards or a TMDL, and protect them from unreasonable liability for their early effort. As with the federal sulfur dioxide market, initial rights could start high and be reduced proportionally over time.
- Establish a program administrator or aggregator to operate a market, either with a statewide water independent system operator (ISO) or water quality trading districts, who would initiate a smart market and manage the credit registry. An aggregator will minimize transaction costs to allow an active market.
- Develop enforcement mechanisms, including measurement and penalties. The regulator could rely on participants to self-report at the start, while holding stronger mechanisms in reserve.
- Consider expanding the market mechanism to other types of runoff, including sediment and flood management.

We identified two main barriers to stakeholder readiness to participate in a wetland-based WQT program: a need to see the wetland practice demonstrated locally in the watershed, and insufficient proof of the ability of the wetland to generate credits reliably. Farmers consider nutrient removal wetlands to be an innovative practice compared to more widely accepted and utilized BMPs. Farmers are not likely to adopt a practice until they see “proof” that it will perform as expected, whether a WQT program provides incentives or not.

Using the science- and technology-based method to identify the locations in the watershed best suited for the constructed wetlands and to determine their nutrient removal potential, the Wetlands Initiative (TWI) is currently working with several landowners interested in installing a demonstration tile-treatment wetland on their properties. The goal is to establish two demonstration wetlands to address stakeholder concerns about performance variability and future credit generation. The demonstration wetlands will follow the NRCS 656 practice standard to allow the landowner to receive financial assistance under a federal and/or state conservation program. Because water and nutrients entering and leaving a wetland can be directly monitored, the nutrient reduction can be shown to be specific and tangible. TWI and its research partners will study the demonstration wetlands to develop the monitoring protocols needed to provide credit certainty while minimizing cost.

At the same time, all stakeholders need to learn more about the viability of a WQT program using wetlands in order to become willing participants. By disseminating the findings of this study to the stakeholders who could participate in a market and/or play a role in its implementation, we can move from the feasibility analysis phase to the program design phase. The readiness of the WQT community can be increased by involving stakeholders (i.e., farmers, WWTP, regulatory agencies, and environmental communities, etc.) in the program design process. Thus far, the uncertainty in regards to future nutrient water quality standards has made stakeholders hesitate to invest time and resources in the development of a program. This study and the demonstration wetlands can help advance the regulatory conversation by showing that reducing nutrient, particularly nitrogen, loads through these targeted wetlands is a practical and fiscally attractive alternative for compliance.

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APPENDIX A: POLLUTANT SUITABILITY SUPPLEMENTAL DATA

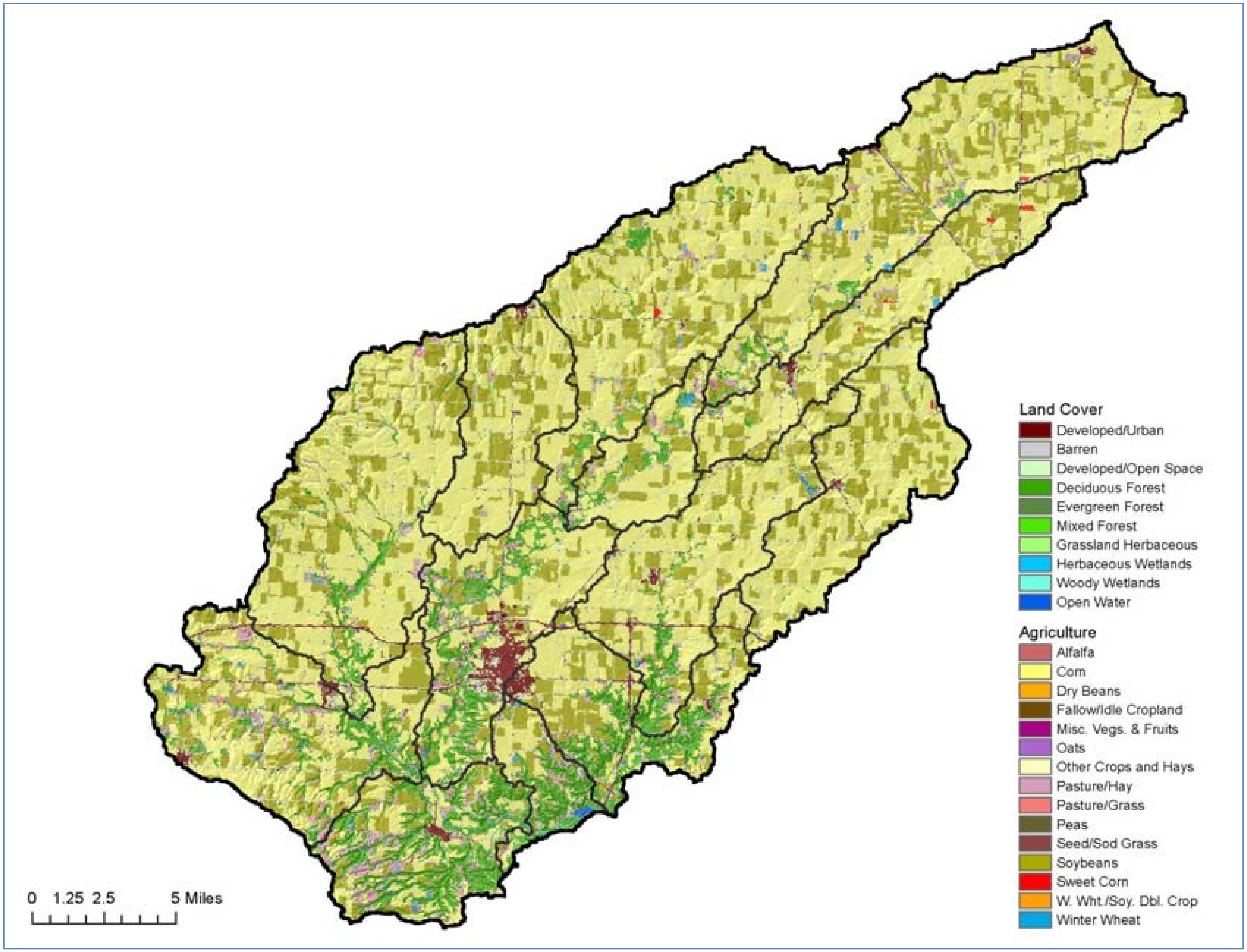

Figure A-1. Land use within the Big Bureau Creek watershed (AnnAGNPS defined boundary) (USDA NASS 2009).

Table A-1. Seasonal percent increase due to point source contribution on nutrient loads within each basin.

BASIN WITH POINT SOURCE DISCHARGE	ID	TOTAL NITROGEN				TOTAL PHOSPHORUS			
		WINTER	SPRING	SUMMER	AUTUMN	WINTER	SPRING	SUMMER	AUTUMN
Lime Creek	1	0.86%	0.26%	0.25%	0.48%	1.06%	0.34%	0.42%	0.92%
Pike Creek	4	0.39%	0.10%	0.17%	0.29%	0.49%	0.21%	0.26%	0.50%
Epperson Run – BBC	7	30.66%	9.03%	8.53%	15.73%	12.87%	4.91%	5.85%	9.79%
East Bureau Creek	9	0.40%	0.04%	0.11%	0.26%	0.42%	0.14%	0.17%	0.34%
Pond Creek	11	1.90%	0.41%	0.44%	1.00%	1.72%	0.42%	0.47%	1.18%
Rocky Run	12	2.81%	0.44%	0.87%	1.59%	3.33%	2.04%	2.37%	4.29%
Old Channel – BBC	13	2.23%	1.00%	0.97%	1.46%	3.39%	1.45%	1.87%	2.37%
OUTLET		1.74%	0.43%	0.53%	1.02%	1.20%	0.46%	0.54%	1.09%

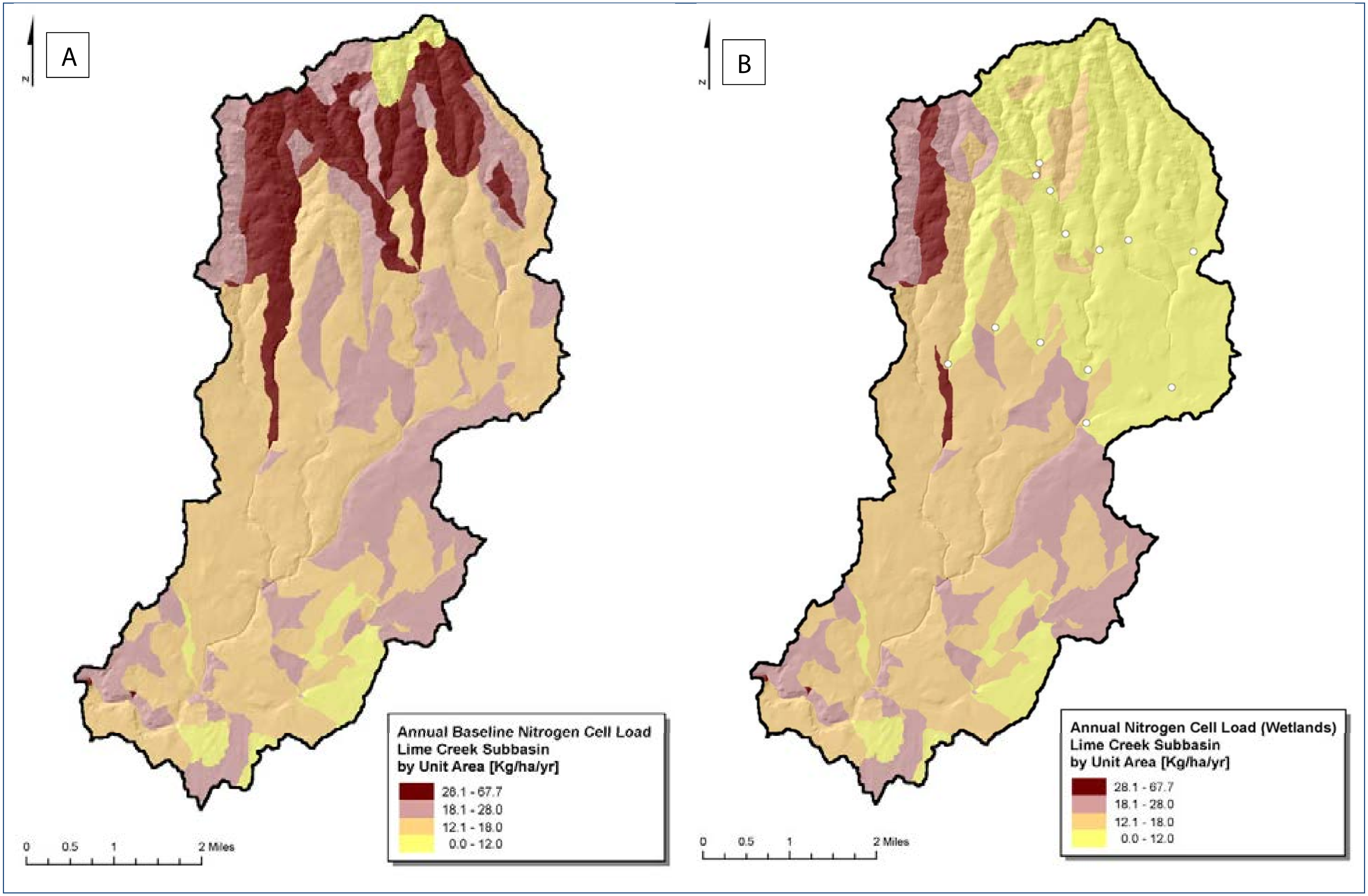

Figure A-2. Average annual nitrogen cell load delivered (kg/ha) to the outlet of Lime Creek sub-basin without (A) and with (B) the individual potential wetlands plus buffers.

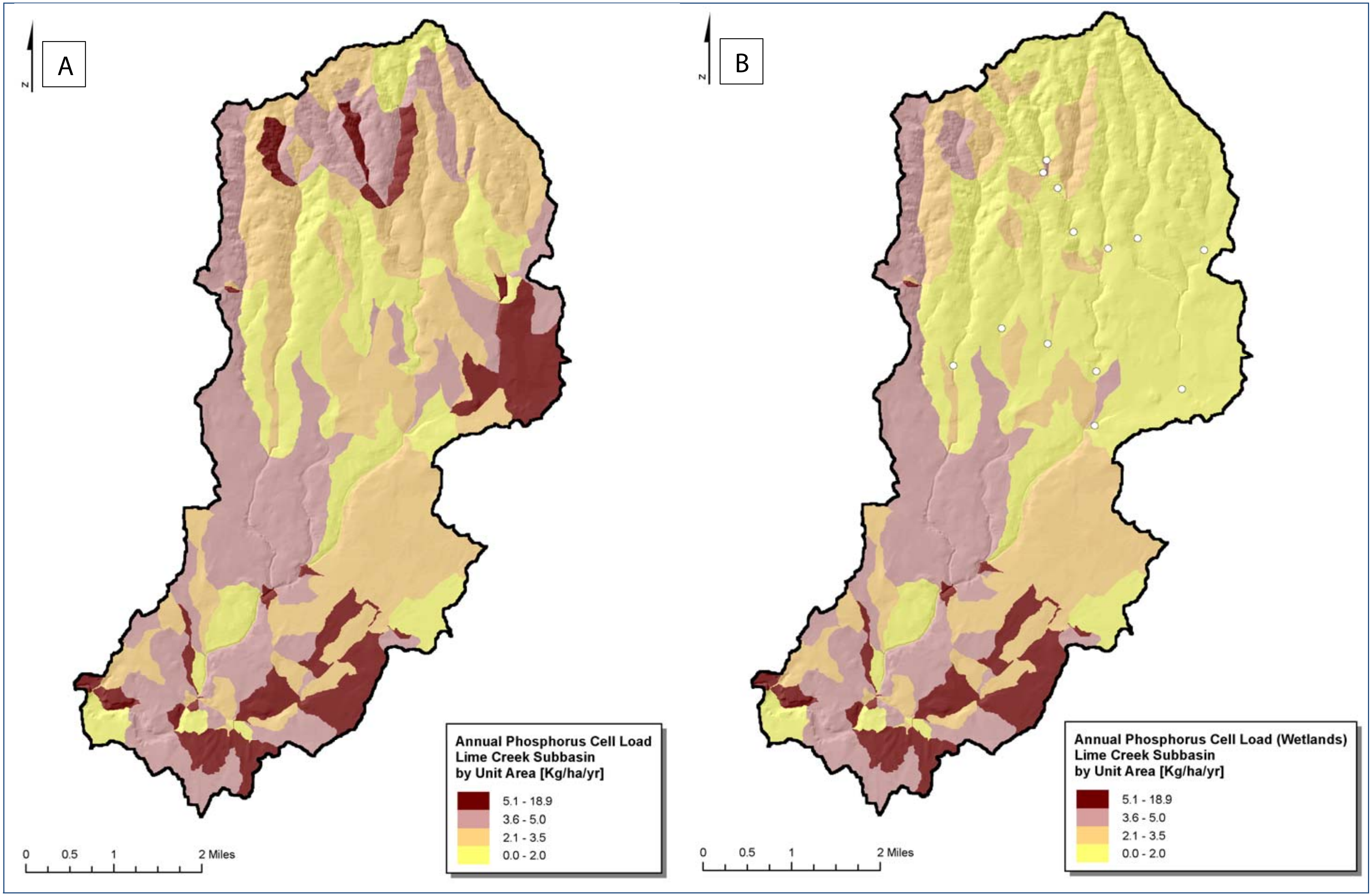

Figure A-3. Average annual phosphorus cell load delivered (kg/ha) to the outlet of Lime Creek sub-basin without (A) and with (B) the individual potential wetlands plus buffers.

Table A-2. Average annual wetland runoff and nutrient load reduction for each individual BBC basin based on the combined effect of all 80 potential sites under the wetland plus buffer scenario.

BASIN	ID	BASIN DRAINAGE AREA	WETLAND PLUS BUFFER AREA	RUNOFF REDUCTION		TN REDUCTION		TP REDUCTION	
		(ha)	(ha)	(Mg)	(%)	(kg)	(%)	(kg)	(%)
Lime Creek	1	7,011	86.33	6,797,235	29.3	50,100	36.1	6,820	29.4
West Bureau Creek	2	15,547	44.61	4,891,869	10.2	50,281	15.2	10,190	13.7
Pike Creek	4	8,325	16.67	1,240,403	4.3	7,996	3.6	1,498	4.1
Sublette – BBC	3	16,260	17.90	2,132,487	3.9	23,845	6.3	2,015	4.0
Masters Fork	6	14,796	13.56	1,709,899	3.5	26,838	9.0	1,904	4.2
Green Oak – BBC	5	3,965	13.07	1,869,218	15.0	17,052	24.8	2,520	19.8
Epperson Run – BBC	7	9,146	13.15	1,630,045	6.0	11,966	9.6	1,572	6.0
Brush Creek	8	9,336	43.75	5,286,552	17.0	60,220	25.1	8,684	20.4
East Bureau Creek	9	10,259	59.95	5,576,057	16.9	61,189	26.0	8,884	21.7
Brush Creek – BBC	10	7,443	16.04	1,237,060	5.9	11,781	8.9	1,468	6.3
Pond Creek – BBC	11	12,098	12.19	1,517,503	4.0	23,347	8.6	2,867	4.8
Rocky Run – BBC	12	7,553	1.52	1,226,802	6.3	5,008	6.8	1,251	7.0
Old Channel – BBC	13	2,813	12.39	245,381	3.4	3,023	11.4	104	2.0
TOTAL AT OUTLET		124,552	351.13	35,360,511	9.0	352,645	13.9	49,778	10.9

Table A-3. Effects of buffer, wetland, and wetland plus buffer on nitrogen and phosphorus loads at the outlet of each BBC basin (no point sources included).

BASIN	ID	BUFFER ONLY						WETLAND ONLY						WETLAND PLUS BUFFER					
		RUNOFF REDUCTION		TN REDUCTION		TP REDUCTION		RUNOFF REDUCTION		TN REDUCTION		TP REDUCTION		RUNOFF REDUCTION		TN REDUCTION		TP REDUCTION	
		(Mg)	(%)	(kg)	(%)	(kg)	(%)	(Mg)	(%)	(kg)	(%)	(kg)	(%)	(Mg)	(%)	(kg)	(%)	(kg)	(%)
LIME CK	1	-	-	6,271	4.5	1,896	8.2	6,752,282	29.2	46,308	33.5	5,642	24.4	6,752,282	29.2	49,648	35.9	6,704	29.0
W BUREAU	2	-	-	10,944	2.3	3,222	3.3	11,644,145	16.4	92,740	19.8	14,704	15.1	11,644,145	16.4	99,924	21.3	16,868	17.3
PIKE	4	-	-	485	0.2	135	0.4	1,240,403	4.4	7,848	3.5	1,455	4.0	1,240,403	4.4	7,996	3.6	1,499	4.2
SUBLETTE	3	-	-	1,612	0.4	466	0.9	2,132,288	3.9	22,383	5.9	1,585	3.2	2,132,288	3.9	23,837	6.3	2,015	4.0
MASTERS	6	-	-	1,663	0.6	487	1.1	1,709,893	3.5	25,287	8.5	1,444	3.2	1,709,893	3.5	26,838	9.0	1,904	4.2
GREEN OAK	5	-	-	2,234	0.3	636	0.6	5,241,905	5.4	47,175	7.0	5,526	5.6	5,241,905	5.4	48,884	7.3	6,033	6.1
EPPERSON	7	-	-	4,087	0.4	1,174	0.7	8,581,844	5.0	84,253	7.8	8,454	5.0	8,581,844	5.0	87,682	8.1	9,471	5.6
BRUSH	8	-	-	4,603	1.9	1,322	3.1	5,286,547	17.0	57,098	23.8	7,785	18.3	5,286,547	17.0	60,220	25.1	8,684	20.4
E BUREAU	9	-	-	5,270	2.2	1,507	3.7	5,576,044	16.9	58,468	24.9	8,084	19.8	5,576,044	16.9	61,190	6.1	8,882	21.7
BRUSH BBC	10	-	-	10,671	1.8	3,035	2.8	12,099,651	14.2	126,683	20.9	17,134	16.0	12,099,651	14.2	133,191	22.0	19,032	17.8
POND	11	-	-	14,440	2.0	4,204	2.7	13,161,632	2.1	113,060	15.3	16,722	10.7	13,161,632	12.1	123,271	16.7	19,752	12.6
ROCKY	12	-	-	18,421	1.0	5,344	1.6	22,970,260	7.7	202,365	10.7	26,453	7.7	22,970,260	7.7	215,959	11.4	30,486	8.9
OUTLET	13	-	-	29,093	1.2	8,377	1.8	35,315,293	9.0	332,056	13.2	43,687	9.6	35,315,293	9.0	352,171	13.9	49,623	10.9

Table A-4. Effects of buffer, wetland, and wetland plus buffer on nitrogen and phosphorus loads within each BBC basin (no point sources included).

BASIN	ID	BUFFER ONLY						WETLAND ONLY						WETLAND PLUS BUFFER					
		RUNOFF REDUCTION		TN REDUCTION		TP REDUCTION		RUNOFF REDUCTION		TN REDUCTION		TP REDUCTION		RUNOFF REDUCTION		TN REDUCTION		TP REDUCTION	
		(Mg)	(%)	(kg)	(%)	(kg)	(%)	(Mg)	(%)	(kg)	(%)	(kg)	(%)	(Mg)	(%)	(kg)	(%)	(kg)	(%)
LIME CK	1	-	-	6,271	4.5	1,896	8.2	6,752,282	29.2	46,308	33.5	5,642	24.4	6,752,282	29.2	49,648	35.9	6,704	29.0
W BUREAU	2	-	-	4,672	1.4	1,326	1.8	4,891,863	10.2	46,431	14.1	9,062	12.2	4,891,863	10.2	50,276	15.2	10,164	13.7
PIKE	4	-	-	485	0.2	135	0.4	1,240,403	4.4	7,848	3.5	1,455	4.0	1,240,403	4.4	7,996	3.6	1,499	4.2
SUBLETTE	3	-	-	1,612	0.4	465	0.9	2,132,288	3.9	22,383	5.9	1,585	3.2	2,132,288	3.9	23,837	6.3	2,015	4.0
MASTERS	6	-	-	1,663	0.6	486	1.1	1,709,893	3.5	25,287	8.5	1,444	3.2	1,709,893	3.5	26,838	9.0	1,904	4.2
GREEN OAK	5	-	-	137	0.2	35	0.3	1,869,214	15.0	16,944	24.7	2,486	19.5	1,869,214	15.0	17,052	24.8	2,519	19.8
EPPERSON	7	-	-	189	0.2	51	0.2	1,630,046	6.3	11,791	10.6	1,485	6.0	1,630,046	6.3	11,960	10.7	1,535	6.2
BRUSH	8	-	-	4,603	1.9	1,322	3.1	5,286,547	17.0	57,098	23.8	7,785	18.3	5,286,547	17.0	60,220	25.1	8,684	20.4
E BUREAU	9	-	-	5,270	2.2	1,507	3.7	5,576,044	16.9	58,468	24.9	8,084	19.8	5,576,044	16.9	61,190	26.1	8,882	21.7
BRUSH BBC	10	-	-	798	0.6	206	0.9	1,237,060	5.9	11,117	8.4	1,265	5.4	1,237,060	5.9	11,781	8.9	1,466	6.2
POND	11	-	-	3,497	1.3	982	1.6	1,517,486	4.0	20,320	7.5	2,018	3.4	1,517,486	4.0	23,347	8.6	2,883	4.8
ROCKY	12	-	-	-106	-0.1	-35	-0.2	1,226,785	6.4	5,052	6.9	1,277	7.3	1,226,785	6.4	5,005	6.8	1,263	7.2
OLD CHANNEL	13	-	-	1	0.0	-2	0.0	245,382	3.4	3,007	11.5	100	2.0	245,382	3.4	3,021	11.6	105	2.1
TOTAL				29,093	1.2	8,377	1.8	35,315,293	9.0	332,056	13.2	43,687	9.6	35,315,293	9.0	352,171	13.9	49,623	10.9

Table A-5. Effects of buffer only, wetland only, and wetland plus buffer on average annual nitrogen and phosphorus loads for each individual wetland (no point sources included). Highlighted wetlands are downstream of another wetland.

WETLAND ID	BUFFER ONLY						WETLAND ONLY						WETLAND PLUS BUFFER					
	RUNOFF REDUCTION		TN REDUCTION		TP REDUCTION		RUNOFF REDUCTION		TN REDUCTION		TP REDUCTION		RUNOFF REDUCTION		TN REDUCTION		TP REDUCTION	
	(Mg)	(%)	(kg)	(%)	(kg)	(%)	(Mg)	(%)	(kg)	(%)	(kg)	(%)	(Mg)	(%)	(kg)	(%)	(kg)	(%)
91	-	-	-	-	-	-	115,922	33.0	1,099	43.2	445	44.3	115,922	33.0	1,099	43.2	445	44.3
160	-	-	1,088	2.2	319	3.5	882,241	18.4	14,635	29.0	1,302	14.4	882,241	18.4	15,598	30.9	1,585	17.5
220	-	-	3	0.0	1	0.1	145,534	15.4	2,034	28.2	376	20.6	145,534	15.4	2,036	28.2	377	20.6
303	-	-	1,691	26.2	480	36.4	489,711	57.1	3,557	55.0	-	-	489,711	57.1	5,248	81.2	480	36.4
337	-	-	100	0.4	26	0.4	2,016,004	53.2	16,997	66.7	3,737	56.4	2,016,004	53.2	17,059	67.0	3,754	56.7
357	-	-	98	1.5	26	1.3	542,389	58.3	3,569	53.2	-	-	542,389	58.3	3,667	54.6	26	1.3
392	-	-	-	-	-	-	124,244	56.3	1,072	71.2	253	62.8	124,244	56.3	1,072	71.2	253	62.8
398	-	-	531	6.4	150	7.9	186,718	21.9	2,879	34.7	473	24.8	186,718	21.9	3,308	39.9	593	31.2
417	-	-	-	-	-	-	197,565	20.6	2,901	31.8	402	21.5	197,565	20.6	2,901	31.8	402	21.5
437	-	-	-	-	-	-	42,924	16.0	832	37.0	154	28.8	42,924	16.0	832	37.0	154	28.8
443	-	-	-	-	-	-	184,193	27.4	2,018	47.7	147	25.1	184,193	27.4	2,018	47.7	147	25.1
471	-	-	-	-	-	-	50,791	21.1	875	39.8	189	32.7	50,791	21.1	875	39.8	189	32.7
480	-	-	159	3.8	45	4.1	454,323	71.9	3,223	76.4	764	69.2	454,323	71.9	3,305	78.3	786	71.2
491	-	-	1,750	19.2	519	25.7	332,626	21.5	3,332	36.5	519	25.7	332,626	21.5	4,906	53.7	970	48.0
492	-	-	349	12.7	98	12.9	147,481	22.1	994	36.2	212	27.7	147,481	22.1	1,308	47.6	297	38.9
505	-	-	520	7.5	145	9.5	587,797	58.8	4,693	67.5	851	55.7	587,797	58.8	5,041	72.5	946	61.9
512	-	-	1,072	20.1	321	33.8	384,496	46.5	3,116	58.4	367	38.6	384,496	46.5	3,913	73.3	604	63.6
515	-	-	304	13.9	90	16.9	123,134	42.4	1,229	56.2	246	46.3	123,134	42.4	1,447	66.2	308	57.9
519	-	-	218	2.7	62	3.7	207,048	16.5	3,073	38.6	452	26.8	207,048	16.5	3,263	41.0	503	29.8
547	-	-	187	3.7	58	8.6	154,527	23.7	2,149	42.1	146	21.5	154,527	23.7	2,289	44.9	190	28.1
555	-	-	1,035	12.3	323	38.7	543,634	38.7	4,875	57.7	253	30.3	543,634	38.7	5,720	67.7	512	61.4
556	-	-	666	14.4	206	47.0	364,058	46.1	2,850	61.4	117	26.8	364,058	46.1	3,406	73.4	289	66.0
561	-	-	3,895	18.9	1,245	46.4	2,013,241	64.4	14,342	69.5	1,163	43.4	2,013,241	64.4	16,433	79.6	1,844	68.8
564	-	-	2,393	18.1	777	42.9	763,401	39.3	7,125	54.0	573	31.6	763,401	39.3	8,530	64.7	1,038	57.3
565	-	-	1,921	24.3	630	58.4	221,332	21.3	3,232	41.0	266	24.7	221,332	21.3	4,519	57.3	696	64.5
566	-	-	1,729	25.5	567	62.3	149,077	16.8	2,434	35.9	192	21.1	149,077	16.8	3,699	54.5	613	67.4
567	-	-	778	20.8	262	50.2	88,184	16.7	1,269	33.9	75	14.3	88,184	16.7	1,917	51.2	296	56.5
573	-	-	882	29.5	275	82.2	338,691	74.5	2,293	76.6	162	48.5	338,691	74.5	2,758	92.2	310	92.6
574	-	-	1,302	4.8	380	8.1	4,040,880	90.4	25,064	92.3	4,106	87.8	4,040,880	90.4	25,330	93.3	4,183	89.5
576	-	-	1,154	4.9	333	7.9	3,662,268	94.6	22,254	94.1	3,815	90.1	3,662,268	94.6	22,442	94.9	3,869	91.3
580	-	-	449	6.2	134	15.7	872,079	81.9	5,795	80.1	476	55.7	872,079	81.9	5,991	82.9	535	62.6
585	-	-	46	0.7	14	1.6	115,878	11.0	1,884	28.7	112	13.0	115,878	11.0	1,924	29.3	124	14.4
758	-	-	-	-	-	-	79,970	10.4	1,361	29.6	227	20.1	79,970	10.4	1,361	29.6	227	20.1
815	-	-	426	1.0	122	2.0	872,662	15.8	12,843	30.5	756	12.4	872,662	15.8	13,229	31.4	866	14.2
818	-	-	0	0.0	0	0.0	223,320	20.3	2,909	31.0	89	7.1	223,320	20.3	2,909	31.0	89	7.1
832	-	-	243	2.4	71	4.6	136,004	9.9	2,484	24.4	177	11.6	136,004	9.9	2,707	26.6	242	15.8
860	-	-	1,169	3.5	358	7.5	699,525	12.7	10,552	31.5	706	14.7	699,525	12.7	11,634	34.7	1,034	21.6
942	-	-	92	1.5	25	2.9	137,706	14.0	2,110	34.3	162	18.6	137,706	14.0	2,197	35.7	185	21.3
1076	-	-	24	1.0	7	2.9	181,033	39.1	1,384	59.2	61	26.4	181,033	39.1	1,404	60.1	67	28.7

WETLAND ID	BUFFER ONLY						WETLAND ONLY						WETLAND PLUS BUFFER					
	RUNOFF REDUCTION		TN REDUCTION		TP REDUCTION		RUNOFF REDUCTION		TN REDUCTION		TP REDUCTION		RUNOFF REDUCTION		TN REDUCTION		TP REDUCTION	
	(Mg)	(%)	(kg)	(%)	(kg)	(%)	(Mg)	(%)	(kg)	(%)	(kg)	(%)	(Mg)	(%)	(kg)	(%)	(kg)	(%)
1083	-	-	128	3.3	40	8.4	434,439	54.4	2,467	63.7	165	34.1	434,439	54.4	2,561	66.2	195	40.2
1111	-	-	228	2.3	69	6.0	1,148,634	66.0	7,508	74.8	560	48.2	1,148,634	66.0	7,666	76.4	608	2.3
1117	-	-	88	2.0	26	5.5	346,357	43.9	2,826	62.9	159	33.8	346,357	43.9	2,901	64.5	181	38.5
1130	-	-	267	3.8	84	10.8	333,895	29.2	3,583	51.0	200	25.6	333,895	29.2	3,819	54.3	273	35.0
1136	-	-	581	5.9	177	16.6	136,819	8.4	2,773	28.2	160	15.0	136,819	8.4	3,318	33.8	322	30.1
1146	-	-	450	2.8	131	5.3	364,255	15.2	5,878	36.3	562	22.9	364,255	15.2	6,296	38.9	679	27.7
1174	-	-	106	1.3	32	2.5	148,685	11.5	2,679	33.8	262	20.6	148,685	11.5	2,779	35.1	291	22.9
1496	-	-	489	5.7	145	8.6	1,240,403	90.8	7,855	91.7	1,474	87.2	1,240,403	90.8	8,003	93.4	1,519	89.8
1516	-	-	-	-	-	-	1,253,743	31.8	13,114	55.6	2,312	40.6	1,253,743	31.8	13,114	55.6	2,312	40.6
1578	-	-	1	0.1	0	0.1	448,832	66.4	1,415	74.6	237	62.0	448,832	66.4	1,415	74.6	237	62.0
1600	-	-	213	1.5	64	2.6	1,101,242	43.6	9,082	64.4	1,116	45.4	1,101,242	43.6	9,261	65.6	1,170	47.6
1669	-	-	12	0.2	3	0.2	1,110,860	79.9	4,679	75.2	1,102	67.7	1,110,860	79.9	4,684	75.3	1,103	67.8
1715	-	-	33	0.4	11	1.1	245,381	16.2	3,117	37.4	166	17.3	245,381	16.2	3,147	37.8	176	18.3
1730	-	-	528	17.7	165	41.1	82,865	18.2	1,329	44.6	112	28.0	82,865	18.2	1,803	60.5	250	62.3
1731	-	-	82	1.8	26	5.6	500,085	70.1	3,598	81.1	284	60.0	500,085	70.1	3,651	82.3	301	63.6
1815	-	-	177	2.8	55	7.3	519,499	46.9	4,247	67.0	339	45.0	519,499	46.9	4,389	69.2	382	50.7
1821	-	-	241	12.9	80	76.3	57,554	19.4	814	43.6	15	13.9	57,554	19.4	1,031	55.3	86	82.5
1846	-	-	88	1.9	26	3.1	517,103	59.4	3,567	75.1	502	59.8	517,103	59.4	3,631	76.4	521	62.1
1904	-	-	371	28.6	111	77.2	149,832	60.1	952	73.5	65	45.3	149,832	60.1	1,170	90.2	131	90.9
1906	-	-	275	3.2	80	5.4	143,755	12.8	2,533	29.1	302	20.6	143,755	12.8	2,775	31.9	371	25.3
1919	-	-	3,392	6.6	989	10.6	2,679,616	46.7	29,002	56.8	4,775	51.1	2,679,616	46.7	30,159	59.1	5,096	54.6
1924	-	-	2,640	8.5	775	14.1	2,145,167	65.1	21,429	69.0	3,692	66.9	2,145,167	65.1	21,917	70.5	3,834	69.5
1926	-	-	2,504	14.4	729	23.3	1,835,133	94.4	15,128	87.0	1,566	50.0	1,835,133	94.4	16,618	95.5	1,994	63.7
1928	-	-	1,491	12.7	442	23.7	1,131,238	89.5	10,622	90.5	1,568	84.1	1,131,238	89.5	11,099	94.5	1,709	91.6
1960	-	-	478	2.1	146	3.5	1,145,042	37.9	12,826	55.4	1,675	40.5	1,145,042	37.9	13,238	57.2	1,799	43.5
1987	-	-	278	4.5	89	8.6	257,032	28.7	3,053	49.4	358	34.5	257,032	28.7	3,297	53.3	435	41.9
1991	-	-	34	1.0	10	2.1	106,611	26.4	1,431	42.7	146	29.8	106,611	26.4	1,462	43.7	155	31.7
2022	-	-	265	3.7	75	5.7	618,964	78.7	5,528	77.9	892	67.2	618,964	78.7	5,668	79.8	931	70.2
2037	-	-	-	-	-	-	35,145	15.7	712	31.4	183	32.1	35,145	15.7	712	31.4	183	32.1
2063	-	-	587	22.8	179	41.8	117,425	47.7	1,416	55.0	209	48.8	117,425	47.7	1,857	72.2	333	77.8
2065	-	-	1,110	4.7	320	6.4	897,021	33.1	10,906	46.1	1,777	35.7	897,021	33.1	11,890	50.2	2,059	41.4
2095	-	-	143	4.3	42	5.8	196,187	39.3	1,867	55.8	301	41.5	196,187	39.3	1,974	59.0	332	45.8
2108	-	-	452	10.8	135	15.6	193,225	30.4	2,039	48.5	323	37.4	193,225	30.4	2,403	57.2	429	49.6
2111	-	-	190	4.8	57	8.0	72,062	15.0	1,158	29.6	180	25.3	72,062	15.0	1,327	33.9	228	32.1
2114	-	-	157	0.8	50	1.7	775,254	34.0	9,676	47.8	969	33.5	775,254	34.0	9,814	48.5	1,013	35.0
2130	-	-	295	1.0	87	1.7	1,446,659	45.2	16,584	54.7	2,212	42.3	1,446,659	45.2	16,821	55.5	2,280	43.6
2139	-	-	-	-	-	-	75,110	15.6	1,335	30.1	233	26.7	75,110	15.6	1,335	30.1	233	26.7
2142	-	-	136	1.4	41	2.6	172,769	17.2	2,913	30.6	392	24.2	172,769	17.2	3,037	31.9	427	26.4
2150	-	-	1,732	9.8	516	15.8	1,588,714	70.0	13,549	76.6	2,112	64.5	1,588,714	70.0	14,231	80.4	2,309	70.5
2151	-	-	-	-	-	-	184,618	36.0	2,167	52.0	466	44.5	184,618	36.0	2,167	52.0	466	44.5
2154	-	-	1,616	26.0	479	52.2	676,905	84.3	5,321	85.5	681	74.2	676,905	84.3	5,935	95.4	860	93.7

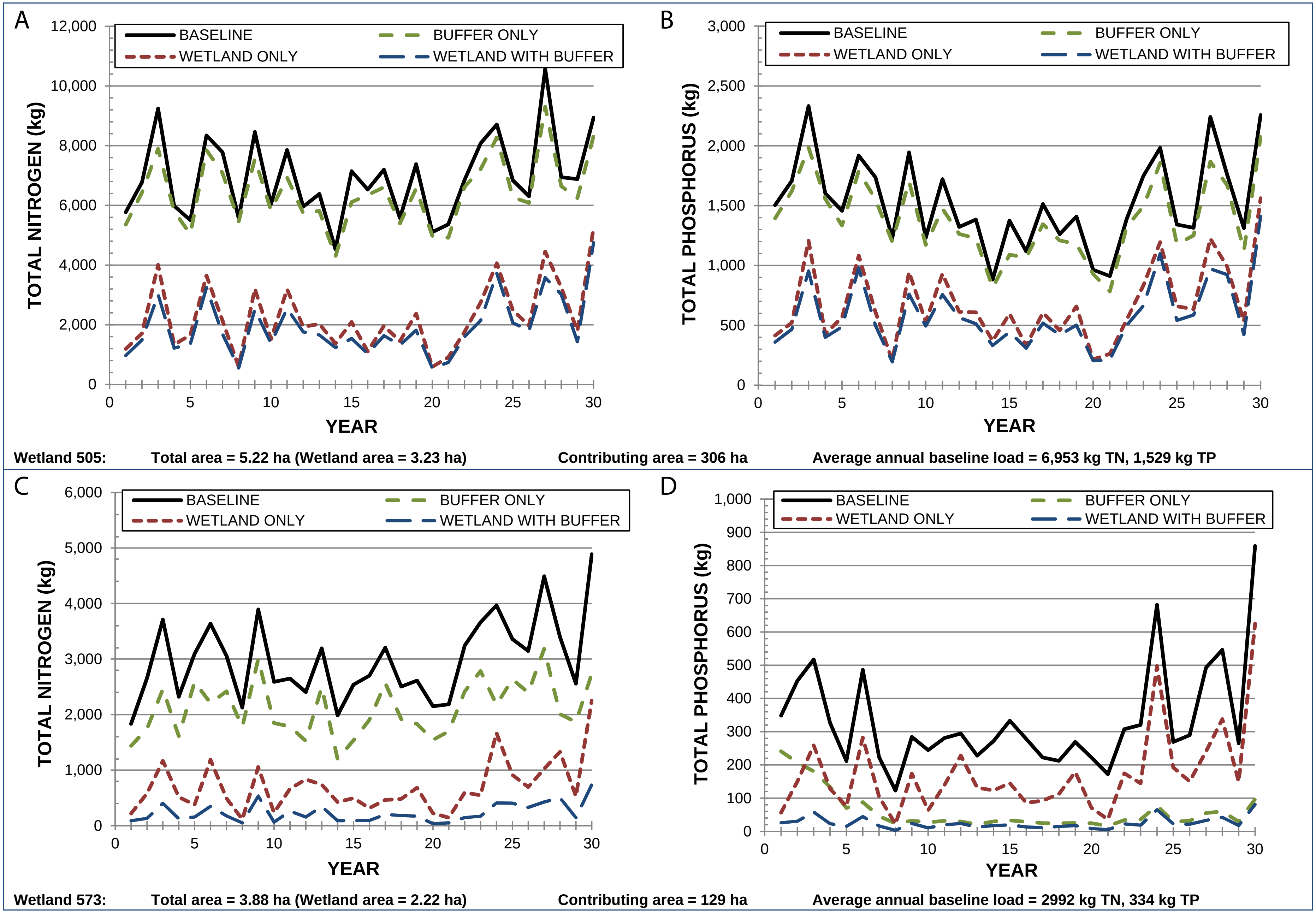

Figure A-4. Effects of buffer only, wetland only, and wetland + buffer on TN & TP loads for wetland 505 (graphs A & B) and wetland 573 (graphs C & D).

Table A-6. Wetland to watershed contributing area ratio (W:W) with average annual nutrient load reduction and rate for each independent wetland plus buffer potential site.

WETLAND ID	BASIN	WETLAND PLUS BUFFER	WETLAND	WATERSHED AREA	W:W Ratio	AHL	TOTAL NITROGEN REDUCTION			TOTAL PHOSPHORUS REDUCTION		
		(ha)	(ha)	(ha)		(m/yr)	(kg)	(%)	(kg/ha)	(kg)	(%)	(kg/ha)
566	1	0.71	0.23	238	0.10	385	3,699	54.5	5,183	613	67.4	859
565	1	1.08	0.30	282	0.11	347	1,906	4.2	1,767	140	13.0	130
758	7	0.81	0.30	268	0.11	257	1,361	29.6	1,671	227	20.1	279
1136	3	1.19	0.48	450	0.11	339	3,325	33.8	2,784	322	0.1	270
815	6	4.04	1.95	1,545	0.13	282	10,019	23.8	2,483	607	10.0	151
832	6	1.17	0.49	389	0.13	280	2,707	26.6	2,320	242	15.8	208
1919	9	4.05	2.11	1,642	0.13	272	30,159	59.1	7,455	5,096	54.6	1,260
1924	9	2.46	1.22	922	0.13	270	6,872	22.1	2,788	1,110	20.1	450
585	1	1.07	0.43	308	0.14	245	1,924	29.3	1,790	124	14.4	116
1174	3	1.40	0.55	378	0.14	235	2,779	35.1	1,981	291	22.9	208
491	2	2.03	0.71	491	0.15	218	3,893	42.7	1,921	747	36.9	369
860	6	5.27	2.63	1,798	0.15	210	11,634	34.7	2,207	1,034	21.6	196
574	1	3.81	2.10	1,350	0.16	213	13,802	50.8	3,626	1,518	32.5	399
1906	9	1.25	0.53	325	0.16	212	2,775	31.9	2,220	371	25.3	296
220	11	1.34	0.57	297	0.19	166	2,036	28.2	1,525	377	20.6	282
555	1	1.52	0.75	398	0.19	187	5,720	67.7	3,769	512	61.4	338
942	6	1.31	0.51	273	0.19	192	2,197	35.7	1,675	185	21.3	141
519	2	1.89	0.80	393	0.20	157	3,263	41.0	1,724	503	29.8	266
1146	3	2.63	1.38	703	0.20	174	6,296	8.9	2,397	679	27.7	259
2037	10	0.54	0.14	71	0.20	160	712	31.4	1,326	183	32.1	340
2111	8	0.90	0.27	138	0.20	178	1,327	33.9	1,481	228	32.1	255
2139	8	0.82	0.29	143	0.20	166	1,335	30.1	1,637	233	26.7	286
437	2	0.60	0.17	84	0.21	158	832	37.0	1,383	154	28.8	256
1715	10	1.85	0.93	449	0.21	163	3,147	37.8	1,699	176	18.3	95
567	1	0.87	0.33	145	0.23	160	1,917	51.2	2,208	296	56.5	341
160	11	6.34	3.33	1,365	0.24	144	15,598	30.9	2,462	1,585	17.5	250
2142	8	1.48	0.64	271	0.24	157	3,037	31.9	2,050	427	26.4	288
492	2	1.48	0.59	236	0.25	113	1,308	47.6	884	297	38.9	201
1730	10	0.79	0.33	131	0.25	138	1,803	60.5	2,272	250	62.3	315
398	2	2.28	0.75	267	0.28	114	3,308	39.9	1,449	593	31.2	260
417	2	1.64	0.72	256	0.28	133	2,901	31.8	1,768	402	21.5	245
1821	9	0.66	0.22	79	0.28	135	1,031	55.3	1,555	86	82.5	130
471	2	0.60	0.21	75	0.29	114	875	39.8	1,466	189	32.7	316
818	6	1.77	0.86	288	0.30	128	2,909	31.0	1,639	89	7.1	50
547	1	1.67	0.61	173	0.35	107	2,289	44.9	1,367	190	28.1	114
443	2	1.88	0.79	205	0.38	85	2,018	47.7	1,073	147	25.1	78
1991	9	1.10	0.43	111	0.39	94	1,462	43.7	1,323	155	31.7	140
91	12	1.52	0.54	136	0.40	65	1,099	43.2	724	445	44.3	293
1987	9	2.19	1.08	268	0.40	83	3,297	53.3	1,508	435	41.9	199
1516	5	7.42	5.65	1,346	0.42	70	13,114	55.6	1,767	2,312	40.6	311
2108	8	1.76	0.82	193	0.42	77	2,403	57.2	1,364	429	49.6	243
1130	3	2.58	1.37	319	0.43	83	3,819	54.3	1,481	273	35.0	106
564	1	4.48	2.53	539	0.47	79	6,586	48.2	1,470	531	27.8	119
2065	8	6.22	3.91	811	0.48	69	11,890	50.2	1,910	2,059	41.4	331

WETLAND ID	BASIN	WETLAND PLUS BUFFER	WETLAND	WATERSHED AREA	W:W Ratio	AHL	TOTAL NITROGEN REDUCTION			TOTAL PHOSPHORUS REDUCTION		
		(ha)	(ha)	(ha)		(m/yr)	(kg)	(%)	(kg/ha)	(kg)	(%)	(kg/ha)
2114	8	4.97	3.27	619	0.53	70	9,814	48.5	1,975	1,013	35.0	204
2151	8	1.61	0.83	156	0.53	62	2,167	52.0	1,345	466	44.5	289
1960	9	8.87	5.12	898	0.57	59	13,238	57.2	1,492	1,799	43.5	203
337	2	9.94	7.59	1,318	0.58	50	15,044	59.1	1,514	3,092	46.7	311
2095	8	1.91	0.99	171	0.58	50	1,974	59.0	1,034	332	45.8	174
1076	5	1.72	0.83	139	0.60	56	1,404	60.1	815	67	28.7	39
2130	8	8.56	5.83	899	0.65	55	15,573	51.4	1,818	2,063	39.5	241
2150	8	6.13	4.30	659	0.65	53	10,250	57.9	1,672	1,352	41.3	220
515	2	1.99	0.59	89	0.66	49	1,447	66.2	728	308	57.9	155
1600	7	7.88	5.30	787	0.67	48	9,261	65.6	1,175	1,170	47.6	148
561	1	8.77	6.00	878	0.68	53	11,576	54.8	1,319	787	28.3	90
1117	3	2.69	1.60	224	0.71	49	2,901	64.5	1,077	181	38.5	67
1815	9	4.44	2.49	325	0.77	44	4,389	69.2	989	382	50.7	86
512	2	3.42	1.81	235	0.80	46	3,913	73.3	1,143	604	63.6	177
556	1	2.86	1.72	226	0.80	46	3,406	73.4	1,191	289	66.0	101
2063	8	1.26	0.56	67	0.80	44	1,857	72.2	1,473	333	77.8	264
1083	5	3.93	2.22	234	0.95	36	2,561	66.2	652	195	40.2	50
357	2	4.71	3.23	338	0.96	29	3,667	54.6	779	26	1.3	5
303	11	4.52	2.71	277	1.00	32	5,248	81.2	1,161	480	36.4	106
392	2	1.58	0.72	73	1.00	31	1,072	71.2	679	253	62.8	160
1111	3	7.41	5.16	502	1.03	34	7,055	70.3	952	506	43.6	68
505	2	5.22	3.23	306	1.10	31	5,041	72.5	965	946	61.9	181
1846	9	5.01	2.89	266	1.10	30	3,631	76.4	725	521	62.1	104
1904	9	1.78	0.88	78	1.10	28	1,170	90.2	659	131	90.9	74
1669	13	12.39	9.18	742	1.20	15	4,684	75.3	378	1,103	67.8	89
1578	7	4.45	2.77	212	1.30	24	1,415	74.6	318	237	62.0	53
480	2	5.35	3.19	211	1.50	20	3,305	78.3	618	786	71.2	147
1731	10	6.16	3.06	200	1.50	23	3,651	82.3	593	301	63.6	49
573	1	3.88	2.22	129	1.70	20	2,758	92.2	711	310	92.6	80
2022	10	7.06	4.49	237	1.90	18	5,668	79.8	802	931	70.2	132
1926	9	14.61	11.04	552	2.00	18	13,861	79.7	949	366	11.7	25
580	1	9.14	6.43	295	2.20	17	5,991	82.9	655	535	62.6	59
2154	8	8.13	5.37	2 22.6	2.37	15	5,935	95.4	730	860	93.7	106
1928	9	13.54	10.06	346	2.90	13	11,099	94.5	820	1,709	91.6	126
1496	4	16.66	13.01	436	3.00	10	8,003	93.4	480	1,519	9.8	91
576	1	46.46	38.65	1,177	3.30	10	22,413	94.8	482	3,858	91.1	83

Table A-7. Average annual baseline nutrient load and reduction for each independent wetland site with standard deviation (for 30-year simulation period).

WETLAND ID	BASELINE						WETLAND WITH BUFFER									
	RUNOFF (Mg)		TN (kg)		TP (kg)		RUNOFF (Mg)		TN (kg)		TN REDUCTION (kg)		TP (kg)		TP REDUCTION (kg)	
	AVG.	ST. DEV.	AVG.	ST. DEV.	AVG.	ST. DEV.	AVG.	ST. DEV.	AVG.	ST. DEV.	AVG.	ST. DEV.	AVG.	ST. DEV.	AVG.	ST. DEV.
91	350,781	131,321	2,544	1,034	1,004	298	234,859	118,479	1,445	756	1,099	1,281	559	217	445	369
160	4,781,976	1,514,949	50,508	21,462	9,067	4,091	3,899,727	1,427,879	34,909	17,200	15,598	27,504	7,482	3,691	1,585	5,510
220	945,133	333,165	7,215	2,955	1,825	679	799,598	317,038	5,179	2,406	2,036	3,811	1,448	614	377	915
303	857,334	322,418	6,465	1,404	1,319	375	367,623	230,215	1,217	648	5,248	1,546	840	265	480	459
337	3,791,327	1,505,933	25,474	6,675	6,626	1,683	2,190,572	1,239,930	10,430	4,943	15,044	8,306	3,534	1,509	3,092	2,260
357	930,434	387,496	6,711	2,166	1,994	558	388,044	274,492	3,044	1,517	3,667	2,644	1,969	546	26	781
392	220,870	88,917	1,505	566	403	113	96,626	63,587	433	269	1,072	627	150	79	253	138
398	854,157	300,734	8,296	2,364	1,903	610	667,438	279,440	4,987	1,900	3,308	3,033	1,310	519	593	801
417	957,639	293,574	9,115	2,329	1,872	611	760,073	273,431	6,214	2,133	2,901	3,158	1,469	578	402	841
437	268,213	100,941	2,248	967	535	202	225,288	94,767	1,416	688	832	1,187	381	161	154	258
443	673,284	241,329	4,234	1,561	587	283	489,091	215,460	2,216	1,021	2,018	1,865	440	222	147	360
471	240,302	90,654	2,196	961	578	212	189,511	83,185	1,321	673	875	1,173	389	168	189	270
480	632,227	254,500	4,218	1,647	1,104	340	177,904	146,910	914	641	3,305	1,767	317	196	786	392
491	1,547,394	490,885	9,127	2,125	2,023	562	1,352,000	473,008	5,234	1,389	3,893	2,539	1,276	355	747	665
492	667,232	221,290	2,745	672	764	199	519,750	206,524	1,437	501	1,308	838	467	144	297	246
505	999,301	341,940	6,953	1,383	1,529	382	411,505	247,045	1,912	994	5,041	1,703	583	286	946	477
512	827,746	233,259	5,337	1,785	950	411	443,250	192,288	1,424	683	3,913	1,911	346	166	604	443
515	290,211	99,456	2,187	638	532	146	167,076	82,512	740	373	1,447	739	224	96	308	175
519	1,256,083	427,537	7,962	1,562	1,688	400	1,049,034	405,599	4,699	1,336	3,263	2,055	1,184	335	503	522
547	651,698	190,825	5,101	1,947	679	514	497,169	177,189	2,812	1,424	2,289	2,412	488	384	190	642
555	1,404,590	453,332	8,450	2,033	835	328	860,954	384,937	2,730	1,346	5,720	2,438	323	151	512	361
556	789,816	259,492	4,639	1,061	438	184	425,758	210,936	1,233	616	3,406	1,227	149	79	289	200
561	3,178,218	965,838	21,127	5,556	2,779	1,391	1,814,218	817,942	9,552	4,818	11,576	7,354	1,992	1,275	787	1,887
564	1,994,285	578,233	13,673	4,070	1,911	1,071	1,348,905	523,473	7,088	3,430	6,586	5,323	1,380	931	531	1,419
565	1,039,933	314,122	7,891	2,453	1,078	659	954,290	307,404	5,985	2,239	1,906	3,321	938	591	140	885
566	886,001	264,317	6,781	2,277	911	607	736,922	251,384	3,082	1,077	3,699	2,519	297	154	613	626
567	526,786	159,289	3,744	1,155	523	309	438,601	151,407	1,827	615	1,917	1,309	227	106	296	327
573	454,697	147,763	2,992	742	334	158	116,006	83,483	234	172	2,758	762	25	18	310	159
574	4,471,621	1,554,287	27,159	6,884	4,675	1,334	3,056,381	1,311,122	13,357	5,282	13,802	8,677	3,157	1,101	1,518	1,730
576	3,869,384	1,360,847	23,638	5,992	4,236	1,231	209,923	329,431	1,225	1,723	22,413	6,235	378	571	3,858	1,357
580	1,065,277	328,327	7,231	2,023	855	506	193,198	161,030	1,240	1,214	5,991	2,359	319	363	535	623
585	1,053,764	358,187	6,564	1,845	863	330	937,886	346,391	4,640	1,599	1,924	2,441	738	304	124	449
758	769,794	304,795	4,605	1,346	1,128	300	689,822	296,357	3,243	1,185	1,361	1,793	901	257	227	395
815	5,506,759	1,767,708	42,150	11,371	6,083	2,449	4,963,690	1,719,268	32,130	10,862	10,019	15,725	5,476	2,404	607	3,432
818	1,099,627	330,241	9,387	3,478	1,245	921	876,304	310,416	6,478	3,189	2,909	4,719	1,156	902	89	1289
832	1,374,051	445,964	10,165	2,779	1,530	565	1,238,046	433,590	7,458	2,550	2,707	3,772	1,288	515	242	764
860	5,522,528	1,795,524	33,503	8,486	4,793	1,618	4,823,002	1,729,459	21,868	7,168	11,634	11,108	3,759	1,406	1,034	2,144
942	981,425	289,814	6,153	1,592	870	284	843,719	279,333	3,956	1,474	2,197	2,170	685	243	185	374
1076	462,444	158,527	2,337	703	233	106	281,411	133,710	933	435	1,404	827	166	83	67	135

WETLAND ID	BASELINE						WETLAND WITH BUFFER									
	RUNOFF (Mg)		TN (kg)		TP (kg)		RUNOFF (Mg)		TN (kg)		TN REDUCTION (kg)		TP (kg)		TP REDUCTION (kg)	
	AVG.	ST. DEV.	AVG.	ST. DEV.	AVG.	ST. DEV.	AVG.	ST. DEV.	AVG.	ST. DEV.	AVG.	ST. DEV.	AVG.	ST. DEV.	AVG.	ST. DEV.
1083	798,284	245,773	3,870	947	484	181	363,845	187,970	1,309	651	2,561	1,149	289	156	195	239
1111	1,739,949	561,487	10,039	2,297	1,162	441	756,945	416,930	2,985	1,502	7,055	2,744	656	327	506	549
1117	788,638	245,087	4,495	1,031	471	196	442,281	204,158	1,594	735	2,901	1,266	290	131	181	236
1130	1,142,683	346,314	7,027	1,977	780	317	808,787	313,305	3,208	1,486	3,819	2,473	507	229	273	391
1136	1,629,274	477,660	9,827	2,710	1,069	459	1,492,258	467,718	6,501	2,252	3,325	3,524	747	334	322	568
1146	2,402,457	791,788	16,172	6,978	2,453	687	2,038,202	756,721	9,876	5,267	6,296	8,743	1,774	542	679	875
1174	1,291,686	424,363	7,916	2,782	1,273	335	1,143,000	410,559	5,137	2,129	2,779	3,503	982	276	291	434
1496	1,365,810	516,086	8,568	2,830	1,691	441	125,406	164,293	565	592	8,003	2,891	173	178	1,519	476
1516	3,947,076	1,568,354	23,584	7,113	5,692	1,440	2,693,331	1,377,977	10,470	4,652	13,114	8,499	3,381	1,203	2,312	1,876
1578	675,531	196,598	1,896	504	382	122	226,699	130,407	481	258	1,415	566	145	73	237	142
1600	2,528,245	913,524	14,110	3,384	2,459	655	1,427,003	746,616	4,849	2,248	9,261	4,063	1,290	531	1,170	843
1669	1,390,499	457,782	6,218	1,963	1,626	496	279,637	249,751	1,534	1,084	4,684	2,242	523	352	1,103	608
1715	1,511,300	495,962	8,337	2,009	962	324	1,265,919	472,103	5,190	1,858	3,147	2,736	786	294	176	438
1730	455,448	149,529	2,982	1,155	401	178	372,583	140,015	1,179	649	1,803	1,325	151	96	250	202
1731	713,470	226,621	4,438	1,559	473	217	213,384	133,780	787	725	3,651	1,719	172	130	301	253
1815	1,107,974	371,005	6,340	1,587	753	233	588,475	298,040	1,951	1,064	4,389	1,911	371	168	382	287
1821	296,933	87,271	1,865	766	104	74	239,378	81,964	834	523	1,031	928	18	20	86	77
1846	870,435	305,453	4,753	1,303	839	210	353,333	215,905	1,122	615	3,631	1,441	318	148	521	257
1904	249,402	92,667	1,296	560	144	87	99,570	63,369	127	80	1,170	566	13	11	131	88
1906	1,124,921	390,378	8,691	3,809	1,464	410	981,166	375,362	5,916	3,272	2,775	5,021	1,094	364	371	548
1919	5,734,172	2,023,474	51,040	24,090	9,337	2,346	3,054,555	1,357,559	20,881	12,212	30,159	27,009	4,242	1,633	5,096	2,858
1924	3,295,139	1,164,328	31,077	15,136	5,516	1,392	2,957,689	1,129,993	24,205	13,357	6,872	20,187	4,406	1,328	1,110	1,924
1926	1,943,836	696,506	17,396	8,364	3,132	758	399,479	351,319	3,535	2,238	13,861	8,658	2,766	609	366	972
1928	1,263,547	438,050	11,742	6,185	1,865	531	132,309	157,077	643	743	11,099	6,229	156	171	1,709	558
1960	3,019,313	1,081,114	23,151	8,669	4,133	1,009	1,874,264	920,778	9,913	5,394	13,238	10,210	2,334	909	1,799	1,358
1987	897,101	322,564	6,186	2,562	1,038	271	640,068	287,552	2,889	1,661	3,297	3,053	604	214	435	345
1991	404,474	134,548	3,348	1,367	488	159	297,862	1,556,084	1,886	9,875	1,462	9,969	333	1,741	155	1,748
2022	786,071	287,261	7,098	2,846	1,327	359	167,107	145,258	1,431	1,054	5,668	3,035	395	260	931	443
2037	223,450	89,616	2,270	1,484	569	196	188,305	84,245	1,558	1,237	712	1,932	387	155	183	250
2063	246,157	85,409	2,573	1,301	427	116	128,732	68,336	716	628	1,857	1,445	95	38	333	122
2065	2,714,092	1,001,644	23,661	12,258	4,974	1,262	1,817,070	871,620	11,771	8,181	11,890	14,737	2,915	1,056	2,059	1,646
2095	498,780	206,602	3,348	1,436	726	273	302,593	170,498	1,374	800	1,974	1,644	393	195	332	335
2108	635,424	215,088	4,202	1,807	865	231	442,199	191,793	1,799	989	2,403	2,060	436	143	429	272
2111	479,340	162,813	3,914	1,850	712	180	407,278	155,510	2,587	1,465	1,327	2,360	484	146	228	232
2114	2,277,171	754,790	20,243	8,592	2,889	903	1,501,913	662,754	10,429	5,765	9,814	10,347	1,877	868	1,013	1253
2130	3,198,745	1,127,177	30,309	13,702	5,225	1,517	1,896,608	949,958	14,737	8,512	15,573	16,131	3,162	1,519	2,063	2,147
2139	482,034	177,211	4,432	2,053	874	221	406,924	168,921	3,097	1,656	1,335	2,638	641	205	233	301
2142	1,006,237	349,228	9,522	4,214	1,619	515	833,468	330,047	6,486	3,419	3,037	5,427	1,192	488	427	709
2150	2,269,326	774,599	17,691	6,848	3,276	955	1,327,734	643,071	7,441	4,674	10,250	8,291	1,925	952	1,352	1,348
2151	513,243	188,693	4,164	2,080	1,048	258	328,625	161,503	1,996	1,322	2,167	2,465	582	250	466	359
2154	803,183	256,479	6,222	2,847	918	431	126,278	102,153	287	478	5,935	2,887	58	47	860	434

Table A-8. Composition of nutrient load reductions for each independent wetland plus buffer potential site.

WETLAND ID	NITROGEN REDUCTION (kg)					PHOSPHORUS REDUCTION (kg)						
	TOTAL	ATT.	%	DISS.	%	TOTAL	ATT. INORG.	%	ORGAN.	%	DISS. INORG.	%
91	1,099	301	27.4	798	72.6	445	314	70.5	52	11.8	78.83	17.7
160	15,598	3,291	21.1	12,307	78.9	1,585	750	47.3	646	40.8	188.74	11.9
220	2,036	435	21.4	1,602	78.6	377	238	63.2	79	21.0	59.64	15.8
303	5,248	1,691	32.2	3,557	67.8	480	455	95.0	310	64.7	(286.07)	(59.6)
337	15,044	1,253	8.3	13,791	91.7	3,092	2,290	74.1	228	7.4	573.07	18.5
357	3,667	98	2.7	3,569	97.3	26	370	1438	17	65.7	(361.29)	(1401)
392	1,072	177	16.5	896	83.5	253	177	70.1	31	12.4	44.29	17.5
398	3,308	1,068	32.3	2,241	67.7	593	317	53.5	197	33.1	79.41	13.4
417	2,901	560	19.3	2,340	80.7	402	236	58.6	107	26.7	59.07	14.7
437	832	198	23.8	634	76.2	154	95	61.7	35	22.9	23.83	15.5
443	2,018	331	16.4	1,687	83.6	147	70	47.4	60	40.7	17.49	11.9
471	875	220	25.1	655	74.9	189	120	63.4	39	20.7	29.97	15.9
480	3,305	794	24.0	2,511	76.0	786	516	65.7	141	17.9	129.30	16.4
491	3,893	1,503	38.6	2,390	61.4	747	357	47.8	300	40.2	89.69	12.0
492	1,308	402	30.7	906	69.3	297	178	59.9	74	25.0	44.78	15.1
505	5,041	977	19.4	4,064	80.6	946	615	65.0	177	18.7	154.19	16.3
512	3,913	1,221	31.2	2,692	68.8	604	287	47.5	246	40.7	71.88	11.9
515	1,447	444	30.7	1,003	69.3	308	180	58.5	83	26.9	45.16	14.7
519	3,263	353	10.8	2,910	89.2	503	351	69.8	63	12.6	88.50	17.6
547	2,289	558	24.4	1,731	75.6	190	59	31.1	116	61.1	14.84	7.8
555	5,720	1,116	19.5	4,604	80.5	512	235	45.8	219	42.7	58.85	11.5
556	3,406	726	21.3	2,680	78.7	289	119	41.1	141	48.6	29.78	10.3
561	11,576	1,489	12.9	10,087	87.1	787	329	41.8	296	37.6	161.81	20.6
564	6,586	1,088	16.5	5,497	83.5	531	186	35.0	219	41.2	126.03	23.7
565	1,906	385	20.2	1,521	79.8	140	48	34.1	80	57.4	11.91	8.5
566	3,699	1,814	49.0	1,885	51.0	613	181	29.6	386	63.0	45.36	7.4
567	1,917	844	44.0	1,073	56.0	296	88	29.9	185	62.7	22.07	7.5
573	2,758	914	33.1	1,844	66.9	310	105	33.8	179	57.8	26.20	8.5
574	13,802	1,976	14.3	11,826	85.7	1,518	905	59.6	387	25.5	226.28	14.9
576	22,413	5,342	23.8	17,071	76.2	3,858	2,271	58.9	1,019	26.4	568.43	14.7
580	5,991	1,510	25.2	4,481	74.8	535	189	35.4	299	55.8	47.33	8.8
585	1,924	225	11.7	1,699	88.3	124	66	53.3	42	33.4	16.58	13.3
758	1,361	95	7.0	1,266	93.0	227	168	74.0	17	7.5	42.10	18.6
815	10,019	918	9.2	9,102	90.8	607	346	56.9	175	28.8	86.63	14.3
818	2,909	197	6.8	2,712	93.2	89	39	43.8	40	45.3	9.75	11.0
832	2,707	514	19.0	2,193	81.0	242	115	47.4	99	40.7	28.84	11.9
860	11,634	1,740	15.0	9,894	85.0	1,034	557	53.9	336	32.5	139.89	13.5
942	2,197	149	6.8	2,048	93.2	185	126	68.2	27	14.6	31.86	17.2
1076	1,404	118	8.4	1,286	91.6	67	36	54.1	22	32.2	9.12	13.7
1083	2,561	357	14.0	2,204	86.0	195	101	51.9	68	35.1	25.30	13.0
1111	7,055	661	9.4	6,393	90.6	506	305	60.3	124	24.6	76.46	15.1
1117	2,901	216	7.4	2,685	92.6	181	112	61.8	41	22.6	28.14	15.5
1130	3,819	377	9.9	3,442	90.1	273	159	58.2	74	27.2	39.86	14.6
1136	3,325	617	18.6	2,708	81.4	322	160	49.5	122	38.0	40.20	12.5
1146	6,296	605	9.6	5,690	90.4	679	453	66.7	113	16.6	113.67	16.7

WETLAND ID	NITROGEN REDUCTION (kg)					PHOSPHORUS REDUCTION (kg)						
	TOTAL	ATT.	%	DISS.	%	TOTAL	ATT. INORG.	%	ORGAN.	%	DISS. INORG.	%
1174	2,779	155	5.6	2,624	94.4	291	209	71.7	30	10.4	52.40	18.0
1496	8,003	1,559	19.5	6,444	80.5	1,519	985	64.9	287	18.9	246.76	16.2
1516	13,114	728	5.6	12,386	94.4	2,312	1,744	75.4	131	5.7	436.27	18.9
1578	1,415	153	10.8	1,262	89.2	237	167	70.4	28	12.0	41.85	17.7
1600	9,261	647	7.0	8,613	93.0	1,170	840	71.8	120	10.3	209.84	17.9
1669	4,684	1,543	32.9	3,142	67.1	1,103	653	59.2	287	26.0	163.31	14.8
1715	3,147	119	3.8	3,029	96.2	176	123	69.6	23	12.9	30.66	17.4
1730	1,803	530	29.4	1,273	70.6	250	118	47.1	103	41.3	28.97	11.6
1731	3,651	303	8.3	3,348	91.7	301	192	63.9	60	20.1	48.22	16.0
1815	4,389	318	7.2	4,071	92.8	382	257	67.2	61	15.9	64.35	16.8
1821	1,031	242	23.4	789	76.6	86	28	32.1	51	59.9	6.86	8.0
1846	3,631	283	7.8	3,348	92.2	521	375	72.1	51	9.9	94.02	18.1
1904	1,170	382	32.6	788	67.4	131	50	38.0	69	52.5	12.46	9.5
1906	2,775	428	15.4	2,346	84.6	371	234	63.1	78	21.1	58.63	15.8
1919	30,159	5,062	16.8	25,097	83.2	5,096	3,315	65.0	952	18.7	829.55	16.3
1924	6,872	452	6.6	6,420	93.4	1,110	818	73.7	86	7.8	205.03	18.5
1926	13,861	1,252	9.0	12,609	91.0	366	638	174.1	240	65.4	(511.10)	(139.5)
1928	11,099	2,078	18.7	9,021	81.3	1,709	1,040	60.9	408	23.9	260.58	15.2
1960	13,238	1,085	8.2	12,153	91.8	1,799	1,275	70.9	206	11.4	318.74	17.7
1987	3,297	419	12.7	2,878	87.3	435	281	64.7	83	19.1	70.39	16.2
1991	1,462	94	6.4	1,368	93.6	155	109	70.5	18	11.8	27.38	17.7
2022	5,668	1,109	19.6	4,559	80.4	931	581	62.4	204	21.9	145.47	15.6
2037	712	192	27.0	520	73.0	183	119	65.0	34	18.7	29.69	16.3
2063	1,857	594	32.0	1,263	68.0	333	175	52.6	114	34.3	43.65	13.1
2065	11,890	1,736	14.6	10,154	85.4	2,059	1,389	67.5	321	15.6	348.44	16.9
2095	1,974	423	21.4	1,552	78.6	332	206	61.9	75	22.6	51.51	15.5
2108	2,403	554	23.0	1,849	77.0	429	263	61.3	100	23.3	65.82	15.4
2111	1,327	254	19.1	1,074	80.9	228	143	62.7	49	21.6	35.84	15.7
2114	9,814	642	6.5	9,172	93.5	1,013	709	70.0	126	12.5	177.60	17.5
2130	15,573	1,229	7.9	14,343	92.1	2,063	1,461	70.8	236	11.4	366.25	17.8
2139	1,335	104	7.8	1,231	92.2	233	171	73.3	19	8.3	42.98	18.4
2142	3,037	306	10.1	2,731	89.9	427	294	68.8	59	13.8	73.98	17.3
2150	10,250	752	7.3	9,498	92.7	1,352	967	71.6	142	10.5	242.37	17.9
2151	2,167	258	11.9	1,909	88.1	466	334	71.7	48	10.3	83.89	18.0
2154	5,935	1,712	28.9	4,222	71.1	860	421	49.0	333	38.8	105.35	12.3

Table A-9. Seasonal nutrient reduction (load and percent) for each independent wetland plus buffer potential site.

WETLAND ID	TOTAL NITROGEN REDUCTION								TOTAL PHOSPHORUS REDUCTION							
	WINTER		SPRING		SUMMER		AUTUMN		WINTER		SPRING		SUMMER		AUTUMN	
	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)
91	160	77	394	40	326	34	219	56	74	64	175	43	112	36	84	50
160	1,883	54	6,009	27	4,824	27	2,883	42	124	32	688	17	575	15	199	22
220	244	52	634	23	731	25	427	40	40	31	138	18	127	18	72	30
303	583	91	1,752	79	1,912	78	1,000	88	7	6	224	41	211	47	37	19
337	2,256	82	4,601	51	4,684	53	3,502	74	539	65	1,113	42	780	39	660	58
357	561	88	973	42	1,262	49	871	75	0	0	12	1	11	2	2	1
392	142	91	312	62	386	67	233	84	37	78	91	58	72	57	53	75
398	353	59	1,152	36	1,172	36	632	52	48	39	241	29	213	29	91	39
417	348	52	985	26	999	29	570	43	36	33	156	19	146	20	63	28
437	102	56	246	30	306	34	178	49	14	33	59	27	52	27	28	37
443	251	70	603	41	735	44	429	61	9	37	67	25	54	22	18	30
471	105	63	267	33	316	36	186	54	20	41	72	30	60	30	36	43
480	378	95	1,042	71	1,224	76	661	88	110	88	300	67	231	66	146	81
491	386	46	1,336	43	1,470	41	702	44	51	28	319	38	279	40	98	33
492	155	63	430	45	467	44	255	53	34	43	121	39	93	37	50	40
505	638	91	1,515	66	1,797	67	1,091	86	125	80	363	59	275	54	183	75
512	439	87	1,258	70	1,462	69	755	80	46	71	260	64	220	61	78	65
515	160	83	471	62	531	62	285	76	32	66	124	57	101	55	52	63
519	439	52	898	35	1,149	38	777	51	64	34	180	27	156	29	104	36
547	255	63	781	39	830	44	423	53	4	27	92	29	84	28	10	20
555	685	78	1,915	62	1,984	67	1,137	75	33	56	225	62	191	62	63	61
556	392	85	1,163	69	1,189	71	662	81	15	70	131	66	112	65	31	68
561	1,524	81	3,811	47	3,783	49	2,458	71	69	61	334	27	268	23	116	42
564	868	73	2,200	41	2,170	44	1,348	61	40	54	227	27	195	24	69	37
565	206	33	591	19	707	24	403	32	4	16	66	13	59	13	11	13
566	286	53	1,376	52	1,454	58	583	54	10	53	289	68	269	68	45	63
567	156	53	684	50	752	51	326	52	5	42	139	57	129	57	22	53
573	255	98	1,021	90	1,012	92	470	95	9	98	144	93	131	92	26	93
574	1,648	62	4,636	47	4,621	47	2,897	60	157	33	615	32	490	32	255	36
576	2,251	99	8,194	95	7,912	92	4,056	97	416	99	1,641	93	1,200	85	601	94
580	602	98	2,349	81	1,993	77	1,047	92	21	93	261	66	203	55	51	70
585	231	40	566	24	694	28	432	39	9	20	51	13	46	13	18	20
758	190	40	388	24	453	27	331	39	32	22	85	19	62	19	48	25
815	1,241	36	3,084	19	3,417	22	2,278	34	50	19	243	9	214	9	101	16
818	389	54	922	23	957	29	641	46	5	20	42	7	31	6	11	11
832	287	36	858	22	982	25	580	35	13	19	104	15	94	15	31	20
860	1,387	46	3,406	30	4,215	32	2,626	43	72	23	422	20	377	21	163	28
942	293	47	654	30	724	34	526	43	19	25	69	19	59	19	38	29
1076	188	81	412	53	490	55	314	73	6	52	29	28	21	23	10	41
1083	321	90	876	61	834	59	530	80	18	75	85	40	64	33	29	54
1111	891	89	2,083	63	2,443	64	1,637	84	59	75	210	42	150	34	88	61
1117	379	82	830	57	996	59	695	77	20	58	74	36	56	32	32	52
1130	490	69	1,155	48	1,283	51	891	65	24	42	112	34	93	32	44	44
1136	385	36	975	30	1,215	34	751	37	22	24	134	30	121	32	46	30
1146	806	51	2,126	33	1,964	37	1,400	48	63	26	259	26	224	28	133	33
1174	373	45	934	31	835	33	637	42	28	20	107	21	92	23	64	28

WETLAND ID	TOTAL NITROGEN REDUCTION								TOTAL PHOSPHORUS REDUCTION							
	WINTER		SPRING		SUMMER		AUTUMN		WINTER		SPRING		SUMMER		AUTUMN	
	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)	(kg)	(%)
1496	859	99	3,176	92	2,634	92	1,334	96	195	98	606	88	457	87	261	93
1516	1,942	77	4,312	49	3,967	49	2,894	68	380	51	832	37	592	35	508	50
1578	241	85	450	70	456	66	325	87	45	76	89	60	64	49	50	76
1600	1,273	84	2,702	59	3,165	60	2,122	78	183	65	434	44	308	40	244	59
1669	488	97	1,838	75	1,534	66	824	86	116	94	454	69	342	57	192	78
1715	470	52	885	31	1,055	36	738	47	20	27	68	17	53	15	34	26
1730	216	63	584	58	656	62	347	62	20	49	106	65	92	68	32	51
1731	499	97	1,174	76	1,199	78	778	92	40	91	121	61	85	52	55	79
1815	591	85	1,377	63	1,445	65	977	80	51	67	148	48	109	44	74	62
1821	129	62	332	49	367	60	203	55	2	60	40	84	37	85	7	74
1846	471	92	1,110	71	1,223	71	828	88	77	81	192	58	138	52	113	76
1904	114	96	371	90	469	88	216	93	5	89	60	91	53	91	12	89
1906	390	43	1,006	27	832	32	546	36	36	26	136	23	129	25	69	31
1919	4,101	72	13,606	55	7,390	57	5,062	64	616	62	1,932	52	1,617	52	931	60
1924	1,157	33	2,580	17	1,833	24	1,302	28	148	25	359	16	353	19	249	27
1926	2,000	97	6,453	77	2,995	71	2,413	88	6	2	170	14	163	16	28	5
1928	1,390	100	5,637	94	2,565	92	1,507	97	193	99	677	92	549	88	290	94
1960	1,976	79	5,077	51	3,509	51	2,676	68	262	59	639	39	517	38	381	55
1987	472	71	1,170	47	963	50	692	62	53	48	159	38	137	40	86	51
1991	223	64	578	37	379	42	281	54	21	44	55	28	46	27	33	43
2022	664	98	2,540	77	1,500	72	963	91	119	94	359	66	286	63	167	83
2037	93	45	235	25	241	33	144	37	20	36	65	28	61	31	37	42
2063	219	82	857	64	517	83	265	76	31	75	133	78	118	80	50	74
2065	1,722	72	4,532	44	3,223	47	2,412	59	278	54	721	36	629	38	431	53
2095	245	84	579	50	736	55	415	74	40	61	130	43	102	41	59	57
2108	333	77	982	54	656	53	432	62	46	54	162	47	144	49	76	54
2111	191	46	540	29	366	36	230	37	23	32	85	30	79	33	41	35
2114	1,585	72	4,151	42	2,332	45	1,745	60	136	52	364	31	300	30	213	49
2130	2,477	77	6,770	45	3,607	46	2,719	64	313	60	737	35	580	33	433	54
2139	219	45	519	24	348	31	248	38	30	30	80	23	74	26	49	33
2142	495	47	1,200	26	788	32	554	41	50	32	154	23	138	25	85	34
2150	1,515	83	3,618	52	2,919	50	2,198	73	200	62	488	37	378	34	285	56
2151	332	76	687	44	641	46	508	65	68	59	166	40	133	39	98	56
2154	578	99	2,223	94	2,125	95	1,008	97	71	99	366	95	309	92	114	94

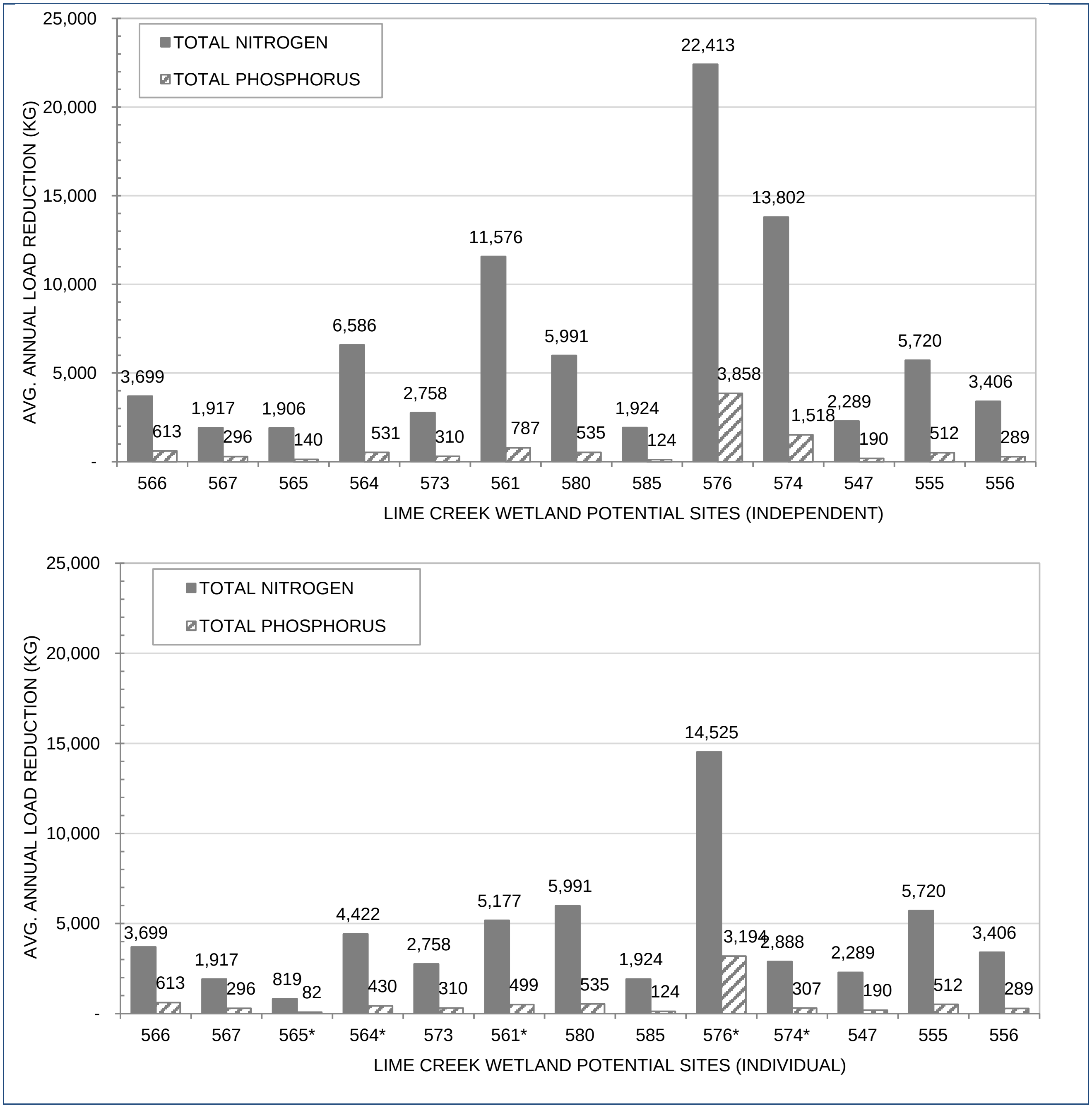

Figure A-5. Comparison of nutrient removal in the Lime Creek wetland plus buffer potential sites as independent wetlands (top) and as individual wetlands in context of other wetlands in the same stream reach (bottom). Wetlands downstream of another wetland(s) are identified by an asterisk.

Table A-10. Location, bid price (i.e., capital cost with opportunity cost), and attenuation (kg) for the potential wetlands in the BBC auction case.

PARTICIPANT		UPSTREAM NODE	DOWNSTREAM NODE	$ FOR BID	NITROGEN ATTENUATION (kg)				PHOSPHORUS ATTENUATION (kg)			
MARSHWREN ID	AnnAGNPS ID				WINTER	SPRING	SUMMER	AUTUMN	WINTER	SPRING	SUMMER	AUTUMN
Wetland 1716	91	1722	1723	$135,645	160	394	326	219	74	175	112	84
Wetland 1561	160	1571	1572	$159,530	1,883	6,009	4,824	2,883	124	688	575	199
Wetland 1523	220	1532	1533	$134,745	244	634	731	427	40	138	127	72
Wetland 1410	303	1409	1425	$150,535	583	1,752	1,912	1,000	7	224	211	37
Wetland 1201	337	1206	1211	$177,379	2,256	4,601	4,684	3,502	539	1,113	780	660
Wetland 1175	357	1186	1187	$151,465	561	973	1,262	871	0	12	11	2
Wetland 1087	392	1102	1103	$135,953	142	312	386	233	37	91	72	53
Wetland 930	398	943	944	$139,441	353	1,152	1,172	632	48	241	213	91
Wetland 827	417	846	847	$136,256	348	985	999	570	36	156	146	63
Wetland 769	437	786	787	$131,107	102	246	306	178	14	59	52	28
Wetland 947	443	961	962	$137,446	251	603	735	429	9	67	54	18
Wetland580	471	596	597	$131,083	105	267	316	186	20	72	60	36
Wetland 507	480	478	524	$154,647	378	1,042	1,224	661	110	300	231	146
Wetland 598	491	614	615	$138,170	386	1,336	1,470	702	51	319	279	98
Wetland 482	492	497	498	$135,454	155	430	467	255	34	121	93	50
Wetland 695	505	711	712	$154,020	638	1,515	1,797	1,091	125	363	275	183
Wetland 564	512	582	583	$145,095	439	1,258	1,462	755	46	260	220	78
Wetland 567	515	586	587	$137,976	160	471	531	285	32	124	101	52
Wetland 720	519	737	738	$137,505	439	898	1,149	777	64	180	156	104
Wetland 657	547	671	672	$136,423	255	781	830	423	4	92	84	10
Wetland 589	555	605	606	$135,647	685	1,915	1,984	1,137	33	225	191	63
Wetland 591	556	571	608	$142,299	392	1,163	1,189	662	16	131	112	31
Wetland 635	561	649	650	$171,609	1,524	3,811	3,783	2,458	69	334	268	116
Wetland 499	564	516	517	$150,338	868	2,200	2,170	1,348	40	227	195	69
Wetland 1819	565	9991	515	$133,473	206	591	707	403	4	66	59	11
Wetland 432	566	442	443	$131,662	286	1,376	1,454	583	10	289	269	45
Wetland 434	567	446	447	$132,428	156	684	752	326	5	139	129	22
Wetland 503	573	520	521	$147,363	255	1,021	1,012	470	9	144	131	26
Wetland 637	574	652	653	$146,994	1,648	4,636	4,621	2,897	157	615	490	255
Wetland 620	576	602	638	$358,397	2,251	8,194	7,912	4,056	416	1,641	1,200	601
Wetland 526	580	544	545	$173,432	602	2,349	1,993	1,047	21	261	203	51
Wetland 496	585	511	512	$133,452	231	566	694	432	9	51	46	18
Wetland 1104	758	1120	1121	$132,162	190	388	453	331	32	85	62	48
Wetland 442	815	424	455	$148,129	1,241	3,084	3,417	2,278	50	243	214	101
Wetland 398	818	388	409	$136,921	389	922	957	641	5	42	31	11
Wetland 383	832	394	395	$133,909	287	858	982	580	13	104	94	31
Wetland 396	860	407	408	$154,251	1,387	3,406	4,215	2,626	72	422	377	163
Wetland 162	942	173	174	$134,627	293	654	724	526	19	69	59	38
Wetland 610	1076	629	630	$136,664	188	412	490	314	6	29	21	10

Wetland 542	1083	557	558	$147,595	321	876	834	530	18	85	64	29
Wetland 356	1111	364	365	$164,846	891	2,083	2,443	1,637	59	210	150	88
Wetland 404	1117	385	415	$141,477	379	830	996	695	20	74	56	32
Wetland 300	1130	309	310	$140,907	490	1,155	1,283	891	24	112	93	44
Wetland 317	1136	324	325	$134,045	385	975	1,215	751	22	134	121	46
Wetland 245	1146	252	253	$141,143	806	2,126	1,964	1,400	63	259	225	133
Wetland 99	1174	104	105	$135,078	373	934	835	637	28	107	92	64
Wetland 660	1496	675	676	$210,718	859	3,176	2,634	1,334	195	606	457	261
Wetland 885	1516	841	901	$164,910	1,942	4,312	3,967	2,894	380	832	592	508
Wetland 1236	1578	1247	1249	$150,201	241	450	456	325	45	89	64	50
Wetland 1190	1600	1202	1203	$167,186	1,273	2,702	3,165	2,122	183	434	308	244
Wetland 1732	1669	1719	1738	$189,550	488	1,838	1,534	824	116	454	342	192
Wetland 1613	1715	1623	1624	$137,307	470	885	1,055	738	20	68	53	34
Wetland 1410	1730	1549	1550	$132,059	216	584	656	347	20	106	92	32
Wetland 1542	1731	1553	1554	$158,641	499	1,174	1,199	778	40	121	85	55
Wetland 1295	1815	1311	1312	$150,121	591	1,377	1,445	977	51	148	109	74
Wetland 1326	1821	1341	1342	$131,411	129	332	367	203	2	40	37	7
Wetland 1126	1846	1144	1145	$152,956	471	1,110	1,223	828	77	192	138	113
Wetland 845	1904	864	865	$136,925	114	371	469	216	5	60	53	12
Wetland 842	1906	860	861	$134,321	390	1,006	832	546	36	136	129	69
Wetland 851	1919	845	871	$148,176	4,101	13,606	7,390	5,062	616	1,932	1,617	931
Wetland 796	1924	742	814	$140,340	1,157	2,580	1,833	1,302	148	359	353	249
Wetland 724	1926	624	743	$200,526	2,000	6,453	2,995	2,413	6	170	163	28
Wetland 607	1928	626	627	$195,215	1,390	5,637	2,565	1,507	193	677	549	290
Wetland 1120	1960	1098	1137	$172,102	1,976	5,077	3,509	2,676	262	639	517	381
Wetland 1257	1987	1271	1272	$138,960	472	1,170	963	692	53	159	137	86
Wetland 1290	1991	1306	1307	$133,599	223	578	379	281	21	55	46	33
Wetland 1389	2022	1401	1402	$163,133	664	2,540	1,500	963	119	359	286	168
Wetland 1323	2037	1338	1339	$130,787	93	235	241	144	20	65	61	37
Wetland 1161	2063	1174	1175	$134,375	219	857	517	265	31	133	118	50
Wetland 1124	2065	1116	1142	$158,979	1,722	4,532	3,223	2,412	278	721	629	431
Wetland 1010	2095	1022	1023	$137,585	245	579	736	415	40	131	102	59
Wetland 854	2108	872	873	$136,855	333	982	656	432	46	162	144	76
Wetland 857	2111	875	876	$132,567	191	540	366	230	23	85	79	41
Wetland 891	2114	907	908	$152,759	1,585	4,151	2,332	1,745	136	364	300	213
Wetland 770	2130	745	788	$170,578	2,477	6,770	3,607	2,719	313	737	580	433
Wetland 664	2139	678	679	$132,166	219	519	348	248	30	80	74	49
Wetland 668	2142	682	683	$135,469	495	1,200	788	554	50	154	138	85
Wetland 755	2150	753	773	$158,514	1,515	3,618	2,919	2,198	200	488	378	285
Wetland 733	2151	751	752	$136,114	332	687	641	508	68	166	133	98
Wetland 737	2154	755	756	$168,414	578	2,223	2,126	1,008	71	366	309	114

APPENDIX B: WATER QUALITY TRADING DISTRICT ACT

Language drafted by Donald Hey of Wetland Research Inc., and George Covington, an attorney specializing in land use issues including conservation easements.

A. Purpose

Sec. A1. Whenever the unified control of a lake and its littoral zone, a stream or river and their floodplains, or a wetland system or portions thereof shall be deemed conducive to the production of beneficial ecosystem-system services such as flood water storage, removal of aquatic and atmospheric contaminants such as nitrogen, phosphorous, and sediment from the water, or carbon dioxide and nitrous oxide from the air, and provision of wildlife habitat and recreational landscapes, these lands can be organized into a Water Quality Trading District (herein referred to as WQT District).

Sec. A2. The benefits produced by said districts can be sold as beneficial ecosystem-system services, such as flood control, water quality management, and enhanced habitat credits to those who externalize their costs by disposing of unwanted water, nutrients, sediment and other water and air borne contaminants. The recreational benefits may be sold on an individual basis or through cooperative arrangements. The WQT DISTRICT also may sell plant materials for food, fiber and shelter as long as the production and harvesting of such plants does not interfere with the main purpose of the district, which is to produce a WQT District as described above.

B. Need

Sec. B1. The need for these WQT Districts has been demonstrated repeatedly in the past. The United States Congress first commissioned a flood study in the late 1800s,[1] after devastating floods on the lower Mississippi River. In 1935, Congress passed the Flood Control Act and spent over $2 billion dollars on levees, dams and other structural means to limit flood damage and yet, flood damage, in constant dollars, has increased to $4 billion dollars[2] annually. The 1992 flood on the upper Mississippi River and Illinois River caused $16 billion[3] of damages. In attempting to reduce flood damages along the Illinois River, over half of the river’s floodplain has been leveed, yet the cities, towns and farms still suffer flood damage. The reasons are simple and obvious: the levees prevent the storage of flood waters on the floodplain, increase the energy and height of the flood wave, which overtops the levee,[4] and encourage the agricultural and commercial development of the leveed floodplains, thus increasing the potential flood damage.

Sec. B2. Since the passage of the Clean Water Act in 1972, $200 million have been spent on building conventional waste water treatment plants. In the watershed of the Illinois River 630[5] plants have been built. These plants contribute 10 percent of the nitrogen and 14 percent of the phosphorous being discharged from the Illinois to the Mississippi River. The rest of the nitrogen and phosphorous loads come from agricultural activities and atmospheric deposition that originates from transportation and energy production sources.

Sec. B3. In 2008, the U.S. Environmental Protection Agency (USEPA) promulgated nutrient standards[6] and charged the states with implementing them. To date, Illinois has not codified the standards and environmental degradation has not been reduced. Illinois is the largest contributor of nitrogen to the Gulf of Mexico, and the hypoxic

[1] Ellet, C Jr. 1852. Report of the Overflow of the Delta of the Mississippi. The War Department Washington, DC.
[2] Hey, D.L. 2012. Modern Drainage: the Pros, the Cons, and the Future. wetlandsresearch.org.
[3] Hey, D L and N. Philippi. 1995. Flood reduction through wetland restoration: The upper Mississippi River basins a case history. *Restoration Ecology* 3 (1).
[4] Sutton, J.G. 1955. Outlet ditches, slopes, banks, dikes and levees. Water—*The Yearbook of Agriculture. U.S. Department of Agriculture,* Washington, DC.
[5] Hey, D.L., J.A. Kostel, A.P. Hurter, R.H. Kadlec. 2005. Nutrient Farming and Traditional Removal: An Economic Comparison. WERF 03-WEM-6CO. Alexandria, VA.: Water Environment Research Foundation.
[6] US EPA. 2001. Nutrient criteria development; notice of ecosystem regional nutrient criteria.

zone in the Gulf of Mexico has increased in size from 1,000 square miles to 10,000 square miles over the last couple of decades. If the Gulf of Mexico is to be restored and its aquatic life protected, Illinois will need to reduce the nitrogen load it now discharges to the Mississippi River.

Sec. B4. The reduction of nutrients in the Illinois River could effectively, inexpensively and sustainably be accomplished by the use of wetlands[7]. If the Metropolitan Water Reclamation District of Greater Chicago (MWRD) purchased nitrogen and phosphorus credits according to the new standards, they would save approximately $100 million dollars per year, equivalent to the electrical power needs of 55 thousand people. Using the service area of the MWRD, the study showed that the district would have to spend $2.5 billion to upgrade their plants to meet a nutrient standard somewhat less than that proposed by the USEPA; if they purchased the required water quality credits over a twenty year period, they would save $1.6 billion. Extrapolating these results to all of the treatment plants in the Illinois portion of the watershed, the net savings would exceed billion of dollars, using the same parameters for creating a landscape (restoring wetlands on floodplains along the Illinois River and its tributaries) that would yield the necessary water quality credits. The required land for the annual nutrient credit supply for the district’s demand would be 200,000 acres, which is equivalent to half of Illinois River floodplain area, or the area of floodplain that is leveed. Using this land to produce water quality credits would increase, at the same time, flood storage and greatly reduce potential flood damage.

C. Formation of WQT District.

Sec. C1. The WQT District, providing the above financial, environmental, wildlife and social benefits shall be formed under this Act in the following manner: One percent or more of the legal voters resident within the limits of such proposed district, and, with respect to petitions filed on or after the effective date of this Act of (the date of passage),one percent of the legal voters resident in each county in which the proposed district is situated, may petition the circuit court for the county which contains all or the largest portion of the proposed district to cause the question to be submitted to the legal voters of such proposed district, as to whether such proposed territory shall be organized as a WQT District under this Act, which petition shall be addressed to the court and shall contain a general description of the boundaries of the territory to be embraced in the proposed district and the name of such proposed district. The description need not be given by metes and bounds or by legal subdivisions, but it shall be sufficient if a generally accurate description is given. Such territory need not be contiguous, provided that it shall be so situated that the public health, safety, convenience or welfare will be promoted by the organization as a single district of the territory described.

Upon filing such petition in the office of the circuit clerk of the county in which such petition is filed as aforesaid it shall be the duty of the court to consider the boundaries of any such proposed WQT District, whether the same shall be those stated in the petition or otherwise. The decision of the court is appealable as in other civil cases.

Sec. C2. The court shall by order fix a time and place for a hearing on the petition not less than 60 days after the date of such order. Notice shall be given of the time and place where such commissioners shall meet for such hearing. The court shall give public notice at least once in one or more daily or weekly papers published within the proposed WQT District, or, if no daily or weekly newspaper is published within such proposed WQT District, then by posting at least 10 copies of such notice in such proposed district, at least 20 days before such meeting, in conspicuous public places as far separated from each other as consistently possible and the court shall send an

[7] Hey, D.L., J.A. Kostel, A.P. Hurter, R.H. Kadlec. 2005. Nutrient Farming and Traditional Removal: An Economic Comparison. WERF 03-WEM-6CO. Alexandria, VA.: Water Environment Research Foundation.

email to all of the adjacent land owners, the email address being provided by the applicants. In addition, the court could publicize the meeting on its webpage.

At such hearing all persons in such proposed WQT District shall have an opportunity to be heard, touching upon the location and boundaries of such proposed district and to make suggestions regarding the same. The court, after hearing statements, evidence and suggestions, shall fix and determine the limits and boundaries of such proposed district, and for that purpose and to that extent, may alter and amend such petition. After such determination by the court, the same shall be incorporated in an order which shall be entered of record in the circuit court or courts of the counties situated in the proposed district and the court shall also by the order provide for the holding of a referendum as herein provided.

Sec. C3. Upon the entering of such order the court shall certify the question of organization and establishment of the proposed WQT District as determined by the court to the proper election officials who shall submit the question at an election in accordance with the general election law. In addition to the requirements of the general election law, notice of the referendum shall specify the purpose of the referendum and contain a description of such proposed district. The clerk of the court shall send notice of the referendum to the county board of each county in which the proposed district is situated.

Each legal voter resident within such proposed WQT District shall have the right to cast a ballot at such election. The question shall be in substantially the following form (the following is only an example). The WQT District may or may not have taxing powers or condemnation powers depending on the majority of the founding participants. The following is only the form of the voting documents:

Yes, the District shall be organized and authorized to levy
an annual tax at a maximum rate of _____(maximum rate authorized under
Section 17 of the WQT District Act) of the value of all taxable property within the limits of the district or

No, the district’s land shall be equalized or assessed by the Department of Revenue.

The ballots cast on the question in each county shall be returned and canvassed by the county clerk of the county in which the ballots are cast. Such county clerks respectively shall file with the county clerk of the county in which the petition is filed a true copy of the return and canvass of the votes cast in each of said counties. Thereupon, the county clerk of the county in which such petition is filed shall canvass the entire vote cast in the election from the returns furnished by such respective county clerks, and shall ascertain the result of such referendum and certify the same to the court. The court shall cause a statement of the results of such referendum to be entered of record in the court. If a majority of the votes cast at such election upon the question shall be in favor of the organization of the proposed WQT District, such proposed district shall thenceforth be deemed an organized WQT District under this Act and a municipal corporation with the powers and duties herein conferred and bearing the name set forth in the petition[8].

Sec. C4. All courts in this State shall take judicial notice of the existence of all districts organized under this Act[9].

Sec. C5. Additional territory may be added to any WQT District as provided for in this Act in the manner following: One percent or more of the legal voters resident within the limits of such proposed addition to such district, in each county in which the proposed addition is situated, may petition the circuit court for the county in which the original petition for the formation of said district was filed. The petition would be to ask the legal voters of such proposed addition of territory whether such proposed additional territory shall become a part of any district organized under this

[8] Source: P.A. 86-1307 in 70 ILCS 2105/2 from Ch. 42, par. 384
[9] Source: Laws 1925, p. 346.of 70 ILCS 2105/3 from Ch. 42, par. 385

Act, and whether such additional territory shall assume a proportionate share of the bonded indebtedness, if any, of such district. Such petition shall be addressed to the court of the county in which the original petition for organization was filed and shall contain a generally accurate description of the boundaries of the territory to be embraced in the proposed addition.

Upon filing such petition in the office of the circuit clerk of the county in which the original petition for the formation of such district was filed, the court shall consider, fix and determine the boundaries of the proposed additional territory, whether the territory shall be those stated in the petition or otherwise. The decision of the court shall be reviewable as in other civil cases. The court shall fix a date and give notice, by the court of the county in which such petition is filed, of the time and place where a hearing shall be held in the manner described in Section 1 of this Act. The conduct of the meeting and the power of the court to fix and alter the boundaries of the proposed addition shall be carried out in the manner described in Section 1 of this Act, as nearly as the court reasonably can. The court shall certify the question to the proper election officials. Those officials shall submit the question at an election in accordance with the general election law. The question shall be in substantially the following form:

For joining the Water Quality Trading District and assuming a proportionate share of bonded indebtedness.

Against joining Water Quality Trading District and assuming a proportionate share of bonded indebtedness.

If a majority of the votes cast upon the question of becoming a part of a WQT District shall be in favor of becoming a part of such district, and if the board of trustees of said district accept the proposed additional territory by ordinance annexing the district, the court shall record an appropriate order of record in the court and such additional territory shall thenceforth be deemed an integral part of such district and shall be subject to all the benefits, responsibilities, and obligations of said district as herein set forth.

Sec. C6. Any such additional territory may also be annexed to such district upon petition addressed to the court for the county in which the original petition for organization of the district was filed, signed by a majority of the owners of lands constituting such territory sought to be annexed, who shall have arrived at lawful age and who represent a majority in area of such territory. The petition shall contain an accurate description of the boundaries of such territory sought to be annexed. Also, the petition shall set forth to assume a proportionate share of the bonded indebtedness, if any, of such district. Upon the filing of such petition and notice of and hearing the decision upon the petition by the court, all as herein before provided in Section 1 of this Act with reference to notice, hearing and decision upon the petition for the original organization of such district, such court shall enter an order containing its findings and decision as to the boundaries of the territory to be annexed. Thereupon, if the board of trustees of such district shall pass an ordinance annexing the territory described in such order to said district, the court shall enter an appropriate order finding that the territory is so annexed. Such additional territory shall thenceforth be deemed an integral part of such district, and shall be subject to all the benefits, responsibilities and obligations of said WQT District as herein set forth[10].

D. Governance of District[11].

Sec. D1. Every district so established shall be governed by a board of trustees. In the statement finding the results of the election to be favorable to the establishment of the district, the circuit court shall determine and name each municipality within

[10] Source: P.A. 86-1307
[11] 70 ILCS 2105/4a) (from Ch. 42, par. 386a)

the district having 5,000 or more population according to the last preceding federal census. In case there are one or more municipalities having a population of 5,000 or more within the district, the trustees shall be appointed as follows:

(a) Where the district has only one such municipality, one trustee shall be appointed from such municipality, and one trustee shall be appointed from each county in the district, except that where the district is wholly contained within a single county, one trustee shall be appointed from that county and one additional trustee shall be appointed from the municipality, and, in either case, 2 trustees shall be appointed at large. A trustee appointed from a county in the district shall be appointed from the area outside any such municipality. If the district is located wholly within the corporate limits of such municipality, 3 of the trustees of the district shall be appointed from such municipality, and 2 trustees shall be appointed at large. In a district wholly contained within a single county of between 60,500 and 70,000 population and having no more than one municipality of 5,000 or more population, regardless of the date of organization, 3 trustees shall be appointed from that municipality, 2 trustees shall be appointed from the district outside that municipality, and 2 trustees shall be appointed at large. No more than 2 appointments by each appointing authority may be from the same political party.

(b) Where the district has 2 or more such municipalities, one trustee shall be appointed from each such municipality, one trustee shall be appointed from each county in the district for each 50,000 population or part thereof within the district in such county, according to the last preceding federal census, and 2 trustees shall be appointed at large. A trustee appointed from a county in the district shall be appointed from the area outside any such municipality. If the district is located wholly within the corporate limits of such municipalities, 2 trustees shall be appointed from the one of such municipalities having the largest population, and one trustee shall be appointed from each of the other such municipalities, and 2 trustees shall be appointed at large.

(c) The heads of the affected units of government, which are named above, shall nominate a list of trustees from which the judge of the presiding circuit court shall select the board of trustees as structured above.

Sec. D2[12]. Each of the trustees shall enter into bond with security to be approved by the appointing authority in such sum as the appointing authority may determine. A majority of the board of trustees shall constitute a quorum, but a smaller number may adjourn from day to day. No trustee or employee of such district shall be directly or indirectly interested financially in any contract work or business or the sale of any ecosystem service or article or land, the expense, price or consideration of which is paid by said district; nor in the purchase of any real estate or other property belonging to the district, or which shall be sold for taxes or assessments or by virtue of legal process at the suit of said district—provided that nothing herein shall be construed as prohibiting the appointment or selection of any person as trustee or employee whose only interest in said district is as an owner of real estate in said district or of contributing to the payment of taxes levied by said district[13].

Sec. D3[14]. Whenever a vacancy in said board of trustees occurs, either by death, resignation, refusal to qualify or for any other reason, the prior appointing authority may fill such vacancy by appointment; and such person, so appointed shall qualify for office in the manner hereinbefore stated and shall thereupon assume the duties of the office for the unexpired term to which such person was appointed.

Sec. D4[15]. The board of trustees shall exercise all of the powers and control the affairs and property of the district. The board at their first meeting in May of each

[12] 70 ILCS 2105/4b) (from Ch. 42, par. 386b

[13] Source: P.A. 77-681

[14] 70 ILCS 2105/5 from Ch. 42, par. 387 and P.A. 77-681

[15] 70 ILCS 2105/6 from Ch. 42, par. 388 and P.A. 79-1454

year shall elect one of their number as president, one of their number as vice-president and one of their number as secretary. The board may appoint an engineer. This engineer may be an individual, co-partnership or corporation. The board may also appoint an attorney, an executive vice-president, a manager, a treasurer, and other engineers, attorneys, agents, clerks and assistants for the district who shall hold office at the pleasure of the board and shall give such service as the board may require. The board may prescribe the duties and fix the compensation of all the officers and employees of the district. A member of the board may not receive more than $3,000 per annum. The board may pass all necessary ordinances, rules and regulations.

Sec. D5[16]. All ordinances imposing any penalty or making any appropriations shall, within one month after they are passed, be published at least once in a newspaper published in said district, or if no such newspaper of general circulation is published therein, by posting copies of the same in ten public places in the district and on the district’s website. No such ordinance shall take effect until ten days after it is so published. All other ordinances and resolutions shall take effect from and after their passage, unless otherwise provided therein.

Sec. D6[17]. All ordinances, orders, and resolutions and the date of publication thereof, may be proven by the certificate of the secretary under the seal of the corporation. When printed in book or pamphlet form, and published by the board of trustees, such book or pamphlet shall be received as evidence of the passage and legal publication of such ordinances, orders and resolutions as of the dates mentioned in such book or pamphlet, in all courts and places without further proof.

Sec. D7[18]. The board of trustees of any WQT District shall, in addition to the other powers and duties by this Act conferred and imposed have the following powers and duties:

(a) Given that the district has obtained the appropriate federal, state and local permits and met the required conditions of the permits, the district can affect the protection, reclamation or irrigation of the land and other property in the district, and to accomplish all other purposes of the district, the board of trustees is authorized and empowered to clean out, straighten, widen, alter, deepen or change the course or terminus of any ditch, drain, sewer, river, water course, pond, lake, creek or natural stream in the district; to fill up any abandoned or altered ditch, drain, sewer, river, water course, pond, lake, creek or natural stream, and to concentrate, divert or divide the flow of water in or out of the district; to construct, maintain, alter or remove main and lateral ditches, sewers, canals, levees, dikes, dams, sluices, revetments, reservoirs, holding basins, floodways, pumping stations and siphons, and any other works and improvements deemed necessary to construct or remove, preserve, operate or maintain the works in or out of the district; to construct, enlarge or cause to be constructed or enlarged or removed any and all bridges that may be needed in or out of the district; to construct or elevate roadways and streets; to construct or remove levees, dams, weirs or any and all of the works and improvements on the district’s properties and across, through or over any public highway, canal, railroad right of way, track, grade, fill or cut, in or out of the district; to remove or change the location of any fence, building, railroad, canal, or other improvements in or out of the district. The board of trustees shall have the right to hold, encumber, control, to acquire by donation, purchase or condemnation, to construct, own, lease, use and sell real and personal property, including the transfer of real property by gift to the State of Illinois, and any easement, riparian right, railroad right of way, canal, cemetery, sluice, reservoir, holding basin, mill dam, water power, wharf or franchise in or out of the district for right of way, holding basin or for any necessary purpose, or for material to be used in constructing and maintaining

[16] 70 ILCS 2105/7 from Ch. 42, par. 389 and Source: Laws 1925, p. 346.
[17] 70 ILCS 2105/8 from Ch. 42, par. 390 and Source: Laws 1925, p. 346.
[18] 70 ILCS 2105/9b from Ch. 42, par. 392a

the works and improvements, to re-plat or subdivide land, open new roads, streets and alleys, or change the course of an existing one; and to design and create a system for the purchase and sale of nutrient credits.(b) Nothing in this Act shall prohibit the district from furnishing water power or electricity for public or private use or otherwise for the operation of the works and instrumentalities of the district; nor shall the board be restricted from selling or otherwise disposing of the waters so collected and impounded except only as otherwise herein permitted.

(b) The board shall have the power and it shall be its duty to supervise, regulate and control the flow within the boundaries of the district of the waters of any river, stream or water course over and through any and all dams and other obstructions, if any, now or hereafter existing or constructed in, upon or along any such river, stream or water course; provided however, that nothing in this paragraph contained shall empower any WQT District to abridge or in any manner curtail any vested water power rights or other rights or laws or regulations.

(c) The board shall have the power and it shall be its duty to construct and efficiently maintain a fish-way or fish-ways through or over any and all dams or other obstructions to the flow of any river, stream or water course within the boundaries of the district, which shall be so constructed and maintained as to permit the free passage of fish over such dam or dams or other obstructions as long as those fish or aquatic organisms are not invasive or nuisance species.

(d) The board shall have the power, if it shall find it conducive to the public health, comfort or convenience, and conducive to its research program to acquire sufficient lands contiguous to its reservoir or reservoirs or other aquatic features or land holdings for the establishment of recreational grounds and the right to permit such reservoir or reservoirs or land to be used for recreational purposes and to construct on such grounds a building or buildings and other improvements for such recreational purposes; provided however, that nothing in this paragraph contained shall in any way interfere with the drainage or research or other use of such reservoir or reservoirs for the purpose of controlling, regulating and augmenting the flow of rivers, streams or water courses of the district.

(e) The board may enter into contracts and other financial means to sell the water quality and atmospheric pollution credits produced by the district, and enter into easements for the storage of flood waters and recreational uses, such as hiking, fishing and hunting of the district’s lands and water resources. When and where appropriate, the board may engage in the production of such commodities as wild rice and other native food crops that can tolerate moist soil conditions.

(f) In the pursuit of these financial activities, the board may petition the appropriate local, state and federal agencies for the necessary authorization and permits.

(g) In the event that any power or powers, authority or authorities given or granted in any paragraph or section of this Act shall be held to be void, such holding or holdings shall not be construed to in any manner affect the validity of any other part or portion of this Act or this Act in its entirety[19].

Sec. E. Authority of District

Sec. E1[20]. Such WQT District may acquire by purchase, any and all real and personal property, right of way and privileges whether within or without its corporate limits that may be required for its corporate purposes.

[19] Source: P.A. 86-129.
[20] 70 ILCS 2105/10a from Ch. 42, par. 393

Sec. E2[21]. (1) The board of trustees of a WQT District incorporated under this Act may acquire, by gift, purchase or lease, land or any of the facilities enumerated below, and may construct, develop, operate, extend and improve such facilities:

(a) Dams and reservoirs for water storage, water wells, water purification works, pumping stations, conduits, pipe lines, regulating works and all appurtenances required for the production and delivery of adequate and pure water to incorporated cities and villages, corporations and persons in unincorporated areas within or without the borders of the WQT District. The board is empowered and legally obligated to build, operate and maintain such water facilities, to adopt and enforce ordinances for the protection of water resources, and to sell water to the incorporated cities and villages and the corporations and persons in unincorporated areas by meter measurements and at rates that will at least defray all fixed, maintenance and operating expenses.

(b) Force mains, conduits, lateral sewers and extensions, pumping stations, ejector stations, and all other appurtenances, extensions, or improvements necessary or useful and convenient for the sanitary collection, treatment, and disposal of sewage and industrial wastes. The board may prohibit and disconnect storm water drains and outlets where necessary to relieve existing sanitary sewers of storm water loads in order to assure the efficient and sanitary collection, treatment, and disposal of sewage and industrial wastes. The board is empowered and legally obligated to establish rates and charges for the services of any such sewerage facilities that at least defray all fixed, maintenance, and operating expenses. For the purposes of producing water quality credits, the district can divert contaminated streams and rivers on to its property and enter into contracts with sanitary districts to directly accept its effluent for the purpose of producing water quality credits.

(2) For the purpose of developing, operating, or financing the cost of any such facilities under subsection (1), the authorized board may combine into one system any 2 or more such facilities and may use or pledge the revenues derived from one to pay for the other. Further, for such purposes, the authorized board shall have the express power to execute a note or notes and to execute a mortgage or trust deed to secure the payment of such notes; such trust deed or mortgage shall cover real estate, or some part thereof, or personal property owned by the district and the lien of the mortgage shall apply to the real estate or personal property so mortgaged by the district, and the proceeds of the note or notes may be used for the purposes set forth in this Section.

For purposes of this Section, the authorized board shall not execute notes bearing a rate of interest that exceeds the rate permitted in "An Act to authorize public corporations to issue bonds, other evidences of indebtedness and tax anticipation warrants subject to interest rate limitations set forth therein", approved May 26, 1970, as now or hereafter amended[22].

Sec. E3[23]. Whenever real estate is to be sold under the authority of this Act, the procedure shall be as follows:

(1) Notice of such proposed sale, giving time, place and terms thereof, and an invitation for bids shall be published for 3 consecutive weeks prior to the date of the sale in a newspaper of general circulation published in the WQT District or, if no such newspaper is published in the district, then in a newspaper having general circulation in each county within which a portion of the district lies. In any event, and without regard to whether the real estate to be sold is located inside or outside of the boundaries of the district, the notice and invitation shall be published in a newspaper and   in the county where the real estate is situated and, if the real

[21] (70 ILCS 2105/11) (from Ch. 42, par. 394)
[22] 70 ILCS 2105/11) (from Ch. 42, par. 394
[23] 70 ILCS 2105/11.1 from Ch. 42, par. 394.1

estate lies in more than one county, the publication shall be in a newspaper published in each such county and the district shall publish it on their website.

(2) On the day of the sale, the board of trustees shall proceed to sell the property by the second price auction to the highest bidder. If the board deems the bids to be inadequate, it may reject such bids, but notice and an invitation for bids must be published for a subsequent sale of the same property in the manner prescribed for any other sale of real estate.

(3) If any natural person or persons from whom the land was acquired are still surviving and bid on the real estate, the real estate shall be sold to such person or persons if the bid submitted equals the highest acceptable bid otherwise received[24].

(a)[25] The board of trustees of a WQT District located in one or more counties may enter into lease agreements for the development of projects that are intended to enhance ecosystem services development, create jobs, and increase tourism. These projects include tourism development projects including, but not limited to, resorts, motels, and other related service and tourism development, built by private developers under the conditions set forth in this Section.

(b) The board of trustees of a WQT District may enter into future agreements for the transfer of certain lands between a State agency or agencies and a WQT District when the district obtains the land from a State agency or agencies for the purposes of ecosystem services development or job creation projects.

(c) A board of trustees authorized to enter into lease agreements under the requirements of subsection (a) may lease land to a responsible person, firm, or corporation for a period not longer than 50 years for development as authorized in this Section and grant the person, firm, or corporation the option to extend the lease for subsequent periods not longer than 50 years.

(d) A board of trustees authorized to enter into lease agreements under the requirements of subsection (a) shall take appropriate steps to insure that, within 5 years after the board enters into a lease agreement, (i) at least 50% of the land for the proposed development is available and developed for public use, and (ii) at least 50% of the buildings constructed for the proposed development are available for public use[26].

Sec.E4[27]. The board of trustees shall have the power to provide and adopt a corporate seal for the district[28].

Sec.E5[29]. All the rights and property of said district in the waters and water courses of said district and in their uses as herein specified, shall be exercised and used in such manner as to promote the welfare of said district and the inhabitants thereof, and to promote the safest, most economical and reasonable use of the waters thereof, and to pay the cost of the construction and maintenance of improvements in so far as practicable.

Sec. E6[30]. Any WQT District organized under this Act may borrow money for corporate purposes and may issue bonds therefor. No WQT District shall become indebted in any manner, or for any purpose, to an amount in the aggregate to exceed 5% of the valuation of taxable property therein, to be ascertained by the last assessment for State and county taxes previous to the incurring of such indebtedness. Whenever the board of trustees of such district desires to issue bonds hereunder, they shall certify the question to the proper election officials. Those officials shall submit

[24] Source: P.A. 80-371.
[25] 70 ILCS 2105/11.5 and Sec. 14b Public development projects.
[26] Source: P.A. 88-472.
[27] 70 ILCS 2105/12a from Ch. 42, par. 395a.
[28] Source: Laws 1931, p. 530.
[29] 70 ILCS 2105/13 from Ch. 42, par. 396 and source: Laws 1931, p. 530.
[30] 70 ILCS 2105/14 from Ch. 42, par. 397

the question at an election in accordance with the general election law. The result of the election shall be entered upon the record of the district. If a majority of the voters voting on the question voted in favor of the issue of the bonds, the board of trustees shall order and direct the execution of the bonds for and on behalf of the district. All bonds issued hereunder shall mature in no more than 20 annual installments. The question shall be in substantially the following form[31]:

Do you favor the WQT District to borrow, by selling bonds, YES
....dollars for the purpose of...., to be repaid by a new tax on ...? YES NO

Sec. E7[32]. At the time of or before incurring any indebtedness, the board of trustees shall provide for the collection of a direct annual tax sufficient to pay the interest on such debt as it falls due, and also to pay and discharge the principal thereof as the same shall fall due, and at least within twenty years from the time of contracting same.

Sec. E8. A WQT District organized under this Act for the purpose of carrying out the powers conferred by Section 11 of this Act may borrow money and as evidence thereof may issue bonds, payable solely from revenue derived from the facilities authorized to be constructed, purchased, or acquired by Section 11 of this Act. These bonds may be issued in such amounts as may be necessary to provide sufficient funds to pay all costs of acquiring the land for any such facility or constructing such facility or both, including engineering, legal and other expenses, together with interest on the bonds to a date 6 months subsequent to the estimated date of completion.

Whenever the trustees determine to acquire land for any of the purposes enumerated in Section ________ of this Act and to issue bonds under this section for the payment of the cost thereof, the board of trustees shall adopt an ordinance describing in a general way the contemplated project and refer to the preliminary plans and engineering reports therefor. These preliminary plans and engineering reports shall be filed with the secretary of the board of trustees and shall be open for inspection by the public.

This ordinance shall set out the estimated cost of the project, fix the amount of revenue bonds to be issued, the maturity or maturities thereof, the interest rate, and all details in connection with the bonds. The interest rate shall not exceed the rate permitted in the Bond Authorization Act. It will be payable annually or semi-annually. The ordinance shall provide that the entire revenue from the facilities to be constructed or acquired with the proceeds of the sale of said bonds shall be set aside as collected and deposited in a separate fund. A sufficient amount thereof shall be used solely in paying the cost of maintenance and operation of such improvement or facility, in providing an adequate depreciation fund, and in paying the principal of and the interest on said bonds, as they mature. The ordinance may also provide for the issuance of additional bonds for the completion of the improvement or facility on parity with the bonds originally issued thereunder. The ordinance shall provide that the district will operate such improvement or facility continuously and that it will fix and maintain rates or charges for service from or use of the facilities constructed or acquired at all times sufficient to pay promptly the cost of maintenance and operation of the facilities so constructed or acquired, to provide an adequate depreciation fund, to pay the principal of and interest on the bonds authorized by the ordinance, and to maintain a proper reserve fund. The ordinance shall empower the district to make such covenants with respect to setting aside the income and revenue to be derived from the operation of the facilities as may be deemed advisable to assure prompt payment of the bonds and interest thereon as they mature.

After this ordinance has been adopted, it shall be published in the same manner and form as is required for other ordinances of the district. The publication of the

[31] Source: Laws 1925, p. 346 and Source: P.A. 81-1489.
[32] 70 ILCS 2105/15 from Ch. 42, par. 398

ordinance shall include a notice of (1) the specific number of voters required to sign a petition requesting that the question of the adoption of the ordinance be submitted to the electors of the district; (2) the time in which such petition must be filed; and (3) the date of the prospective referendum. The secretary of the board shall provide a petition form to any individual requesting one.

If no petition is filed with the secretary of the board as provided in this section within 30 days after the publication or posting of this ordinance, the ordinance shall be in effect after the expiration of this 30 day period. If within the 30 day period a petition is filed with the secretary of the board signed by voters of the district numbering 10% or more of the registered voters in the district asking that the question of acquiring land for the district or constructing or acquiring the facilities described in the ordinance and the issuance of the specified bonds be submitted to the electors thereof, the board of trustees shall certify the question to the proper election officials, who shall submit the question at an election in accordance with the general election law. During this time, the ordinance shall have no effect.

If a majority of the votes cast on the question are in favor of the project, and in favor of the issuance of the specified bonds, the ordinance shall be in effect. But if a majority of the votes cast on the question are against the project and the issuance of the bonds, the ordinance shall not become effective. If the ordinance becomes effective it shall be recorded in the recorder's office in the county or counties in which the property is located.

Bonds issued under this section are negotiable instruments, and shall be executed by the president and by the secretary of the board of trustees. In case any officer whose signature appears on the bonds or coupons ceases to hold office before the bonds are delivered, his signature, nevertheless shall be valid and sufficient for all purposes, the same as though he had remained in office until the bonds were delivered[33].

Sec.E9[34]. Bonds issued under Section 15.1 shall be payable solely from the revenue derived from the operation of the land or facilities for which the bonds were issued. These bonds shall be purchased, within the meaning of any constitutional or statutory limitation. Each bond shall plainly state on its face that it has been issued under the provisions of Section 15.1 and 15.2 of this Act and that it does not constitute an indebtedness of the district within any constitutional or statutory limitation.

These bonds shall be sold in such manner and upon such terms as the board of trustees shall determine. If the bonds are issued to bear interest at the maximum rate authorized by the Bond Authorization Act, as amended at the time of the making of the contract, they shall be sold for not less than par plus accrued interest. If the bonds are issued to bear interest at a rate of less than the maximum rate authorized by the Bond Authorization Act, as amended at the time of the making of the contract, the minimum price at which they may be sold shall be such that the interest cost to the municipality of the proceeds of the bonds shall not exceed the maximum rate authorized by the Bond Authorization Act, as amended at the time of the making of the contract, computed to maturity, according to the standard table of bond values.

With respect to instruments for the payment of money issued under this Section, it is and always has been the intention of the General Assembly(i)that the Omnibus Bond Acts are and always have been supplementary grants of power to issue instruments in accordance with the Omnibus Bond Acts, regardless of any provision of this Act that may appear to be or to have been more restrictive than those Acts, (ii) that the provisions of this Section are not a limitation on the supplementary authority granted by the Omnibus Bond Acts, and (iii) that instruments issued under this Section within the supplementary authority granted by the Omnibus Bond Acts are not invalid because

[33] Source: P.A. 87-767.
[34] 70 ILCS 2105/15.2 from Ch. 42, par. 398.2

of any provision of this Act that may appear to be or to have been more restrictive than those Acts[35].

Sec. E10[36]. Whenever revenue bonds are issued under Section _________ of this Act, all revenue derived from the operation of the specified land or facilities shall be set aside as collected and shall be deposited in a separate fund designated as the "Revenue Bond Fund" of the district. This fund shall be used only in paying the cost of operation and maintenance of the facility, in providing an adequate depreciation fund, and in paying the principal of and interest upon the revenue bonds issued under Section 15.1.[37]

Sec. E11[38]. Any holder of a bond issued under Section _______ or of any coupon representing interest accrued thereon, may, in any civil action, compel the performance of the duties of the officials of the district set forth in Sections _______ through ______ of this Act.

If the Board of Trustees defaults in the payment of the principal of or interest upon any of these bonds, any court having jurisdiction in any proper action may appoint a receiver to administer the land and facilities on behalf of the WQT District with power to charge and collect fees to provide sufficient revenue for the payment of the operating expenses and for the payment of such bonds and interest thereon and to apply the income and revenue in conformity with Sections _______ through _______ and the ordinance providing for the issuance of these bonds[39].

Sec. E12[40]. Whenever any land or facilities financed by the issuance of bonds under Section _______ is combined with any other land or facilities to be financed by the issuance of bonds under Section ________, and the District has unpaid obligations which are payable solely from the revenue derived from the operation of the land or facilities to finance which the bonds were issued, the unpaid obligations may be refunded by the issuance and exchange therefore of revenue bonds with the consent of the respective holders of the unpaid obligations, if such obligations are not by their terms then callable for redemption in advance of their stated maturities. Whenever any such outstanding unpaid obligations are refunded, the unpaid obligations shall be surrendered and exchanged for revenue bonds of a total principal amount which shall not be more but may be less than the principal amount of the obligations exchanged and the interest thereon to the date of exchange[41].

Sec. E13.[42] Nothing in this Act shall in any way limit the powers conferred upon WQT DISTRICTs under the Industrial Building Revenue Bond Act[43].

Section F. Contracts, acquisitions, and taxes

Sec. F1[44]. All contracts for work other than professional services, to be done by such WQT District, the expense of which will exceed $2500, shall be let to the lowest responsible bidder therefor upon not less than thirty days' public notice of the terms and conditions upon which the contract is to be let, having been given by publication on the District’s website or in a newspaper of general circulation published in said district, and the said board shall have the power and authority to reject any and all bids, and re-advertise.

Sec. F2. In all other respects such contract shall be entered into and the performance thereof controlled by the provisions of an Act entitled "An Act concerning local improvements," approved June 14, 1897, in force July 1, 1897, and amendments thereto

[35] Source: P.A. 86-4.
[36] 70 ILCS 2105/15.3) (from Ch. 42, par. 398.3
[37] Source: Laws 1957, p. 647.
[38] 70 ILCS 2105/15.4) (from Ch. 42, par. 398.4
[39] Source: Laws 1957, p. 647.
[40] 70 ILCS 2105/15.5) (from Ch. 42, par. 398.5

[41] Source: P.A. 76-720.
[42] 70 ILCS 2105/15.6 from Ch. 42, par. 398.6
[43] Source: P.A. 85-293
[44]70 ILCS 2105/16) (from Ch. 42, par. 399

as nearly as may be; provided, that contracts may be let for making proper and suitable connections between the mains and outlets of the respective sewers in said district, with any conduits, main pipe or pipes that may be constructed by such WQT District[45].

Sec. F3[46]. Purchases made pursuant to this Act shall be made in compliance with the "Local Government Prompt Payment Act", approved by the Eighty-fourth General Assembly[47].

Sec. F4[48]. The board of trustees annually may levy and collect taxes for corporate purposes upon property within the territorial limits of such district, the aggregate amount of which for each year shall not exceed __________% of the value, as equalized or assessed by the Department of Revenue, of the taxable property within the corporate limits.

The right to levy such additional tax, authorized by the legal voters of the district, may, at any time after one or more tax levies, be terminated by a majority vote of the electors of such district at a referendum. Upon the petition of 10% of registered voters of the district, the duty of the trustees of any such district shall be to certify the proposition to terminate such additional taxing power to the proper election officials. Those officials shall submit the proposition at an election in accordance with the general election law.

The board shall cause the amount required to be raised by taxation in each year to be certified to the county clerks in each county within such district on or before the second Tuesday in August, as provided in the General Revenue Law of Illinois. All taxes so levied and certified shall be collected and enforced in the same manner and by the same officers as State and county taxes, and shall be paid over by the officer or officers collecting the same to the treasurer of the WQT District in the manner and at the time provided by the General Revenue Law of Illinois. When the moneys of the district are deposited with any bank or savings and loan association, the treasurer shall require such bank or savings and loan association to pay the same rates of interest for such moneys deposited as such bank or savings and loan association is accustomed to pay depositors under like circumstances in the usual course of its business. All interest so paid shall be placed in the general fund of the district, to be used as other moneys belonging to such district raised by general taxation.

No bank or savings and loan association shall receive public funds as permitted by this Section, unless it has complied with the requirements established pursuant to Section 6 of "An Act relating to certain investments of public funds by public agencies", approved July 23, 1943, as now or hereafter amended[49].

Sec. G Expansion and maintenance of infrastructure

Sec. G[50]. Every such WQT DISTRICT is authorized to construct, maintain, alter and extend its sewers, pipelines, channels, ditches, drains, levees, orifices, control gates along, upon, under and across any highway, street, alley or public ground in the State as a proper use of highways, but so as not to incommode the public use thereof, and the right and authority are hereby granted to any such district to construct, maintain and operate any conduits, mains or pipes, wholly or partially submerged, buried, or otherwise, in, upon and along any of the lands owned by said State and under any of the public waters therein, provided that the extent and location of the lands and waters so used and appropriated shall be approved by the Governor of said State of Illinois, upon application duly made to him asking for such approval: and provided further, that the rights, permission and authority hereby granted shall be subject to all public rights of commerce and navigation, and to the authority of the

[45] Source: P.A. 82-356.
[46] 70 ILCS 2105/16.1 from Ch. 42, par. 399.1
[47] Source: P.A. 84-731.
[48] 70 ILCS 2105/17 from Ch. 42, par. 400
[49] Source: P.A. 83-541.
[50] 70 ILCS 2105/18 from Ch. 42, par. 401

United States in behalf of such public rights and also to the right of said State of Illinois to regulate and control fishing in said public waters[51].

Sec. G2[52]. Whenever there shall be located within the bounds of any such district incorporated under the provisions of this Act, any United States military post, reservation or station, or any naval station, the board of trustees of said district are hereby authorized to enter into contracts or agreements with the appropriate authorities of the United States, permitting either party to the contract to connect with and use any conduits, channels, pipes and to use any other structures or work installed by the other party to the contract[53].

Sec. G3[54]. The board of trustees of any such district shall have power and authority and it shall be their legal obligation and duty to prevent the pollution of any waters from which a water supply may be obtained by any city, incorporated town, individual or village within said district, provided that the authority of the Pollution Control Board of the State of Illinois or its successor as may be fixed by law shall not be superseded and said board of trustees shall have the right and power to appoint and support a sufficient police force, the members of which may have and exercise police powers for the purposes of this Act only over the territory within such district, and over the territory outside of said district included within a radius of fifteen miles from the intake of any such water supply in any such waters, for the purpose of preventing the pollution of said waters and any interference with any of the property of such district; but such police officers when acting within the limits of any such city, town or village, shall act in aid of the regular police force thereof, and shall then be subject to the direction of its chief of police, city or village marshals, or other head thereof; provided, that in so doing, they shall not be prevented or hindered from executing the orders and authority of said board of trustees of such district[55].

Sec. G4[56].

(a) The board of trustees of any WQT District incorporated under this Act shall have the power to build and construct and to defray the costs and expenses of the construction of drains, sewers, or laterals, septic tanks and other works for the disposal of sewage, water pipes, streets and roads, or local shore improvements, together with other necessary adjuncts thereto, including pumps and pumping stations and also may construct dams, deepen or improve the channel, bed, banks or shore or shores or any part thereof of any stream, water course or other body of water in such district, and acquire both real and personal property, in the execution or in furtherance of the powers granted to such district, by special assessment or by general taxation, or by special service area taxation if authorized as provided under this Section, as they by ordinance shall prescribe. The board of trustees of any WQT District shall have power to contract with any sanitary district now or hereafter organized or with any municipality having sewage disposal works for the disposal of any sewage within the district. It shall constitute no objection to any special assessment that the improvement for which the same is levied is partly outside the limits of such WQT District, but no special assessments shall be levied upon property situated outside of such WQT District, and in no case shall any property be assessed more than it will be benefited by the improvement for which the assessment is levied.

(b) The proceedings for making, levying, collecting and enforcing of any special assessment levied hereunder, the letting of contracts, performance of the work and all other matters pertaining to the construction and making of the improvement shall be the same as nearly as may be as is prescribed in Article 5

[51] Source: Laws 1925, p. 346.
[52] 70 ILCS 2105/19 from Ch. 42, par. 402
[53] Source: Laws 1925, p. 346.
[54] 70 ILCS 2105/20 from Ch. 42, par. 403
[55] Source: P.A. 76-2439.
[56](70 ILCS 2105/21 from Ch. 42, par. 404

of the "Illinois Drainage Code", approved June 29, 1955, as heretofore and hereafter amended. Whenever in said Article the word "Commissioner" is used, the same shall apply to the board of trustees constituted by this Act.

(c) The proceedings for making, levying, collecting and enforcement of any special service area taxation levied hereunder shall be the same as nearly as prescribed in "An Act to provide the manner of levying or imposing taxes for the provision of special services to areas with the boundaries of home rule units and non-home rule municipalities and counties", approved September 21, 1973, as now or hereafter amended. Whenever in such Act the words "municipality" or "county" or "municipal clerk" or "county clerk" are used, with the exception of the provisions of Section 10 providing for the extension of the tax by the county clerk, the same shall be construed in relation to the board of trustees constituted by this Act, and the words applying to the municipality or county in that Act shall be held to apply to the district created under this Act and its officers, and the words "municipal clerk" or "county clerk" shall be held to apply to the secretary of the district created under this Act.

However, no special service area taxation shall be imposed hereunder unless a petition has been filed with the board of trustees by either the owners of a majority of the acreage or a majority of the owners of the acreage of the WQT District which lies in the proposed special service area. The petition shall be accompanied by a description of the proposed special service area, an explanation of the proposed program, and a notation of the proposed tax rate. The board of trustees of the district shall publish the petition and certify the results[57].

Sec. G5[58]. When any special assessment is made under this Act, the ordinance, authorizing such assessment may provide that the entire assessment and each individual assessment be divided into annual installments, not more than twenty in number. In all cases such division shall be made so that all installments shall be equal in amount, except that all fractional amounts shall be added to the first installment so as to leave the remaining installments of the aggregate equal in amount. The said several installments shall bear interest at the rate of not to exceed six per cent per annum; both principal and interest shall be payable, collected and enforced as they shall become due in the manner provided for the levy, payment, collection and enforcement of such assessment and interest, as provided in Article 5 of the "Illinois Drainage Code", approved June 29, 1955, as heretofore and hereafter amended[59].

Sec. G6[60]. Whenever any ordinance providing for any improvement shall in pursuance of authority conferred in this Act provide for payment for same, either in whole or in part, by special assessment, said board of trustees may issue bonds to anticipate the collection of the second and succeeding installments of said assessments payable only out of such assessment when collected and bearing interest at the same rate as provided upon the installments of such assessment. Said bonds shall be issued and subject to call and retirement in the same manner as provided in Article 6 of the "Illinois Drainage Code", approved June 29, 1955, as heretofore and hereafter amended[61].

Sec. G7[62]. It shall be the duty of the board of trustees of any district organized under this Act to proceed diligently to the fulfillment of all the purposes and objects of this Act subject to the proper use and disposition of available funds[63].

Sec. G8[64]. Before any work is commenced under the provisions of this Act, the plans therefore shall be submitted to, and approved by the federal, state and local agencies

[57] Source: P.A. 81-862.
[58] 70 ILCS 2105/22 from Ch. 42, par. 405
[59] Source: P.A. 81-862.
[60](70 ILCS 2105/23 from Ch. 42, par. 406
[61] Source: P.A. 81-862
[62] 70 ILCS 2105/24 from Ch. 42, par. 407
[63]Source: Laws 1925, p. 346
[64]70 ILCS 2105/25) (from Ch. 42, par. 408

having jurisdiction over the waters of the state and federal governments or their successor as may be fixed by law[65].

Sec. G9[66]. It shall be the duty of the board of trustees of any WQT DISTRICT organized under this Act to proceed diligently and without delay to prevent pollution of any stream or any other body of water within the confines of such district and to proceed at once to diligently cause any and all parties, persons, firms and corporations to cease any and all pollution of any such streams or body of water within such district; provided that the authority of the Pollution Control Board of the State of Illinois or its successor as may be fixed by law shall not be superseded[67].

Sec. G10[68]. In the execution of the powers herein granted and the duties vested in the Board of Trustees of districts organized under this Act, such districts may cooperate and enter into agreements with the proper agencies of the United States Government, Municipal Corporations of this State, political subdivisions and persons and associations, for the formulation of plans, and for the construction of any and all improvements for the control of destructive floods, and for the conservation, regulation, development and utilization of water, waterways and water resources, or other purposes of this Act. Such agreements may assign to the several cooperating agencies particular projects or portions of projects for the purposes herein stated and may provide for joint understandings for said purposes and for contribution to execute any works agreed upon with any other of the above mentioned agencies in the State of Illinois to carry out the provisions of the Act[69].

Sec. G11[70]. A WQT District organized under this Act may be dissolved in the following manner: Its board of trustees shall adopt an ordinance finding and determining that all outstanding debts and obligations have been discharged or assumed by another public agency and that the public interest does not require continuation of the district. The publication of the ordinance shall be accompanied by a notice of (1) the specific number of voters required to sign a petition requesting the question of dissolving the district to be submitted to the electors; (2) the time in which such petition must be filed; and (3) the date of the prospective referendum. The district secretary shall provide a petition form to any individual requesting one.

Unless a petition shall be filed with the board within 30 days after such publication containing the signatures of a number of electors residing in the district equal to 10% or more of the registered voters in the district requesting that the question of the dissolution of the district be submitted to an election, the district shall be deemed to be dissolved at the expiration of the 30 day period. If such a petition is filed, the question of the dissolution of the district shall be certified to the proper election officials, who shall submit the question to the electors of the district at an election in accordance with the general election law. The question shall be in substantially the following form:

"Shall the .... YES
Water Quality Trading District ------------------------- be dissolved?" NO

The result of the election shall be entered upon the corporate records of the district. If a majority of the ballots cast on the question are marked "yes" the district shall be dissolved. But if a majority of the ballots on the question are marked "no", the corporate authorities shall proceed with the affairs of the district as though the dissolution ordinance had never been adopted, and, in such case, the question shall not again be considered for a period of one year. When the business and affairs of any such district have been closed up after dissolution, such fact shall be

65 Source: P.A. 81-840
66 70 ILCS 2105/26 from Ch. 42, par. 409
67 Source: P.A. 76-2439
68 70 ILCS 2105/26a from Ch. 42, par. 409a
69 Source: Laws 1951, p. 933.
70 70 ILCS 2105/26b from Ch. 42, par. 409b

certified by the board of trustees to the county clerk and recorder of the county or counties in which the district was situated and to the Secretary of State. All assets of the district remaining after the closing up of business affairs and the retiring of all debts and obligations shall be paid to the corporate fund of the township in which such district was situated. If such district was situated in 2 or more townships, the assets shall be divided on a pro rata basis between the corporate fund of each township according to the value, as equalized and assessed by the Department of Revenue, of all taxable property in each township situated within the boundaries of such district[71].

Sec. G12[72]. Nothing in this Act contained shall apply to or be construed in any manner to affect the property, real, personal or mixed and wherever situated, or the channels, drains, ditches and outlets and adjuncts and additions thereto and their use, operation and maintenance and the right to the flow of water therein for sewage dilution, or affect the jurisdiction, rights, powers, duties and obligations of any existing sanitary district or any sanitary district or any city or village which now has a population of one million or more within its territorial limits[73].

Sec. G13. Governance of the production of water quality credits and other activities of the WQT District shall be overseen by the Illinois Environmental Protection Agency (IEPA) including licensing, permitting, monitoring and site inspections by the IEPA and other regulatory agencies such as the Army Corps of Engineers, USEPA, U.S. Fish and Wildlife Service, U.S. Department of Agriculture and the Illinois Department of Natural Resources and its subordinate agencies.

Sec. G14. Monitoring will include the following: cost (to be kept confidential), credit sales and the contract governing the conditions of sale (mass and concentration of constituents with flow), income (to be kept confidential), water processed (reported in acre-feet per day), energy consumed (reported in kwh/day), written monthly report submitted to IEPA and an annual report summarizing all of the above data and providing their analyses. Only the IEPA, and upon special request the USEPA, will have access to the contracts, data and analyses. This information will be kept confidential because of the competitive nature of the market.

Sec. G14[74] (Short title). This Act shall be known and may be cited as the "Water Quality Trading Act”[75].

Sec. H. Water quality credits and other ecosystem-system service credits, including other fungible activities produced by the district, shall be reviewed and approved by the following agencies:

1. Flood control easements—US Army Corps of Engineers
2. Integrity of the hydraulic infrastructure—State Water Control Division
3. The district is empowered to petition the Pollution Control Board relative its operation and in particular to its effluent and air emission standards
4. Sale of water quality credits such as contaminants, as measured by their load and concentration reduction and contract period relative to the contractee’s NPDES permit and effluent characteristics of the district—IEPA having primary responsibility and the control of the USEPA. These two agencies will coordinate the certification and review activities.
5. Recreational hunting and fishing permits—Illinois Department of Natural Resources.
6. Commercial fishing permits (Carp and other invasive and destructive species)—Illinois Department of Natural Resources.
7. Camping and hiking—public health and safety and required permits—Illinois Department of Natural Resources.

[71] (Source: P.A. 87-767.)
[72] 70 ILCS 2105/27 from Ch. 42, par. 410
[73] Source: Laws 1925, p. 346.
[74] 70 ILCS 2105/28 from Ch. 42, par. 410a
[75] Source: P.A. 79-1454.

Sec. I. The state agencies, working with their federal counterparts, shall prepare the necessary detailed guidelines and requirements for the operations of the districts in producing their various ecosystem services. The production of these documents shall be the responsibility of the state agencies and shall be produced no later than six months from the date of passage of the Water Quality Trading Act.

APPENDIX C: PROJECT RELATED PUBLICATIONS

Peer-reviewed publications resulting from project research:

Tomer, M.D., Crumpton, W.G., Bingner, R.L., Kostel, J.A., and James, D.E. 2013. Estimating nitrate load reductions from placing constructed wetlands in a HUC-12 watershed using LiDAR data. *Ecological Engineering* 56:69-78.

Tomer, M.D., Porter, S., James, D.E., Boomer, K., Kostel, J.A., and McLellan, E. 2013. A framework to merge precision technologies and provide a planning resource for agricultural watershed conservation. *Journal of Soil & Water Conservation* 68(5): 113A-120A.

Lentz, A.T.B., Ando, A.W., and Brozovic, N. 2013. Water quality trading with lumpy investments, credit stacking, and ancillary benefits. *Journal of American Water Resources Association* 50(1): 83-100.

M.S. Thesis:

Lentz, A. 2011. Water Quality Trading: Credit Stacking and Ancillary Benefits. University of Illinois at Urbana-Champaign M.S. Thesis.

Lentz, A. 2011. Physical Criteria for Wetland Targeting on a Watershed Scale. University of Illinois at Urbana-Champaign M.S. Thesis.

Presentations:

Bingner, R.L., Kostel, J.A., Monchak, J.J., Yuan, Y., and H. Momm. 2014. Evaluating wetland impacts on nutrient loads within watershed systems using AnnAGNPS. Accepted paper for 69th SWCS International Annual Conference. Lombard, IL, July 27-30, 2014.

Kostel, J.A., Monchak J.J., and R.L. Bingner. 2014. Evaluation of nutrient reductions for potential wetland locations using the wetland and buffer features of AnnAGNPS. Accepted paper for 69th SWCS International Annual Conference. Lombard, IL, July 27-30, 2014.