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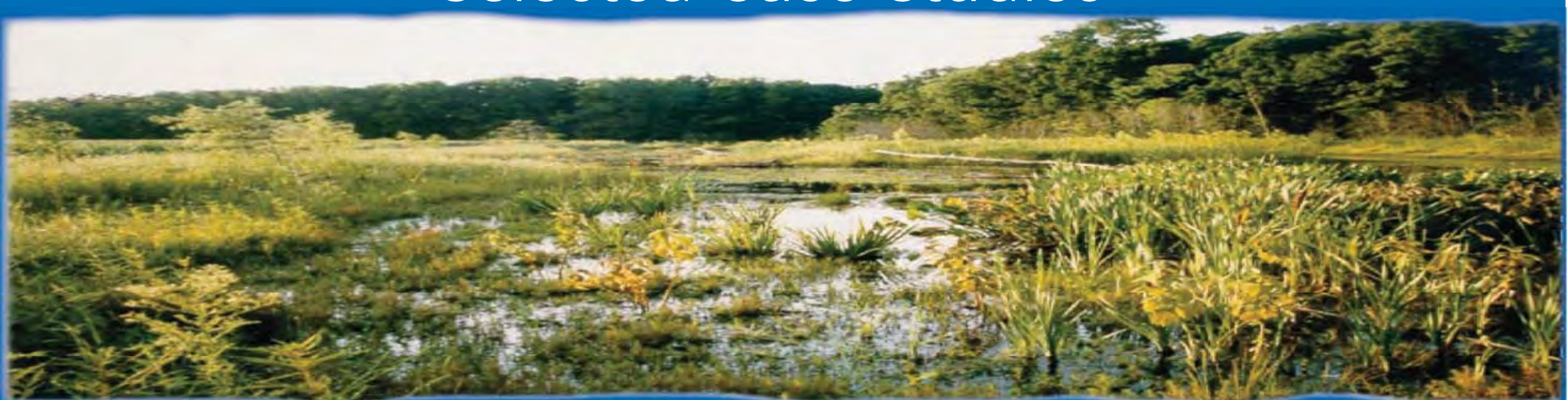
Wetlands and Water Quality Trading:

Review of Current Science and Economic Practices with Selected Case Studies



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Wetlands and Water Quality Trading:
Review of Current Science and Economic Practices With Selected Case Studies

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Notice

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Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threatens human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

The goal of this report is to provide a review of the existing science and economic practices of using wetlands as part of water quality trading programs. This report evaluates the technical, economic, and administrative components of developing and implementing water quality trading (WQT) programs to nutrient removal is the primary focus to improve water quality. This report collates and synthesizes current literature with the goal of providing a baseline understanding of the current state of the use of wetlands in water quality trading programs. Although this document is intended to gather a significant amount of the current scientific literature available at the time of publication, it should be noted that it does not include all possible literature available on the subject due to the constantly evolving work in this area. This document should be used as a component of all the science on this subject and not considered as the sole document in this area.

Stephen G. Schmelling, Director
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Acronyms and Abbreviations

µg/L	micrograms per liter
ACWWA	Arapahoe County Water and Wastewater Authority
ADAPT	Agricultural Drainage and Pesticide Transport (model)
Association	Tar-Pamlico Basin Association
ASWCD	Ada Soil and Water Conservation District
CCBWQA	Cherry Creek Basin Water Quality Authority
BMP	best management practice
CBOD	carbonaceous biological oxygen demand
CENR	Committee on Environment and Natural Resources
cfs	cubic feet per second
CH_4	methane
CN	curve number
CO_2	carbon dioxide
CSCD	Canyon Soil and Water Conservation District
CWA	Clean Water Act
CZARA	Coastal Zone Management Act Reauthorization Amendments
DCFROI	discounted cash ow return on investment
DSWC	Division of Soil and Water Conservation (North Carolina)
EEP	Ecosystem Enhancement Program
ETN	Environmental Trading Network
GIS	geographic information system
GWERD	Groundwater and Ecosystem Restoration Division
ICWC	Idaho Clean Water Cooperative
IDAPA	Idaho Administrative Procedures Act
IDEQ	Idaho Department of Environmental Quality
ISCC	Idaho Soil Conservation Commission
LAC	local and basin committees
lb/yr	pound(s) per year
LBR	Lower Boise River
LNBA	Lower Neuse Basin Association
mg/L	milligram(s) per liter
mgd	million gallons per day
MOU	Memorandum of Understanding
MPCA	Minnesota Pollution Control Agency
MPP	maximum purchase price
MSP	minimum selling price
N_2	nitrogen gas
N_2O	nitrous oxide
NADB	North American Wetlands for Water Quality Data Base

NANI	net anthropogenic nitrogen inputs
NBOD	nitrogenous biochemical oxygen demand
NCAC	North Carolina Administrative Code
NCDWQ	North Carolina Division of Water Quality
NCEDF	North Carolina Environmental Defense Fund
NCEMC	North Carolina Environmental Management Commission
NH_4	ammonium
NH_4-N	ammonium nitrogen
NLEW	Nitrogen Loss Evaluation Worksheet
NO_3	nitrate
NO_3-N	nitrate-nitrogen
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	nonpoint source
NRCA	Neuse River Compliance Association
NRCS	Natural Resources Conservation Service
NRET	Neuse River Education Team
NRMRL	National Risk Management Research Laboratory
NSW	nutrient sensitive waters
O&M	operation and maintenance
PLAT	Phosphorus Loss Assessment Tool
PRF	Pollution Reduction Facility
PS	point source
PTRF	Pamlico-Tar River Foundation
Rahr	Rahr Malting Company
RBC	River Basin Center
SD	standard deviation
SDA	System Dynamics Analysis
Shaw	Shaw Environmental, Inc.
SISL	Surface Irrigation Soil Loss
SR-HC	Snake River-Hells Canyon
SWAT	Soil Water Assessment Tool
TD	technical directive
TKN	total Kjehldahl nitrogen
TMAL	total maximum annual load
TMDL	total maximum daily load
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids
TWDB	Treatment Wetland Database
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
WQT	water quality trading
WTF	wastewater treatment facility
WWTP	wastewater treatment plant

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Cover Photo:
Clover Island - Restored wetland on a marginal agricultural field. Blacksten Wildlife Area., Kent Co. Delaware -T. Barthelmeh

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Executive Summary

The Groundwater and Ecosystems Restoration Division of the National Risk Management Research Laboratory serves as the U.S. Environmental Protection Agency's (USEPA) center for risk management research on ecosystem protection and restoration. It provides detailed technical guidance through Technical Directives (TD) for the technical review of papers, technical consultation, short-term project support, and field support. The current assignment for Shaw Environmental, Inc. (Shaw) addressed by this technical report is initiated by TD No. 2OA618SF and titled "Water Borne Stressor (Nutrient) Trading Program to Improve Water Quality: Science and Economic Review."

The study evaluates the technical, economic, and administrative aspects of establishing water quality trading (WQT) programs where the nutrient removal capacity of wetlands is used to improve water quality. WQT is a potentially viable approach for wastewater dischargers to cost-effectively comply with regulations and to improve water quality. The premise of WQT is that dischargers who cannot cost-efficiently reduce their ef uent loads (i.e., high cost) may buy water quality from more cost-efficient (i.e., lower cost) dischargers. Such trades may include point source (PS) dischargers, nonpoint source (NPS) dischargers, or both. This study focuses on WQT programs that allow PS-NPS trades where wetlands are used to achieve the NPS discharge reductions. The report integrates the review of published peer-reviewed literature and data sources addressing the nutrient removal function of wetlands, WQT, and the review of four case studies of existing WQT programs. Findings are used to illustrate opportunities and challenges associated with using wetlands in NPS nutrient trades. Along with any resulting research, this study should provide a technical basis for USEPA to prioritize research and publish related information resources.

The literature review addresses three concepts: (1) wetland nutrient removal, (2) trading economics, and (3) trading regulations. The case studies investigate these concepts in practice. Criteria to select the case studies included the type of program (PS-NPS); the constituent traded (nitrogen and phosphorus); implementation status; whether or not wetland construction/enhancement could be used to generate credits; and the extent to which published information was available on the program. Four case studies are evaluated: (1) Cherry Creek, Colorado; (2) Minnesota River and Rahr Malting Company (Rahr), Minnesota; (3) Lower Boise River (LBR), Idaho; and (4) Tar-Pamlico and Neuse Rivers, North Carolina.

The first category of literature review evaluates wetland nutrient removal of nitrogen and phosphorus. Constructed and natural wetlands are compared and contrasted. Both buffer downstream nutrients by storing and transforming nutrients, thereby effectively treating discharge from PSs and NPSs. The fate and transport of nutrients in wetlands is a function of dynamic biological, physical, and geochemical processes. The resulting complexities render each wetlands application unique. As such, each application warrants an evaluation of nutrient availability and the wetlands removal efficiency. Besides nutrient removal, wetlands also provide several human and ecological benefits such as ood control, habitat for endangered and economically important species, erosion control, and recreation. Caution must be exercised, though, to avoid unintended consequences of constructed wetlands. Potential negative consequences include the loss of other productive land uses, the impairment of adjacent water bodies, danger to wildlife attracted to the wetland, in ux of invasive plants, odor issues, and in ux of dangerous or nuisance animals. In order for wetlands to be used for WQT, it is necessary to be able to quantify the nutrient load reduction to calculate tradable credits. Performance measurements or models/calculations of nutrient removal data can be used to quantify these credits. The lifespan of the credits, which is a function of how long the best management practice (BMP) is effective at removing nutrients, with a margin of safety, is also critical to determining the value of the wetlands for a given trade.

Economics are examined as the second category of the literature review. WQT involves buyers, sellers, and, to varying degrees, regulators. Each of these stakeholders has their own interests, concerns, challenges, and gaps. Special interests with diverse specific concerns and the general public also affect economic decisions. There are several economic trading challenges that make the risk and/or return of investing in WQT strategy unattractive to the stakeholder, thereby hindering efficient and fair deal-making and ultimately suppressing WQT. These challenges include simplified modeling of natural system impacts, expensive risk factors, high transaction costs, and undefined property rights.

Several changes to WQT program design could help overcome these obstacles by facilitating stakeholder decision-making based on an improved understanding of value and risk. While some of the changes may not necessarily increase the number of active trades, they all serve to improve the market so that trades reflect intended goals. Measures to increase the efficiency of the trading programs would ultimately reduce the cost to develop and operate WQT exchanges. They also reduce the transaction costs of individual trades. Increasing PS compliance liability will provide a significant driver for trading. Improvements to market and non-market economic valuations of ecological services must be achieved and would help to increase the real or perceived value and opportunities NPSs can realize as a result of participating in WQT. WQT would also benefit from making tools for applying economic investment decision methods available to potential participants. Probabilistic analyses for evaluating the risk and opportunity associated with WQT should replace single-point estimate inputs, which are subject to error and bias. Probabilistic analysis would provide decision-makers with more confidence in committing capital to WQT. Finally, System Dynamics Analysis (SDA), which is a modeling process that evaluates the consequences and sequencing of complex events and phenomena inherent in many systems, would optimize the performance of the WQT market. Many of these changes simply require modifications to existing policies and have proven effective for other applications, such as business strategy development and resource management.

Finally, trading regulations are examined in the literature review. The report describes the USEPA Water Quality Trading Policy, specifically examining regulations related to wetlands. In 2003, the USEPA released its Water Quality Trading Policy to offer guidance and assistance in developing and implementing trading programs. Trading is particularly encouraged by the policy for phosphorus and nitrogen loads. The geographic area for trading programs is described by the policy as the watershed or area covered by an approved total maximum daily load (TMDL). Surplus credits are defined by the policy as constituent reductions greater than those already required by a regulation. Clear authority to trade along with unambiguous legal protection for using the purchased credits to meet established regulatory requirements is crucial for a successful WQT program. Success also mandates compliance and enforcement provisions. Programs vary based on the location and circumstances of the trading and are thus administered by the states. While strict limits on discharges drives demand for WQT, the 2007 Farm Bill will likely drive supply by compelling more NPS participation in trading. If supported by Congress, BMPs subsidized by tax dollars will become eligible to generate sellable credits.

Four case studies are evaluated according to technical, economic, and regulatory concepts. The first of these is the Cherry Creek, Colorado, case study, which is an example of a clearinghouse type of market. In 1989, the Cherry Creek Reservoir Control Regulation, listed as Regulation #72, set the stage for WQT between PS and NPS discharges of phosphorus and mandated the Cherry Creek Basin Water Quality Authority (CCBWQA) to administer the basin. The CCBWQA has been dedicated to creating and maintaining its own phosphorus reduction facilities. Furthermore, it has been committed to fostering and evaluating other BMP sources in the watershed. Three trades have occurred, one of which involved an NPS. Although these trades allowed PSs to offset some of their discharges more cost effectively, the water quality goal has yet to be achieved because the TMDL was established to accommodate growth. Nonetheless, with its flexible trading approaches and unambiguous guidelines and oversight by the CCBWQA, future success is possible.

The second case study, Rahr, in Minnesota, is an example of a sole-source offset accomplished without an established market there. In 1997, the Minnesota Pollution Control Agency (MPCA) issued to Rahr a discharge permit requiring WQT in order to satisfy the conditions of no additional oxygen-demanding discharge into the Minnesota River Basin. The permit specified acceptable BMP options, which included the three selected: critical area set-asides and wetland restoration, erosion control, and livestock exclusion. The NPS controls achieved the offsets within four years and must be maintained as long as Rahr discharges effluent. The trades were necessary for Rahr's growth. The NPS controls implemented also resulted in other environmental and economic benefits beyond improvements to water quality. Despite the successes, limitations to the program's success exist. Instead of validating the performance of NPS controls through monitoring, reductions were evaluated by conservative assumptions, thereby requiring larger water quality improvements from the BMP projects to compensate for uncertainty, and this added expense. Furthermore, NPSs are not regulated and therefore do not have the same marketable incentive to engage in trading. Rahr will have to overcome this in the event it needs to purchase additional credits. Overall, the benefits far outweighed the limitations, rendering this trading program a success.

The third case study is the trading program in the LBR in Idaho. The Effluent Trading Demonstration Project is a start-up program for phosphorus trading in the LBR watershed in Idaho. Although the framework of this exchange market has been established, the phosphorus TMDL has yet to be set, thereby delaying the need for trades. Nonetheless, the WQT simulation of a scenario for generating credits used sediment basins and constructed wetlands to reduce discharge. Unfortunately, high costs and use of resources to develop the trading framework hinder the program. Water rights issues discouraged buyers and sellers from participating. Potential regulation also deterred NPSs participation. Despite these issues, the participants in the demonstration project felt that the LBR framework was successful. The project highlighted issues of efficiency and uncertainties in credit calculations and BMP lifespan, and long-term fate of phosphorus removed using BMPs such as constructed wetlands.

The fourth case study comes from the Tar-Pamlico and Neuse Rivers in North Carolina. Both of these programs are based on a group cap-and-trade system and both rely on associations of PS dischargers. A nutrient offset fee must be paid for each pound of nutrient discharged beyond that collectively allowed for the association. This fee is paid to a state-administered fund for implementing BMPs to reduce the nutrient load from NPSs. Both programs successfully implemented strategies to reduce nutrient loads. The nutrient-sensitive water strategies for both basins relied heavily on public and stakeholder input. While many lessons were learned, there remain many unanswered questions regarding issues such as seasonality, nutrient removal efficiencies over time, and lifespan of the BMPs.

The literature review and case studies support a synthesis of the information regarding WQT involving NPS reductions that utilize wetlands. This synthesis summarizes the key observations of the state of WQT using wetlands based on examples provided by the case studies as well as warranted research and modifications to encourage its viability. As a cautionary note, of the more than 80 WQT programs, pilots, and simulations identified in the process of selecting the four case studies, these programs are among the longest-standing. All were developed before the USEPA issued the Water Quality Trading Policy in 2003. It is therefore recommended that some of the most recent WQT programs, for which there is currently very little published data, be evaluated to determine how and to what extent these programs are addressing the research needs and data gaps identified in this document. This said, the observations made in this document include a comparison of performance monitoring versus conservative presumption; motivations for NPS participation; effects of compliance thresholds; comparison of program structure; credit life; economic challenges to trading; and property rights and transfer of liability.

Uncertainty drives the question of performance monitoring versus conservatism, whereby high trading ratios are used to offset uncertainty. Such uncertainty derives from the dynamic, complex factors affecting wetland nutrient removal efficiency and from spatial differences between the wetlands and the PS location. Applying conservative safety factors often mitigates such uncertainty. The case studies illustrate that typically program participants presume it is more cost-effective to apply such conservatism than to directly measure the effectiveness of the constructed wetland.

WQT with NPS contributors depends on their desire to participate. The case studies demonstrate that NPS nutrient loads often exceed PS loads to a watershed. WQT programs may be used to create an economic incentive for NPSs to control their contributions by compensating them for load reductions. This is feasible in certain circumstances based on the significant difference in costs. Unfortunately, NPS contributors have a subtle disincentive to participate in trading programs in that they may lose their non-regulated status or face stricter enforcement. Stronger incentives for NPS participation call for a better understanding of nutrient loading on a watershed scale. Compliance thresholds directly affect trading attractiveness. Discharge limits must be strict enough to oblige trading, while enforcement of these limits must be credible to avoid dischargers from gaming the system instead of participating in trading.

Program structures vary considerably and include sole-source offsets, clearinghouses, and compliance associations. The various models may all be valid when executed appropriately. Questions regarding lifespan of BMPs concern the protocol beyond the expiration of credits, the temporal differences between the times of credits generation and application, and the procedure to deal with surplus credits. Economic trading challenges could suppress WQT by making the net economic value of trading less attractive than alternate compliance management strategies due to risks and uncertainties. These challenges could hinder efficient and fair deal-making because they make the risk and/or return of investing in WQT high to the buyer, the seller, or both. Lastly, the way property rights and liability transfer are addressed depends on the program. Each of the case studies manages differently the question of liability in the event of BMP failure. Lingering liability for the seller leaves unknown risk associated with trading plus additional costs, and logistics associated with monitoring BMPs implemented on the credit seller's property make WQT less attractive to PSs. Additionally, the property rights to a wetland after the credits have expired must be clear. Such doubts deter the use of constructed wetlands as a BMP in WQT programs. Long-term regulatory implications of building constructed wetlands to generate credits for WQT programs need to be clarified.

Finally, additional research recommendations within technical, economic, and regulatory categories are presented in the final section of this document. Technical research needs concern reducing uncertainty in trades involving wetlands. Several possible research topics emerge to address uncertainty in wetland performance. SDA can evaluate the complex events and phenomena inherent in many systems, thereby reducing uncertainty and quantifying risk. To address economic challenges, research must aim to determine value and risk associated with strategies that use wetlands to reduce nutrient loads. Administrative research targets regulations that promote opportunities, minimize transaction costs, formally supervise WQT implementation and compliance, assess methods to promote NPS participation, and minimize gaming risks.

WQT using wetlands is a potentially viable alternative for achieving water quality standards. This report reviews the current technical, economic, and regulatory status of this option. Based on the observed strengths and identified challenges, Shaw recommends actions to promote such programs to their fullest potential.

1.0 Introduction

The Groundwater and Ecosystems Restoration Division (GWERD) of the National Risk Management Research Laboratory (NRMRL) serves as the U.S. Environmental Protection Agency's (USEPA) center for risk management research on ecosystem protection and restoration, focusing its efforts on studies to assess and enhance the ability of terrestrial and aquatic ecosystems to support and maintain water quality, support native species of plants and animals, and to provide ecological services on a watershed scale. Shaw Environmental, Inc. (Shaw) receives detailed technical guidance and direction from NRMRL/GWERD in the form of Technical Directives (TD) for the areas of technical review of papers, technical consultation, short-term project support, and field support. The current assignment addressed by this technical report is initiated by TD No. 2OA618SF and titled "Water Borne Stressor (Nutrient) Trading Program to Improve Water Quality: Science and Economic Review."

The relative importance of point sources (PS) and nonpoint sources (NPS) of nutrients varies from watershed to watershed. However, according to an agriculture handbook published by the U.S. Department of Agriculture (USDA), "national-scale water quality assessments strongly suggest that agriculture is a leading source of remaining water quality problems" (Heimlich, 2003). Nutrient inputs into the waters of the United States continue to be one of the major reasons that water bodies do not meet their designated uses as defined under the Clean Water Act (CWA; Federal Water Pollution Control Act Amendments of 1972, later amended in 1977). USEPA instituted a Water Quality Trading Policy to encourage trading as an innovative way of meeting water quality goals within a watershed context (USEPA, 2003a). The policy is based on the idea that different sources within a watershed may face drastically different costs to control the same constituent. Trading programs, which have proved to be very successful in meeting air quality standards, allow facilities facing higher discharge control costs to meet their regulatory obligations by purchasing environmentally equivalent, or superior, reductions from another source at lower cost than they would incur by installing additional controls. To date, this policy has been implemented to a limited extent for PS-PS trading. There is a great deal of interest in increasing the implementation of this policy for PS-NPS trading, particularly through the use of wetlands (Schubauer-Berigan, 2005; Raffini and Robertson, 2005), but there appear to be a number of possible gaps in the available scientific and economic knowledge needed to implement such trading as part of a regulatory program.

1.1 What is Water Quality Trading?

Water quality trading (WQT) is a voluntary alternative for achieving regulatory compliance with water quality standards. It is a program whereby parties can meet their discharge allowances by trading with each other. Although it has been available for over two decades, this option is just recently garnering more attention. In WQT, cost-inefficient dischargers[1] buy water quality credits from cost-efficient dischargers, who have earned credits by voluntarily implementing best management practices (BMPs) for nutrient control. By trading credits, the overall cost of achieving nutrient reduction is minimized. In an efficient market, WQT leads to lowest-cost nutrient reduction.

An established market or exchange provides the structure for the WQT transactions. The regulator or some other entity plays a third-party role in the market, protecting the interests of the public by ensuring that trading maintains or improves water quality and does not lead to degradation of the environment.

Overall, economists, regulators, dischargers, environmentalists, and other stakeholders have advocated WQT as a way to use market-based solutions to reduce the cost of complying with water quality discharge limits. The approach provides PSs with alternatives for controlling discharges with less regulation, less cost, and accelerated compliance. The exibility afforded by WQT that includes NPSs can create ecological value without increasing natural resource risk. Regulatory oversight controls the process.

1.2 Report Overview

The initial work plan for the study included a broad assessment of published literature pertaining to WQT programs that include NPS trades. As the study progressed, collaboration between the study sponsors and the authors focused the scope of the study on the use of wetlands as an NPS control to reduce nutrient loads and create credits for trade.

1 In this document, "discharger" is a term used to refer to both PSs and NPSs whose discharge is due to human influences.

The study evaluates the technical, economic, and administrative aspects of establishing WQT programs that can use and have used wetlands to generate credits for NPS trades. The evaluation relies upon a review of technical literature combined with selected case studies. The literature review and case studies are used to identify critical scientific and economic knowledge gaps that would impede the implementation of a WQT program including both PSs and NPSs. Although examples from several case studies facilitate specific points in the wetlands, economics, and regulatory reviews, this report considers the four programs included as case studies to illustrate the current state of practice of using wetlands in WQT programs. Although the programs described in the case studies are not markets, they are illustrative of important aspects of WQT involving wetlands. Based on the synthesis of this work, the USEPA will be able to develop a plan to research gaps regarding using wetlands to generate NPS credits in WQT. Addressing these gaps will provide insight towards assessing the feasibility of such programs and identify factors to opt for certain approaches.

2.0 Methods for Identifying Technical and Economic Analysis Needs

The current investigation combines a review of published literature and a case study analysis to establish and evaluate the state-of-the-art in WQT programs. By evaluating existing regionally focused WQT programs, the study identifies data and knowledge gaps and recommends research to address them. Ultimately, this review and any resulting research would enable USEPA to publish technical information for using wetlands in PS-NPS WQT programs. This study integrates two primary components: (1) review of published peer-reviewed literature and data sources addressing WQT and wetlands nutrient removal functions, and (2) review of four case studies of existing WQT programs. The literature review and case study analysis results are used to assess opportunities and potential pitfalls associated with using wetlands in NPS nutrient trades.

Shaw collaborated with USEPA to develop a list of critical questions to screen and compile relevant literature and other available sources of information for the area of WQT programs for nutrients. The primary sources of information are derived from published peer-reviewed literature, including articles from scientific and economic journals, conference proceedings, and books. Other information sources include relevant federal and state regulations. Information gained from secondary and non-peer-reviewed sources, including conference proceedings, workshops, white papers, fact sheets, web sites, etc., is used to illustrate the level of interest in WQT.

The literature review will produce a list of issues pertaining to the successful operation of WQT programs along with published data and a bibliography addressing each of these issues. The association of issues and available data will illustrate the nature and extent of data and knowledge gaps.

2.1 Literature Search Methodology

The literature review was conducted as an iterative process by listing issues to inform an initial literature search. Candidate source documents were compiled, screened according to the critical questions, and then sorted according to subject. A combination of methods was used to identify documents included in the literature review. These methods included use of internet search engines; personal communications with experts, such as the contact people for each of the case studies; agency internet sites, such as the web pages for individual WQT programs; reviewer comments; and references contained in publications already identified. A complete list of all documents identified during the literature review is composed as an annotated bibliography in Appendix A.

The following internet search engines and search terms were used to identify relevant documents.

Table 2-1. Internet Search Engines and Search Criteria

Search engines	Search terms	Date limits
Agricola http://agricola.nal.usda.gov/webvoy.htm	Wetland and nitrogen, wetland and treatment, wetland and constructed, WQT, assess WQT, assess nutrient trade, assess nutrient credit, assess nutrient models, validate nutrient models, compare nutrient models, nutrient trading	2000 to January 2006
Ecological Society of America http://www.esajournals.org/esaonline/?request=search-simple	Wetlands, nitrogen, nutrients, WQT, nutrient trading	None
Elsevier http://www.elsevier.com	Minnesota Pollution Control Agency (MPCA), Rahr Malting Company (Rahr), Cherry Creek, publications, WQT, total maximum daily loads (TMDL), equivalence, wetlands AND WQT, specific author names, nutrient trading	None
Google Scholar http://scholar.google.com/	WQT, NPS trading, pollutant trading programs, North Carolina case study specific terms: Tar-Pamlico, Neuse, Trading Program, water quality, wetlands, specific author names, TMDL, nutrient trading	None

Search engines	Search terms	Date limits
Google http://www.google.com	WQT, assess WQT, assess nutrient trade, assess nutrient credit, assess nutrient models, validate nutrient models, compare nutrient models, MPCA, Rahr, Cherry Creek, WQT, Idaho DEQ, Idaho Soil Conservation Commission (ISCC), Lower Boise River (LBR), nitrogen, phosphorus, TMDL, equivalence, wetlands AND WQT, specific author names, nutrient trading	None
PubMed database http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?CMD=search&DB=pubmed	Wetlands, nitrogen, nutrients, WQT, NPS trading, nutrient trading	None
Science Direct http://www.sciencedirect.com/	Wetlands, nitrogen, nutrients, assess WQT, assess nutrient trade, assess nutrient credit, assess nutrient models, validate nutrient models, compare nutrient models, WQT, NPS trading, nutrient trading	None
State environmental organization search engines	MPCA, Rahr, Cherry Creek, publications, WQT, TMDL, equivalence, wetlands AND WQT, specific author names, NPS pollution, nutrient trading	None
Wetlands website (SWS journal) http://www.sws.org/wetlands/	Wetlands, nitrogen, nutrients, WQT nutrient trading	None
Environmental Trading Network (ETN) http://www.envtn.org/index.htm	Workshops 2nd National Water Quality Trading Conference, held May 23-25, 2006 in Pittsburgh. (http://www.envtn.org/WQTconf_agenda.htm) Environmental Credits Generated Through Land-Use Changes: Challenges and Approaches held March 8-9, 2006 in Baltimore. http://www.envtn.org/LBcreditsworkshop/agenda.htm	None
Environmental Law Institute http://www2.eli.org/index.cfm	Workshop National Forum on Synergies Between Water Quality Trading and Wetlands Mitigation Banking held July 11-12, 2005 in Washington, DC. http://www2.eli.org/research/wqt_main.htm.	None

2.2 Literature Review Questions

Literature screening criteria are grouped into three categories: Level 1 – Preliminary Screening Questions for Identification of Case Studies; Level 2 – Case Study Analysis Questions; and Level 3 – General "State of the Art" Questions. The case studies are used to address the Level 1 and 2 questions. The Level 3 group of questions was created with the recognition that the case studies may not be able to directly answer these questions.

2.2.1 Level 1 – Preliminary Screening Questions for Selection of Case Studies

1. Are there any published case studies of WQT programs within the United States or other countries?
2. How far (spatially) are the benefits of a local nutrient load reduction realized within a water body? How does this vary for different designated water uses? How does this vary between watersheds or different water body types (e.g., estuary, river, lake) with distinct hydrologic, geologic, and ecologic conditions? How can appropriate geographic trading areas be established?
3. To what extent does seasonal variability need to be accounted for in trading programs?
4. What are the economic factors that drive the feasibility of various nutrient load reduction measures? How do these factors vary depending on location and watershed conditions?
5. How should the cap for nutrient concentrations in water bodies be defined, especially in multi-state waters? How should a baseline be established?
6. What factors determine the effectiveness of wetlands for reducing or removing nutrients from surface water?
7. If the price for a nutrient loads reduction credit from an NPS is fixed (e.g., $/lb) within a trading program, how are agencies determining the credit price?

8. How can nutrient reductions from NPSs be quantified? How is “effectiveness” of various management practices measured and documented? How can a reduction be measured after a management practice has been implemented? How can the initial NPS nutrient load be quantified?
9. What are the various ways that trading is being managed? What are the advantages (or drawbacks) of each management approach? To what extent is the management approach dependent on program scale or types of water body included in the program?
10. For multi-state (multi-jurisdiction) trading programs, how can legal authority be established?

2.2.2 Level 2 – Case Study Analysis Questions

1. What have been the key drivers for the implementation of a WQT focused on nutrients, or other environmental performance trading programs (such as air quality and wetland mitigation)?
2. What factors contribute to the success of active WQT programs or limit their effectiveness?
3. What type of institutional framework can provide accountability of NPSs? How can compliance with regulations be assured and enforced?
4. What role should environmental groups have in the planning and implementation process? How much public participation is appropriate?
5. What is public perception of water-borne stressor (nutrient) trading programs? Are there organizations opposed to this type of program?

2.2.3 Level 3 – General “State of the Art” Questions

1. What federal regulations and guidance documents address WQT?
2. What state regulations and guidance documents address WQT?
3. Which states have active WQT programs?

2.3 Case Study Selection

A few basic selection criteria were used to choose case studies from the list of existing WQT programs compiled in Table 2-2. The selection criteria include type of program (PSs and NPSs); constituent traded (nitrogen and phosphorus); implementation status (the program needed to be fully developed); whether or not wetland construction/enhancement could be used to generate credits; geographic distribution; and the availability of published literature. Four case studies were selected:

1. Cherry Creek, Colorado
2. Minnesota River and Rahr, Minnesota
3. LBR, Idaho
4. Tar-Pamlico River and Neuse River, North Carolina

These case studies were selected to represent programs in different regions of the country in an attempt to illustrate region-specific issues or limitations on feasibility if they exist. To the extent possible, case studies were selected to include distinct watershed types varying in scale, topography, land use distribution, and proximity to coastal waters. Market structure was not a selection criteria; the Cherry Creek and North Carolina programs may not fit the definition of a “true market” because purchase and sale of credits occur via a clearing house. In addition, water quality credits in the North Carolina program function more like an exceedance tax than trades within a market. The need for published literature on the WQT program was also a factor that shaped this analysis. Of the more than 80 WQT programs, pilots, and simulations identified in the process of selecting the four case studies, these programs are among the longest-standing. All were developed before the USEPA Water Quality Trading Policy was published in 2003, although these programs are far from static. As a result, it is likely that some of the newest programs have already been able to apply lessons learned from the programs in their design and implementation.

The collective results of the case studies combined with the results of the literature review are used to identify common lessons learned, successes and failures, and variations in key issues related to geography, watershed scale, land use, and any other factors observed to affect the success of the case study trading programs.

Table 2-2. Waterborne Stressor (Nutrient) Trading Programs

Project	Water body	State	Constituent	Ref. (doc#)	Program-specific papers	Wetlands used in trading?	Candidate study (why)
1. Montgomery Water Works and Sanitary Sewer Board	Coosa River	AL	Undefined - nutrients	10	No	No	No – Initial development
2. City of Santa Rosa	Russian River	CA	Undefined - nutrients	10	No	No	No – No trading
3. Grassland Area Tradable Loads Program	San Joaquin River	CA	Selenium	10, 261	Yes	No	No – Selenium trading
4. Lake Tahoe Water Quality Trading Strategy	Lake Tahoe	CA & NV	Nutrients and sediment	10	No	Yes – wetland controls, wetland type not specified	No – Initial planning stages
5. Sacramento Regional County Sanitation District's Mercury Offset Program	Sacramento Area	CA	Mercury	10	No	No	No – Mercury trading
6. San Francisco Bay Mercury Offset Program	San Francisco Bay	CA	Mercury	10	No	No	No – Mercury trading
7. Bear Creek Trading Program	Bear Creek Reservoir	CO	Phosphorus	10	No	No	No – Point-to-point
8. Boulder Creek Trading Program	Boulder Creek	CO	Nitrogen	10	No	Yes – habitat restoration and constructed wetlands (riparian)	No – Limited information available
9. Chatfield Reservoir Trading Program	Chatfield Reservoir	CO	Phosphorus	10, 114	Yes	? – BMPs for stream bank restoration and stormwater runoff	No – Limited information available
10. Cherry Creek Basin Trading Program	Cherry Creek Reservoir	CO	Phosphorus	1, 10, 11, 150, 225, 293	Yes	Yes – constructed wetlands, (riparian)	Yes – One of the original projects involved creation of a wetland. Credits established on case-by-case basis.
11. Clear Creek Trading Program	Clear Creek	CO	Heavy Metals	10, 181	Yes	No	No – Mine discharge
12. Lower Colorado River	Colorado River	CO	Selenium	10	No	No	No – Selenium trading
13. Lake Dillon Trading Program	Dillon Reservoir	CO	Phosphorus	10, 181, 236,149	Yes	No	No – Wetlands not used

Table 2-2. Waterborne Stressor (Nutrient) Trading Programs

Project	Water body	State	Constituent	Ref. (doc#)	Program-specific papers	Wetlands used in trading?	Candidate study (why)
14. Long Island Sound Trading Program	Long Island Sound	CT	Nitrogen	1, 10, 174	Yes	No	No – Point-to-point
15. Blue Plains Wastewater Treatment Plant (WWTP) Credit Creation	Chesapeake Bay	VA	Nitrogen	10		No	No – Point-to-point
16. Tampa Bay Cooperative Nitrogen Management	Tampa Bay	FL	Nitrogen	10	Yes	No	No – Wetlands not used
17. Lake Allatoona Watershed Phosphorus Trading Program	Lake Allatoona Watershed	GA	Phosphorus	10, 195, 215	Yes	? – type not specified	No – In development
18. Cargill and Ajinomoto Plants Permit Flexibility	Des Moines River	IA	Ammonia and CBOD		No		No – Limited information available
19. Bear River Basin	Bear River	ID, WY, UT	Phosphorus	10	No	?	No – In development
20. Lower Boise River Ef u-ent Trading Demonstration Project	Lower Boise River	ID	Phosphorus	1, 10, 174, 270, 236	Yes	Yes – Constructed wetlands, wetland type not specified	Yes – Constructed wetlands on approved BMP list, which also identified life span.
21. Mid-Snake River Demonstration Project & Development of Idaho Water Pollutant Trading Requirements	Mid-Snake River	ID	Phosphorus		No	No	No – Limited information available
22. Lake Erie Land Company/Little Calumet River	Little Calumet River	IN	Undefined	10	No	No	No – Initial development
23. Illinois Pretreatment Trading Program	IL waters	IL	Multiple	10	No	No	No – Point-to-point
24. Piasa Creek Watershed Project: Water Quality Trading - PS for NPS	Piasa Creek Watershed	IL	Sediment	10, 36	Yes	? – sed. ctrl. structures	No – No wetlands
25. Monocacy River	Monocacy River	MD	Undefined	10	No	No	No – Initial development
26. St. Martin's River Watershed	St. Martin's River Watershed	MD	Undefined	10	No	No	No – Initial development
27. Wicomico River	Wicomico River	MD	Undefined	10	No	No	No – Initial development
28. Charles River Flow Trading Program	Charles River	MA	Water ow	10, 98	Yes		No – Water ow trading

Table 2-2. Waterborne Stressor (Nutrient) Trading Programs

Project	Water body	State	Constituent	Ref. (doc#)	Program-specific papers	Wetlands used in trading?	Candidate study (why)
29. Edgartown WWTP	Edgartown River	MA	Nitrogen	10	No	No	No – Sewer/septic only
30. Falmouth WWTP	Falmouth Harbor	MA	Nitrogen	10	No	No	No – Sewer/septic only
31. Massachusetts Estuaries Project	Popponesset Bay, Three Bays and Warham Bay and Agawam River	MA	Nitrogen	10	No	Yes – wetland type not specified	No – Limited information available
32. Nashua River	Nashua River	MA	Phosphorus	10	No	No	No – Initial development
33. Town of Acton POTW	Assabet River	MA	Phosphorus	10	No	No	No – No trades
34. Specialty Minerals, Inc. in Town of Adams	Hoosic River	MA	Temperature	10	No	No	No – Temperature trading
35. Wayland Business Center Treatment Plant Permit	Sudbury River	MA	Phosphorus	10	No	No	No – Sewer/septic only
36. Maryland WQT Policy	Chesapeake Bay, other MD waters	MD	Phosphorus and nitrogen	10	Yes	No	No – Wetlands not used
37. Kalamazoo River Water Quality Trading Demonstration	Kalamazoo River, Lake Allegan	MI	Phosphorus	10, 261, 233, 236, 204, 226	Yes	agri. BMPs	No – Wetlands not used
38. Michigan Water Quality Trading Rule Development	MI waters	MI	Phosphorus and nitrogen	1, 10, 174, 236	Yes	No	No – Regs. only
39. Saginaw River Basin	Saginaw River Basin	MI	Nutrients and sediment	236	Yes	? – type not specified	No – No trades
40. Minnesota River Basin	Minnesota River	MN	Phosphorus	10, 63, 174, 233, 236,105, 242, 252	Yes	Yes – BMP and wetland type not specified	Yes – High volume of trades
41. Minnesota River WQT Study	Minnesota River	MN	Phosphorus	10	Yes	No	No – Point-to-point
42. Rahr Permit (lower Minnesota River)	Minnesota River	MN	Phosphorus, nitrogen, $CBOD_5$ and sediment	1, 10, 261, 133, 193, 194	Yes	Yes – restored riparian wetlands	Yes – Specifically tied to National Pollutant Discharge Elimination System (NPDES) permit requirements

Table 2-2. Waterborne Stressor (Nutrient) Trading Programs

Project	Water body	State	Constituent	Ref. (doc#)	Program-specific papers	Wetlands used in trading?	Candidate study (why)
43. Southern Minnesota Beet Sugar Cooperative Plant Permit	Minnesota River	MN	Phosphorus	1, 10	Yes	Yes – constructed wetlands, wetland type not specified	No – Limited information available
44. Mississippi River/Gulf of Mexico	Mississippi River/ Gulf of Mexico	MS	Phosphorus and nitrogen	233, 68, 30, 31, 74, 76	Yes	Yes – wetland restoration, wetland type not specified	Yes – But in concept stage of development
45. Chesapeake Bay WQT Program	Chesapeake Bay	Multiple states	Phosphorus and nitrogen	10	Yes	No	No – Wetlands not used
46. Great Lakes Trading Network	Great Lakes	multi-defined by individual programs	Undefined		Yes	No	No – See Kalamazoo
47. Cape Fear River Basin	Cape Fear River	NC	Undefined	10		Yes – wetland restoration and constructed wetland, wetland type not specified	No – Initial planning stages
48. Neuse River Nutrient Sensitive Water (NSW) Management Strategy	Neuse River Estuary	NC	Nitrogen	10, 174, 96,46, 129, 132, 46, 129, 132	Yes	Yes – wetland restoration and constructed wetland (riparian)	Yes – Cooperative - PS purchase credits, central agency (North Carolina Wetland Restoration Fund) allocates funds to projects. Nutrient offset payments targeted toward restoration of wetlands and riparian areas within the Neuse River Basin.
49. Tar-Pamlico Nutrient Reduction Trading Program	Pamlico River Estuary	NC	Phosphorus and nitrogen	1, 10, 261, 178, 96, 157, 236, 52, 112, 116, 128, 130, 131, 151, 178	Yes	Yes – emphasis on agricultural BMPs, wetland restoration and constructed wetland (riparian)	Yes – One of the oldest trading programs in the US. Cooperative - PS purchase credits, central agency allocates funds to projects.
50. Passaic Valley Sewerage Commission Ef u-ent Trading Program	Hudson River	NJ	Heavy Metals	10	No	No	No – Dissolved metal trading

Table 2-2. Waterborne Stressor (Nutrient) Trading Programs

Project	Water body	State	Constituent	Ref. (doc#)	Program-specific papers	Wetlands used in trading?	Candidate study (why)
51. Truckee River Water Rights and Offset Program	Truckee River	NV	Phosphorus, nitrogen, or total dissolved solids	10	No	No	No – Wetlands not used
52. East River	East River	NY	Nitrogen	10, 166	No	No	No – Point-to-point
53. New York City Watershed Phosphorus Offset Pilot Programs	Hudson River	NY	Phosphorus	10	Yes	Yes – wetland restoration, type not specified	No – Limited information available
54. Greater Miami River Watershed Trading Pilot Program	Greater Miami River Watershed	OH	Phosphorus and nitrogen	10	Yes	? – see types of agricultural BMPs	No – Limited information available
55. Clermont County Project	Little Miami River, Harsha Reservoir	OH	Phosphorus, nitrogen or total dissolved solids	10	No	No	No – Wetlands not used
56. Ohio River Basin Trading	Ohio River Basin	OH – Multi-state	Nutrients	10	No	No	No – Initial development
57. Shepard Creek (tributary to Mill Creek)	Shepard Creek	OH	Peak storm-water ows	256	Yes	No	No – Stormwater retention
58. Honey Creek Watershed	Honey Creek	OH	Phosphorus	10	No	No	No – BMP case study, not trading
59. Lower North Canadian River	Lower North Canadian River	OK	Undefined	10	No	No	No – Feasibility study
60. Tualatin River Watershed NPDES Permits	Tualatin River Watershed	OR	Temperature	10	No	No	No – Riparian restoration
61. Conestoga River	Conestoga River	PA	Phosphorus and nitrogen	10	No	No	No – Wetlands not used
62. Pennsylvania Water-based Trading Simulations	Delaware River, Moshanon Creek, Swatara Creek and Spring Creek	PA	Multiple	10	No	No	No – Simulation, not program
63. Pennsylvania Multimedia Training Registry	State-wide	PA	Phosphorus and nitrogen	10	No	No	No – Wetlands not used

Table 2-2. Waterborne Stressor (Nutrient) Trading Programs

Project	Water body	State	Constituent	Ref. (doc#)	Program-specific papers	Wetlands used in trading?	Candidate study (why)
64. Ef uent Trading Program	Providence and Seekonk Rivers, Rhode Island	RI	Salinity	10	No	No	No – Salt trading
65. Boone Reservoir	Boone Reservoir	Total nitrogen (TN)	Phosphorus, nitrogen and BOD	10	No	No	No – No program developed
66. Colonial Soil and Water Conservation District	Lower James River	VA	Nutrients and sediment	10	No	No	No – Planning
67. Henry County Public Service Authority and City of Martinsville Agreement	Smith River	VA	Total dissolved solids	10	No	No	No – Point-to-point
68. Virginia Water Quality Improvement Act and Tributary Strategy	Chesapeake Bay, other VA waters	VA	Phosphorus and nitrogen	10	No	No	No – Planning
69. Chehalis River	Chehalis River	WA	Undefined	10	No	No	No – Not implemented
70. Puyallup River	Puyallup River	WA	Ammonia and BOD	10	No	No	No – No trades
71. Yakima River	Yakima River	WA	Water ow	10	No	No	No – Water quantity
72. Fox-Wolf Basin Watershed Pilot Trading Program	Green Bay	WI	Phosphorus	10, 178	Yes	No	No – Point-to-point, nonpoint not defined
73. Red Cedar River Pilot Trading Program	Tainter Lake	WI	Phosphorus	10	Yes	No	No – Wetlands not used
74. Rock River Basin Pilot Trading Program	Rock River Basin	WI	Phosphorus	10, 236	Yes	Yes – wetland restoration (return farmland to wetland), type of wetland not specified	No – Limited information available
75. Wisconsin Ef uent Trading Rule Development	WI waters	WI	Phosphorus	10	No	No	No – Wetlands not used
76. West Virginia Trading Framework	State-wide	WV	Multiple	10	No	? – some info on wetlands, type not specified	No – Concept stage

Table 2-2. Waterborne Stressor (Nutrient) Trading Programs

Project	Water body	State	Constituent	Ref. (doc#)	Program-specific papers	Wetlands used in trading?	Candidate study (why)
77. Cacapon/Lost River	Lost River	WV	Undefined	10	No	No	No – Feasibility study
78. Cheat River, West Virginia	Cheat River	WV	Heavy Metals and acidity	10	No	No	No – Concept stage
79. Hunter River Salinity Trading, USEPA Department of Environment and Conservation	Hunter River	Australia	Salinity		Yes	No	No – Salinity trading
80. Dutch Nutrient Quota System	Country-wide	Netherlands	Nutrients		Yes	No	No – Livestock production
81. South Nation River Watershed	South Nation River	Ontario, Canada	Phosphorus	34, 273, 272, 290	Yes	?	No – Focus on agriculture BMPs and riparian stabilization
82. Kaoping River Basin	Kaoping River Basin, Taiwan	Taiwan	Multiple	70, 75	No	No	No – Limited information available

Candidates for case studies are highlighted in green.

CBOD = carbonaceous biological oxygen demand.

3.0 Literature Review – Wetland Nutrient Removal

The utility of wetlands in managing nutrient loads and their historical, current, and anticipated future implications in WQT warrant focused review. Numerous studies or summaries of studies have investigated the function of wetlands in the removal of pollutants, including high levels of nutrients (USEPA, 2005a; Fisher and Acreman, 2004; Mitsch and Gosselink, 2000; Hunt and Poach, 2001; Kadlec and Knight, 1996; USEPA, 1999; USEPA, 1993a; Cooper and Findlater, 1990). Results from these studies have been summarized and used to guide the development of constructed wetlands to treat water high in nitrogen and phosphorus (Kadlec and Knight, 1996). This review does not attempt to re-summarize these studies, but references them for readers who desire more information. Rather, this review summarized information on the nutrient removal function of wetlands specifically applicable to WQT.

A bibliography of published documents regarding constructed wetlands was compiled by USDA staff from the Ecological Sciences Division of the Natural Resources Conservation Service (NRCS) and the Water Quality Information Center at the National Agricultural Library. The references were acquired in part through searches of the AGRICOLA database. The bibliography has been updated several times, most recently in June of 2000, and contains hundreds of entries, many with abstracts (USDA, 2000). An annotated bibliography of urban stormwater and nonpoint nutrient control was conducted by the Washington State Department of Ecology in 1986 and updated in 1991. The review was conducted to determine the extent of information available on the long-term ecological impacts of stormwater on wetlands and on the ability of wetlands to improve the water quality of urban stormwater (Stockdale, 1991).

Both constructed and natural wetlands function to buffer downstream nutrients by storing and transforming nutrients, which are gradually released downstream (DeBusk, 1999). Consequently, wetlands have been considered an effective means to treat PSs and NPSs of nutrients and improve water quality in downstream lakes and rivers. The benefits of using wetlands to treat NPSs of pollutants include the ability to operate under a wide range of hydraulic loads, provide internal water storage capacities, and remove or transform contaminants (Dierberg *et al*., 2002).

3.1 Wetland Removal of Nitrogen and Phosphorus - Technical Overview

Nutrients enter wetlands through various geologic, biologic, and hydrologic pathways; however, hydrologic inputs generally dominate elemental inputs into wetlands. The cycling of nutrients in wetlands has been extensively described and studied (Mitsch and Gosselink, 2000). Inundation, water level uctuations, and biota result in both aerobic and anaerobic processes within the water column and wetland soils. These processes allow the transformation of nutrients like nitrogen and phosphorus as they interact with the biogeochemistry of the wetland environment.

Wetlands function to remove phosphorus through sedimentation, plant uptake, organic matter accumulation, immobilization, and soil sorption. Nitrogen is removed in wetlands by filtration, sedimentation, uptake by plants and microorganisms, adsorption, nitrification, denitrification, and volatilization. Gaseous losses of nitrogen through denitrification are generally the most significant nitrogen removal mechanism in natural as well as constructed freshwater wetlands (DeBusk, 1999; Bowden, 1987; Faulkner and Richardson, 1989).

A description of inputs, outputs, and internal cycling of nutrients in wetlands can be described by chemical mass balances. These mass balances for wetlands have been developed and discussed by others to describe the functions of wetlands in nutrient production and cycling. Literature reviews of this subject have been provided by DeBusk (1999), Nixon and Lee (1986), Johnston *et al*. (1990), and Johnston (1991). However, few investigators have developed a complete mass balance for wetlands that includes measurement of all the nutrient pathways, sources, and sinks. Despite this lack of comprehensive study, some generalizations have been made (Mitsch and Gosselink, 2000).

The function of wetlands as sources, sinks, and transformers of nutrients depends on the wetland type, hydrologic condition, and the length of time the wetland is subjected to nutrient loading. Wetlands have been shown to be sinks or storage places for nitrogen and phosphorus, although not all wetlands exhibit this trait. One study found seasonal and permanent swamps had a net export of organic matter. Most of the inorganic phosphorus (60 to 90 percent) was retained, but there was a net release of nitrates, probably associated with the net export of organic matter (Mwanuzi *et al*., 2003). The location and chemical form of nutrients change within wetlands during the exchange of water and sediment as well as during plant uptake and decomposition (Atlas and Bartha, 1981). The availability of nutrients and the extent to which biogeochemical processes function affect the intracycling of nutrients and the productivity in wetlands. The function of wetlands is closely related to adjoining land and water bodies; changes upgradient of a wetland will affect processes occurring within the wetland. For example, the depth of an adjoining water body or the conveyance capacity of the outlet stream are likely to modulate functions such as depth and storage capacity of natural wetlands (Kadlec and Knight, 1996).

The productivity of wetlands is also directly correlated with nutrient input and transformation. Thus, the ability of wetlands to store and transform nutrients is directly connected to the amount of nutrients available for storage and transformation. However, this ability is not limitless, and once storage and transformation capacity is reached, excess nutrients leave the wetland through atmospheric, surface, and subsurface outflows (Mitsch and Gosselink, 2000). If long-term nutrient removal is an objective of a constructed wetland, significant maintenance up to and including re-construction may be necessary, although expecting a constructed wetland to perform this function in perpetuity is likely ecologically and economically unrealistic at best, and not reasonably feasible at worst.

Although several generalizations can be made regarding the function of wetlands as sources, sinks, and transformers of nutrients, the complex and unique situation revolving around each wetland limits the application of generalizations. Wetlands can be a sink for a form of nitrogen at one moment in time and a source for the same nitrogen element at another time. Generalizations are also hampered by inconsistent study results and by the variety and imprecision of approaches to measuring nutrient fluxes in wetlands. There is little consensus in the literature about nitrogen and phosphorus fate in wetlands. A few chemical imbalances have been studied and described, but a complete mass balance for wetlands has yet to be developed (Mitsch and Gosselink, 2000). Furthermore, there has been a terrestrial-biased (i.e., applying processes found in uplands) approach in wetland research, especially regarding vegetation and productivity, that limits the understanding and employment of soil and microbial processes specific to wetlands in nutrient reduction (Wetzel, 2001; Johnston, 1991).

The chemical transformation of nitrogen and phosphorus is important to understanding how wetlands perform in nutrient removal and sequestration. Inorganic and organic nitrogen and phosphorus enter wetlands through water inputs such as overland runoff, outfall pipes, groundwater, and to a lesser degree rainfall. The inorganic and organic forms are transformed or stored in the water, soil, and biota through several processes, including nitrification, denitrification, ammonification, diffusion, plant uptake, litterfall, decomposition, adsorption, precipitation, sedimentation, volatilization, and peat accretion (DeBusk, 1999). Following transformation and storage, both inorganic and organic forms of nitrogen and phosphorus exit the wetland in water outflows or by gaseous states such as nitrogen gas (N_2). Other gases are emitted from wetlands, including carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), which are produced under highly reduced conditions (Mitsch and Gosselink, 2000).

To use wetlands to reduce nutrients from water before the flows enter downstream water bodies, the amount of nutrients in the wetland outflow needs to be less than in the wetland inflow, and the reduction must be measurable. The USEPA found that sequential nitrogen transformation within wetlands used to treat water quality results in a unidirectional shift of elevated total and organic nitrogen forms to oxidized or gaseous nitrogen forms (USEPA, 1999). In addition, plant detritus provides long-term storage of nitrogen in wetlands, and a portion of this nitrogen can eventually become available for nutrient cycling following decomposition, which can take from months to many years (Kadlec and Knight, 1996). A summary of data collected in North American Wetlands for Water Quality Data Base (NADB) found that free water surface wetlands on an annual mean average removed 61 percent of the total phosphorus (TP) in inflow water with a standard deviation (SD) of 30 percent (USEPA, 1999). An approach to control the impacts of elevated nutrients is for the nutrients to be in a form not readily available to biotic organisms such as algae, which consume oxygen during uptake of nutrients. For example, phosphorus chemically bound to minerals (e.g., iron, aluminum, calcium, and organic compounds) is not as readily available as dissolved phosphorus to algae or plants, but represents a long-term source of phosphorus in a water system (NRCS, 2001).

One of the key environmental drivers in nutrient transformation is inundation. Inundation affects the oxygen content of the soil and produces anaerobic conditions, although the near-surface soil tends to retain an oxidized layer due to the proximity to the water column, oxygen translocation within rooted plants, and microbial activity (Tanner, 2001a). Some studies have found oxygen availability to the sediment was the greatest limiting factor for nitrification (White and Reddy, 2003). Oxidation affects the reduction of elements such as iron, resulting in a brownish-red color at the soil surface compared to the bluish-gray color of reduced sediments dominated by ferrous iron. Subsurface systems have been found to display marginal or negative nitrogen removal because of the lack of oxygen (USEPA, 1993a). Inundation also affects pH and redox potential, which influences the rates of nutrient transformation (Mitsch and Gosselink, 2000).

The results from studies on nutrient removal have shown inconsistencies in amount and efficiency of nutrient removal. For example, results from an experimental constructed wetland showed that nutrient removal was primarily the result of plant uptake and harvesting (15 percent of TN input, 10 percent of TP input). Other processes had a relatively minor contribution: denitrification (8 percent of TN input), sedimentation and accumulation of organic matter in the soil (7 percent of TN input, 14 percent of TP input) (Meuleman *et al.*, 2003). Other studies have shown that denitrification is one of the more important mechanisms for removing nitrogen in wetlands. Nitrogen removal from septage with high solids concentration resulted from sedimentation of waste solids (57.6 percent), denitrification (40.9 percent), and direct uptake by plants (0.5 percent) of the total influent nitrogen (Hamersley *et al.,* 2001). Recent studies show a wide range of nutrient removal efficiency values. Studies of constructed surface flow wetlands in Norway found nitrogen removal efficiencies between 3 and 15 percent, due to high hydraulic load and low temperatures (Braskerud, 2002). In constructed horizontal reed bed wetlands in Germany, more than 90 percent removal of TN and phosphorus was achieved (Luederitz *et al*., 2001). A compilation of data from 60 studies of 57 natural wetlands in 16 countries showed the mean percent change in nutrient load between water entering and exiting the wetlands was 67 percent (SD of 27 percent) for nitrogen and 58 percent (SD of 23 percent) for phosphorus (Fisher and Acreman, 2004).

One of the primary ways nutrients are removed from inflow waters is through storage within the wetlands, typically within soil, organic matter, or biota. For example, phosphorus is stored in wetlands in the soil by adsorption (i.e., surface accumulation) with sediment particles and precipitation with other compounds, within peat and plant litterfall, and in living plant and animal biomass (e.g., bacteria, algae, and vascular macrophytes). Sediment containing high organic matter accumulated twice the nitrogen (Tanner, 2001b) and six times the phosphorus (Tanner, *et al*., 1998) of live and dead plant tissue. Peat is considered a long-term storage location for nutrients (DeBusk, 1999). One study found that twice as much phosphorus was sequestered in submerged aquatic vegetation as in sediment, but these nutrients had a greater probability to be mobilized as plants decay (Dierberg *et al*., 2002). Dissolved organic phosphorus and insoluble forms of organic and inorganic phosphorus are generally not biologically available until they are transformed into soluble inorganics (Mitsch and Gosselink, 2000). Therefore, both storage of phosphorus within wetlands and the reduction of downstream export of soluble inorganic phosphorus decrease the effective nutrient load of downstream waters and the associated eutrophication.

Nutrient removal in constructed wetlands has been found to follow a seasonal pattern in most temperate conditions. The amount of nitrogen and phosphorus removed depends on the form of the nutrient, type and density of the aquatic plants, nutrient loading rate, and climate. During winter, nutrients sequestered in plants and plankton are released back into the water column upon decomposition (USEPA, 1999). Typically, nutrients taken up by plants and microorganisms in dissolved organic forms are returned later in complex organic forms (Tanner, 2001a). Seasonal temperatures also influence transformation of nutrients. For example, nitrification is limited by temperature during all seasons when plant gas exchange and oxygen input into the rhizosphere are limited. Denitrification was almost complete in midsummer and was restricted at seasonal temperatures below 15°C in a study conducted on a constructed subsurface horizontal flow wetland in Germany (Kuschk *et al.*, 2003). Spring and autumn removal efficiencies responded to the nitrogen load in a linear fashion. Efficiencies in winter and summer differed extremely (mean removal rates of 0.15/0.7 $g\ m^{-2}\ d^{-1}$ [11 percent/53 percent] in January/August) and appear to be independent of the nitrogen load (0.7–1.7 $g\ m^{-2}\ d^{-1}$) (Kuschk *et al.*, 2003). Wetland treatment systems in Hungary showed that removal performances varied by 40 percent between summer and winter (Szabó *et al*., 2001). Several studies found that temperate regions show a rapid uptake of nutrients in early spring with rising temperatures, which stimulates mineralization of organic matter accumulated over the previous winter (Tanner, 2001a).

Although several studies demonstrated seasonal influences in water quality performance, a study of constructed wetlands in Florida found no seasonal pattern in phosphorus removal despite fluctuations in air temperature and sunshine (Dierberg *et al*., 2002). Sub-tropical wetlands lack the annual cycle of fall-winter senescence and nutrient release that is characteristic of northern climates. However, this lack of seasonality may add to the long-term stability of sediments and detritus-bound nutrients in sub-tropical regions. Another regional characteristic found in Florida, but applicable to other similar areas, is the high level of calcium and high alkalinity in runoff. This regional condition of runoff allowed more phosphorus to be sequestered by co-precipitation with calcium carbonate (Dierberg *et al*., 2002). These examples illustrate the influence regional factors have on nutrient removal performance of wetlands and may explain why wetland nutrient removal performance is better in some regions than in others.

Climate influences the amount and timing of nutrient input, as well as nutrient concentration and transformation within wetlands (Mitsch and Gosselink, 2000). Temperature affects growth and productivity of wetland biota. Also, oxygen levels in wetlands fluctuate with temperatures; oxygen saturation is greater at cooler temperatures. Oxygen levels, in turn, affect several nutrient transformation processes. For example, Woodwell and Whitney (1977) found a salt marsh uptake of phosphate in cold months and export of phosphate in warm months. Areas with high precipitation have increased hydrologic inputs, which can dilute nutrient concentration or increase nutrient concentrations if the precipitation picks up nitrogen and phosphorus before entering the wetland through overland or groundwater flows. A study of several streams throughout the United States found that concentrations of nitrogen and phosphorus increased with precipitation in disturbed watersheds because of increased erosion, but decreased with stream flow in natural watersheds, presumably because of reduced erosion and increased dilution (Omernik, 1977). Arid regions can concentrate nutrients as water evaporates from wetlands, which leaves increased salts, affecting chemical binding rates and biological diversity. Additionally, groundwater may be more influential in arid regions as the subsurface water picks up nutrients within the soil prior to outfalling to wetlands (USEPA, 1993a).

Climate also has considerable effect on the plant and microorganisms growing in wetlands. The quantity and variety of these organisms influence the nutrient transformation and removal within wetlands. For example, temperate wetlands retain more nutrients in the growing season primarily because of the higher microbial and macrophyte productivity. Nutrients stored in biomass can be released back into the water column in the autumn following litter fall and subsequent leaching. This seasonality has application to the concept of using wetlands to reduce downstream nutrient loads. Wetlands can function as sinks for nitrogen and phosphorus in summer, when the biotic community is most productive, which corresponds favorably with the need to reduce summer algae blooms in downstream waters as a result of elevated nutrients (Klopatek, 1978; Lee *et al*., 1975).

Nutrient removal has been shown to be higher in wetlands containing plants, mostly through denitrification and secondarily through plant uptake (Stein *et al*., 2003; Lin *et al*., 2002; Jing *et al*., 2002; Tanner, 2001a). Macrophytes have been found to enhance nutrient removal by assisting solid sedimentation, reducing algae production, improving nutrient uptake, and releasing oxygen (Jing *et al*., 2002; Bavor *et al*., 2001). Studies of surface flow horizontal reed beds in Australia found removal efficiency with plants to be greater than 96 percent for both nitrogen (9.7 milligrams per liter [mg/L]) and phosphorus (0.56 mg/L) and without plants to be 16 percent for nitrogen (1.6 mg/L) and 45 percent for phosphorus (0.26 mg/L) (Huett *et al*., 2005). Another study of constructed wetlands in Taiwan found that planted wetlands removed 80 to 100 percent of ammonium (NH_4)-nitrogen (NH_4-N) (Jing *et al*., 2002). High denitrification rates in the presence of plants has been attributed to a high degree of soil oxidation (Matheson *et al.,* 2002). An assessment of subsurface constructed wetlands found that oxygen transport down to the roots by emergent plants was the prime source of oxygen needed for nitrification (USEPA, 1993a).

Submerged aquatic vegetation communities have been found to exhibit phosphorus removal mechanisms not found in wetlands dominated by emergent macrophytes (Dierberg *et al*., 2002). Constructed wetlands using floating aquatic macrophytes have been used to improve drinking water supplies in Brazil (Elias *et al*., 2001). The submerged plants directly assimilated phosphorus from the water column and mediated the pH so phosphorus co-precipitated with calcium carbonate in soil sediment. Leaves and stems can also act as nucleating sites for co-precipitation. Under high iron and oxygen conditions, phosphorus has been found to co-precipitate on iron oxide as evident from purple plaques observed on roots and stems, contributing to a removal efficiency of 83.6 percent (Jardinier *et al*., 2001). Removal efficiencies for organics, NH_4-N, and orthophosphates were influenced by the health and growth rate of macrophytes (Jing *et al*., 2002).

Even wetlands designed to treat wastewater through subsurface flows showed enhanced nitrogen and initial phosphorus removal when planted versus unplanted wetlands with gravel-bed substrates (Tanner, 2001a). Uptake and storage of nitrogen and phosphorus in live plant biomass accounted for a fraction (3 to 19 percent TN; 3 to 60 percent TP) of the improved performance of planted wetlands. The author suggests that plants primarily facilitate improved nutrient removal indirectly through their effects on other removal processes rather than direct nutrient uptake (Tanner, 2001a). A recent study of nitrogen uptake in the rhizosphere concluded that nitrate (NO_3) uptake by wetland plants may be far more important than previously thought. The modeled calculations showed that substantial quantities of NO_{-3} can be produced in the rhizosphere of wetland plants through nitrification and taken up by the roots under field conditions and that rates of NO_{-3} uptake can be comparable to those of NH_{+4}. In addition, the model showed that rates of denitrification and subsequent loss of nitrogen from the soil remain small even where NO_{-3} production and uptake are considerable (Kirk and Kronzucker, 2005).

Many studies have shown that different species of plants perform better than others at nutrient removal from waste water. Cattails were most efficient at nitrogen removal, and aquatic plants increased phosphorus removal in wetlands constructed to treat saline wastewater in Thailand (Klomjek and Nitisoravut, 2005). Careful consideration should be given to the choice of plant species used for nutrient removal systems. While many species can be desirable and effective for nutrient removal in some regions, those same plants can be undesirable in other regions (Mitsch and Gosselink, 2000) and can often be highly invasive, spreading to and causing problems in nearby aquatic systems. Other species that have shown high rates of nitrogen removal from waste water include *Phragmites* (Mayo and Bigambo, 2005), *Typha angustifolia* (Belmont *et al*., 2004), *Scirpus validus* (Fraser *et al*., 2004), and *Schoenoplectus* (Poach *et al*., 2003). However, some studies found that plant species had little impact on nutrient concentration or removal (Jing *et al*., 2002; Huang *et al*., 2000). A study of constructed wetlands in the Florida Everglades found that species differed in their uptake and accumulation in plant tissue, but it was a minor contributing factor in overall nutrient removal (Dierberg *et al*., 2002). In addition to plants affecting transformation processes, plants also take up nutrients into their tissues. Much of the storage of nutrients in plants occurs in below-ground tissues, particularly in emergent species where up to 90 percent of the plant productivity occurs in below-ground tissues (Tanner, 2001a; Wetzel, 2001). This is particularly true when plants enter maturity and senesce as nutrients are translocated to root tissues for storage until the next growing season. Consequently, the removal of above-ground tissue is often not a practical method for removing nutrients from the wetland (Wetzel, 2001; Matheson *et al.,* 2002). Plant tissue analysis has shown that a single annual harvest of plant material accounted for 10 percent or less of the nitrogen removed from constructed subsurface wetlands. Increased harvest frequency may increase this performance, but would increase the operation costs of the constructed wetland (USEPA, 1993a).

Studies of the effect of hydrologic and hydraulic conditions show inconsistent results. Hydrologic and hydraulic conditions in a wetland can influence the efficiency of processes that remove nutrients from water (Jing *et al*., 2002; Sakadevan and Bavor, 1999). Hydraulic residence time was negatively correlated with TN and phosphorus removal in constructed subsurface flow wetlands (Schulz *et al.*, 2003). NH^+_4 and total Kjehldahl nitrogen (TKN) concentrations within a wetland decreased exponentially with increased residence time (Huang *et al.,* 2000). TKN is the organically bound nitrogen in a water sample that is released from organic matter through a digestive process before analysis. Knight *et al*. (2000) found that removal of nutrients was a function of inlet concentrations and hydraulic loading rates, but in other studies nutrient removal efficiencies were unaffected by variation in hydraulic loading rates (Lin *et al*., 2002). Dierberg *et al*. (2002) found the greater the residence time, the greater reduction in nutrients.

Ideally, the optimal performance of a constructed wetland can be achieved by affecting the inflow concentration and residence time. Consideration should be given to designs of constructed wetlands with localized inflows, which generate a nutrient soil gradient. A study of wetlands used for 40 years to treat wastewater in Florida found that TP in wetlands sediments was significantly correlated with depth and distance from the point of surface water inflow (White and Reddy, 2003). Nutrient retention has been found to be affected by wetland size relative to the watershed (and therefore retention time), land use of the watershed, any intrusion of groundwater, and the nature of the wetland in terms of its shape and vegetation (Raisin and Mitchell, 1995). An assessment of subsurface constructed wetlands found that the media (e.g., gravel, sand) affected the hydraulic conductivity and, subsequently, the nutrient removal performance. Systems with sandy substrate had low conductivity and, therefore, needed to be larger in size to generate a retention capacity effective at removing nutrients, which requires more land surface for construction and operation (USEPA, 1993a).

3.2 Factors that Affect Nutrient Load Reduction Efficiencies

Wetlands that are undersized compared to the amount of water that will flow through them are more susceptible to frequent flushing by storms (which can flush out nutrients and organic matter) and are therefore not as effective as properly sized wetlands. Wetlands need to be large enough to be able to store the total from the "first flush," the first 1 inch of precipitation (Hunt and Doll, 2000). Bass (2000) indicated that current recommendations are that a wetland surface area should be at least 1 percent of the contributing watershed area. However, given that the amount of runoff from a drainage area will vary considerably depending of the amount of impervious area within the watershed, Hunt and Doll (2000) calculated surface areas of wetland ranging from 7 percent for a watershed with a low permeability (curve number [CN]=98)[2] to slightly more than 1 percent for residential areas with fairly clayey soils (CN=60).

This illustrates one limitation of constructed stormwater wetlands relative to other stormwater BMPs: they require a large area of land. Wetland designs can improve the overall performance of the wetland and partially address the problem of stormwater flows flushing wetlands by including a high flow bypass (flow splitter) that allows larger storms to circumvent the wetland (Hunt and Doll, 2000). In North Carolina, constructed stormwater wetlands have been located on watersheds as small as 4 to 5 acres, but they are most commonly used for larger drainage areas and typically serve watersheds ranging from 15 acres to more than 100 acres.

Geographic position and land use affect the nutrients flowing into wetlands (Mitsch and Gosselink, 2000). The size of the watershed, the steepness or slope of the landscape, soil texture, and variety of topography influence these nutrient inputs. The position of the wetland within the landscape, in addition to the climatic situation, influence the cycling of nutrients within and through wetlands. For example, tidal salt marshes have significant tidal exchange while closed ombrotrophic bogs have little material exchange except for gaseous matter into and out of the wetland. Upstream wetlands have the ability to affect the amount and form of nutrients flowing into wetlands (e.g., a series of wetlands will produce a different outcome compared to a single wetland). Land uses can affect nutrient inputs by affecting erosion rates, applying fertilizers, modifying hydrologic flows, and altering buffer features of wetlands. Adjacent land use practices also may impact a wetland's ability to store nutrients, thereby altering the structure and function of the wetland (Gathumbi *et al.,* 2005). Obvious direct input from sewage effluent, urban runoff, and industry can have dramatic impacts on nutrient loads within wetlands. Studies of a natural wetland in New Zealand that received sewage oxidation pond effluent for more than 30 years showed elevated nutrient concentrations in ground and surface water, increased weed invasion and plant growth, and high concentrations of certain heavy metals (Chague-Goff *et al*., 1999).

Anthropogenic sources of nitrogen and/or phosphorus include sewage, fertilizers, animal waste, erosion, industrial discharge, mining, drinking water treatment, synthetic materials, and fossil fuel burning. As previously discussed, both phosphorus and nitrogen are present in wetlands in inorganic and organic forms. Both nutrients are used by living organisms for basic life processes, but too much can be harmful to aquatic environments. The potentially harmful effects associated with anthropogenic enrichment of nutrients are most noticeable in environments where these nutrients are normally in limited supply, such as within surface water bodies (e.g., eutrophication). Nitrogen and phosphorus are often found in higher than natural levels in areas of human activity. Consequently, the negative effects of too much nitrogen

2 CN reflects the ability of a watershed to store water through initial storage and subsequent infiltration. A high CN indicates a watershed with limited storage capacity.

and phosphorus are concentrated downstream of these areas, leading to the need to reduce nitrogen and phosphorus within water bodies. Removal of nutrients from water before the water is discharged downstream can reduce the potential for eutrophication; however, upgrades to treatment processes cannot eliminate this potential. For example, sewage treatment typically decreases ammonia discharge, which results in increased NO_3 discharge, but does not address TN discharge concentrations (Murphy, 2005).

Additional studies focusing on the design issues of constructed wetlands are necessary. These studies should look at the impacts of scale and edge effects in research wetlands. Also, the delivery of treatment water at a single point or dispersed delivery and in batches versus continuous flows should be studied further for modeling and application of constructed wetlands and as treatment BMPs. Longer-term studies are also lacking within the literature. Further study is needed on quantifying and comparing the oxygen release characteristics of different emergent species in response to root-zone treatments and the effect of this release on removal efficiencies (Tanner, 2001a).

3.3 Natural versus Constructed Wetlands

Natural wetlands exist where water inundates land, even seasonally, or groundwater is shallow enough to create hydric soils near the surface, which supports hydrophytic plants adapted to living in water or saturated soils. Constructed wetlands developed to improve water quality are defined as engineered or constructed wetlands that use natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist in the treating of effluent or other water sources (USEPA, 2000a). Because constructed wetlands are typically designed specifically for water quality improvement functions, many of the wildlife habitat functions provided by natural wetlands are lacking in constructed wetlands (DeLaney, 1995). A third type of wetland, often referred to as a created wetlands, are often designed to provide wildlife habitat functions similar to natural wetlands as mitigation for project impacts (Hammer, 1996). There are generally two types of constructed wetlands: subsurface and free-water-surface systems (USEPA, 1999; USEPA, 1993a; Hammer, 1989).

Restored and enhanced wetlands are historical, naturally occurring wetlands that have been disturbed through filling, dredging, water elevation changes, plant community alterations, and/or modifications to buffers surrounding the wetland that impact the wetland characteristics or functions. Restoration of disturbed wetlands usually involves rehabilitation of hydrologic conditions and reestablishment of vegetation (Mitsch and Gosselink, 2000). Degraded wetlands offer opportunities for restoration and enhancement through the careful application and operation of them for water quality treatment. However, this approach should only be attempted if the water quality of the wetlands would not be degraded, there was a net benefit to the wetland, and it would promote a return of historic or natural conditions to the wetland (USEPA, 2000a). In natural wetlands with low productivity, nitrogen and phosphorus are often limiting factors, and adding nutrient-rich water can increase productivity (Mitsch and Gosselink, 2000; Ewel and Odum, 1984). Restoring wetlands is an effective strategy for reducing agricultural NPS nutrient discharge. These systems can remove 90 percent to 100 percent of suspended solids, 85 percent to 100 percent of TP, and 80 to 90 percent of TN (DeLaney, 1995). A compilation of data from 60 studies of 57 natural wetlands in 16 countries showed that 80 percent of the wetlands reduced nitrogen loading and 84 percent reduced phosphorus loading. The mean percent change in nutrient load between water entering and exiting the wetlands was 67 percent (SD of 27 percent) for nitrogen and 58 percent (SD of 23 percent) for phosphorus (Fisher and Acreman, 2004).

Constructed wetlands designed to retain nutrients from wastewater can function similarly to natural systems. They have similar physical and biological processes and the operation is more passive and requires minimal operator intervention as compared to WWTPs (USEPA, 2000b). Planning and design considerations for building constructed wetlands have been developed by USEPA (1999). Wetzel (2001) provides a summary of the fundamental processes in natural and constructed wetlands. Both natural and constructed wetlands exhibit plant and microbial metabolism involved in nutrient/pollutant uptake, sequestering, and retention that is highly dynamic on daily, seasonal, and long-term annual scales (Wetzel, 2001; Kadlec and Knight, 1996; Ewel and Odum, 1984). Furthermore, the amount and concentration of nutrient loading influence these processes at all scales. Nutrient removal rates have also been shown to be very high in some natural and constructed wetlands. A study of 50 years of treating wastewater by flowing it through existing forested wetlands in the Mississippi Delta showed that nitrogen and phosphorus were reduced by more than 90 percent (Day *et al*., 2004). A constructed wetland in France was reported to have removed 54 to 94 percent of TN from coke plant wastewater (Jardinier *et al*., 2001).

Though there are similarities between natural and constructed wetlands, there are also several differences. Constructed wetlands often vary in the shape and structure from natural wetlands. Often, constructed wetlands are shaped to fit into the landscape with other features such as roads, buildings, or mature vegetation. This “fitting in” can limit the ability to create a natural-looking and -functioning wetland. Many of the studies of constructed wetlands use conveniently-sized plots (e.g., mesocosms) that provide straightforward control of soils, plants, and water levels as well as inflow and outflow controls, which ease measurement of water quality parameters (Dierberg *et al*., 2002; Jing *et al*., 2002). Additionally, constructed wetlands often have engineered substrates composed of gravels or artificial liners, which affect the subsurface nutrient removal processes.

Natural wetlands are typically higher in biodiversity, while constructed wetlands are typically planted with a few select plants and occasionally are inoculated with microorganisms (Wetzel, 2001). This greater diversity often allows more light to penetrate deeper into the water, increasing the vertical extent of photosynthesis and survival of microorganism assemblages. The increased species diversity and productivity maximizes nutrient retention, recycling, and storage (Wetzel, 2001).

Guidelines for constructing wetlands produced in 2000 identified more than 600 active projects using constructed wetlands to treat municipal and industrial wastewater, as well as agricultural and stormwater sources (USEPA, 2000a). Using these projects and wetland science, USEPA developed "Guiding Principles for Constructed Treatment Wetlands" to develop wetlands that improve water quality as well as provide wildlife habitat (USEPA, 2000a). The document gives guidance on planning, siting, designing, constructing, operating, maintaining, and monitoring of constructed treatment wetlands. Other guidance documents on constructing wetlands have been developed and provide useful information to consider when constructing wetlands (Davis, 2003; Moshiri, 1993; Cooper and Findlater, 1990; Hammer, 1989 and 1996; Kadlec and Knight, 1996). USEPA also developed two technical assessments of different constructed wetlands: *Free Water Surface Wetlands for Wastewater Treatment: A Technology Assessment* (USEPA, 1993a), and *Subsurface Flow Constructed Wetlands for Wastewater Treatment: A Technology Assessment* (USEPA, 1999). These can help determine the selection and design of an appropriate constructed wetland.

Some recent studies provided additional information on design and performance of constructed wetlands. For example, interspersing open water with emergent vegetation appears to maximize NH_4 removal efficiency (Thullen *et al*., 2002). Adding maerl (calcified seaweed) to a laboratory wetland resulted in 98 percent reduction in phosphorus (Gray *et al*., 2000). Wetzel (2001) suggests that all wetland treatment strategies should maximize physical contact and duration of contact between water and microorganisms and periphyton. Periphyton growing on aquatic vegetation have been found to be significant in their assimilation of nutrients (Dierberg *et al*., 2002). The importance of submerged aquatic vegetation and periphyton in improving constructed wetland performance in removing nutrients was demonstrated in studies in the Florida Everglades (Goforth, 2001). Research also indicates that the uptake and return of nutrients are separated in time and occur on different temporal scales, which should be taken into account during the design and operation of constructed wetlands (Tanner, 2001a). A comparison of subsurface systems found that wetlands performed better at removing ammonia when incorporating three design elements: no algae, longer detention times, and deep root penetration of emergent plants, rather than only one or two elements (USEPA, 1993a).

Even though natural and constructed wetlands have been used for water quality treatment for many years, there are still gaps in knowledge on performance and design factors. Studies are still needed to better understand the chemical and physical characteristics of various nutrient fractions in runoff as well as the nature of nutrients that remain after passage through wetlands (Dierberg *et al*., 2002). Other studies have suggested the need for a widespread measurement program to provide a more detailed evaluation of wastewater treatment systems to identify variability and factors contributing to variability (Szabó *et al*., 2001). The nutrient removal rates and capacity in both natural and constructed wetland systems need further investigation to allow identification and comparison of nutrient removal in a wide spectrum of wetland types, scales, landscape positions, regional climates, geology, and nutrient inputs.

3.3.1 Related Outcomes of Constructed Wetlands

Constructed wetlands designed to treat water high in nutrients generate related beneficial and detrimental outcomes. These outcomes provide additional advantages and disadvantages to using constructed wetlands as BMPs in a WQT program that should be considered when selecting this BMP to generate WQT credits. Knight (1992) provides an overview of the ancillary benefits and potential problems with the use of wetlands for NPS nutrient discharge. These related outcomes are discussed brie y and incorporated with other study findings.

Constructed wetlands can provide many benefits in addition to water quality treatment (Kadlec and Knight, 1996). These benefits include: photosynthetic production; secondary production of fauna, food chain, and habitat diversity; export to adjacent systems; and services to human society such as aesthetics, hunting, recreation, and research (Knight, 1992). One of the key biological benefits of constructed wetlands is their ability to provide habitat for plants and animals. Many plants and animals live in wetlands, and many periodically use wetlands as drinking sources, breeding sites, or foraging areas. For example, a series of shallow ponds constructed to maximize NO_3 removal in California had an average avian specie richness ranging between 65 and 76 species per month, including both common and rare species. Wetlands also provide a food source for animals such as nutria and muskrats; however, these species can consume much of the vegetation and reduce the nutrient removal function of constructed wetland (USEPA, 1999).

A summary of 17 case studies located in 10 states found that constructed wetlands can provide valuable wetland habitat for waterfowl and other wildlife (USEPA, 1993b). However, wildlife can sometimes be detrimental to the nutrient removal efficiency of wetlands. For example, in a constructed wetlands near Chicago, a large number of carp were found foraging and resuspending sediment, thus decreasing the performance of the wetland. These fish had arrived as juveniles in the in ow and grew up in the wetland. In another example, a wetland constructed to remove nitrogen from municipal wastewater included open water habitat to attract waterfowl. Wintering waterfowl and colonial red-winged blackbird (*Agelaius phoeniceus*) used the open water areas, but contributed a small amount (2.6 percent nitrogen and 7.0 percent phosphorus of mean daily loads from WWTP) to nutrient loading during November through March (Andersen *et al.,* 2003).

Using wetlands for nutrient treatment can have demonstrated additional water resources benefits within the wetland and downstream. The use of a natural forested wetland in the Mississippi Delta for wastewater treatment over 50 years has shown significant sedimentation and resulted in increased accretion rates (Day *et al.,* 2004). The results of the study suggest that the application of nutrient-rich wastewater, and the resulting sedimentation, can also gradually increase wetland elevations and counteract some of the negative effects of sea level rise on coastal wetlands.

Adding nutrient-rich water into natural wetlands has been demonstrated to increase productivity of woody vegetation, measured as stem diameter growth, and growth of herbaceous emergent and aquatic vegetation (Day *et al*., 2004). The additional growth of emergent and aquatic vegetation contributes more to sediment accretion. This sedimentation function also improves downstream habitat. Water typically flows slowly through both natural and constructed wetlands because of their gentle gradient and vegetation. The slow flow allows fines to settle out or deposit on vegetation. Consequently, fewer fines are transported downstream, benefiting fish. Fines in streams can fill interstitial spaces within gravel substrates, reducing the quality of spawning success in fish.

In addition to improving fish spawning habitat, constructed wetlands can provide additional benefits by ameliorating flood waters, storing water for multiple uses, and recharging groundwater (Feierabend, 1989; Slather, 1989; Knight, 1992). Watersheds composed of 5 to 10 percent wetlands are capable of providing a 50 percent reduction in peak flood period compared to those watersheds that have none. Therefore, constructed wetlands can be valuable in watershed management strategies, especially in areas where wetlands have been lost (DeLaney, 1995). The effectiveness of wetlands is determined in part by the location of each wetland in the watershed. In arid regions, the reuse of wastewater through treatment wetlands can be especially helpful in serving to conserve water, provide habitat, recharge groundwater, and maintain longer instream flows downstream (USEPA, 2000a).

Wetlands built along shorelines of streams, lakes, and marine environments can help control erosion from flows, wind, and shoreline uses. The erosion is largely controlled by the rooted vegetation established in the wetland, which disrupts the flow velocities and binds the soil. Constructed wetlands positioned along shorelines need to be carefully designed, constructed, and maintained to ensure inflow water is treated by the wetland before discharging to adjacent water bodies (Hammer, 1992).

There are several direct human benefits possible from constructed wetlands. The improvement of water quality by wetlands has been found to benefit human health by reducing disease-causing bacteria and viruses (Jing *et al*., 2002). Wetlands remove toxic chemicals found in wastewater in addition to nutrients. Harvesting of wetland vegetation has been used for the production of methanol (USEPA, 1999). Constructed wetlands with public access and public use provide recreation, research, and educational opportunities. Public education has ancillary benefits of generating support for water quality and watershed protection. Constructed wetlands have been used in combination with other treatment mechanisms to provide safe drinking water (Elias *et al*., 2001).

Even though there are many benefits from constructed wetlands designed to treat water quality, these wetlands can also have detrimental outcomes. For example, the use of farmland to construct a wetland results in a loss of that land for farming or another land use. Constructed wetlands located in other water bodies (i.e., wetland, stream, or lake) or immediately adjacent to natural water bodies can negatively affect the natural water quality or quantity of these water bodies (USEPA, 2000a). This effect depends on the quality of the natural water body and the design of the constructed wetland.

Constructed wetlands that attract wildlife may have a negative consequence. For example, siting a constructed wetland near an airport might attract birds, which present a hazard for airplanes and the birds. Constructed wetlands can also be a hazard to wildlife if they provide large amounts of habitat where many birds of various species can interact and spread diseases. Attraction of wildlife could also lead to increased encounters with domestic animals, leading to direct or indirect harm to both animal groups (USEPA, 1999). As mentioned above, wildlife can negatively affect the nutrient performance of a wetland through direct input of nutrients or remobilization of nutrients. If water input is episodic or seasonal, the high fluctuations in water level and potential drought periods could be detrimental for organisms that reside in the wetland. Constructed wetlands can be directly harmful to organisms if the water quality is poor or even toxic. For example, selenium has been found to bioaccumulate in constructed wetlands, leading to reproductive failure in fish and aquatic birds (Nelson *et al.*, 2000; Lemly and Ohlendorf, 2002).

The building of constructed wetlands requires disturbance of soil and vegetation. Disturbed areas are prime locations for colonization by invasive plant species, especially if sources are nearby. Additionally, nutrient loading of wetlands can result in a shift in plant species assemblages, often seen as an increase in weed invasion at the point of effluent discharge (Chague-Goff *et al.,* 1999). Consequently, constructed wetlands can provide habitat and opportunity for spreading invasive species.

Public health and safety may be compromised by constructed wetlands if they are not designed and maintained carefully. Wetlands can have odors that are unpleasant for neighboring communities. Odors in constructed wetlands are typically associated with high organic loadings, especially near the inlet. Also, without safeguards, wetlands can pose a safety hazard to visitors to the wetland. Constructed wetlands used to treat wastewater need to prevent human contact with the untreated water, which could carry pathogens harmful to human health (USEPA, 1999). In some areas of the country, dangerous reptiles, including poisonous snakes and alligators, could be attracted to constructed wetlands. A USEPA study is examining if treatment wetlands are more or less likely to create risks to wildlife species than adjacent natural wetlands (USEPA, 1999).

Another species attracted to wetlands that can be a nuisance or harmful to humans is mosquitoes. Studies of mosquitoes have concluded that the number of breeding mosquitoes in treatment wetlands is not higher than in adjacent natural wetlands (Crites *et al*., 1995). Controlling vegetation to create dispersed open water patches can result in reduced mosquito populations by limiting mosquito refuge areas and increasing predation areas (Thullen *et al*., 2002). However, another study found that vegetation management within constructed wetlands conducted in autumn to stimulate denitrification correlated with higher mosquito abundance than control wetlands lacking management (Walton and Jiannino, 2005). According to a USEPA fact sheet (2004), as long as wetlands function as healthy ecosystems—i.e., are able to sustain mosquito-eating fish, amphibians, birds, and insects—they are not uncontrolled breeding grounds for mosquitoes. In fact, it was found that mosquito habitat was reduced by almost 100 percent and the *Culex* species of mosquito almost eliminated after a degraded wetland no longer requires mosquito control measures (USEPA, 2004).

There are also potential negative impacts to air from constructed wetlands. Denitrification process within microbes that occur in wetlands converts NO_3 to N_2O, which is released to the atmosphere and has negative effects on local ground-level ozone (DeBusk, 1999). This process occurs in anaerobic conditions, typically below the soil surface. A study of constructed wastewater treatment wetlands in Sweden showed that N_2O emissions varied seasonally during two years of measurements: large spatial and temporal variations were measured in N_2O flux; the largest positive flux of N_2O occurred in October, and the smallest positive flux in July (Johansson *et al*., 2003). The release of CH_4 gas is also a negative outcome of denitrification (Wetzel, 2001). CH_4 gas emissions from wetlands can contribute to local odor issues and add to greenhouse gas levels. Emissions of greenhouse gases (CH_4 and CO_2) were measured throughout an annual cycle and shown to be positively correlated with water temperature in shallow wetland ponds constructed for nitrogen removal (Stadmark and Leonardson, 2005). CH_4 production was most pronounced from May to September when NO_3 concentrations were low. The study concludes that constructed nutrient removal ponds emit greenhouse gases comparable to lakes in the temperate region.

Knight (1992) provides guidance on optimizing the appropriate ancillary benefits and avoiding undesirable side effects while achieving primary nutrient control goals. Many of the benefits and problems with constructed wetlands can be addressed during the planning and designing process. Maintenance following construction of the wetland is also important in prolonging and enhancing the nitrogen and phosphorus removal efficiency and ancillary benefits, while minimizing detrimental outcomes. Thus, the design for constructed wetlands needs to provide access for maintenance.

There are several techniques to improving nutrient removal. For example, partial nitrification of swine waste water prior to discharge to a constructed wetland increased TN removal rates (Poach *et al*., 2003). Another study found that adding iron to the substrate significantly improved phosphorus retention (Cerezo *et al*., 2001). A model showed that increasing nitrification rates in the summer and denitrification rates in the winter would improve nitrogen removal efficiencies. This might be accomplished by increasing carbon supply in winter (Gerke *et al*., 2001).

The selection of the appropriate plants for constructed wetlands affects the performance and maintenance of the wetland. Floating aquatic systems are more affected by pests and cold temperatures and are more expensive to construct and operate than surface-flow systems planted with emergent plants (Payne and Knight, 1997; Hunt and Poach, 2001).

Common plant species used as emergents include bulrushes (*Scirpus sp*.), cattails (*Typha sp*.), and rushes (*Juncus sp*.). These plants are important in transporting oxygen from the leaves and stems to roots, providing an oxidized microenvironment in the typically anaerobic root zone of wetlands (Armstrong, 1964).

The juxtaposition of aerobic and anaerobic zones at the soil-water interface is important for nitrification when ammonia is transformed into NO_3 (Hunt and Poach, 2001). Thus, the amount of oxygen reaching the root zone affects the rate of nitrification. Different plant species transport oxygen at different rates to this zone; therefore, plant selection affects the performance of constructed wetlands at treating nutrients. For example, bulrushes have higher rates of oxygen transport than cattails (Reddy *et al*., 1989; Szögi *et al*., 1994), and the sediment around bulrush roots was aerobic 30 percent of the time versus 0 percent of the time around cattails (Szögi *et al*., 2004). Even so, Wetzel (2001) suggests that rooted emergent plants cannot be expected to aerate saturated sediments because the function of translocating oxygen to the roots is to support the metabolic needs of the root tissues, not to oxidize the sediments.

Although the results of some of the studies cited above suggest that certain plants may transport excess oxygen down to the sediments, if very high levels of nitrogen removal are required from a treatment wetland, procedures that increase oxidation of wastewater prior to entering the wetlands or designs to include open water areas might be needed to increase nutrient removal efficiency (Hunt and Poach, 2001).

Removing accumulated emergent biomass and physically limiting the area available for vegetation reestablishment significantly improved the ammonia removal efficiency. Limiting emergent plants mimics early successional patterns with actively growing plants and results in interspersed open water, which also reduces mosquito populations by increasing predation areas (Thullen *et al*., 2002). Harvesting shoots may not be important for long-term nitrogen removal because most of the nitrogen is removed through denitrification (Wetzel, 2001; Matheson *et al*., 2002). Tanner (2001b) found that sediment containing high organic matter accumulated twice the nitrogen and six times the phosphorus than live and dead plant tissue (Tanner *et al*, 1998). Therefore, harvesting the above-ground portions of emergent vegetation might provide only a small contribution to long-term removal of nitrogen and phosphorus from the system.

Because constructed wetlands mimic natural systems, they are, by design, naturally functioning, passive, and require limited operational maintenance. However, the imitation of natural systems does not eliminate the need for maintenance of constructed wetlands. The most critical element of maintenance is the quick identification and action when water level adjustments are needed (USEPA, 2000b). Water level affects many of the processes occurring within the wetland and the survival of aquatic organisms. Regular inspections are fundamental to identifying problems and taking corrective actions, such as adjusting weirs or other water level control features (Kadlec and Knight, 1996).

Constructed wetlands have maintenance requirements similar to stormwater ponds, including hydraulic water and depth control, inlet/outlet structure cleaning, grass mowing of berms, inspection of berm integrity, wetland vegetation management, disease vector (e.g., mosquito) control, and accumulated sediment/organic matter management. Subsurface systems are prone to clogging and are limited in function by oxygen diffusion (USEPA, 1993a). Surface systems may need extraction of built up sediments or vegetation that block ows (USEPA, 1999). Inspections may identify the need to eliminate or control invasive or nuisance species (USEPA, 2000a). Sprinklers have been used successfully to control adult mosquito populations in constructed wetlands because the sprinklers disrupt the water surface, affecting ovipositioning (Epibare *et al*., 1993).

Review of the related outcomes of constructed wetlands identified several research needs. The quantitative magnitude of related benefits and detriments may vary greatly from one system to another (Knight, 1992). Therefore, related outcomes need to be quantified and compared to different designs, regional variation, human values, etc. For example, studies are lacking on odor associated with constructed wetlands used for water quality treatment, especially in comparison with natural wetlands (USEPA, 1999). The causes, controls, and magnitude of odors as well as their community acceptance would benefit from research.

There is additional need to monitor reference wetlands to compare performance of constructed wetlands and impacts of external factors on wetlands. Monitoring should also include surrounding area as well as the constructed wetland. The design and management of constructed wetlands lack complete understanding and incorporation of problems of channelization, altered microhydrology at the spatial scale of microbes, and assimilation versus physical absorptive retention (Wetzel, 2001). More research is needed on the temporal nature of nutrient removal by constructed wetlands. For example, one study found nitrogen removal efficiency dropped from 79 to 21 percent in one year (Tanner *et al*., 2005). Removal efficiencies also dropped between the first and second year in experimental mesocosms (Hench *et al*., 2003). These changes in removal efficiency could be attributed to seasonality, wetlands maturity rates, or regional factors. The use of constructed wetlands for trading programs could benefit from additional planning and understanding about the long-term performance and fate of constructed wetlands.

3.4 Modeling Nitrogen and Phosphorus Removal by Wetlands

Modeling is used to quantify the performance of processes and to attempt to optimize this performance. Models are useful for acquiring information about performance when actual measurement is prohibitively expensive (Johansson *et al*., 2004). The benefits of accurate models include improved designs, reduced monitoring, and predictability of performance. This predictability could be used to define credits in a market-based WQT program. A predictive model for constructed wetlands should be able to describe and predict wetland hydraulics, because this directly affects the treatment performance of a wetland according to basic water quality modeling such as the k-C* model (Bojcevska, 2005; Persson, 2005; Kadlec, 2000; Persson *et al*., 1999; Wong and Geiger, 1997; Kadlec and Knight, 1996).

Although the physical and biological processes that drive wetland systems are complex, many mathematical models have been developed to simulate nutrient removal in wetlands. Many of these models were developed by accounting for hydrologic conditions and nutrient dynamics. A mathematical model was developed from studies of lowland rice fields and can be used to assess the extent of absorption from the rhizosphere by wetland plants growing in ooded soil, incorporating important plant and soil processes (Kirk and Kronzucker, 2005). McBride and Tanner (1999) developed a mathematical model to simulate patterns of nitrogen removal that were observed in experimental studies of constructed wetlands treating NH_4-rich water. Brown (1988) developed a simulation model to predict water quality of outflow water from natural and constructed wetlands. The model requires data input for wetland type, discharge rate, and concentration of nutrients in surface water inflow (Brown, 1988). Another mathematical model that simulates wetland hydrology and nutrient-driven interactions between wastewater and wetlands was tested by comparing simulations with data from a wastewater treatment facility (WTF) (Kadlec and Hammer, 1988). The simulation accurately predicted solute concentrations, biomass growth patterns, changes in the litter pool, and soil accretion rates. Another two-part model was developed by Dorge (1994) that contains a hydrological submodel and a more complex biological submodel. The model was developed to determine the retention and removal of nitrogen in wetlands as water flows from cultivated agricultural land through wetlands to aquatic systems. The model can be used to describe the transport and turnover of nitrogen from fertilization through soil and groundwater to aquatic systems (Dorge, 1994).

Some models have focused specifically on plant uptake of nutrients (Langergraber, 2001; Mankin and Fynn 1996; Romero *et al*., 1999; Wegehenkel, 2000). Langergraber (2001) developed a model (CW2D) to simulate plant uptake of nutrients in constructed subsurface flow wetlands relative to water uptake. The model was tested with indoor pilot-scale constructed wetlands. Langergraber (2005) tested the CW2D model for the portion of nutrient removal attributable to plant uptake and concluded that it is possible to simulate plant uptake of nutrients in constructed wetlands with a model that links nutrient uptake with water uptake. Another model, HYDRUS-2D, also models nutrient uptake by plants coupled with water uptake (Simunek *et al*., 1999). A mass balance method was used to quantify the performance of nutrient storage systems in an experimental artificial wetland (Breen, 1990). In this simulation, hydrologic design to maximize wastewater-root zone contact was determined to be important for treatment performance. Furthermore, uptake by plants was found to be responsible for most of the nutrient removal, and plant biomass was determined to be the primary nutrient storage mechanism. Other studies that included field measurements of nutrient uptake in constructed wetlands often come up with the opposite result; plant uptake is a relatively small component of total nutrient uptake compared to microbial processing (Hamersley *et al.,* 2001; Lin *et al.,* 2002; Stein *et al.,* 2003).

Simulations of natural wetlands have also been modeled. A model was developed specifically for riverine wetlands to describe the interaction and processing of carbon, nitrogen, and phosphorus (van der Peijl and Verhoeven, 1999). The simulation results showed a good fit to data collected on riverine wetlands in southwestern England. In a later test of the model to study nutrient enrichment of a riverine wetland, results diverged from the field studies when the simulations predicted a far greater role for nitrogen as limiting factor than the field experiments (van der Peijl *et al*., 2000). The lack of agreement between the simulation and the field experiments was attributed to differences in the environmental conditions (e.g., weather and area measurements) between the field experiment and the computer simulation.

Field-scale simulation models have recently been practiced instead of intensely and expensively surveying farms or conducting field trials for the myriad of conditions in a watershed (Johansson *et al*., 2004). The advantage of field-scale models is that they account for variability in land cover, soil, tillage, and drainage practices. An example of this type of model is the Agricultural Drainage and Pesticide Transport (ADAPT) model. This model simulates the nutrient loads and crop yields resulting from alternative phosphorus BMPs using variable management practices (e.g., crop choice, fertilizer use) and climatological data (Johansson *et al*., 2004).

Watershed modeling has been used to predict nutrient loadings (Arheimer and Wittgren, 2002; Gowda *et al*., 1998). For example, a study in Eastern Europe between Estonia and Russia used a large-scale geographic information system (GIS)-based nutrient transport model over a 15-year period to model the change in nutrient levels caused by reduced agriculture experienced by the region since the restructuring of the former USSR (Mourad and van der Perk, 2004). The study applied the modeling approach developed by De Wit (1999, 2001), the PolFlow model, which used large-scale, spatially variable estimates of sources, transport, and decay of TN and TP over five-year periods. The model consists of three steps: estimating both diffuse (i.e., nonpoint) and PS emissions; calculating long-term hydrological fluxes; and modeling the transport of emitted nutrients through the soil, groundwater, and surface network.

Results from applying the PolFlow model were compared to measured loads and were found to coincide reasonably well with one river and overestimate loadings for another with a smaller drainage basin. In the model, nutrient retention within a drainage basin is simply modeled using a transport fraction factor that is determined by slope and discharge. The study found that modeling was complicated by the transfer of nutrients from nonpoint emissions, which is strongly governed by the retention in and periodic release from storages such as root zone, tile drains, ditches, channels, substrates, floodplains, etc. Future research is needed to refine the quantification of this nutrient transport fraction. Improvement to modeling nonpoint emissions was suggested by increasing knowledge about the spatial and temporal distribution of various nutrient storage and fluxes along pathways between the soil surface and water bodies (Mourad and van der Perk, 2004).

In north Georgia, watershed-scale modeling is being used to estimate phosphorus loads for different NPS agricultural practices. The Soil Water Assessment Tool (SWAT), based on the USEPA Better Assessment Science Integrating Point and Nonpoint Sources software, is used for rural watersheds and can estimate phosphorus loads by calculating soil loss. The model is calibrated using field samples and local watershed data. Calibration is conducted for two reasons: to determine the parameter values that characterize the general hydrology of the watershed, and to find the parameter values that describe phosphorus and sediment losses from agricultural sources and the effect of BMPs (River Basin Center [RBC], 2003).

The DUFLOW model was developed in The Netherlands for simulating one-dimensional unsteady flow and water quality in open channel systems (EDS, 1998). This model allows for the modeling of pollutant transport and defines processes and pollutant interactions. A similar model was developed and applied to wetlands surrounding Lake Victoria, Tanzania, to simulate the buffering process of wetlands and the capacity of individual natural wetlands to absorb sediments, nutrients, and pollutants. This model estimated the impacts of inputs on water quality, quantity, and accumulation rates in permanent fringe wetland and seasonal floodplain wetlands. This model included both nitrogen and phosphorus compounds and 28 different parameters. The application of the model showed that there was seasonal flow from the lake to the wetlands (Mwanuzi *et al*., 2003).

A study in southwest Sweden was conducted to examine the applicability of the GLEAMS model to simulate the drainage discharge and nitrogen and phosphorus concentrations in the discharge water from a clay field with drain tiles (Shirmohammadi *et al*., 1998). The results indicated that GLEAMS was capable of simulating reduction of NO_3 and dissolved phosphorus losses reasonably well, but there were no algorithms to simulate the particulate phosphorus losses via drain tiles. Therefore, a submodel, “PARTLE,” was developed and tested. These two models, combined, provided reasonable estimates of particulate phosphorus loss via drainage through soil. The study concluded that considering the impact of preferential flow and the ratio of annual drainage discharge to annual precipitation is necessary for proper predictions of particulate phosphorus in structured soils.

Modeling fate and behavior of pollutants requires simulation of both transport and controlling processes such as sedimentation, biomass uptake, sorption, etc. (Mwanuzi *et al*., 2003). Modeling nitrogen flux in the lower Mississippi River has been investigated by McIsaac *et al*. (2002). One model they examined accounted for 85 percent of the variation in observed annual NO_3 flux, but tended to underestimate high NO_3 flux and overestimate low NO_3 flux. Another model that used water yield and net anthropogenic nitrogen inputs (NANI) accounted for 95 percent of the variation in riverine nitrogen flux. The NANI approach accounted for nitrogen harvested in crops and assumed that crop harvest in excess of the nutritional needs of the humans and livestock in the basin would be exported from the basin. The U.S. White House Committee on Natural Resources and Environment (CENR) developed a more comprehensive nitrogen budget that included estimates of ammonia volatilization, denitrification, and exchanges with soil organic matter. The residual nitrogen in the CENR budget was weakly and negatively correlated with observed riverine NO_3 flux. When the CENR nitrogen budget was modified by assuming that soil organic nitrogen levels had been relatively constant, and ammonia volatilization losses were redeposited within the basin, the trend of residual nitrogen closely matched temporal variation in NANI and was positively correlated with riverine NO_3 flux in the lower Mississippi River (McIsaac *et al*., 2002).

Crop yield simulation models that incorporate spatial information may apply to modeling nutrient removal in constructed wetlands. Many of these models predict nutrient cycling such as nitrogen and phosphorus fertilization, nutrient transformations, crop uptake, and nutrient movement (Priya and Shibasaki, 2001).

Typically, robust and general models combine both empirical and mechanistic modeling. To gather large amounts of data for empirical modeling, large databases have been developed. One of the most comprehensive summarization efforts to date was the development of the NADB, funded by USEPA (USEPA, 1994). Two versions of the database were ultimately distributed. Version 1, completed in 1994, used an MS®-DOS database system known as Dbase III and was the most widely distributed version. Version 2 of the NADB was built upon an MS® Windows Access database engine. Collected data is analyzed using regression to determine relationships between variables. However, regression does not necessarily indicate causality; thus, spurious relationships can be modeled. Research databases have been used to validate and modify computer models (Humboldt University, 2000).

The first NADB database fell short of meeting its goal of providing sufficient information to optimize the design of treatment wetlands (USEPA, 1999). The bulk of the entries in the revised USEPA-sponsored database (NADB Version II) have been placed into a new database called the Treatment Wetland Database (TWDB). This web-based database adds many additional treatment wetlands to the USEPA-revised database. While the emphasis is on constructed wetlands, natural wetlands are also included in the TWDB database (Humboldt University, 2000).

Rigorous models for constructed wetland systems need to be developed by designing a comprehensive series of iterative studies, collecting data based on quality-controlled specifications, and analyzing the relationships between design features, environmental parameters, and performance. An assessment of current modeling efforts suggests that an effective plan is needed for the design of studies that will provide a comprehensive understanding of the processes that occur within constructed wetlands. The study design should include extensive, quality-assured, transect data at numerous selected sites to capture spatial variation over an extended period of time to identify temporal variation. Using existing mathematical models of wetlands processes combined with the study data, an iterative model of complex systems can be developed and used (USEPA, 2000b).

Modeling constructed wetlands is complicated by the complexity of the reaction mechanisms within these systems, the difficulty in charactering the constituents within the inflow water, and the accountability of influential physical and external factors. Additional challenges include the ability to scale up, shortcomings in analytical and sampling methods, and the capacity to verify models with long-term monitoring (USEPA, 2000b). Modeling is also problematic because wetlands are highly ephemeral in capabilities and efficiencies for uptake and especially biologically-mediated retention of nutrients and pollutants (Wetzel, 2001). Proper model selection is one of the most important steps in any modeling exercise (Priya and Shibasaki, 2001). Many of the current design models for constructed wetlands rely on the assumptions of steady-state water flow conditions and first-order decay of pollutants. Studies have suggested that this is not representative of field conditions (Kadlec and Knight, 1996; Persson *et al*., 1999; Persson and Wittgren, 2004). Thus, there is a need for more experimental data to further define how hydraulic patterns are affected under different environmental conditions, both spatial and temporal.

Further research is needed to improve nutrient models, including detailed hydraulic investigations of full-scale wetlands, simulations of outdoor constructed wetland systems, investigation of plant uptake models, improving the simulation tool by accounting for substrate clogging processes, and developing experimental techniques to measure model parameters (Langergraber, 2003). More work is needed to adequately account for field environmental conditions in computer simulations (van der Peijl *et al*., 2000). Modeling nutrient removal by wetlands should account for delays in nutrient flow pathways through groundwater. There are temporal lags in groundwater flow depending on the size of the aquifer extent and recharge zone, as well as soil type and geology. Consequently, land-use management practices to reduce nutrient loading to a watershed might not result in water-quality improvements for many years, especially if implemented on land far from streams (Wayland *et al*., 2002).

Additional incorporation into models of microbial and hydrological influences on nutrient uptake could improve the predictability of nutrient reductions. Models tend to underestimate that most nutrients from influent sources are assimilated directly by microbiota (i.e., bacteria, algae, fungi) rather than plants and are intensively recycled amongst these microbial communities, which cover all wetted surface in aquatic ecosystems (Wetzel, 2001). Channelization and variability in flow velocity are among the greatest limitations to maximizing retention capacities of nutrients in wetlands (Wetzel, 2001). If these channels and flow patterns are not included in models, then the predictability of the models is hindered by the inadequate consideration of these patterns and their effect on absorption/adsorption rates. Advances in understanding the hydraulic performance in wetlands can be gained by studying water flow patterns or hydraulic residence time distributions obtained from tracer experiments (Persson, 2005).

3.5 Defining Nutrient Load Reduction Credits

A comprehensive review of WQT in the United States identified 40 trading initiatives in 17 states, 29 of which specifically cover nitrogen or phosphorus (Breetz *et al*., 2004). According to the information on WQT programs compiled by Breetz *et al*. (2004), potential NPS WQT partners include: new or expanding WWTPs trading with stormwater BMP retrofits, street sweeping, land reclamation, surplus reductions from existing WWTPs, diverted flow from existing WWTPs, conversion from surface to subsurface discharges, removal of poorly functioning septic systems, or wetland restoration.

The service area for WQT programs (i.e., the area in which trades are allowed) is most often defined by a watershed or sub-basin boundary. A trading program in New York allowed trades only within the same basin, with the exception of one WWTP that received credit for reduction in upstream phosphorus in a basin hydrologically connected to the basin of discharge (Breetz *et al*., 2004). Establishing a trading service area can be further complicated by political boundaries, particularly in watersheds that cross state boundaries. Further division of hydrologically-related boundaries into trading zones may be necessary in some area because of non-uniform mixing of nutrients in water bodies (Kramer, 2000). Credits are often restricted to sources upstream from the point of discharge (Breetz *et al*., 2004).

Building sufficient credit inventory to make a trading program cost-effective can be accomplished in areas that have certain conditions favorable for the establishment of WQT programs. Favorable conditions usually include a wide variation in PS control costs, a large number of PSs, and the availability of low-cost NPS reductions (Kramer, 2000). The seasonality of NPS reductions through implementation of BMPs is also an important factor to consider. The extent to which the spatial and temporal patterns in wetland (or other BMP) nutrient removal performance match the spatial and temporal patterns in load reductions needed by the PSs can determine whether NPS reductions would be appropriate to offset PS discharges (Crumpton, 2006). Further organizational details that are required for a successful trading program are outlined by Stavins and Whitehead (1996). These details include clearly defining responsibility for total discharge; defining trading area; establishing legal authority for trades through rulemaking, legislation, and NPDES permits; monitoring or statistical models to verify compliance; establishing procedures to reduce the costs of identifying potential trading partners, negotiating trades, and program administration; encouraging public involvement to help speed the regulatory process; and regular evaluation of the program for overall efficiency.

Most BMPs used in WQT programs are general and are applicable to many agricultural operations; a few are specific to certain farming activities. Example BMPs used in WQT programs include: livestock exclusions, buffer strips, constructed wetlands, wet ponds, alternative surface tile inlets, cover cropping, roof gutters, filter walls and filter strips, manure storage pits, conservation tillage, runoff control systems, settling basins, concrete barnyards, diversions, underground outlets, livestock exclusion rotational grazing, wetland restoration, land set-asides, nitrogen application restriction, manure incorporation, sediment reductions through land acquisition, conservation easements, streambank stabilization, development of silt basins, dry dams, terraces, grassed waterways, filter strips, and grade control structures (Breetz *et al*., 2004; Kramer, 2000).

Determining credit value for NPS operations is primarily based on getting agency concurrence of acceptable BMPs that reduce nitrogen and phosphorus loading. Some agencies have developed a list of BMPs that are eligible to be used in WQT programs (Idaho Department of Environmental Quality [IDEQ], 2003). The nutrient reductions from these BMPs are usually required to be surplus, quantifiable, permanent, and enforceable.

Creating credits can be difficult in watersheds where agricultural sources are significant contributors to nutrient loads. A common assumption is that agriculture can be a primary supplier of these credits; however, the willingness of farmers to participate in such programs can be problematic for several reasons. Often, trading guidelines prohibit farmers from selling credits when making legally required (e.g., by state regulation) land management changes[3] or for which the farmer has already been paid (e.g., green payments). These prohibitions reduce the ability of farmers to supply low-cost credits. Because they require farmers create credits by implementing BMPs in addition to current practices and then demonstrate that the BMPs do indeed reduce discharge levels (King, 2005). Many BMPs do not show direct improvements and are not easily validated. Rahr, LBR and North Carolina have skirted this issue by assigning typical performance values to specific BMPs. Applying additional BMPs and validating their effectiveness can be a risky endeavor for credit producers because there is no guarantee that the time and money spent will generate more credits.

The need to establish a baseline nutrient load and show reduced discharge levels after BMP implementation creates two additional obstacles for farmers considering supplying credits. First, in order to establish the baseline to quantify marketable credits, an outside party must determine what nutrient-reducing land management practices and/or BMPs farmers have already implemented.) This evaluation is something most farmers are leery about because it could generate questions regarding their justification for green payments or repercussions related to the legality of their land use practices with respect to state requirements. Second, farmers know that their NPS nutrient discharge is currently not regulated as much as PS discharge because NPSs can be difficult to measure, are weather-dependent, and can be costly to control. By showing that they can create baseline information and then reduce their discharges below baseline, they are actually demonstrating that NPS discharge is measurable and that perhaps it should be regulated the same as PS discharge (King, 2005). Farmers are reluctant to participate in a program that could lead to additional regulatory controls over their activities. The LBR program attempts to sidestep this issue through the approach for calculating nutrient credits. The baseline load of a NPS is first determined using the USDA-NRCS Surface Irrigation Soil Loss (SISL) model. Credits generated by a BMP are calculated by subtracting the individual NPS share of nutrient reduction required in the TMDL from the total nutrient reduction created by a BMP (baseline load multiplied by the BMP effectiveness ratio [Breetz *et al*., 2004]).

3.5.1 Measuring Nutrient Removal Performance

Estimating or quantifying existing NPS nutrient loads is necessary for calculating credits and for providing a baseline to measure performance. Methods for measuring baseline conditions and performance of NPS nutrient reduction efforts are highly dependent on the type of activity being conducted and the associated land use practices. Credits have been granted for reductions in nutrient loads achieved through livestock exclusion, stabilization of eroding stream banks, conversion of farmland back to oodplain, and vegetation restoration. These activities result in reductions in sediment and soil loss as well as the associated nutrient reductions (Fang and Easter, 2003). Other programs have granted credits for voluntary reductions as quantified by a "qualified soil and water conservation professional" according to standardized procedures (Breetz *et al*., 2004).

Where nutrient reduction data are limited and models contain uncertainties, as is currently the case of constructed wetlands on a watershed scale, measurements of nutrient reductions can be taken to determine credits. Performance can be measured as power (nutrient mass removed over time) or efficiency (nutrient fraction removed over time). Direct measurement of nutrient reduction performance of a constructed wetland requires measuring the difference in nutrient concentration between water in ows to and out ows from the wetland. The amount of actual nutrient reduction can be measured using grab samples taken during the BMP operation. In the LBR WQT program, the measurement schedule is determined in the trading contract for specific watershed-scale BMPs and regulatory guidance (ISCC, 2002).

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3 State land management requirements are relatively rare. North Carolina is an example of a state with land management requirements in some watersheds.

Measuring the nutrient removal performance of a BMP has advantages and disadvantages. An advantage of measuring over calculating nutrient reduction is that it diminishes uncertainties, especially in terms of modeling nutrient loss, nutrient removal by the BMP, and final nutrient loading in downstream water bodies. A disadvantage of measuring the effectiveness of nutrient reduction is that it is very difficult and time-consuming in natural and restored wetlands because the inlets and outlets often extend over relatively broad areas. It is much easier to measure the effectiveness of constructed wetlands than natural wetlands because they can be designed with limited inlets, and outlets are often confined in order to control water levels. The difference in concentrations of phosphorus, nitrogen, and other water quality parameters of interest can be measured at the inlet and outlet, and can be taken as a direct measure of nutrient removal efficiency of the wetland. However, measurement approaches need to account for diurnal, seasonal, and spatial variability in nutrient retention efficiency (Wetzel, 2001). A review of 60 wetland studies showed that the duration and frequency of sampling, as well as which nutrient forms were analyzed, influenced in part whether the wetland appeared to reduce or increase nutrient loading (Fisher and Acreman, 2004). Studies that included frequent sampling during high-flow events, or that were conducted for more than one year, were more likely to indicate that the wetland increased nutrient loading, which is the opposite of the expected result. Nutrients can be flushed out of wetlands during high-flow events, which results in an increase of nutrients contained in water exiting a wetland. Wetland design can be used to mitigate or prevent this from happening. Measurements need to be taken throughout the year in order to capture the variations in removal efficiency that wetlands experience over time and seasons (Fisher and Acreman, 2004).

In addition to temporal factors, removal efficiency can vary depending on the position the wetland has in the landscape and in the watershed. For example, wetlands high in the watershed may have limited opportunity to intercept nutrients, and wetlands low in the watershed may have a flow-through rate that limits efficiency. Efficiency is also affected by the geologic and ecologic conditions in the wetland, where different plant species or vegetation structure vary in their ability to influence nutrient removal (Mitsch and Gosselink, 2000). As described in the following section, WQT ratios can be designed to account for the location of a BMP within a watershed.

3.5.2 Modeling and Calculating Nutrient Removal

Credits generated by implementation of BMPs can be modeled or calculated if it is too costly or infeasible to measure the actual performance of the BMP. The first step in calculating credits is to determine the amount of nutrients produced at a location. For example, to estimate the current phosphorus loads from cropland, formulas, such as the Revised Universal Soil Loss Equation and SISL Equation, are used as the most accurate and simple method to estimate soil loss from surface-irrigated cropland (ISCC, 2002; ETN, 2003). These tools can be used to calculate the tons of soil loss per acre per irrigation season. Phosphorus reduction is compared against the phosphorus loads in baseline years used for the TMDL (ISCC, 2002). As another example, reductions in phosphorus loads from cattle exclusion and rotational grazing can be derived by calculating the volume of manure deposited and the associated phosphorus content and delivery ratio (Breetz *et al*., 2004).

Once the nutrient load has been calculated, the nutrient reduction from BMPs is needed to generate credits. One method of calculating potential nutrient reduction is by estimating the average nutrient load reduction associated with a BMP. Nutrient load reductions achieved through agricultural BMPs can also be estimated using field-scale water management simulation models such as the ADAPT model. The ADAPT model can be used to model erosion and sediment transport, which allows for an estimate of phosphorus load reductions from cover cropping, tillage practices, fertilizer applications, crop rotation systems, and planting/harvest dates (Fang and Easter, 2003).

When modeling or calculations are used to estimate nutrient reductions, WQT programs tend to apply a discount to compensate for the uncertainty associated with the effectiveness of the BMP, the accuracy of the modeling results, and geographic variations in nutrient loads and environmental benefits. The multiplier, which is often expressed as a ratio (e.g., 2.1:1 is the trading ratio used by the Neuse River Basin WQT program), is used by WQT programs to reduce the number of transferable credits generated by a BMP. The trading ratio is designed to account for the level of uncertainty associated with the methodology selected to calculate credits, and it is also often established for WQT between NPSs and PSs to include a margin of safety to account for uncertainty in the determination of load reduction (Kramer, 2000).

Credits are also sometimes discounted using delivery ratios to account for location of the BMP project versus the location of the nutrient source that is purchasing the credit. Location within the trading service area can affect credit value. Delivery ratios were developed for the LBR program, which vary from 100 percent in riparian areas, to 20 percent within ¼ mile of the receiving water body, to 10 percent at distances greater than ¼ mile from the receiving water body (Breetz *et al*., 2004). Ratio discounts range from 1.1:1 to 3:1. Overall, trading ratios are applied in WQT programs to ensure that water quality in a watershed is protected and trades between sources distributed throughout a watershed result in environmentally equivalent or better outcomes at the point of environmental concern (IDEQ, 2003). To minimize local impacts or hot spots from PSs off-setting some of their nutrient discharges through trades, NPDES permits may place a limit on the total amount of the nutrient discharge the PS may be off set through Another common approach to minimizing the creation of hot spots, requiring prior approval from the organization that administers the trading program or the state WQ regulator ensures the trade does not result in localized impacts to water quality.

Other WQT programs have developed several ratios used in combination to address uncertainties. In Idaho, a River Location Ratio accounts for the transmission loss of phosphorus occurring within the river system. Site Location Factors account for transmission loss due to phosphorus uptake by plants, water reuse, and the portion of phosphorus that will bind with river sediments and settle out. Drainage Delivery Ratios are determined using a linear calculation of phosphorus transmission loss in the subwatershed's main channels (IDEQ, 2003). Additional information on trading ratios is also included in Section 4.3.2.5.

3.5.3 Assessing and Verifying Performance

The performance of BMPs needs to be assessed and verified to ensure a WQT program is successful. In the Idaho WQT program, BMPs are certified as installed according to NRCS and meeting applicable laws and regulations. Once the BMP is certified and operational, phosphorus reduction credits can be generated and traded (IDEQ, 2003). Monitoring is another way to evaluate performance of BMPs. In Idaho they are used to demonstrate that the BMP is designed and maintained properly, and the program guidance requires at least one annual field inspection to evaluate BMP performance. Constructed wetlands are to be evaluated before and during the middle of the season of use (ISCC, 2002). Another program suggests field spot checks should be performed for BMPs with a maintenance life of over one year. The number of checks is determined based on an annual percentage of those BMPs (ETN, 2003).

Although protocols that produce reliable, quantifiable results have been established to monitor discharges from PSs for most industries, similar protocols are not available to measure discharges from NPSs. Generating reliable, long-term monitoring data of NPS discharges is one of the major challenges faced by WQT programs (Breetz *et al*., 2004). Many trading programs do not have systems for monitoring discharges from NPSs because it would be prohibitively expensive and a long monitoring period is required to provide conclusive results (Breetz *et al*., 2004; Jaksch 2000, Fang and Easter 2003). Periodic reviews of BMPs are often used in lieu of quantifiable monitoring. Some programs use a combination of site-specific inspection at 5 to 10 percent of BMPs and continuous water sampling every eight hours at four locations on a sub-watershed scale (Breetz *et al*., 2004).

Models used to determine nutrient loads and nutrient reductions also need to be verified. A common method to verify models is to calibrate them using local data. For example, stream flow conditions are monitored and grab samples are collected to calibrate SWAT for flow and phosphorus removal rates. In addition, background levels of soil phosphorus are determined by soil samples and used to calculate a soil phosphorus extraction coefficient, which is used to calibrate SWAT. Other models can also be calibrated using daily data of groundwater, interflow, and overland flow from different land use and soil combinations. Several years of data are required for accurate calibration (RBC, 2003). Validating models must consider spatial and temporal scales as well as data sources and manipulation (Priya and Shibasaki, 2001). Modeling nutrient fate and transport within a watershed is an extremely complex technical field, and a large volume of information is available on various modeling techniques used in watersheds across the United States. Assessing the various methods being used to model nutrients within a watershed is beyond the scope of this paper, but is an important research need.

3.5.4 Determining the Useful Life of Credits

Many programs establish time limits on the useful life of BMPs, after which it may no longer be effective. The length of time a BMP can be used to generate credits, tends to be a function of how long it tends to be effective at removing nutrients, with a margin of safety added (ETN, 2003). A comprehensive survey of trading initiatives found that structural BMP credits were assigned a 10-year useful life, and non-structural BMP credits were typically good for 3 years (Breetz *et al*., 2004). A BMP's maintenance life and a margin of safety for uncertainties are used to determine the duration of credits (ETN, 2003). Credited reductions are also sometimes limited in time to be contemporaneous with credit use (e.g., the term of a NPDES permit) (Kramer, 2000).

BMPs have been given individual life spans to assure credit buyers that credits would be available and to assure credit sellers that opportunities to market their credits persist for at least the designated life span of the BMP they choose to implement. In some WQT programs, the life span assigned to BMPs reflected the professional judgments of scientists, regulators, and field practitioners. In the LBR case study, constructed wetlands were originally assigned a 5-year life span, but this was increased to 15 years based on discussion within a technical focus group (Koberg, 2006). In the Tar-Pamlico case study, the credit life span for constructed wetlands is currently 10 years. The handling of credits that have been banked, but not used within 10 years, is one of the issues participants in this WQT program are currently working to resolve (Huisman, 2006). More research and discussion are needed to evaluate and determine the ecologically and programmatically functional life spans for constructed wetland BMPs used in WQT programs throughout the United States, the change in BMP performance over this life span, and the relationship of this life span and performance to water quality credit value.

4.0 Economic Literature Review

Traditionally, PS dischargers have three alternatives for managing their discharger liability: (1) meet allowances by investing in additional control measures, (2) meet allowances by trading for WQT credits, or (3) evade regulations and use legal and political processes to minimize enforcement penalties that are unavoidable (Kydland and Prescott, 1977). Because direct action (i.e., items 1 and 2) has been expensive and financially ineffective, strategies involving avoidance or liability transfer have become popular recently (King, 2005; Faeth, 2000).

WQT is a voluntary alternative for achieving regulatory compliance. It is a relatively new program, whereby parties can meet their discharge allowances by trading with each other. In WQT, cost-ineffective dischargers buy nutrient allowances or credits from cost-effective[4] dischargers, who have earned them by voluntarily implementing BMPs for nutrient control. By trading credits, parties reduce the overall cost of achieving nutrient reduction targets. In an ideal market, this process minimizes the cost of nutrient abatement.

An established market or exchange provides the mechanism for WQT transactions. The regulator may play a third-party role in the market, protecting the interests of the public by ensuring that trading does not lead to degradation of the environment, and setting the ground rules for trading. At a minimum, the regulator must recognize WQT as a legitimate alternative to discharge compliance.

Overall, economists, regulators, dischargers, environmentalists, and other stakeholders have advocated WQT as a way to use markets to reduce the cost of nutrient compliance. For example, a simulated trade for the Idaho LBR trading program estimated cost savings to be $10 to $158 per pound of phosphorus reduction using a sediment basin and constructed wetland in series over PS controls (Breetz *et al.*, 2004). Furthermore, the Tar-Pamlico Basin Association (Association) estimated potential costs at $7 million to achieve a comparable level of nutrient reduction that a $1 million investment in NPS controls yielded (DeAlessi, 2003). The approach diversifies discharger alternatives for controlling nutrient with less regulation, less cost, and accelerated compliance. This diversification allows for optimum utility of the watershed without increasing natural resource risk. In all the case studies reviewed, regulatory oversight controls the process.

WQT is an attractive strategy for managing and reducing nutrient discharge. It presumes that PS dischargers will prefer to meet their allowances by buying credits on the market if it is less expensive than installing and operating new controls. It also presumes that NPS dischargers will elect to generate and sell credits by implementing and operating BMPs, if risks and return on investment are favorable compared to other uses of the land.

As of 2004, more than 70 WQT initiatives have been set up in the United States, establishing several WQT trades and pilot projects (Breetz *et al.*, 2004). USEPA (2004) has simplified the task for future exchanges, providing technical information for setting up an exchange, measuring equivalency of nutrient discharges, developing rules of exchange, establishing trading baselines, and structuring liability transfers (see Section 5.0 for more information on the USEPA Water Quality Trading Policy).

Despite established market infrastructure and strong institutional support, nutrient trades have been relatively scarce to date. However, some trades have resulted, especially PS-NPS trades characterized by high financial leverage. Scarce nutrient credit supply from NPSs and lackluster credit demand from PSs are primarily responsible for this weak market performance (King, 2005; King and Kuch, 2003). Incomplete economic valuations of WQT alternatives may lead to hesitation to participate in WQT. Price should re ect the intersection of the supply and demand curves, which define the relationships between how much a seller will supply and a buyer will demand for a given price, respectively. However, several factors affect each of these relationships and thus the market efficiency. A more reliable approach to credit pricing, based on thorough and cost-effective economic valuation accounting for risk, which will more accurately define

4 *Cost effectiveness refers to the cost of achieving desired outcomes in terms of relevant outputs, programs or administered expenses. Cost effectiveness of an output or program is different than efficiency. The latter refers to output per unit of input.*

Economic efficiency allocates resources to people who are the most successful at gaining social power. In the economist's ideal world, the rich get richer and the poor get poorer… There is an assumption in economics that the market system handles resource allocation in an efficient manner unless proven otherwise (Tietenberg, 2001; Nguyen et al., 2004).

the supply-demand curves, is needed to enable traders to value their option to reduce their nutrient management costs by WQT.

Based on a review of past initiatives, particularly those of the four case studies presented in Sections 6 through 9, this section identifies the primary economic challenges to developing a robust WQT market involving wetlands and to setting up these exchanges. Potential solutions to these problems are introduced and suggestions are offered to stimulate the WQT market and accelerate nutrient reductions in watersheds and receiving waters. With the focus on the utility of wetlands as a means to earn sellable credits, these challenges are not necessarily generalizations applicable to all of WQT.

WQT provides an alternative way to quickly implement policy that includes NPSs and ensures a reduction in water nutrient loads. Two strategies are available to the NPS dischargers: (1) function as status quo, discharging at accepted baseline levels and (2) reduce discharges from baseline levels through BMPs, thereby generating tradable credits The selection of a strategy involves an assessment of costs and benefits, accounting for risk. Only the second strategy provides NPS dischargers with opportunity to invest in BMPs and WQT. Only the generation of credits by NPSs and the demand for credits by PSs provide the environment for a trade. This does not mean a trade will be executed.

Agency policy controls the risk of degrading the watershed. As such, the value of WQT is well defined in terms of "overall reduced pollution rate," (pounds/time) within concentration limits (mg/L), rather than the rate of economic value creation (dollars/time). As a result, regulators supporting WQT only have to guide strategies that lead to constituent mass rate reductions. Beyond that, regulators may also contribute to developing, implementing, and monitoring the market. The implication is that reducing nutrient discharge for credit generation increases the services of ecosystems reliant on that water, and thereby the potential to create economic value in the future.

In WQT, nutrient reduction is driven by discharge limits imposed on PS. The price of nutrient credits is in part determined by the demand for and supply of credits. Economic valuation of strategic alternatives, i.e., accounting for risk aversion, is a valuable metric for potential trading participants to decide whether to trade, and negotiating the terms and conditions of the trade. Although a full economic valuation may encourage an active market, it is not critical for successful trades.

4.1 What Factors Determine the Cost of Creating a Market?

WQT requires establishing certain structures: (1) approved use of discharge credit trades to achieve compliance, (2) a trading platform or exchange, (3) sources of supply and demand, (4) a pricing structure that accounts for liability transfer, and (5) a governing body responsible for oversight and enforcement. Although Step 1 mandates regulatory involvement, the remaining steps are plausible with varying degrees of it. Likewise, actual trading involves private transactions with varying degrees of regulatory oversight.

A team of oversight and contributing agencies assumes most concept development and market development costs. Individual and associated dischargers, independent investors, private and public grant institutions, and other enterprises contribute as well.

Certain costs are usually incurred when WQT markets are developed and launched, as listed below. These are one-time set-up costs, which may span several years. Once the market is operational, administration and governance costs are embedded in transaction costs, as described in Section 4.3.3

- Concept review and approval cost
- Baseline assessment cost
- Objective–setting cost
- Allowance allocation cost
- Market development cost
- Pricing structure cost
- BMP development cost
- Stakeholder buy-in cost

Each of the selected case studies—i.e., Cherry Creek in Colorado, Rahr in Minnesota, LBR in Idaho, and Tar-Pamlico River and Neuse River in North Carolina—demonstrate these cost structures (e.g., Breetz *et al.,* 2004; Jaksch, 2000; Anderson, 2000; Kieser and Associates, 2004).

To cut costs and improve internal efficiencies, certain lead agencies hire dedicated staff for WQT market and permit development. In the Rahr (PS) Malting Company trade, MPCA absorbed 85 percent of the dedicated staff cost. As the WQT credit buyer, Rahr paid the remainder (Jaksch, 2000).

4.1.1 Concept Review and Approval Cost

Agencies and/or dischargers interested in WQT thoroughly assess the viability of WQT in their jurisdictions, considering watershed-specific issues, such as hydrology, geology, biology, ecology, economics, source distribution, stakeholder interests, and so forth. The agencies engage local, state, and federal stakeholders potentially interested in the process (e.g., USEPA, US Department of Fish and Wildlife Service). They explore the viability of forming teams of regulators experienced in WQT, as well as agricultural, industrial, environmental, and other stakeholders.

The cost of completing this review is highly variable, and dependent on watershed-specific physical conditions, natural resources, stakeholder views, agency positions, and other matters. For example, each of the four trades for Rahr required concept review and approval, contributing to total transaction costs of $105,000 (Fang and Easter, 2003).

4.1.2 Baseline Assessment Cost

As part of concept evaluation to achieve a watershed's TMDL, agencies oversee field studies that assess the distribution of nutrients in surface waters and shallow groundwater. Ecosystems, hydrology, biota, and other natural systems are studied as well. In addition, field investigations and records audits establish or approximate nutrients discharge history for PSs (e.g., NPDES-permitted dischargers) and NPSs (e.g., non-permitted agricultural, forested and urban land) in the watershed.

In certain situations, validated information from detailed studies is needed to implement watershed management models, ecosystem models, land use models, or commodity models (e.g., timber production). For example, $300,000 were spent to develop a special estuary model to track and predict the behavior of nutrients in the Tar-Pamlico WQT region of North Carolina, (Gannon, 2005a). An association of prospective PS traders paid the cost to develop this sophisticated model.

Environmental grants, subsidies, and special contributions might be available to offset most or all of the baseline assessment costs, including those for model development.

4.1.3 Regional Water Quality Objective Costs

Regional watershed water quality objectives, such as TMDLs, provide the over-arching driver for WQT. These water quality objectives can be expressed as constituent caps, step-down caps, fractional rate reductions, or other metrics that are clearly measurable in space, time, and mass. When distributed to individual PS dischargers, these measures become potentially tradable allowances.

Typically, the regulatory cost to set up and manage watershed discharge limits is built into existing regulatory duties. However, in some cases, regulators undertake special scientific studies to establish the bioequivalence of nutrients discharged to different parts of the watershed. Depending on scope, these studies can comprise simple calculations or expensive field measurements and laboratory analyses. The studies are used to aid in fair allocation of allowances in a heterogeneous watershed, and provide a balanced platform for trading water quality credits from different source areas. The cost of such "equivalence studies" is described in Section 4.3.1.

Delayed promulgation of a watershed's water quality objectives, such as TMDLs, can add significant cost to WQT. As a specific example, WQT markets were developed in a Maryland jurisdiction, but were only used when regional TMDLs (and thus individual allowances) were imposed (King, 2005). Lacking a tradable commodity, buyers and sellers did not appear. In the interim, regulators developed innovative command-and-control measures to encourage PS investment in traditional wastewater treatment. Innovative subsidies were also offered to NPSs, for the use of BMPs. This procedure led to nutrient reductions at a risk-free cost significantly higher than would be expected in WQT. The difference between the use of WQT market compliance and the implemented programs is an avoidable opportunity cost[5] of delayed TMDL development.

4.1.4 Allowance Allocation Cost

Whether a constituent-specific cap is driven by a TMDL, total maximum annual load (TMAL), a remedial action plan, or some other water management action plan, allocations must be distributed amongst dischargers. The total load for a water body is generally determined as the sum of the loads from PSs and NPSs, accounting for projected growth, seasonality, and a margin of safety. Monitoring and modeling typically determine the distribution of total load to individual dischargers. Sensitivity analyses on various combinations of allocations factor into allocation development, with the aim to collectively meet a desired load reduction (Michigan DEQ, 2002; USEPA, 1996; USEPA, 2002a). By allocating allowances, regulators create a marketable commodity with an exchange value.

5 *The opportunity cost of capital is the minimum rate of return, or "hurdle rate," which is used for discounted cash flow analysis calculations.*

Allowance allocations are critical for creating a WQT program. However these costs are generally considered external to the costs for developing and implementing a WQT program because the requirement to establish an allowance allocation (TMDL, TMAL, etc) is present, regardless of whether or not a WQT program is established.

4.1.5 Market Development Cost

Market structures must be created to fit the stakeholder needs, physical situation, regulatory jurisdiction, local economy, and impacted natural resources. Regulatory agencies may facilitate this process by establishing a marketable commodity, proposing an attractive market framework, and retaining control of nutrient discharge risk. However, the onus for this in a predominantly free market environment falls solely on the buyers and sellers. In the Cherry Creek case, 40 percent of the Cherry Creek Basin Water Quality Authority's (CCBWQA) budget is assigned to monitoring, special studies, planning documents, technical reports or memoranda, and administrative costs (CCBWQA, 2005). While some of those allotted funds are used for previously discussed costs, they mostly fall into the market development category.

4.1.5.1 Creating the Exchange

Creating the exchange begs several questions, such as which kinds of trades should be allowed (e.g., PS-PS; NPS-PS, NPS-NPS), and how to delineate the geographic limit of allowed trades. At a minimum, regulators must authorize WQT as a valid alternative to internal control methods to satisfy discharge limits and confirm the necessary generation of credits. In a free market, regulator involvement would cease there. However, regulators may structure the market framework so that engaging in the market is attractive. Efforts are made to control the transactional cost of trading (see Sections 4.3.3 and 4.4.2.3). In addition, the regulators may create and manage the trading organization responsible for approving trades, protecting the environment, and administering the data generated by trading. The regulators could also appoint and advise the governing body for the exchange, which is usually a Board of Directors, an independent enterprise, an academic institution, a government organization, or other group.

Market structures are categorized as exchanges, clearinghouses, bilateral negotiations, and sole-source offsets[6] based on several criteria, including: (1) the commodity traded, (2) the market size, (3) the market structure, (4) the purpose of the program, and (5) the governing authority for water quality (King and Kuch, 2003). As examples, the Cherry Creek Basin program functions on a clearinghouse structure; the Rahr trade is a sole-source offset; the Association and Neuse River Compliance Association (NRCA), each of which is issued a collective NPDES permit based on the sum of members' allocations, create exchanges internally and function as an exceedance tax or group cap and trade program within the watershed; and the LBR program in Idaho relies on bilateral negotiation. (Breetz *et al.,* 2004).

Ultimately, market structures must balance the needs for fluid, low-cost trades that ensure environmental protection with minimal oversight. Clear delineation of rights, responsibilities, and liability are essential considerations. The selection of best market structure involves research, professional collaboration, optional fee consulting, and careful assessment of stakeholder perspectives.

4.1.5.2 Creating Demand

Market designers create demand by assigning source responsibility for effluent control and setting discharge limits. The allowances should be measurable, and readily quantified or calculated by all parties.

Demand for WQT arises when the command-control cost of compliance is significantly higher than the trading cost of compliance, accounting for risk. The wider the spread between control cost and traded cost, the higher the demand for credits. Note, however that gaming the system[7] becomes an attractive strategy when either: (1) regulations are weak or

6 The literature on this topic is confusing and contains references to credit trading, allowance trading, offset trading, emission trading, pollution trading, etc. It also refers to different types of trading systems using terms such as clearinghouses or market style or commodity-type trading as opposed to bilateral trades or centrally managed allowance offset contracts or sole-source agreements. The taxonomy used here was presented in a recent paper by Richard T. Woodward & Ronald Kaiser, Market Structures for U.S. Water Quality Trading, 24 ***Rev. of Agric. Econ.*** *373 (2002), which does a good job of explaining critical differences in these market structures (quoted verbatim from King and Kuch, 2003).*

7 "Gaming the system" refers to when a dischargers perceive small expected environmental liability in failing to meet permitted discharge requirements. These dischargers may elect to "game the system" as a preferred strategy. They invest to avoid, defer, or dispute compliance requirements, accepting the expected cost of enforced compliance as a cost of doing business.

absent, or (2) the cost of enforcement and penalties is low (King, 2005).[8] Either of these conditions suppresses demand for WQT, and for NPSs to sell credits.

As an example, strict regulations prohibiting any new discharges compel trading with NPS dischargers. Rahr had to implement BMPs in order to build its own treatment facility. Without trading with NPSs, their only other alternative was to continue paying fees to the WTF, sti ing growth.

Only three trades have been executed in the Cherry Creek Basin program, and water quality standards for phosphorus remain in violation. In this case, WQT demand has been soft because the cost of command-control compliance has been low, due to TMDLs that are achieved through affordable technology. More stringent load allocations would likely improve water quality and stimulate trading.

Demand-side risk is an important factor in creating WQT credit demand and in credit pricing. As described below, revocation risk, insolvency risk, and knowledge risk apply to WQT, but not to adding control measures. To some extent, each risk suppresses demand. Accordingly, although regulations addressing these issues are not critical to WQT, they should encourage trading.

- Revocation risk: Regulatory enforcement risk presents significant concerns to both buyers and sellers. A major concern is that WQT schemes will not meet the requirements of the CWA in the future, if challenged. A CWA ruling against WQT could negate or reverse credit sales, returning the compliance liability to the PS discharger. A similar result could be caused by regulatory changes or rulings that revoke permission to trade nutrients as a way to achieve compliance. A revocation would require the PS discharger to reassume compliance liability. Compliance could require significant investment in technology, capital equipment, and regulatory relations over a long time. This would be substantially more expensive than using WQT to comply with discharge allowances.
- Insolvency risk: This is the risk that an NPS trading partner becomes insolvent, and financially unable to meet BMP requirements established by agencies. In this case, the PS discharger might have to take direct responsibility for maintaining, monitoring, operating, and reporting on BMP activities at the NPS property. The relative cost of this scenario is unclear, but certainly less than direct compliance through traditional command-and-control.
- Knowledge risk: The buyer may be responsible for implementation of a BMP on an NPS property. In that case, the buyer assumes certain, limited risk by having to pay for practices of business and environmental compliance in which they are not expert. In this area of exposure, the buyer hopes that the Seller does an efficient job managing their BMPs.

4.1.5.3 Creating Supply

Supply is created when NPSs (and other low-cost dischargers) implement cost-effective BMPs, which reduce their discharges below their allowances. In so doing, the NPSs earn tradable credits that can be sold or banked for later use. Tradable credits are in surplus when supply exceeds demand, signaling that credit prices should decrease. Many factors in uence the supply of nutrient credits, including compliance risk, financial risk, the cost of the BMP, the expected selling price (unserved demand) and transaction costs.

- Following is a list of risks that in uence the generation or tradability of WQT credits. The magnitude of these risks depends on the site-specific conditions of the NPS, including discharges, allowances, receiving water conditions, impacted ecosystems, business operations, NPS finances, regulatory jurisdiction, and impacted stakeholders. Revocation risk: Likewise for the buyer risk premium, contractual enforcement risk presents significant concerns to both sellers, as well. A revocation would require the NPS to maintain BMP obligations and liabilities without offsetting (credit sale) contributions from PSs.
- Non-compliance risk: By joining a WQT program, NPSs accept regulatory audit and inspection of existing operations. Despite their typically unregulated discharge, NPSs may be regulated for other facets of operation. The inspection will determine if current operations meet practices that are already required by law. If not, regulators could cite the facility for non-compliance. Thus, by joining a WQT program, a non-compliant NPS assumes the risk that inspections will identify liabilities that had been avoided previously.
- Subsidy and green payment risk: In conducting baseline assessments, regulators might evaluate how subsidies and green payments are used to control or mitigate discharges at NPSs. This review could identify situations where

8 *Certain dischargers may perceive small expected environmental liability in failing to meet permitted discharge requirements. These dischargers may elect to game the system as a preferred strategy. They invest to avoid, defer, or dispute compliance requirements, accepting the expected cost of enforced compliance as a cost of doing business. Perceived enforcement costs might be high, including fines, penalties, imposed "best-available technology," dispute cost, and regulatory charges. However, dischargers electing this strategy view the probability of enforcement and penalties as exceedingly low, offsetting the cost exposure.*

funds are used inefficiently, resulting in additional regulatory obligations or loss of compensation. The risk is that the net income from subsidies or green payments could be reduced with additional regulatory scrutiny or obligations. The frequency or likeliness of it occurring is neither readily measurable nor reported.

- Discharger status risk: Most NPSs are unregulated or implementing voluntary discharge programs. By entering a WQT program, these dischargers embark on a path that increases regulatory involvement in their operations. Once tradable discharge allowance is definable, an NPS could become liable to manage nutrient loads as a discharger named in a waste discharge agreement or permit. Thus, certain NPSs might risk losing their "non-regulated" status, potentially leading to substantial future regulatory liabilities and costs. For example, the American Beef Cattle Association worries that a nutrient discharge baseline set by allocated allowances would be a disincentive for WQT. They propose that most beef producers would prefer to set voluntary discharge limits (voluntary baseline), and gain credits by exceeding them. Farmers would be encouraged to apply BMPs to generate credits and drive the market.
- Trade risk: This is the risk that NPS credits are not salable once generated on the WQT market, leaving the NPS with a residual, uncompensated BMP risk or cost. This could happen if the NPS implements a BMP due to speculation when the market is robust only to have the market lose its viability. The actual demand could fall so far short of the predicted demand so as to preclude a sale. It could also occur if the contracted buyers could no longer afford the credits.
- Performance risk: There is no guarantee that all BMPs will perform up to expectations. However, BMPs that turn out to be expensive will be unmarketable, leaving an NPS discharger with the cost of operating the BMP (or discontinuing maintenance and foregoing the possibility of selling credits) without offsetting contribution from a PS. In these situations, the return on BMP investments may be low or possibly even negative.
- Litigation defense risk: Failing to manage nutrient loads or implement BMPs presents litigation risk to the NPS committed by contract. Advocates of public interest might sue NPS dischargers for failing to contain or mitigate known or should-have-known nutrient discharges. This risk increases as the values of natural resources increases, and special interests become more effective in using litigation as a way to leverage green behavior by NPS.

As with the effects of risks on demand, each of these risks may suppress supply. The structure of the WQT market should aim to alleviate these concerns. Doing so at the outset or during WQT programs will encourage participation, credit supply, and the benefits of trading. Agencies can reduce nearly all these risks when they structure the WQT market programs by removing regulatory uncertainty, in uencing price, protecting discharger status and income, and providing legal protections. Accordingly, although regulations addressing these issues are not critical to WQT, they should encourage trading.

In one example, supply issues were blamed for lackluster trading in the Cherry Creek Basin market. Aside from the credits for the Phosphorus Bank, phosphorus reductions achieved from BMPs were not eligible for trading if they were funded by the CCBWQA, the government entity charged with administering and managing the water quality issues of this watershed. Furthermore, additionality[9] dictated that credits be generated from controls satisfying one of the following criteria: (1) controls where there were not any previously, (2) modifications to existing controls to improve the reduction capabilities, or (3) new controls to reduce phosphorus loadings to less than the NPS TMAL allocation (Breetz *et al.*, 2004). Eliminating these as potential sources for trading has dampened the supply of nutrient credits.

4.1.5.4 Creating Pricing Structure

Depending on the market environment, regulators, prospective traders, and other stakeholders all may be responsible for creating the broad pricing structure for WQT during market creation and initial trading. This structure is set by direct negotiations, auctions, or by a permitting authority. Direct negotiations are used when buyers and sellers together decide on the price of a credit for the specific trade. The trades for Rahr were priced in this way. This approach may be inefficient for larger markets due to complexities of scale. Instead, several auction alternatives are available. Uniform price auctions promote equitability in that a single credit price is determined through the bidding of buyers' and sellers' bids and offers for credits. Once determined, the credit price is used for all transactions. Finally, the permitting authority may set the price of credits in a reserve pool to sellers in default.

The authority-set price for credits in the reserve pool is greater than the market-set price for credits exchanged between buyers and sellers. Reserve pool credits are to supplement the credits of a seller who would otherwise default on the trade agreement with a buyer. The Cherry Creek and Tar-Pamlico programs offer examples of this special case of price setting (Negotiation Team, 2001).

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9 Additionality stipulates that any NPS offset that would have occurred regardless of the trading program cannot count toward a trade. This prevents double counting by ensuring that a nutrient control activity counts toward only one objective if multiple objectives are met (Fang and Easter, 2003; Jaksch, 2000).

Private value is reflected in the buyer's cost of compliance (or avoided compliance) and the seller's cost of BMP-generated credits eligible for trading. The cost to create market-pricing structure depends on the type, size, and complexity of the developed WQT market. New programs should draw lessons from previous programs in North Carolina, Minnesota, Colorado, Idaho, and other states.

4.1.6 Acceptable BMP Cost

Regulatory lead agencies may be charged with identifying and listing BMPs that NPSs could use to generate credits. In a de-regulated environment, the traders would have to identify appropriate BMPs; however, regulatory agencies would still have to approve the chosen approach. In most cases, this list is extracted from a broader list of potential mitigation technologies and strategies that have been used in site-specific instructions to dischargers. Initial cost assessments may extrapolate from previous experiences or from literature. The first phase of the Tar-Pamlico cost assessment drew from BMP development for the adjoining Chowan River basin (Research Triangle Institute & USEPA, undated). The incremental cost for this activity should be modest unless special studies or extensive research are needed.

4.1.7 Stakeholder Communication Cost

Lead agencies may be responsible for identifying and engaging stakeholders at the WQT program level and individual project level. However, this is often not the case, few states have led trading efforts. Most pilots have been bottom up, with state agencies coming to the table as participants. Grants have supported most of these efforts. Obligations include arranging education and public outreach, leading public hearings, addressing stakeholder concerns with appropriate strategies, developing and maintaining communication channels, maintaining public records, and so forth. The regulatory cost of these services is relatively high at the outset of WQT market development. Project-specific costs for these services vary, depending on the regulatory structure proposed and the stakeholder sensitivities and special interests involved (Fang and Easter, 2003). The project-specific stakeholder costs are included as transaction costs, described in Section 4.3.3, or are subsidized.

4.2 What Factors Determine the Cost of Creating a Credit?

The private cost of the party seeking to generate credits is the sum of three sub-costs: (1) the cost to create the opportunity by engaging trading parties, (2) the cost to implement the BMP, and (3) the cost to manage the BMP. Analysis of WQT cost-effectiveness must consider the sum of these costs, not just the cost of the BMP implementation, versus the cost of alternative actions, i.e., PS control, gaming the system, or zero-growth (King and Kuch, 2003). Because credits are marketable goods and services, the costs of creating credits may be estimated and used to guide credit development and trading strategy decisions, a potentially daunting task in the absence of an established market.

The private benefit includes the increase in marketable value afforded to the seller and other responsible parties. Examples include improved land use (e.g., more efficient farming) and asset creation (e.g., higher property value).

Since BMPs leverage private investment to create public benefit, a thorough *net benefit* valuation is appropriate to assess the value of BMP strategy for: (1) selecting the BMP to implement, (2) obtaining stakeholder approval, and (3) valuing credits in the marketplace. Such an evaluation is not critical and has yet to be thoroughly performed, but it could indicate additional BMP value, thereby encouraging WQT.

4.2.1 Project Initiation Cost

Low-cost dischargers who seek to earn credits by implementing BMPs to reduce discharges may incur regulatory cost, especially if a third party is not involved. Agencies may be involved in every step of the process, starting with an assessment of the applicability and potential success of BMP projects under consideration. This can involve field studies, baseline assessments, technical research, stakeholder communication, and negotiations with the discharger. They may also support or directly pursue grant applications for funding, on the part of the discharger or the agency. Alternatively, in a de-regulated environment, these tasks fall on the traders.

4.2.2 BMP Selection Cost

A free market requires dischargers to invest in the identification, evaluation, and selection of BMP alternatives. As market regulation increases agencies take on an increasingly larger share of these responsibilities. Acceptable alternatives are based on: (1) the physical and constituent conditions of the discharger and the watershed, (2) the available investment budget, (3) the regulatory and discharger objectives, and (4) the project timeline. This process usually involves a short-listing of BMP alternatives and some level of field testing. Analytical testing of system performance is an optional step, aiming to optimize project design. Investments in formal work planning, permitting, documentation, risk communication, and stakeholder involvement are inevitable and appropriate.

The total cost of this phase of work can vary widely, depending on the complexity and size of the project, the diversity of stakeholder interests, the risk of failed innovative technology, and the sensitivity of impacted ecosystems (private and public).

4.2.3 Approval and Permitting Cost

The regulatory cost to review, approve, and permit proposed BMPs depends on the complexity of the program. Involving stakeholder participation and even public hearing(s) may add to these expenditures. Project-specific costs may be wrapped into cost for typical regulatory activity.

4.2.4 BMP Implementation Cost

The responsibility to manage the cost of BMP implementation is typically borne by the PS without compensation, by the NPS with compensation, or by a third-party entity. For example, cost management for Rahr's traded BMPs was managed by a five-person board, with one member being an employee of Rahr, but otherwise independent.

This cost normally includes expenses incurred in the design, installation, and management of BMPs during construction. Most BMPs are simple, and involve no one other than the discharger (e.g., relocation of livestock) or farm equipment operators (e.g., change in tillage by tractor operator). The discharger maintains records of these BMP expenditures for regulatory reporting, tax reporting, real estate appraisals, WQT credit pricing, and other purposes.

Private dischargers typically determine the cost of implementing BMPs. Once committed, these costs are sunk, regardless of credits generated or trades made. On the other hand, the regulator (market administrator) values the BMP investment from a public perspective, whereby they participate in the selection of BMPs. Their value metric is cost per mass of nutrients reduced, which measures the effectiveness of BMPs before the application of a safety factor. This value is calculated by dividing the cost of implementation ($) by the nutrient reduction achieved (pound).

The cost of BMP implementation can range widely. In the Tar-Pamlico case, values for agricultural BMPs ranged from $1 to $80 per pound of nitrogen reduced from discharge streams. Similar values for wetland restoration ranged from $11 to $20 (Table 4-1). More expensively, values for stormwater BMPs ranged from $57 to $86 per pound of nitrogen removed from urban runoff (Gannon, 2005a).

Table 4-1 Nitrogen Removal Cost-Effectiveness Comparison

Practice	$/lb Reduced (30-year life equivalent)
Agriculture	
• Water control structure	$1.20
• Nutrient management	$7 - $9
• Vegetated filter strip	$7 - $8
• Conservation tillage	$20 - $80
Stormwater / Bioretention	$57 - $86
Riparian wetland restoration	$11 - $20

Source: Gannon, 2005a.

The owner of many BMP projects for Cherry Creek has been the CCBWQA, the government entity charged with administering and managing the water quality issues of this watershed. Using three-year projections, BMP implementation costs are separated into design, capital, land acquisition, and operation and maintenance (O&M). Their 2004 projections totaled $9,691,000 for capital costs, $600,000 for land costs, and $243,000 for O&M costs. Water requirements were also considered, but were not valued (CCBWQA, 2005). These costs were phased over three years.

A simulated BMP development for the Idaho trading program estimated costs by breaking them down into capital, including engineering, construction, contingency, land acquisition, and O&M. Capital was estimated at $3,004,000, including a 20 percent contingency factor and $10,000 per acre of land. O&M was estimated at $145,800, including $71,800 for annual O&M and $74,000 for harvesting wetlands plants every five years. Assuming a 30-year life span and a 3 percent in ation rate, annualized cost for removal of TP was $118 per pound or $67,000 per acre. This simulated cost is very high compared to the cost of constructing wetland systems for treating stormwater, estimated at $10,000 to $30,000 per acre (Zentner, 1995; Reed, 1991).

The Rahr trades with four NPSs cost $250,000 (plus an extra $50,000 for a failed BMP) to implement. The cost of credits was estimated based on the capital and O&M costs of the project, the estimated pounds of offset nutrients it could deliver, trading ratios, and safety factors. Assuming a 20-year lifetime and applying an 8 percent discount rate, the average cost of reduction decreases to $0.20 per pound $CBOD_5$ and $1.56 per pound of phosphorus. The long-term measures, such as conservation easements and re-vegetation, are the most effective of the BMPs because they provide greater nutrient reduction with low investment. Furthermore, the BMPs are expected to remain effective for the same amount of time over which the nutrient reductions are estimated, minimizing the uncertainties associated with the trade (Fang and Easter, 2003).

4.2.5 BMP Monitoring Costs

Once BMPs are operational, the installing discharger is responsible for meeting permit requirements including, but not limited to, uninterrupted monitoring, appropriate maintenance, organized data management, and timely compliance reporting. The WQT process is available to compensate the NPS discharger for his costs for system installation and these ongoing responsibilities.

Failure to comply can result in fines or penalties paid by either the NPS discharger (before trading) or the PS discharger (after acquiring credits by trade). As an example, the Tar-Pamlico WQT market stipulates that the ultimate penalty for non-compliance is reversion to Best Available Technologies discharge regulations (Gannon, 2005b).

Monitoring criteria may be judged by performance, i.e., how well the BMP reduces discharges, or by activity, i.e., that changes to reduce discharges have been implemented. (King and Kuch, 2003). Costs will be negligible for simple practices, such as rearranging ranch grazing. Costs for network monitoring will be low to moderately expensive, depending on: (1) the technology applied, (2) the size and density of the monitoring network, and (3) the frequency of monitoring events. Capital costs for fixed monitoring devices can add to the costs significantly.

4.3 What Factors Determine the Dollar Value of a Credit?

WQT credits are private goods and services that have private value set by trader negotiation, and are subject to a few adjustments that are made to protect public interests (environmental goods and services). The marketplace sets the value of WQT credits, specifically: (1) the buyer and seller cost of compliance using non-trading strategies, and (2) the difference between generating and transacting water quality credits accounting for risk. The dollar value of WQT credits is unique to the trading situation, and dependent on many criteria. For simple agricultural BMPs, the cost of credits is a function of: (1) the present worth cost to implement BMPs for an extended time period, (2) an equivalency factor,10 (3) a contingency for technical uncertainty, or "safety factor"[11] designed to ensure non-degradation of natural resources, (4) an "administrative factor,"[12] designed to finance agency oversight of WQT, and (5) the number of credits generated. Stormwater and other NPS credits are priced using more complicated formulae involving stormwater ows, the cost-effectiveness of nutrient management, nutrient reduction goals, project life span, drainage rate, land cost, and so forth. The pricing structure for WQT is based on simple supply and demand for credits, within guidelines set by those responsible for administering the market or by the market itself.

4.3.1 Equivalence

Water quality varies in space and time. As a result, the actual and potential human health and natural resource damage or loss caused by discharges is site-specific. Therefore, the nutrient allowances should vary from place to place. As a preliminary step in valuing credits, regulators establish a baseline discharge allowance that applies equally throughout the watershed. Site-specific nutrient discharges and credits are normalized to this watershed baseline by applying equivalency factors (multipliers) to measured rates. Discharges that are less harmful to the environment than the baseline will have equivalency factors less than 1.0. Discharges that are more harmful will have equivalency factors greater than 1.0.

Equivalency factors are applied in trading, to normalize the risk of continuing discharge at one location in exchange for reducing discharge elsewhere.

Establishing nutrient equivalency for trading can be expensive. For example, the Rahr WQT case spent roughly $100,000 of regulatory, trader, and third-party consulting time to establish quality equivalency factors for discharges of malt in Minnesota (Fang and Easter, 2003). This case posed unique challenges to achieving equivalence. In particular, the traded nutrients were not the same as the TMDL targeted constituent, requiring equivalence among phosphorus, nitrogen, sediment, and CBOD (Jaksch, 2000). Diligent efforts used site-specific modeling to estimate ratios.

10 An equivalency factor is a multiplier to establish the environmental substitutability of PS and NPS loading (Jaksch, 2000).

11 A safety factor is a multiplier to account for a margin of safety.

12 An administrative factor is a multiplier to account for administrative costs associated with the trade.

4.3.2 Establishing Offset Fees

Offset fees are the cost basis for trading, incorporating BMP cost, safety factors, administrative factors, and BMP efficiency in reducing nutrient. Following are descriptions of the components of these fees.

4.3.2.1 BMP Cost

BMP cost comprises seller investments made to design, permit, and implement a BMP that potentially generates credits for trading. Note that, depending on the program, credits from certain BMPs may not be tradable, including those generated from practices that are required by law and practices that are funded by subsidies, green payments, or government programs that do not involve WQT. This reduces NPSs' potential to generate credits (King, 2005). As presented in Section 5.2, if a 2007 agricultural bill passes, it would indeed recognize subsidized BMPs as eligible for WQT, likely driving more NPS participation in WQT.

The total cost to implement a BMP is the net present value of cash ow for: (1) the plant, property, and equipment needed to construct the BMPs, plus (2) the operational, regulatory, maintenance, and replacement costs to effectively run the system throughout its useful life, minus (3) relevant subsidies or green payments received, plus (4) depreciation and other accounting benefits. The unit credit cost is the total BMP cost divided by the number of credits generated by the process.

4.3.2.2 BMP Effectiveness

The effectiveness of BMPs in reducing nutrient discharges is an important component of credit value. Relatively ineffective BMPs are worth proportionally less than effective ones, and this value impact is re ected in trading ratios, equivalence factors and price. The BMP effectiveness is less than or equal to 1.0.

4.3.2.3 Safety Factors

A "safety factor" is a multiplier that is applied to offset the uncertainty or risk of degradation or other negative consequences of WQT. Since each BMP and trade is unique, safety factors are unique to site-specific BMP and trading opportunities. Within a watershed, separate safety factors might be developed for separate watershed zones, different seasons, and constituent species. As such, safety factors often account for equivalency factors.

A risk-neutral trading opportunity would have a safety factor of 1.0, meaning the risk of compliance without trading is the same as the risk of compliance with trading. In contrast, high safety factors are applied to WQT where the risk of negative environmental effects is high, relative to compliance without trading.

Predictably, conservative (large) safety factors inhibit trading, by deeply discounting the value of the NPS credit to the PS buyer. However, overly optimistic safety factors can lead to abundant trades that threaten the environment by allowing too much PS discharge above limits. Thus, the regulatory challenge is to use safety factors to encourage trading while protecting the environment.

Most safety factors are in the range of 1 to 2.5. Safety factors of 3 (or more) can suppress the market, because buyers have to pay for three (or more) credits in order to acquire one credit. Nonetheless, the CCBWQA for the Cherry Creek program, which sets a minimum trading ratio of 2:1, recently removed the trading ratio cap of 3:1 to stimulate more trading with NPSs farther from the Cherry Creek Reservoir (CCBWQA, 2005).

4.3.2.4 Administrative Factors

Administrative factors are applied to baseline cost to cover the cost of setting the ground rules for the WQT program. In the Tar-Pamlico and Neuse River Basin case studies, this value was 10 percent, i.e., 1.1:1 (Breetz *et al*., 2004). The Tar-Pamlico program also applied a 200 percent safety factor to the 10 percent administration fee, creating a 2.1:1 "trading ratio" for purchase of nitrogen offset credits. The fee to purchase nitrogen offset credits in the Neuse River Basin Nutrient Trading Program takes into account a required 30-year BMP life span, as well as land costs (Breetz *et al.,* 2004; Gannon, 2005b).

4.3.2.5 Trading Ratio

The trading ratio is the number of credits that a buyer must purchase in order to receive one nutrient credit. It is a function of the safety and administration factors, such that:

Trading Ratio = *(1+safety factor)*(1+admin factor)*

Every WQT has a trading ratio. Nearly all these ratios exceed one because safety factors are usually significantly greater than 1.0.

As trading ratios increase, the demand for nutrient credits is reduced. Payoffs, in terms of avoided capital cost to the buyer or return to the seller, become relatively small, compared to risks plus “transaction costs.”[13]

4.3.2.6 Offset Fee

The offset fee is the present worth BMP cost times the trading ratio. As an example, the offset fee for the Tar-Pamlico program in North Carolina considered uncertainty in BMP effectiveness and administration costs (Gannon, 2005a). The base offset fee took into account farmers' capital costs, maintenance costs, BMP effectiveness, area affected, and BMP life expectancy. BMP effectiveness values were based on a literature review that included empirical studies of conservation tillage, terracing, and buffer strip BMPs in the Chesapeake Bay. The offset fee also includes the 2.1:1 trading ratio that re ects a 10 percent administrative factor and a 200 percent safety factor (Breetz *et al.*, 2004; Gannon, 2005b).

Within a program, evaluations of different BMPs should re ect their specific lifetimes. Tar-Pamlico credits for structural BMPs were assigned a useful life of 10 years, while non-structural BMPs were assigned a credit life of 3 years (Breetz *et al*., 2004; Gannon, 2005b). Evaluations often analyze the sensitivity of lifetime impacts as a way to compare costs per year.

4.3.3 Transaction Costs

Transaction costs may be incurred by the regulator and/or by the traders. These costs are built into the price of credits, as a cost of doing business. Keeping transaction costs to a minimum is essential for robust trading, as these are bottom-line expenses to a WQT strategy. Excessive transaction costs are cited as a primary reason for limited trading within well-established markets and exchanges (Collentine, 2003; Fang and Easter, 2003; Tietenberg, 2001).

4.3.3.1 Agency Transaction Costs

Several regulatory expenditures are directly tied to the agency development, execution, and oversight of specific trades. Trade-specific regulatory transaction costs are incurred for:

- <u>Audit and verification cost</u>: These costs are incurred when regulators confirm the site-specific baseline for trades at the NPS facility. This work includes site inspection and confirmation of correct BMP implementation by the seller. Sampling and analysis cost might be included.
- <u>Administrative and consulting costs:</u> Regulatory costs to track the status and performance of the trade, and provide regulatory consultation to traders as requested. Included are regulatory costs incurred to confirm that trades adhere to transaction standards for equivalency, additionality, and accountability.
- <u>Trade oversight:</u> These costs relate to obtaining regulatory approval for the trade concept and the preparation of agreements and permits. This includes unbiased trust fund management costs assigned to the project and construction management oversight.
- <u>Monitoring and enforcement cost:</u> Trade management, monitoring, and enforcement were trade-specific agency duties in the case studies. These costs include, but are not limited to, direct measurement of discharges at PSs, indirect calculation of discharges, or fractional discharge reductions at NPSs. Also included are costs for internal tracking of discharges, credits, credit reallocations, computerized data, stakeholder communications, and external reporting to state and USEPA.
- <u>Stakeholder communication cost</u>: The regulator incurs costs associated with communicating with stakeholders potentially impacted by the proposed trade to gain consensus support for the trade. Included are costs for education, public hearings, special meetings, expert consultation, presentations, and related expenditures.

The detail of agency transaction costs is often blurred, since certain trade support activities overlap with normal agency duties. However, documentation usually presents the overall costs, which must be borne by credit traders. For example, for the Cherry Creek program, applications cost $100 and a discharger must pay an additional $500 to cover costs incurred by the CCBWQA to evaluate the request for credit withdrawal from the Phosphorus Bank. The cost to apply for credits from the Reserve Pool, regardless of the number of credits involved, is $2,500 (Breetz *et al*., 2004).

4.3.3.2 Trader Transaction Costs

In a free WQT market, many of the agency transaction costs described above, particularly trade oversight, monitoring and enforcement, and stakeholder communication costs, fall instead on the traders. Additional costs that accrue directly to the traders are proportional to their activities in the trade (Collentine, 2003; Fang and Easter, 2003). The buyer and/or seller incur these trade-specific transaction costs:

13 If these transaction costs are borne by taxpayers in general rather than the parties involved in the offset contracts, they may not inhibit trading. However, these transaction costs reduce the economic gains from trade regardless of who pays them and they will affect the acceptability of trading (quoted verbatim from King and Kuch, 2003).

- Broker costs: Expenses to find trading partner and secure an exchange. Brokers in WQT can include private entities operating under fee agreement or public agencies. The efficiency of brokering is directly proportional to experience.
- Legal and accounting costs: Both buyers and sellers require a certain degree of professional service consultation, to ensure leveraged negotiation support and appropriate tax and financial management strategies. Additional legal costs include liability management services and seller creditworthiness assessment, to mitigate loss in the event of seller insolvency. Risk transfer instruments might be valuable in certain situations as well, necessitating the participation of insurance or risk management specialists.
- Engineering consulting costs: Consulting scientists are typically used to advise traders during the course of trade development and execution. These specialists provide traders with information that would influence the risk-adjusted value of the proposed trade, from public and private perspectives.

As trading ratios increase, the price differential between buyers and sellers decreases, suppressing the demand side. Payoffs, in terms of avoided capital cost (buyer) or offset BMP cost (seller) become relatively small, compared to risks plus "transaction costs."

4.3.4 The Asking Price

The seller's asking price for one credit is the seller's PS offset fee plus the seller's share of transactional cost plus the amount of profit the seller seeks for taking risk in implementing BMP and entering WQT agreements. Price inflation that is built into the offset cost, i.e., the safety and administrative factors, is allocated to agencies responsible for managing compliance, and is not distributed to the seller.

4.3.4.1 Minimum Selling Price

The seller's minimum selling price (MSP) is the minimum amount the seller will accept for selling a credit in a nutrient trade. This amount is the present worth cost of implementing BMPs, plus a reasonable profit, plus seller's share of transaction cost (see Section 4.3.3), divided by the number of credits sold. The minimum safety, administrative, and efficiency factors established by agencies are applied to MSP to establish the lowest trading price that would be acceptable in a nutrient trade.

Sellers may expect to generate profit from implementing WQT when the returns are high relative to other uses of the land. As a guideline, the level of profit should meet or exceed their opportunity cost of capital, or minimum rate of return. To the extent possible, sellers will build negotiable profit expectations into the price of their credits unless they are motivated to implement the BMP for other reasons, e.g., their operations will benefit in other ways in addition to income earned from implementing the BMP. For example, stream bank stabilization projects completed as a part of the Rahr BMP projects was very valuable to the property owners whose land was being eroded away by the Minnesota River.

4.3.4.2 Seller Opportunity and Risk

NPSs and other prospective credit sellers commit capital to WQT programs in order to create value for their organizations. Participation presents risk and opportunity to value creation, however. Example risks include the potential loss of subsidies, or assumption of discharge restrictions, increased regulatory liability, or negative cash flow. Representative opportunities include improved land value, reduced liability, avoided cost of compliance, reduced operating costs, and so forth.

Sellers should assess the risk and opportunity of WQT before committing to a WQT program. Sellers can use experienced WQT brokers, strong advisers, BMPs with precedent, and risk-transfer mechanisms to lessen the risks and increase the opportunities of implementing BMP and trading water quality credits.

In ideal markets, investors build their cost of risk into the price of their goods and services. Typically, credit prices have not been structured to compensate sellers for their risk in implementing BMPs and engaging in WQT, but clearly need to be. Based on the literature reviewed and the examples provided in the case studies, not pricing credits to include the cost of investor risk may be a reason that WQT supply and trading are suppressed.

4.3.5 The Bid Price

The bid price is the fully loaded amount a buyer is willing to pay to obtain a credit, considering the risk of compliance by trading. Despite the role of regulations in establishing the market, traditional market factors, such as supply, demand, and competition, strongly affect the bid price. Internal business factors are relevant as well, especially: (1) the cost of the next-best long-term compliance alternative (e.g., command-control or gaming the system), (2) exposure to liability (e.g., potential litigation), and (3) opportunity to create assets (e.g., Rahr; Fang and Easter, 2003). Chosen alternatives will depend on the business attitude of the buyer. Some, focused on reputation and societal obligation, will not game the system. For them, the only alternative to compliance by WQT is command-control. Others, willing to take enforcement risk, prefer to game the system.[14]

4.3.5.1 The Cost of Command-Control

Most PS dischargers comply with evolving regulations by adding or modifying discharge control measures. This strategy is attractive because it enables dischargers to be in permit compliance (and operations status) and compliance cost at low risk. Through trade and enterprise associations, PSs may be able to leverage their permit requirements.

Adding control measures is a relatively costly compliance strategy in terms of risk-neutral cash flow compared to costs to implement BMPs for NPS. Depending on the permit requirements, expensive capital equipment, monitoring, and regulatory reporting may be needed. Cost offsets, capital benefits, and other benefits may alleviate the financial burden that these requirements pose for the PS. Special subsidies, grant relief, and tax incentives may be available to reduce or offset these capital requirements. Capital investment realizes additional benefits including the improvement or addition of plant, property, and equipment assets. Finally, reduced regulatory and third-party liability may result as well. It is important to quantify these sources of value when deciding whether to meet permit requirements by adding control measures by WQT or by an alternate strategy.

4.3.5.2 The Cost of Alternative Strategies

Intuitively, discharge sources would likely first search for inexpensive ways to improve internally in order to avoid paying another source to reduce discharges. In most cases, simple measures are implemented to reduce nutrient discharges before long-term compliance strategies are adopted.

Buyers estimate the present worth cost of implementing their chosen alternative to establish a baseline for pricing water quality. If the chosen alternative is to game the system, the buyer's estimate must include the cost to ultimately comply plus the cost of implementing the gaming strategy, plus the uninsured expected (probable) liability of litigation defense, regulatory enforcement, and other exposures.[15]

According to King (2005), the expected marginal cost of gaming relates negatively to the strength of the laws and enforcement and positively to the penalties for non-compliance. This would peg the MSP for WQT near zero, as gaming would be the least-expensive alternate strategy. As a result, demand for credits would presumably be soft, weakening the market despite well-designed exchanges for trading (King, 2005).

If the chosen alternative is command-control, the cost of compliance is readily estimated using traditional means that include the value of assets at the end of their lifetime and financial benefits, such as subsidies or tax treatments. Importantly, some WQT structures require that PS buyers pay NPSs "incentive fees" for discharges above the regional cap. The rationale for this scheme is to encourage PSs to satisfy their discharge requirements, but if that were not accomplished, to provide funds for BMP implementation. For example, under the Tar-Pamlico WQT agreement (Anderson, 2000), the PS association is obliged to pay $13 per pound of nutrients exceeding the discharge cap to the North Carolina Agriculture Cost Share Program, a pre-existing program administered by the Division of Soil and Water Conservation (DSWC) that funds 75 percent of the capital costs associated with voluntary implementation of agricultural BMPs. This structure, which is analogous to a penalty, motivates the PS dischargers to invest in their own remedies to stay within allowances.

Comparisons between alternatives are based on the metric of expected (probable) *net present value of cash flow*. To the extent possible, the value of strategic flexibility of broad alternatives is included in these comparisons, such that various designs of a BMP may be compared to various designs of a given PS end-of-pipe technology. Buyers commit to compliance by WQT when the fully loaded cost[16] of other options exceeds the fully loaded cost of WQT, accounting for the time value of money, risk, liability, feasibility, efficiency, cash flow, and other important considerations of the buyer.

4.3.5.3 Maximum Purchase Price

A buyer's maximum purchase price (MPP) equals the fully-loaded cost to implement the least-expensive option divided by the number of credits needed to achieve compliance. Water quality priced above the buyer's MPP will not be tradable without special terms and conditions (e.g., indemnification) that create value for the buyer.

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14 Gaming is a theoretical issue identified by economists, however this review did not identify literature regarding the extent to which gaming is actually practiced and whether in practice this is an issue for WQT.

15 Reputation risk, which is difficult to quantify, is an important aspect of gaming strategy. Many dischargers resist the temptation to "game" the regulatory process to protect their reputation from discredit, even when the expected costs of additional controls are significantly greater than the penalties associated with gaming the system.

16 In this use, the "fully loaded cost" is the present worth sum of all known and potential direct and indirect costs, liability, and assets that would be caused by the implementation of strategy, accounting for uncertainty (risk). Uncertainty and risk are not the same thing.

Quantifying MPP should account for strategy risk, transactional cost, and the time value of money. The importance of accounting for risk is apparent in comparing strategies, such as “additional control measures” (not risky) with “gaming the system” (highly risky). The selected strategy should not reflect the regulatory cost to comply, but rather the discharger’s perceived least cost to manage his regulatory liability (which might involve non-compliance cost, litigation defense, or liability transfer expense).

In some cases, the MPP is based on asset-driven considerations. For example, Rahr was willing to pay $250,000 to set up a trust fund dedicated to implementing BMPs because it had no choice but to trade with NPSs. Otherwise, it would not have been allowed to build its treatment facility at all, thereby hindering its growth. Furthermore, cooperating with the community and environmental organizations served to elevate its social reputation.

4.3.5.4 Value Created by Trading

NPSs can create value over and above the value of mitigating nutrient discharge compliance liabilities by implementing BMPs. Such value can include social benefits, increased property values, decreased liabilities, if any, unrelated to compliance or WQT, improved cash flow or NPS net worth, and other private benefits that accrue to the NPS. These values are quantified in terms of explicit (short-term) and continuing (long-term) value, discounting cash flow at a reasonable rate of return.

The owners of land at two of the BMP sites that Rahr funded in its trade reaped the added benefit of controlling severe bank erosion that had threatened their property. Since 1988, the property owners had been trying, unsuccessfully, to gain financial means to control the bank erosion. Rahr accomplished for them what they had unsuccessfully tried to fund for nearly a decade (Breetz *et al*., 2004; Fang and Easter, 2003). Many of the Cherry Creek BMPs have improved the quality of the Cherry Creek State Recreation Area (CCBWQA, 2003a).

4.3.5.5 Avoidance Strategy: Game the System

Certain dischargers may perceive little expected environmental liability in failing to meet permitted discharge requirements. These dischargers may elect to “game the system,” or evade compliance, as a preferred strategy. They invest to avoid, defer, or dispute compliance requirements, accepting the expected cost of enforced compliance as a cost of doing business. Perceived enforcement costs might be high, including fines, penalties, imposed “best-available technology,” dispute cost, and regulatory charges. However, dischargers electing this strategy view the probability of enforcement and penalties as exceedingly low, offsetting the cost exposure. Due to the covert nature of this activity, the frequency or likeliness of it occurring is neither readily measurable nor reported. Given the $25,000/day fines and reporting requirements NPDES permit holders are subject to, the application of this strategy by NPDES permit holders may be limited, but there is no literature to support or refute this conclusion.

4.3.5.6 Buyer Risk Premium

It is important that buyers account for their risk attitude, especially risk aversion, in establishing MPP. Particular risks of concern, as described in Section 4.1.5.2, include revocation risk, insolvency risk, and knowledge risk.

4.3.6 Minimum Selling Price

In WQT, the MSP is the minimum amount the seller will accept for selling a credit in a nutrient trade. Typically, it would consider the seller’s costs to generate one credit (cost to generate credits divided by credits generated, or $BMP), the expected risk premium (r), the unit credit value created from the BMP divided by the credits generated, and the expected profit (p) calculated at a reasonable opportunity cost of capital. Following is a general formula for MSP:

$$MSP = \{\$BMP*(1+r) + \$Val\} * (1+p)$$

MSP does not include costs that are beyond the seller’s control and that do not accrue to the seller, such as regulatory upcharges reflected in “trading ratios.” These price inflations concern the public value (cost) of strategy, and they are allocated to those who manage the trade and BMP implementation. BMPs can also create value by increasing sellers’ assets, such as building the value of real property. In this model, transaction costs are split, and not part of the MSP.

4.3.6.1 BMP Cost

BMPs are calculated in discounted cash flow, including all costs incurred by the seller, regulator, contractors, technical consultants, and professional advisers. Sellers should include WQT subsidies they receive in calculating their BMP cost and MSP. However, buyers and sellers would negotiate the amount of these subsidies that would be included in the terms of a trade.

The offset fee for the Tar-Pamlico program in North Carolina accounted for administration costs and for uncertainty in BMP effectiveness (Gannon, 2005a). The offset fee was refined when the Phase II agreement was developed. The base offset fee takes into account farmers’ capital costs, maintenance costs, BMP effectiveness, area affected, and

BMP life expectancy. BMP effectiveness values were based on a literature review that included empirical studies of conservation tillage, terracing, and buffer strip BMPs in the Chesapeake Bay. The offset fee also includes a trading ratio that re ects a 10 percent increase for administrative costs and a 200 percent margin of safety (Breetz et al., 2004; Gannon, 2005b). The offset payments made to the Agriculture Cost Share Program are used to fund voluntary BMP implementation (75 percent state, 25 percent producer) and pay for staff resources to track and target contracts and verify compliance.

4.3.6.2 Seller Risk Premium

Sellers must assess program risk, as described in Section 4.1.5.3, before exercising the option to develop BMPs for the purpose of WQT. NPSs must assume certain roles and responsibilities in participating in the program. Most outcomes of these commitments will be worse (risky), or better (opportunistic), than the current situation.

As an example, some believe that regulated PSs do not compete equally (on a cost basis) with NPSs, which use subsidies and green payments to implement voluntary programs. They argue that certain actions should level the compliance "playing field," including (1) shifting more responsibility for nutrient reduction to NPSs; (2) reducing subsidies; or (3) regulating PS and NPS dischargers equally.

Offsetting opportunities, such as the chance to improve land value or reduce operating costs, are present, also. We infer that risks exceed opportunities for most BMPs for three reasons: (1) the price structure for credits is fixed in some programs, such as for the clearinghouses for the Long Island Sound, Tar-Pamlico, and Neuse River programs, and there is no way for the investor to recoup the cost of taking risk, (2) most WQT benefits and opportunities accrue to the public (watershed), and (3) most WQT costs and risks accrue to the private investor (discharger). The inability of investors to generate return on their investment while taking risk explains why many BMPs remain to be undertaken.

Ideally, investors would build risk-related costs into the price of goods and services. However, in the WQT markets reviewed, the third-party regulator set credit prices using established nutrient reduction cost and site-specific contingency factors. The contingency factors represented public interests (regulatory cost, non-degradation cost, equivalency cost). Contingencies re ecting private interests, such as program risks to the seller and investor, were not accounted. In a free market, in which transactions occur directly between buyers and sellers or are facilitated by a broker or aggregator, the price of credits would depend on traditional market forces: supply and demand. The LBR project is structured in this way: however; no trades have occurred. Thus, in theory, WQT credit prices have been artificially suppressed. This should stimulate PS demand and encourage trading. However, it should also suppress supply, as NPSs will be reluctant to invest in the WQT market if their net risk is significant.

4.3.6.3 Profit

Sellers may expect to generate profit from implementing WQT, especially if the risk they assume (Section 4.3.6.2) is not offset by value created. As a guideline, the level of profit should meet or exceed their opportunity cost of capital. A minimum of 10 percent is reasonable for most businesses. To the extent possible, sellers will build negotiable profit expectations into the price of their credits.

4.4 Challenges and Gaps

It might take substantial modification of views to better understand the economic value that public and private interests may generate by managing nutrients with WQT. Immediately needed are thorough economic valuations of strategic alternatives that involve WQT. These valuations will enable decision makers and policy makers to quantify the value of investing in WQT as a discharge management strategy of choice.

4.4.1 The Perspective Problem

WQT involves four essential stakeholders, each with his own interests, concerns, challenges, and gaps: (1) the buyer, (2) the seller, and (3) the regulator, and (4) special interests and other stakeholders. The buyer and seller are concerned with the financial risk and return of private transactions involving WQT. The regulator is concerned with protecting public values in natural resources, i.e., enforcing non-degradation and conservation of natural resources such as water, wetlands, habitat, and species. Other stakeholders may in uence the regulators, who in turn will in uence the market.

Importantly, each stakeholder perceives different gaps in the current WQT exchanges, policies, programs, and transaction structure. These gaps should be addressed in order to achieve a smoothly functioning and robust trading marketplace. To complicate this challenge, differences from program to program, because of the need to tailor them to the specific needs of the stakeholders within the watershed, creates potential for discord or potential litigation.

4.4.2 Challenges to WQT

Many established WQT exchange programs are relatively inactive. The challenges appear to lie not with the development of exchanges, but with the viability of trading as a cost-effective mechanism of liability transfer between buyers and sellers. Economic trading challenges suppress WQT by making the risk-adjusted net economic value of trading less attractive than alternate compliance management strategies. Four economic challenges threaten the development of robust, sustainable WQT programs because they reduce the discounted cash flow return on investment (DCFROI) of trading. These are: (1) simplified modeling of natural system impacts, (2) costly environmental protection, (3) high transaction costs, and (4) ill-defined property rights. These challenges hinder efficient and fair deal making, usually because they make investing in WQT strategy risky to the buyer, the seller, or both.

4.4.2.1 Simplified Modeling of Natural System Impacts

Most problems are analyzed as simplified forecasts of natural system behavior in the presence of nutrients. In reality, nutrient discharges impact a complex web of interconnected ecosystems, hydrologic systems, biosystems, geologic systems, and other natural conditions that evolve over time. Even with seemingly simple scenarios, such as a bilateral trade between a PS and an NPS utilizing wetlands downstream, the system is still complex in terms of reaching equivalence between the spatially and temporally distinct discharges.

Continuous time modeling and analysis of nutrient impacts to complex natural systems is a daunting task. This approach allows the mapping and analysis of meaningful cause-and-effect relations within the natural environment and the nutrients that affects it. Such analyses identify the total system cost and value of strategy, accounting for feedback behavior among system components, including unintended consequences and counterintuitive behavior. They provide platforms for real-time testing of new and evolving conditions, on a periodic or event-driven schedule.

In addition to the complexities of executing a single trade (quantification, ensuring equivalency, etc.) between a PS and NPS, BMPs usually produce a variety of interlinked private and public; market and non-market values. For example, the size of a wetland (e.g., private investment) not only delivers value in terms of water quality, it also provides flood control, fish habitat, erosion control, recreation opportunities, etc. (e.g., public benefit, when used). This “non-market” value is not accounted for in the price for a water quality credit. However, if implementation of BMPs, such as wetlands is to be encouraged, a strategy that thoroughly accounts for public market value is needed. This could results in the following possible outcomes: a multiple market system whereby a landowner is able to sell or otherwise gain compensation for the other ecological services provided by a BMP, or a more complete understanding of the multiple ways a landowner will benefit by implementing a BMP on their property, in addition to the income from selling water quality credits.

Incorporating public market values in decision analyses would allow traders to more accurately quantify and report their return on investment in WQT. This would provide important information that would increase trading and market support among NPS.

4.4.2.2 Expensive Risk Factors

Everything that is not known and provable is uncertain. This includes all future events. Quantitative analyses deal with uncertainty by: (1) assuming it away, (2) assuming median values, (3) estimating to conservative values, (4) estimating to optimistic or best-case scenario values, (5) estimating using multiple experts, and/or (6) calculating “expected values.” Every calculation that includes uncertainty assumes the risk that the future will be worse than calculated, and the opportunity that the future will be better than calculated.

Each uncertain variable carries some risk of inaccurately estimating its value. Together, these risks compound the estimation risk of the overall outcome of concern. The default approach to evaluating the performance of a complex system is to make assumptions that simplify the system and to include contingencies to account for risk of inaccurate estimates. As a result, behavioral models are replaced with simple formulas. This process does not account for the influence of underlying variables (e.g., seasonal precipitation on peaking flow rates and reduced residence time of nutrients in rivers). Averaging reasonably approximates some of this variability. Other rate changes are more difficult to assume, such as increasing nutrient removal efficiency with evolving wetland ecosystems.

Uncertainty of future events is quantified by mean or conservative assumptions without calculation of the potential impacts of under- or over-estimation. As a result, calculations of values for a WQT strategy are filled with arbitrary assumptions, guesses, and/or estimates of what the future may hold. Regulators tend to use aggressive safety factors to offset their lack of knowledge about how the polluted watershed system will perform given all complexities and uncertainties (e.g., Breetz *et al.*, 2004). Thus, WQT credit asking prices are often inflated beyond the buyers’ willingness to pay, suppressing demand.

Agencies are charged with protecting the public trust, specifically the human, environment and natural resources that are directly and indirectly impacted by nutrient discharges. They aim to protect the public from trade risks that are assigned neither to buyers nor to sellers.[17] Lacking quantitative methods for this assurance, agencies apply risk factors to calculations of TMDL and other discharge limits. Necessarily, these factors are conservative to the extreme, reflecting the most risk-averse stakeholders in the public trust. This conservative risk management has the effect of inflating market prices and may in turn prohibit trading. The challenge is thus in balancing the protection of public interests and stakeholder concerns. A quantitative method of finding this balance and tools to achieve it would allow for a reduction in risk factors to a level that still benefits the public without overwhelming the market. As a result, the trader's return on investment would increase, thereby encouraging more trading.

4.4.2.3 High Transaction Costs

WQT transaction costs are fairly well established by practice, precedent, and policy. However, trades can flounder if parties are compelled to bear onerous agency transaction costs. The barrier to robust WQT is created when the transaction costs are high relative to the value created by trading. High transaction costs are caused by (1) unprecedented circumstances or inexperienced programs, (2) complex trades, (3) large agency commitments, (4) inefficient BMPs, and (5) overly conservative safety factors. The latter is often a problem, whereby multiple conservative assumptions together require the number of PS credits purchased per those needed to be cost-prohibitive.

It is possible to significantly reduce many transaction costs by using dynamic system modeling (rather than static system modeling) to analyze natural system behavior in the face of discharge alternatives. In a large market, with multiple potential buyers and sellers, the long-term benefits would justify the fact that developing the model incurs costs up front.

4.4.2.4 Undefined Property Rights

The discharge volume is considered a property right that requires quantification and ownership, thus challenging successful WQT. In a free market, property rights belong to the buyer and sellers. Whoever drives the market, i.e., sellers or buyers, assigns the limited property rights of the transaction. The other extreme is where the regulator assumes property rights. In a seller's market, the regulating agency, representing the demand side, assumes the property rights of the discharge from the NPS. As such, the NPS transfers liability and control of the BMPs to the agency. On the other hand, in a buyer's market, the regulating agency, representing the supply side, owns the property rights of the discharge. It may transfer a limited set of these rights, including the liabilities associated with those rights, to a PS buyer through a discharge permit, while still retaining control of the BMPs (Collentine, 2003). Without a clear definition of liability and control of the property rights, stakeholders cannot weigh the true risks and returns of the potential trade.

4.5 Potential Solutions

The gaps and challenges to WQT complicate value- and risk-based decision making, leading to default decisions to not trade. Current decisions to commit to WQT and negotiate the terms of WQT deals are based on partial information that emphasizes known or predictable management, implementation, and transaction costs. The contributions of assets created, liabilities reduced, risks and opportunities incurred or avoided, risks transferred at cost, public and private economic valuation, and simplifications that compound uncertainty combine to restrain trading. These challenges need to be addressed to enable WQT to thrive. Each of the following objectives and tools could be used alone or in conjunction with another to gain insight into the utility of WQT and to streamline its application. Performing a thorough economic valuation or System Dynamics Analysis (SDA) analysis for a program would help other programs to do the same because they would not need to start from scratch.

4.5.1 Regulatory Efficiency

Inefficient regulatory practices increase the cost to develop and operate WQT exchanges. Reducing the regulatory cost (and risk) of WQT exchange operations and trading would lower the administrative factor in credit price, thereby improving the traders' DCFROI. Examples of such measures could involve special training for agencies, dedicated WQT agency staff, clarification of legal issues that reduce disputes, improved system modeling, and simplified data management. Free WQT markets minimize regulatory involvement, such that the regulatory agency sets the minimum rules of engagement and then let the market propel itself.

These improvements could greatly increase the rate of WQT, which could further reduce the carrying cost of exchange administration while accelerating the environmental benefits of reduced nutrient discharges.

17 *Trade risk in this context does not involve financial risks to buyers or sellers, but rather the likelihood that the trades will not result in gains in environmental functions and values equal to losses. A recent review of wetland mitigation trading in the United States, for example, concludes that the inherent riskiness of wetland mitigation trades and trade terms that do not assign liability to trading partners have resulted in a significant loss in wetland functions and values, and, possibly, a net loss in wetland acres. See **National Research Council, Committee on Mitigating Wetland Losses, Compensating** for Wetland Losses Under the Clean Water Act (2001) (quoted verbatim from Kuch and King, 2003).*

Measures to improve efficiency are both technically and economically feasible. The only caveat to the economic feasibility is finding the agency budget to invest in improving staff, policies, practices, and equipment. Financing these improvements by increasing the administrative cost of WQT could help fund this effort, but could be counterproductive to stimulating trading.

4.5.2 PS Liability

The command-control compliance liability for PS dischargers is a significant potential driver for trading. As PS command-control liability rises, the value of satisfying the requirements would rise and the MPP for buyers would increase. Stricter water quality objectives would improve the overall quality of the receiving waters, allowing agencies to decrease the “safety factors” built into credit prices, which in turn would stimulate the generation and trading of water quality.

All things remaining unchanged, stricter PS discharge limits should increase the economic attractiveness of WQT, encouraging more trades and better environmental protection. For Rahr, very strict restrictions against any additional discharges into the Minnesota River Basin left the company no practicable alternative to engaging in WQT.

It would be technically and economically simple to stimulate WQT by shifting PS liability through a change in relevant regulations. Politically, however, that change is daunting. If regulations were to occur, the economic impacts of such changes would warrant extremely close inspection and justification before implementation. With current regulations, PSs typically retain liability to meet permit limits, while NPSs take on the contractual obligations of the trade. In some cases, however, liability transfers to a third party, such as for the cases in NC where the State assumed liability for a failed BMP and the NPS would have to return subsidies.

4.5.3 Market Economic Valuation

Thorough valuations that are critical for informed decision-making may facilitate participants to engage in WQT. Ecosystems supply stock and flow resources that are resources for productivity and growth, thereby generating societal value or benefit. Establishing values for these resources is important to policymakers who are challenged to use regulations, laws, and incentives to responsibly manage publicly owned natural resources, habitat, and species. The total economic value of an ecosystem is the amount of money that all people who benefit from the watershed would be willing to pay to see it protected (Whitehead, 1992). This total economic value is the amount society would be willing to pay for the services and attributes of the ecosystem if they were not provided free of charge. This value comprises: (1) market economic value, which is established by transactional precedent, and (2) non-market economic value, which is estimated by methods that rely on public opinion surveys or costs of alternate strategies incurred without the resource.

Society values watersheds and wetlands because their existence and outputs (goods and services) are sources of current and future consumptive and non-consumptive uses. For example, consumptive uses of wetlands include conversion to cropland, and consumptive uses of wetland outputs include the harvesting of fish from wetland fisheries. Non-consumptive benefits are long-lived, such as aesthetics or flood control. Values are multi-dimensional, and measured from several perspectives: (1) individual owner, (2) individual user, (3) regional, and (4) societal (Leitch and Frigden, 2000). Overall, market values are lower than non-market values for watersheds and wetlands (Stedman and Hanson, 2005).

Market values are economic values established and directly observable in functional markets, where landowners and investors realize economic benefits. Since few markets exist for wetlands or watersheds, typical valuations focus on the goods and services within those natural systems, such as harvested plants or animals, rather than the systems themselves.

Components of ecosystems are potentially marketable, and suitable to market economic valuation. For example, ecosystem health will influence the rate of tree growth, the rate of commercial tree harvesting, and the net economic (market) value of timber produced. Fisheries and commercial fishing provide an analogous source of economic value. However, it is more difficult to quantify this value because fish are migratory, and their growth rate and net economic value as a commodity are influenced by the conditions of multiple, complex aquatic ecosystems.

Importantly, the total economic value of an ecosystem or hydrologic system is expressed in terms of the cost to keep the land in its current use. The opportunity cost of alternate land use, such as draining a wetland and using it for cropland, is not considered.

Public policy makers face strategic decisions that affect the short-term and long-term health and productivity of natural resource systems, including watersheds and wetlands. Strategic alternatives are always available for managing such systems. Economic valuation provides a consistent metric for comparing the performance of strategic alternatives over time, and justifying and communicating decision choices to stakeholders.

Several design criteria required for a quality market economic valuation, such as: (1) a clear definition of the system (e.g., named wetland) or system component (e.g., annual shrimp production, in pounds) to be valued, (2) a clear determination of the valuing party (municipal tax authority, commercial fisherman, regional grocery stores), (3) the years to be used in establishing value, and (4) the regional market to be used in establishing value.

The cost of establishing the market economic value of a natural system (or a zone within a system) is directly proportional to the complexity of the system and its components, the diversity of the valuing population, and the volatility of defining markets. The methods for establishing the market value of a watershed or a wetland are well established and not controversial. However, difficulties exist in the interpretation, including: (1) communication challenges among scientific disciplines, (2) economic principles not followed, (3) site-specific nature and variability, (4) unclear context of valuation (why and how needed), and (5) shortage of scientific and economic information, leading to assumptions (Leitch and Frigden, 2000). These challenges are readily overcome provided adequate time is available for the analysis and sufficient resources are invested.

4.5.4 Non-market Economic Valuation

Watersheds and wetlands generate marketable and non-marketable natural goods and services, in economic terms. Examples of non-marketable economic values include water quality control, stream ow control (and habitat management. These non-marketable economic values primarily benefit the public. Unfortunately, because they are difficult to quantify, non-market economic values often weigh less than market economic values in determining policy and natural resource management strategy. However, including these values in economic assessments of strategy or policy should encourage trading.

The ideal method for non-market valuation depends on the purpose or application of the valuation and the quality of available information, and no single method applies to all situations. Non-market economic valuation methods are site-specific, focusing on the physical properties, location, and the socio-economic context of the condition to be valued.

Wetlands, watersheds, and other natural systems perform multiple geologic, biologic, and hydrologic functions that produce goods or support ecological services and socially valued outcomes. These functions, goods, services, and outcomes are intricately intertwined, or bio-economically linked. For example, valuing the non-market benefit (e.g., downstream water quality and fish habitat) of investing in management controls (e.g., nutrient source reduction or wetland restoration) is difficult because the bio-economic linkage between cause and effect is indirect and complicated by multiple physical and biological functions. Non-market (e.g., fish habitat) and market (e.g., commercial fishing revenue, employment and tax revenue) goods and services are also linked, adding to the complexity of valuing strategies that impact natural systems such as wetlands.

As an example, estuaries and their wetlands evenly distribute stream ow and runoff energy (ood control) and loadings (water quality), thereby generating market economic value in the fishing industry. The National Oceanic and Atmospheric Administration (NOAA) reports that marine fisheries contributed $19.8 billion to the United States gross national product in 1993. The business employed more than 364,000 fishers and onshore workers in 1991. Freshwater and saltwater recreational fisheries in 1991 supported 924,600 jobs, contributing $1.1 billion in state sales tax, $227 million in state income tax, and $2.1 billion in federal income tax. At a local level, it is possible to roughly approximate the minimum non-market value of an estuary wetland loss as the replacement cost of lost local fishing revenue, including tax, employment, and other economic considerations.

Non-market economic valuation techniques are established, and widely used in the valuation of strategy and policy. They are essential in the valuation of natural resource strategy, regulations, and policy, because the non-market component of natural resources economic value typically outweighs the market component of economic value.[18]

In many situations, it is difficult to complete a non-market economic valuation rapidly enough and with enough sensitivity to usefully inform cost/benefit decision makers. However, the techniques are appropriate when environmentally sensitive, large-scale (e.g., watershed), or long-term and/or policy decisions are at stake. Overall, non-market economic valuation should focus on what is indicated or learned by the valuation process, i.e., effective interpretation of results, rather than the numeric results themselves.

4.5.5 Economic Investment Decision Methods

Economic investment decision methods comprise the classic DCFROI calculations used to evaluate competing capital investment opportunities (Stermole and Stermole, 1993). These analyses quantify DCFROI, cash ow, and break-even metrics. These methods map the expected performance of an investment in a cash ow format. Spreadsheets are often used as the platform for these calculations. Cell data are entered as known, assumed, or expected (probabilistic) values

18 In their review and synthesis of the economic value of open space, Faushold and Lilieholm (1996) note, de Groot (1994) has suggested a system for valuing natural systems based on a checklist of 37 functions, grouped into four categories: regulation functions (ecological processes and life-support systems that supply and protect the quality of air, water and soil); carrier functions (providing space and substrate for habitat, recreation, and cultivation); production functions (producing food, fiber, energy and genetic material); and information functions (providing opportunities for reflection, spiritual enrichment, and cognitive development).

for revenues, costs, assets, and liabilities. Cash flow is discounted at a rate set by the analyst. Decision makers select strategy based on the net present value of cash flow or return on investment.

This method is used ubiquitously in business and is taught as a core course in business schools as a way to compare the economic value of strategic alternatives, including “no change.” This methodology gives decision makers confidence in the merit of their decisions, accelerating commitment of capital, leveraging negotiations, and structuring exit strategies. Using this can accelerate the approval and implementation processes for each project, benefiting the environment as a result.

Economic decision methods are completely feasible as they are already applied broadly to assess and select environmental and other business strategies. Any costs would be borne by the trader. The cost to complete such analyses depends on the complexity of the trading situation.

4.5.6 Probabilistic Analysis

Probabilistic analyses define uncertainty of known possible outcomes in terms of “probability of occurrence” and “magnitude of occurrence.” Calculations that are based on probabilistic inputs or data are more accurate than single-point estimate inputs, which are subject to error and bias. Inputs for calculations are derived from experts in appropriate fields of inquiry, such as the cost to treat water or the cost to dredge sediment from a specific location. Experts provide inputs as guesses, estimates, range values, probable values, or other methods. Risk and opportunity are accounted for in probable values, making them more reliable than the alternative inputs. Probabilistic inputs can be used for all, part, or none of the uncertainties in a value calculation.

Probabilistic analysis is applicable to many kinds of problems, and is well established in practice and literature. This approach may be widely employed at present, but reports of its use for WQT are not published. The cost of probabilistic analysis of WQT strategy is higher than the cost of an assumption-based analysis. No agency cost would be required, except when agency staff serve as experts providing information for analyses. This approach would provide decision makers with more confidence in committing capital to WQT, thereby accelerating the rate at which all parties may agree to the transaction terms. This approach is technically and economically feasible, providing a better understanding of the data and uncertainties surrounding the data to improve the decision-making process.

4.5.7 System Dynamic Analysis

SDA is a modeling process that enables decision makers to evaluate the outcomes of their decisions by modeling in advance of making investments. This process evaluates the consequences and sequencing of complex events and phenomena inherent in many systems. Multiple strategies are always available to the investor or decision-maker. SDA is capable of evaluating how systems will behave as a result of change, whether it is due to decided actions or uncontrolled events.

The WQT market and watersheds, like all complex systems, are networks of positive and negative feedback loops. Complex interactions lead to possible unintended consequences and counter-intuitive behavior. SDA addresses these characteristics inherent in the real world, simultaneously managing continuous and discontinuous relationships. Model development and analyses proceed iteratively, refining the model with increasing knowledge of the system. Furthermore, SDA supports sensitivity analyses, either Monte Carlo or ad hoc, for the communication and defense of choices to stakeholders. The different drivers, goals, and risk attitudes of buyers, sellers, and regulators necessitate quality forecasts of information in order to commit capital to good use. Intuition and experience are not adequate when the problem is too complicated and dynamic. The SDA structure is capable of resolving many of the challenges hindering WQT. To adequately and cost-effectively ensure equivalence, SDA analyses may elucidate the complex processes affecting equivalence and trading effectiveness. This tool has benefited many similar projects, including planning water resources. Unfortunately, there are no available precedents for using this tool for WQT improvements.

4.6 Conclusions and Recommendations

To date, there is little direct evidence that WQT creates the advantages ascribed to it. However, specific trades have demonstrated its utility, which lends to optimism that it may still be a compelling alternative to achieve water quality. Many changes could be implemented to grow the WQT markets and encourage trades within the existing policies and regulatory framework. For example, trading ratios could be distributed to include third-party beneficiaries (e.g., public stakeholders), credits earned by implementing BMPs could be increased, or agencies could absorb specific transaction costs currently paid by traders. Indeed, a number of options could facilitate this growth to the extent they address the identified challenges.

Economic considerations must support WQT for it to be a viable tool to achieve water quality standards. The market should acknowledge the true valuation of an exchange. Currently, several information gaps typically elicit ineffective valuation that does not accurately address risks and returns, thereby generating economic trading challenges. Establishing sophisticated methods of decision-making and of evaluating and managing risk would promote WQT’s viability. Without complete valuations of the WQT alternative, which comprehensively address the information gaps and challenges, the market may not achieve its optimum potential. In fact, it may lose its marketability entirely. To clarify, every trade does not mandate a rigorous valuation process. Rather, the market viability would benefit from a framework within which to more readily qualify costs and benefits of WQT and specific designs. These valuations will enable decision makers and policy makers to quantify the value of investing in WQT as a discharge management strategy of choice.

5.0 Trading Regulations Literature Review

The Federal Water Pollution Control Act, or CWA, of 1972 provides the foundation for WQT in that it establishes regulations to protect water quality and allows flexibility with respect to how those requirements can be met. This national law was enacted to restore and maintain the chemical, physical, and biological integrity of the nation's waters. The act established national policy and preserved the primary responsibilities and rights of the states to prevent, reduce, and eliminate nutrient discharges. In order to carry out this policy, USEPA was given the authority to require permits of PSs that discharge nutrients into waters of the United States, through the NPDES permit program (CWA Sections 402 and 404). PSs are discrete conveyances, such as pipes or man-made ditches (40 CFR 122.2). These permits set effluent quality limitations and require implementation of best available technologies that may include specific BMPs. USEPA allowed the states to decide how NPSs should be regulated (IDEQ, 2005c).

Amendments to CWA (Section 319) in 1987 included the requirements for states to develop and implement programs to control NPSs of nutrient discharges. Section 319 does not provide direct authority to regulate NPSs of nutrient discharges (Heimlich, 2003), but it does establish mechanisms for states, tribes, and territories to receive support for programs developed to control NPSs of nutrients in the form of technical and financial assistance, training, technology transfer, and monitoring to assess the success of projects to control NPSs of nutrients (USEPA, 2005b). Programs developed by the states to control NPSs of nutrients have tended to emphasize voluntary actions (Heimlich, 2003). According to Heimlich (2003), 31 states have taken additional steps towards controlling NPSs of nutrients by passing laws or implementing programs that include enforceable mechanisms to protect water quality from agricultural sources of nutrients. These enforceable mechanisms tend to emphasize technology standards. The Tar-Pamlico and Neuse River Basin NSW Strategies in North Carolina provide two examples of state rules that emphasize technology standards to address agricultural and urban NPSs of nutrients by requiring that these sources achieve nutrient discharge requirements by implementing their choice of BMPs from a pre-approved list for which the state had determined average nutrient removal efficiencies (see Section 9.0 for more information).

The NPDES program has made significant progress in reducing pollutants discharged by PSs to the nation's waters (USEPA, 2003b); however, between 40 and 50 percent of the streams, rivers, and lakes still remain below water quality standards. Advocacy groups blame the USEPA for waters still being impaired due to the delays in issuing guidance and providing assistance, states for not reaching beyond conventional knowledge and approaches, and the US Congress for not providing adequate resources to meet USEPA and state needs. More than 40 lawsuits, in 38 states, have been filed against USEPA and states for failure to fulfill requirements of the CWA. Consequently, innovative approaches are being sought to further recover water quality. WQT is one such approach that promises greater efficiency in achieving water quality goals on a watershed basis (USEPA, 2003a). WQT projects have occurred in the United States since the early 1980s (Copeland, 2005).

The CWA also requires the development of water quality standards for all contaminants in surface waters, which include standards for designated uses, water quality criteria, and antidegradation provisions (Section 303[c]). The act also requires the establishment of TMDLs (Section 303[d][1]). TMDLs are the amount of an identified pollutant that a specific stream, lake, river, or other water body can "accommodate" without violating state water quality standards and an allocation of that amount to the pollutant's sources (USEPA, 2003c). States are required by CWA to address both PSs and NPSs by establishing TMDLs for waters that do not meet water quality goals. These TMDLs typically function to set the baseline for determining trading units called credits. TMDLs must be approved by USEPA and developed for every pollutant that causes a watershed to exceed clean water limits; thus, TMDLs are generated specifically for nutrients such as nitrogen and phosphorus.

In addition to the CWA, the Coastal Zone Management Act Reauthorization Amendments (CZARA) of 1990 contains NPS water nutrient requirements. The CZARA requires that states with approved coastal zone programs submit plans to implement measures for NPSs of nutrients to restore and protect coastal waters. States can employ voluntary measures, such as education, technical assistance, and financial assistance, but must be able to enforce these measures should voluntary approaches fail (Heimlich, 2003).

Arguably, one factor that seems to have hampered the ability of USEPA and states to protect water quality and ensure that state water quality standards are not violated is the challenge of developing programs (regulatory or voluntary) to control NPSs of nutrients. As discussed in Section 1.0, NPSs, particularly agriculture, are important sources of water nutrients. It is difficult to measure the contribution of an individual NPS of nutrients or the actual effectiveness of various BMPs to control discharges because of the diffuse nature of this type of discharge, as discussed in Section 3.0. WQT programs are yet another mechanism that may increase the participation of NPSs in implementation of BMPs to improve water quality by providing another platform for education and means by which land owners receive outside funds to make improvements to their properties (by implementing BMPs).

5.1 USEPA Water Quality Trading Policy

To encourage the implementation of WQT programs, USEPA developed a WQT policy in 2003 (USEPA, 2003a). This policy provides guidance for states, interstate agencies, and tribes to assist them in developing and implementing such programs. Specifically, the policy is intended to encourage voluntary trading programs that facilitate implementation of TMDLs, reduce the costs of compliance with CWA regulations, establish incentives for voluntary reductions, and promote watershed-based initiatives. Voluntary trading before TMDLs are established could decrease the pollutant reduction required by the TMDL and possibly improve water quality enough to meet water quality goals and eliminate the need for a TMDL.

Within the trading approach, ecological benefits that complement water quality improvements are promoted by the policy. For example, two of the trading objectives of USEPA's trading policy discuss the use of wetlands in trades, and are stated as follows:

> *F. Achieves greater environmental benefits than those under existing regulatory programs. EPA supports the creation of water quality trading credits in ways that achieve ancillary environmental benefits beyond the required reductions in specific nutrient loads, such as the creation and restoration of wetlands, floodplains and wildlife and/or waterfowl habitat.*
>
> *H. Combines ecological services to achieve multiple environmental and economic benefits, such as wetland restoration or the implementation of management practices that improve water quality and habitat.*

Trading is particularly encouraged by the policy for nutrient (e.g., phosphorus and nitrogen) and sediment loads. Other pollutants may pose a higher level of risk and should receive a higher level of scrutiny to ensure that they are consistent with water quality standards. The geographic area for trading programs is described by the policy as the watershed or area covered by an approved TMDL. Trading credits are defined by the policy as nutrient reductions greater than those required by a regulatory requirement or established under a TMDL. USEPA encourages the inclusion of specific trading provisions in the TMDL itself, in NPDES permits, in watershed plans, and the continuing planning process (USEPA, 2003a).

USEPA's water quality policy identifies several mechanisms for providing provisions for trading, including legislation, rule making, incorporating provisions for trading into NPDES permits, and establishing provisions for trading in TMDLs or watershed plans. As discussed in the case studies presented in Section 6.0 through 9.0, NPDES permits have provided an essential part of the regulatory basis for WQT programs, and TMDLs have furnished the driver for trading. For example, the NPDES permit issued to Rahr (Section 7.0), stringently capped the company's oxygen-demanding discharge into the Minnesota River Basin. The cap was set according to the TMDL, which allocated 53,400 pounds per day of CBOD at mile 25 and downstream of Rahr.

North Carolina took a slightly different approach to using NPDES permits in WQT programs. Both the Tar-Pamlico and Neuse River Basin WQT programs (Section 9.0) tailored the NPDES permits of PSs within the river basin to provide them with exibility in meeting permit requirements, which furnished the option of trading. Both programs establish associations that include a majority of the PS dischargers within the basin. The NPDES permits of the Association members do not contain limits for TN and TP, which means that if they overperform, they are not subject to the antibacksliding requirements in the federal CWA (these requirements would result in adjustments in permit limits if association members showed they could meet more stringent requirements). The NPDES permits do, however, contain a "reopener" clause stating that if conditions in the agreement signed by the Association, the North Carolina Environmental Management Commission (NCEMC), the North Carolina Division of Water Quality (NCDWQ), and the Department of Soil and Water are violated, then permits would be revised to impose new discharge limits (Kerr *et al.,* 2000). The agreement specifies a group discharge allowance for TN and TP. As with Tar-Pamlico, the NPDES permits of individual dischargers within the NRCA do not contain a discharge limit for TN. Instead, the TN limit for the NRCA is specified in the group compliance NPDES Permit (USEPA, 2002b). Both of these programs were established prior to development of TMDLs for the river basin, but the final TMDLs agreed with the limits that had already been established by these programs. These programs allow for trading among PSs and trading with NPSs via a state-administered fund for every pound by which the aggregate annual discharge of the association exceeds the established limit.

The Water Quality Trading Policy also identifies several key elements that should be incorporated into trading programs so that they are credible and successful. Units of trade (e.g., nutrient-specific credits) are necessary for trading to occur. These may be expressed in rates or mass per unit time. Credits should be generated before or during the same period they are used to comply with a monthly, seasonal, or annual limitation or requirement specified in an NPDES permit. As long as the discharge controls or management practices are functioning to reduce nutrients that generate credits, credits may be generated (USEPA, 2003a). To encourage trading, there needs to be clear authority to trade and clear legal protection for using the rights purchased (in the form of water quality credits) to meet established regulatory requirements (Kieser and Fang, 2005).

Specific requirements for trading programs will vary based on the location and circumstances of the trading. These requirements are left up to the states to generate, although USEPA's trading policy encourages consultation with USEPA during program development. USEPA believes trading programs must have clear and consistent standards for measuring compliance and to ensure that appropriate enforcement action can be taken for noncompliance. The incorporation of compliance and enforcement provisions within a trading program framework is an essential element for a credible trading program, according to USEPA's water quality policy (USEPA, 2003a). These may include a combination of record keeping, monitoring, reporting, and inspections.

Enforcement provisions within the trading program must ensure legal accountability for generation of credits that are traded. Compliance audits should be conducted frequently enough to ensure that a high level of compliance is maintained across the program. If compliance is not maintained, the NPDES permit holder using those credits would be responsible for complying with discharge limitations as if the trade had not occurred. For example, in the Cherry Creek WQT program in Colorado (Section 6.0) and the LBR WQT program in Idaho (Section 8.0), the PS project owner that initiated the trade is responsible for ensuring BMPs selected to generate credits are properly implemented and for any ensuing liability issues. The Idaho program also requires the BMP implemented to be certified as installed before the phosphorus credit can be generated and traded. In the Rahr trading program, the NPDES permit ensured legal enforceability of the selected controls by prescribing the types of BMPs, selection process, reporting, and goals. MPCA was charged with verifying each trade and confirming annual nutrient reductions prescribed in the permit (Breetz *et al.*, 2004).

On the subject of liability, Raffini and Robertson (2005) noted that wetland mitigation banking has dealt with liability differently than WQT in order to ensure that the service offered by wetland mitigation banking is attractive to developers and dischargers. The transfer of liability from the credit purchaser to the third-party mitigator was identified as critical to making wetland mitigation banking work: credit purchasers are not interested in buying healthy wetlands or clean water; they are purchasing rapid permitting and avoidance of liability if a mitigation site fails. In the case of Cherry Creek and Rahr, the credit purchaser is not offered a release from liability if the mitigation is ineffective and may be faced by the need to continuously monitor and maintain the mitigation measures, incurring additional costs and being exposed to ongoing uncertainty. The LBR also places liability on the credit purchaser to ensure that the BMPs are performing. This makes the purchase of credits much less attractive to PSs. Transfer of legal and financial liability from the credit purchaser to another entity is one way of making nutrient credits a more desirable commodity (Raffini and Robertson, 2005). North Carolina handled the issue of liability in the Tar-Pamlico and Neuse River Basins by assigning identification and management of WQT mitigation projects to existing government entities which are responsible for ensuring NPS credits are generated. However, PS compliance associations have not needed to purchase nutrient credits to date.

Another form of program auditing included in the USEPA water quality policy is providing program transparency to the public. Public participation and comments on trading program development, use, and evaluation should be sought to ensure that water quality objectives and economic efficiencies are achieved, and that trading does not result in an impairment of designated uses (USEPA, 2003a).

Some states have passed water quality laws, rules, regulations, and/or policies supporting and regulating watershed-specific trading operations. As discussed in the case studies, Colorado, Idaho, and North Carolina developed regulations to support and govern WQT. In the case of the LBR, no trading has occurred to date because the phosphorus TMDL has not been finalized; as a result, the trigger for trading is missing. New trading programs would also need to develop similar watershed-specific policies, rules or regulations. These provide the drivers and trading framework necessary for watersheds to implement exible programs to accommodate local conditions and socioeconomic factors (Kieser and Fang, no date). Regional or state trading policies exist for 10 states. There are several different models for managing trades, including:

- State-managed exchange – state is broker (CT)
- NPDES Compliance Association – association is the broker (NC Neuse and Tar-Pamlico)
- Third party is broker, such as a non-profit, private enterprise, conservation organization, or district, etc. (Idaho; South Nation, Ontario)

Credit managers can facilitate trading by assisting numerous credit buyers and sellers in finding each other. Furthermore, they can identify and facilitate trades among multiple buyers and potential sellers. Multiple locations with small amounts of credit could be consolidated by an administering organization for sale to a large buyer. Other functions of credit managers or brokers could perform include: verifying and discounting credits that vary widely in performance and uncertainty, optimizing the selection and location of BMPs, and providing escrow or backup credits in case of BMP failure (Hough and Hall, 2005).

5.2 Agricultural Policy Drivers for Using Wetlands in WQT

For decades, the USDA has encouraged conservation measures on farmland. Towards that goal, several “Farm Bills” have established agricultural policy to increasingly rely on financial incentives to promote conservation practices. Many of the provisions of the farm bills encourage the use of wetlands to achieve environmental quality.

- The 1985 Farm Bill created the Conservation Reserve Program, which included a provision to link eligibility for financial incentives to wetland conservation practiced on ecologically sensitive land.
- The 1990 Farm Bill created the Wetlands Reserve Program, a federal program to restore and place conservation easements on wetlands, and authorized the Water Quality Incentives Program.
- The 1996 Farm Bill consolidated several programs created in previous Farm Bills into the Environmental Quality Incentives Program. Among other functions, the Environmental Quality Incentives Program funds BMPs on working farmland.
- The 2002 Farm Bill dramatically increased funding for CS, making it possible to restore much of the country’s lost or damaged wetlands.

The USDA has been promoting the applications of private-sector markets for achieving environmental goods and services (USDA, 2005). While traditional financial incentives have been through cost-share programs, trading in environmental credits will provide the next generation of incentives for conservation. In large measure, the World Trade Organization has driven this potential expansion of using environmental markets by disputing trades associated with agricultural production subsidies. Specific restrictions limit the amount of financial support the farm may receive without losing their eligibility to be considered “green box”, a status that exempts them from annual limits on support. Alternatively, WQT markets would allow agricultural operations to earn income by providing nutrient credits to those that need them. In fact, Congress will vote on a proposed 2007 Farm Bill that would allow credits generated by BMPs implemented with federal funds to be sold within the market (USDA, 2006). Support by Congress of this measure would significantly promote the participation of agricultural NPSs in WQT.

5.3 Regulations Related to Wetlands and Trading Programs

The CWA contains requirement that could have implications for wetlands constructed as a part of a WQT program. Waste treatment systems designed to satisfy the requirements of the CWA are by definition not considered waters of the United States (USEPA, 2000a). However, if a constructed wetland is constructed in a water of the United States, the area will remain a water of the United States unless a CWA Section 404 permit is obtained that identifies it as an excluded waste treatment system. It is possible that the constructed wetland will revert to a water of the United States if it is abandoned or is no longer being used as a treatment system and it fits the definition of a water of the United States. This definition is met if the constructed wetland has wetland characteristics (hydrology, soils, vegetation), is an interstate wetland, is adjacent to another water of the United States, or is an isolated intrastate water that has connections to interstate commerce (USEPA, 2000a). These requirements have regulatory implications. If a constructed wetland is built to generate credits for a WQT program and the credits are assigned a finite duration, then the wetland could become regulated under the CWA, thereby limiting potential uses of the land. This could serve as a deterrent to using constructed wetlands as a BMP in WQT programs. If USEPA and states would like to encourage the use of constructed wetlands in WQT programs, then the long-term regulatory implications of building constructed wetlands to generate credits for WQT programs will need to be modified.

6.0 Case Study – Cherry Creek, Colorado

6.1 Overview

The Cherry Creek Basin trading program aims to protect water quality in the basin through trades between two PSs and between PSs and NPSs. Several tributaries and the Cherry Creek mainstem ow into the 850-acre Cherry Creek Reservoir, located in southeast Denver, Colorado (Figure 6-1) (CCBWQA, 2005). The U.S. Army Corps of Engineers (USACE) constructed the dam establishing the Cherry Creek Reservoir in 1950 to protect Denver from ooding (USACE, undated). The USACE owns the Cherry Creek Reservoir and the 3,915 acres of land surrounding it, but leases both to the State of Colorado. That land is now the Cherry Creek State Recreation Area. Cherry Creek ows from the reservoir supplying a watershed of 245,500 acres for Denver. Groundwater also ows into Cherry Creek from beneath the dam downstream of the reservoir, supplementing the watershed supply (CCBWQA, 2003a). The CCBWQA administers and manages the water quality issues of this watershed. Within the watershed, six WTFs discharge ef uent as PSs into the streams owing into the Cherry Creek Reservoir. Trading between PSs occurred as early as 1985, expanding to allow trades with NPSs in 1989. Final guidance for trades was approved in 1997. Since then, three trades have occurred, one of which involved an NPS (Breetz *et al.*, 2004).

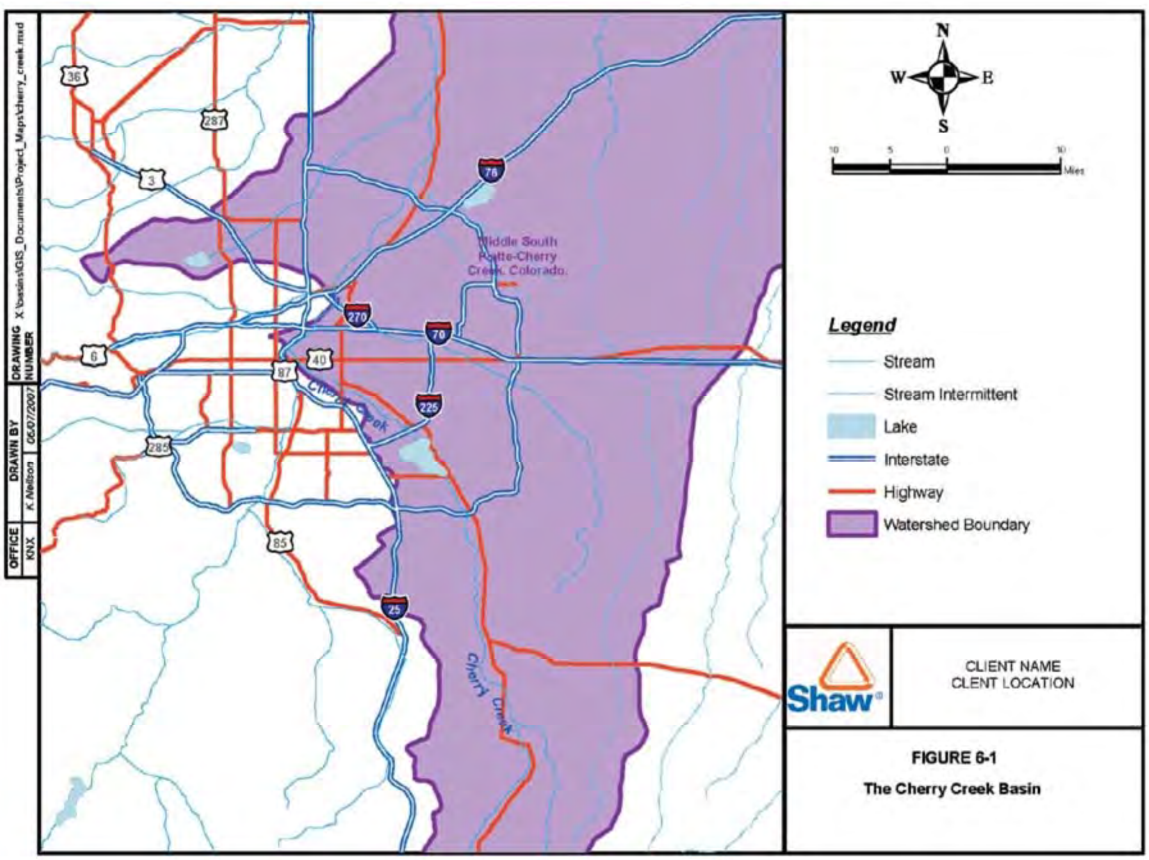

Figure 6-1 *The Cherry Creek Basin (CCBWQA, 2005).*

6.2 Background

The State of Colorado initiated WQT in 1989 through the state's Department of Public Health and Environment when its Water Quality Control Commission embraced the Cherry Creek Reservoir Control Regulation, listed as Regulation #72. The regulation approved WQT between PS and NPS discharges of phosphorus. Four years earlier, the Water Quality Control Commission distributed TMDL allocations of phosphorus aimed to control eutrophication of the Cherry Creek Reservoir to the PSs with discharges into the reservoir. PS dischargers had to obtain a permit under NPDES before discharging ef uent into the streams owing into the Cherry Creek Reservoir. The Department of Public Health and Environment accepted trades with NPSs despite the fact that these sources were unregulated. Their rationale was that NPSs at that time represented approximately 80 percent of the phosphorus load into the basin. The state's impetus for the trading program was to allow growth while preserving the aquatic ecosystem of the basin. Regulation #72 also legally mandated the CCBWQA to administer the basin (Breetz *et al.*, 2004).

In 1997, approval of guidelines for Regulation #72 trading finally gave direction to the program. Guidance identified trading opportunities, determination of trading ratios and credits, procedures for applicants, evaluation criteria, and trade implementation. Revisions to Regulation #72 in 2001 established the TMAL allocating phosphorus loads into the basin to both PSs and NPSs. In 2003, they issued the Cherry Creek Reservoir 2003 Watershed Plan with new guidelines to re ect the updated trading program. The plan set the surface water standard for TP at 40 micrograms per liter (µg/L). The Trading Program Guidelines offered more detail on trade evaluations and implementation. The TMAL was set at 14,270 pounds of phosphorus per year, of which the CCBWQA allocated approximately 72 percent (10,300 pounds per year [lb/yr]) to NPSs and regulated stormwater sources, 13 percent (1,900 lb/yr) to municipal and industrial PSs, 8 percent (1,150 lb/yr) to background sources, and 3 percent (450 lb/yr) to individual septic systems (CCBWQA, 2003a, 2003b, and 2003c). An additional 3 percent was allocated to reductions achieved by the Reserve Pool and Phosphorus Bank.

The CCBWQA set up these two entities (Reserve Pool and Phosphorus Bank), each initially worth up to 216 pounds of phosphorus per year to broker trades. The Phosphorus Bank obtained its 216 pounds of phosphorus per year through four projects the CCBWQA initiated in the early 1990s and has been maintaining since then. The Reserve Pool could earn its 216 pounds of phosphorus per year through new NPS control projects. A PS discharger could apply for Reserve Pool credits either for a BMP project or for extending their wastewater service to a semi-urban area. In total, PS dischargers could buy or lease up to 432 pounds of phosphorus per year, i.e., the sum of the Reserve Pool and Phosphorus Bank, of new or increased allocations, bringing their total allocation to 2,310 lb/yr, or 16 percent of the TMAL. Semi-urban areas, which are not designated to a service area but are planned for urbanization in the future, were allocated 236 credits, already included in the PS allocation (CCBWQA, 2003a; CCBWQA, 2005).

Recent amendments to Regulation #72, effective as of December 30, 2004, removed the upper limit of 216 pounds of phosphorus per year that the Reserve Pool could achieve. The NPSs and regulated stormwater sources were also increased to 10,506 pounds of phosphorus per year to include the Phosphorus Bank's 216 pounds of phosphorus per year (CCBWQA, 2005). These changes are intended to encourage more interest in trading by eliminating ceilings on a trade's potential.

Stormwater is included in the trading program as another regulated discharge. Colorado regulates stormwater discharges through a mandate for NPDES permitting. The permit adds requirements for stormwater BMPs to reduce phosphorus discharges into surface waters (Breetz *et al.*, 2004).

6.3 Program Performance

The four criteria fundamental to a successful trading program involving NPSs include equivalency, additionality, accountability, and efficiency (Fang and Easter, 2003). The first three criteria address technical and administrative issues, necessary to evaluate efficiency. Equivalency, which is a measure of how nutrient loads from various sources relate to the constituent of concern to be offset, is vital to avoid surpassing the TMDL. Conversion ratios accounted for temporal, spatial, and/or chemical differences in the sources. Such differences are often complex, so this criterion is fraught with uncertainties, which must also be factored into the trade. Additionality stipulates that any NPS offset that would have occurred regardless of the trading program cannot count toward a trade. This prevents double counting by ensuring that a nutrient control activity counts toward only one objective if multiple objectives are met. For example, phosphorus reduction from a BMP that is already necessary for land development activities is not eligible for trading (Breetz *et al.*, 2004). Finally, accountability mandates appropriate monitoring and oversight to ensure proper implementation of all program requirements. Performance, design monitoring, and reporting could satisfy this criterion. Conservatively setting the conversion and trading ratios also contributes to satisfying this criterion. The last criterion is one of economics. Efficiency mandates the trade proceed only when one source is able to more cost-effectively reduce its discharges than another source. This condition is critical to making the program financially attractive, and thus marketable (Fang and Easter, 2003; Jaksch, 2000).

The Cherry Creek trading program structure is conducive for success in achieving these four criteria. Conversion ratios account for differences in particulate versus dissolved forms of phosphorus. In addition, trading ratios, which qualitatively account for spatial differences in loads, add a level of certainty to equivalency. Additionality precludes a credit from counting towards a trade if it already existed or was required. Monitoring and reporting are essential components of the program, providing accountability. A PS could increase its TMAL allocation through trading more cost-effectively than through implementing its own controls.

However, as the following sections present, threats to these criteria, particularly to equivalency and efficiency, have thus far hindered this success. Complexities involved in the determination of conversion and trading ratios hindered the certainty of equivalency. However, this factor should be more quantitative, and account for temporal differences, as well. In fact, equivalency must account for the effects of the dynamic interactions of processes, such as concentrations of other nutrients. Establishing equivalency with more certainty must be achieved without burdening the program with added costs. Financial incentives are critical to perpetuating the program, and are currently not sufficient to stimulate trading. Currently, there is not enough need for most PSs to reduce their phosphorus loads.

6.4 Technical Performance

The trading program operates on a system where one credit is equivalent to 1 pound of phosphorus per year. Trading credits functions through a clearinghouse structure, whereby the CCBWQA may sell credits to dischargers needing to increase their allocation. A PS discharger may also trade directly with another PS discharger if the buyer at least strives to minimize phosphorus loadings (Breetz *et al.*, 2004).

Success of the trading program is predicated on PSs abiding by their discharge limits. The CCBWQA mandates that, prior to discharge, PSs must remove as much phosphorus as possible through advance treatment or secondary treatment followed by land application. The 30-day average concentration of phosphorus in ef uent must not exceed 0.05 mg/L. Dischargers using land application must achieve a 30-day average concentration of phosphorus less than 0.05 mg/L divided by the return ow rate, unless lysimeters are used, in which case the ef uent concentration limit is 1.0 mg/L (CCBWQA, 2005). Such restrictions aim to control the release of phosphorus in the solid phase into the watershed through stormwater runoff.

The trading program incorporated safety factors to provide accountability. These factors aimed to account for project uncertainties, particularly those in Pollution Reduction Facility (PRF) effectiveness and those associated with complex dynamic fate and transport processes. The CCBWQA set equivalency at 2.9:1 for TP and 2.2:1 for dissolved phosphorus. These ratios were derived from a USEPA-approved method to assess the settling of suspended solids, ratios of dissolved-to-total suspended solids (TSS) from a comparable facility, and a fate and transport adjustment (Breetz *et al.*, 2004). These ratios indicate 2.9 credits of reduced TP discharge or 2.2 credits for dissolved phosphorus discharge are needed for each pound of phosphorus discharged from a PS. Accordingly, Equation 6-1 calculates the number of credits of phosphorus earned based on the weight of phosphorus reduced per year, using a conversion ratio.

$$\text{credits\_earned}_P = \frac{\text{pounds\_per\_year}_{P\_reduced}}{CR} \qquad (6\text{-}1)$$

where credits_earnedP = credits earned from trade, defined as pounds of phosphorus per year
pounds_per_year$_P$ = lb/yr of phosphorus reduced by BMPs
CR = conversion ratio

Credits that are earned from the BMP implementation are added to the allocation. With a minimum trading ratio of 2:1, a minimum of twice the earned credits is lost from the entity trading its credits (Breetz et al., 2004).

$$\text{credit\_lost}_P = \text{credits\_earned} \bullet TR \qquad (6\text{-}2)$$

where credit_lost$_P$ = credits lost from allocation
TR = trade ratio

Four "historic trade projects" supplied the Phosphorus Bank with its 216 credits. These PRFs include the Shop Creek detention pond and wetlands established in 1990 (Figure 6-2), Quincy Drainage detention pond established in 1996, Cottonwood Perimeter Road Pond established in 1996, and improvements to the East Shade Shelter streambank established in 1996 (CCBWQA, 2005; Wulliman, undated). The CCBWQA is charged with maintaining and managing these PRFs. If approved, a PS discharger may buy credits from the CCBWQA for a price set by the CCBWQA. For example, a PS discharger needing an additional 20 credits, worth 58 credits with a 2.9:1 equivalence, could purchase twice that, i.e., 116 credits, from the CCBWQA's Phosphorus Bank, which is now part of the NPS and regulated stormwater allocation. To date, no discharger has requested a withdrawal from the Phosphorus Bank (CCBWQA, 2005).

These historic PRFs earned their credits primarily through erosion and wetland restoration, and continue to reduce phosphorus loads into the Cherry Creek Reservoir. The performance of each PRF is monitored annually by measuring and comparing phosphorus loads upstream and downstream of each PRF. Development had significantly eroded Shop Creek and eliminated all of its vegetation. The Shop Creek Water Quality Improvement Project created wetlands to stabilize channel erosion and reduce phosphorus load to the Cherry Creek Reservoir. The project established a 9-acre-foot detention pond upstream of five wetland channels in series, each stepped down from the previous. Detention ponds typically fill with water during storm events and then allow for slow drainage thereafter, allowing time for the particulates with phosphorus to settle. Each wetland channel adds settling time, as well as natural biological, chemical, and physical treatment, and infiltration. Between 1990 and 2000, phosphorus leaving the Shop Creek wetlands to enter the Cherry Creek Reservoir averaged 173 pounds less than that entering the detention pond, representing an average reduction of 63 percent. The Quincy Drainage detention pond reduced phosphorus loads by restoring a vegetated infiltration basin. Measurements collected before and after this PRF from 1996 to 1999 calculated average load reductions of 138 pounds and efficiencies of 99 percent. The Cottonwood Creek Perimeter Road Pond PRF involved road improvements to decrease water flow, restoring vegetation through the channel, thereby reducing phosphorus loadings. In 2004, phosphorus measurements before (3,334 pounds) and after (2,592 pounds) the pond indicate an average annual load reduction of 742 pounds, i.e., 22 percent (CCBWQA, 2005). Finally, the East Side Shade Shelters area had suffered from severe erosion, which was remedied through gravel benching and vegetation along the shoreline. This stabilization reduced phosphorus loadings into the Cherry Creek Reservoir. Although actual data on the performance of this PRF is not readily available, the 2003 Watershed Plan reports an average of 15 lb/yr. In total, annual measurements of phosphorus loads before and after the PRFs indicate that they reduce on average over 1,100 pounds annually. With equivalency and trading ratios considered, the reductions support the 216 credits for the Phosphorus Bank (Wulliman, undated; CCBWQA, 2005; CCBWQA, 2003a).

Although trading with the Phosphorus Bank has yet to occur, three projects have created new credits that reside in the Reserve Pool available for trade. New BMP projects or PRFs supply credits for the Reserve Pool to allow for growth and expansion. The CCBWQA may purchase NPS phosphorus reductions for Reserve Pool credits. Any entity constructing or planning a PRF may apply to the CCBWQA for credits anticipated with that PRF. If granted CCBWQA approval, that entity may then buy those credits to offset its own discharge, sell them to another discharger, or retire them.[19] No longer capped at 216 credits, the Reserve Pool may achieve however many credits an innovative approach may offer. The trading ratio for the latter must be at least 2:1, but should increase for PSs that are farther than the NPS is from the Cherry Creek Reservoir. These ratios aim to assure equivalence. Until December 30, 2004, the trade ratio could not exceed 3:1, but the amendments removed that upper limit (CCBWQA, 2005).

Of the three new credit trades, two were needed to satisfy significant growth to semi-urban areas since initial allocations. Specifically, in 2004, the Pinery Water and Sanitation District granted use of 25 of its credits to the Plum Creek Wastewater CCBWQA, and 25 credits were taken from the semi-urban area allocation. Another 10 credits from the semi-urban allocation went to the City of Aurora for Land Applications within the Cherry Creek Watershed (CCBWQA, 2005). The third trade was between PS and NPS, the first of its kind for the program. In 2004, the Arapahoe County Water and Wastewater Authority (ACWWA) planned to modify one of its stormwater detention ponds, located 2 miles upstream of its discharge point. In doing so, it would reduce 165 pounds of phosphorus to supplement its own TMAL allocation. Trading ratios were critical to the amount of credits that the transaction was worth. According to the TP ratio of 2.9:1, the reduction will earn ACWWA 57 credits. While ACWWA receives 57 credits, the minimum trade ratio of 2:1 reduces the NPS allocation by 114 credits, resulting in a reduction in the TMAL (CCBWQA, 2005).

Despite effective reductions, mass balances indicate approximately 4,000 pounds of phosphorus annually accumulate in the Cherry Creek Reservoir (CCBWQA, 2003a). Accumulated phosphorus acts as an internal load for which the TMAL allocations do not account.

The CCBWQA continues to pursue other PRFs intended to improve the water quality as much as possible. In 2002, the CCBWQA contributed 16.5 percent of the funds needed for the Piney Creek Reclamation project, which was completed in 2004. Soil erosion controls and restoration of riparian vegetation along 5,100 feet reduce approximately 90 pounds of phosphorus annually from entering the Cherry Creek Reservoir. In 2002, another PRF involved a second detention pond on Cottonwood Creek just outside the Park, west of Peoria Street, aimed to complement the Park Perimeter Road PRF. By 2004, this PRF reduced phosphorus loads, measured at 2,590 pounds upstream and 1,499 pounds downstream of the detention pond. The Cottonwood Reclamation project of 2003 aimed to reclaim the natural wetlands capabilities of the area covering 11,600 feet along the stream. Annual phosphorus loadings are estimated to decrease by approximately 730 pounds through soil erosion control, wetlands treatment, infiltration, and settling.

19 When a credit is retired, it is no longer eligible for credit, but rather serves solely to improve the environment.

The only available indication of a method to derive this estimate is comparisons with Shop Creek results and a 2004 study that indicated its feasibility. The CCBWQA has also been conducting feasibility studies to restore, reclaim, and construct wetlands in the Cherry Creek State Park. An agreement drafted in 2004 identifies those responsible for any PRFs within the park. When completed, 60 acres of wetlands will control approximately 600 pounds of phosphorus per year. Again, a methodology to derive this estimate is not clear, but sampling and analyses in 2004 and testing of wetlands reclamation on a smaller scale seem to have factored into this methodology (CCBWQA, 2005). Credits from CCBWQA-funded projects, aside from those for the Phosphorus Bank, are not eligible for trading, but instead aim to further improve water quality (Colorado Department of Public Health and Environment, Water Quality Control Commission, 2001).

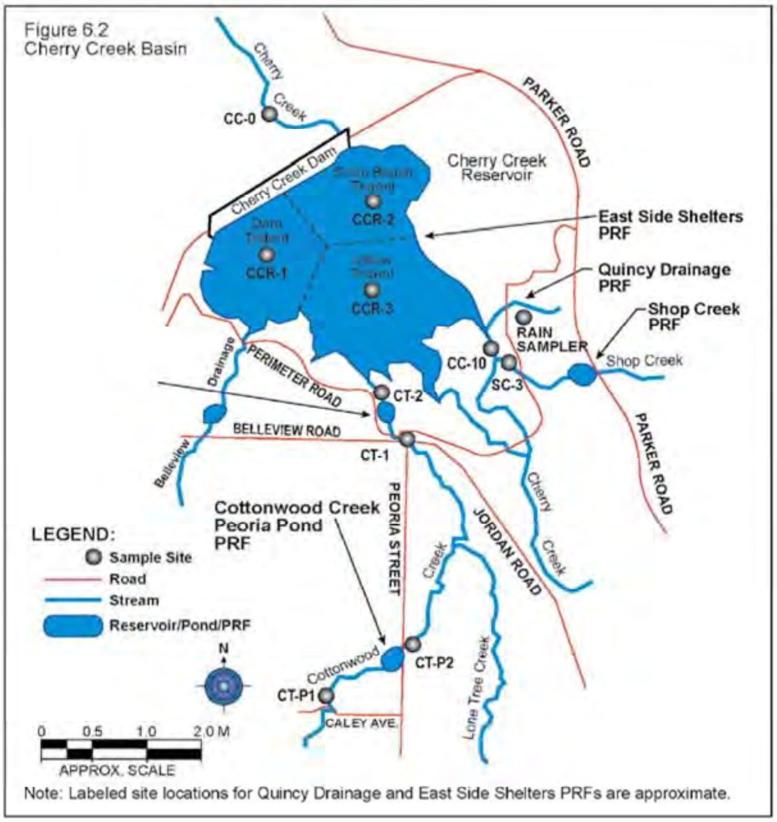

Figure 6-2 *Cherry Creek Basin with selected PRFs identified (CCBWQA, 2005).*

6.5 Economic Performance

The CCBWQA is funded through a combination of property taxes, user fees and grants. The Base Price for credits purchased from the Phosphorus Bank is based on the minimum cost the CCBWQA would incur to pursue additional projects that would achieve comparable reductions (CCBWQA, 2003b). Applications to create Reserve Pool credits cost $2,500, and a discharger must pay an additional $500 to cover costs incurred by the CCBWQA to evaluate the request for credit withdrawal from the Phosphorus Bank. The cost of Reserve Pool credits depends on the BMP implemented to achieve the offset. When the ACWWA retrofitted the detention pond, they achieved 57 credits. Therefore, with each credit worth $8,000 (the unit cost for traditional controls), and a cost to retrofit the detention pond to achieve those credits of $400,000, the gain in value was $56,000 (Breetz et al., 2004). Subtracting the cost of $2,500 to apply for credits from the Reserve Pool, the net value for just 57 credits is $53,500. Considering the avoidance of the alternative potential fines for violations, which range from $10,000 to $25,000 per day (Breetz et al., 2004), the detention pond retrofits are worth even more.

While NPSs face a total load allocation, regulations do not apply to individual NPSs. To offer incentive for NPSs to engage in trading where they otherwise may not have any, the CCBWQA puts the implementation of the BMP and any ensuing liability issues onto the PS project owner (Breetz et al., 2004). This incentive for the NPS places a liability issue onto the PS.

Financial incentive exists in that BMP implementation to gain credits is typically more cost-effective than PS controls to abide by their allocated credits. The incentive is lost, however, if the PS already easily complies with its waste load allocation. TMAL allocations were distributed with growth in mind. Trading will only achieve efficiency as this growth is realized or the TMAL is lowered and allocations re-distributed. The relationship between PS discharge levels directly determines the market demand for credits and the regulatory thresholds set for individual and collective PSs.

The CCBWQA is required to spend at least 60 percent of it annual budget, derived from property taxes, user fees, and grants, on construction and maintenance of PRFs. It applies the remaining funds towards administrative costs. In 2004, the $1,400,000 budget distributed $840,000 toward construction and maintenance of PRFs and $560,000 to administrative costs. To account for anticipated future financial burdens, the CCBWQA as of 2005 has a “sinking fund” in its annual budget. Using three-year projections, PRF costs are separated into design, capital, land acquisition, water requirements, and O&M. The CCBWQA contributed $118,000 to the Piney Creek Stream Stabilization, which will cost $714,000 when completed. The long-term average cost to the CCBWQA will be $115 per pound of phosphorus per year. The Cottonwood Creek Reclamation will cost $2,100,000 with a long-term average annual cost of $330 per pound of phosphorus per year. The Cherry Creek State Park Wetlands Project represents a capital cost of $1,928,000 with a long-term average cost of $280 per pound of phosphorus per year (CCBWQA, 2005). The intent of these projects has not been to compete against PS controls, but rather to supplement them in the pursuit of achieving water quality standards.

6.6 Administrative Performance

The CCBWQA must approve any withdrawal from the Phosphorus Bank. For each potential trade, approval requires a thorough evaluation of treatment capacity and population estimates of the potential buyer as well as of the other dischargers in the watershed. All activities related to a trade with the Reserve Pool also require approval by the CCBWQA, who must consider the type of trade, corresponding trade ratios, and monitoring and reporting (CCBWQA, 2003a).

The CCBWQA conducts annual water quality monitoring in the Cherry Creek Reservoir and basin. It evaluates reservoir water quality, reservoir in ow and loading, surface and groundwater quality in the watershed, and effectiveness of CCBWQA PRFs. Permits for PSs are contingent on monthly reports of 7-day and 30-day averages of phosphorus concentrations and loadings (CCBWQA, 2003a). Continued allocation of traded credits relies on both PSs and NPSs complying with Regulation #72 and abiding by their revised shares (Water Quality Control Commission, 2001).

Besides the CCBWQA’s annual report on watershed activities, every three years the Water Quality Control Commission must update Regulation #72 as necessary (Water Quality Control Commission, 2001). This triennial review is critical to satisfying current needs of the dynamic basin.

6.7 Summary

The trading program has been successful in that PS phosphorus discharges with trading have remained below the TMAL. Loads of phosphorus into the Cherry Creek Reservoir in 2004 totaled 12,512 pounds, 1,758 pounds below the allowed 14,270 pounds. Furthermore, PRFs have proved effective, with approximate removal efficiencies as follows: Cottonwood-Peoria Pond – 42 percent, Cottonwood Perimeter Pond – 22 percent, Shop Creek – 63 percent, and Quincy Drainage – 99 percent. These successes have not yet translated to compliance with the goal of 40 µg/L TP in the Cherry Creek Reservoir (CCBWQA, 2005). This discrepancy may indicate that improvements are not immediate but rather will emerge over time. Alternatively, internal loadings in the reservoir could be to blame, indicating that the TMAL may be too lenient for the water body to achieve the target of 40 µg/L TP. PS allocations were typically large enough to preclude the need for credit purchases. Such purchases, however, may be more attractive as population growth demands expansion of WTF capabilities. When growth of a facility exceeds the point where its discharge equals its allocations, or when expansion occurs in a semi-urban area, which is not included in the allocated districts, interest in trades with NPSs through the Reserve Pool will likely grow. Trading ratios can become higher depending on location within the watershed, which suppresses trading, and more research should go into the development of the TMAL, as well as that of conversion and trading ratios. These critical determinations would benefit from insight into fate and transport issues such as (1) competing ions, such as magnesium (Mg^{+2}), calcium (Ca^{+2}), and hydrogen (H^{+})—i.e., those that compete to bind with sediment and organisms; (2) biological activity; and, moreover, (3) the dynamic nature of the ecosystem. The CCBWQA needs to take actions which would achieve short-term improvements. Decreasing the TMAL would likely have the most dramatic effect in terms of driving trading and meeting water quality goals.

Nonetheless, the exibility of trading approaches, coupled with clear guidelines and oversight by the CCBWQA, suggests that future success for this trading program is possible. The CCBWQA demonstrates a strong commitment to design and implementation of its own PRFs, as well as facilitation, coordination, education, and monitoring of other potential BMP sources in the watershed. With determination, PSs will benefit from WQT to realize water quality objectives.

7.0 Case Study – Minnesota River and Rahr Malting Company, Minnesota - Rahr Malting Company Water Quality Trading: A Multifaceted Success

7.1 Overview

The MPCA issued to Rahr in 1997 one of the first wastewater discharge permits in the U.S. requiring WQT. Rahr is in Shakopee, Minnesota, in the Minneapolis-St. Paul metropolitan area (MPCA, 1997). Permit MN0031917, issued under NPDES, stringently capped the company's oxygen-demanding discharge into the Minnesota River Basin (Figure 7-1) (USEPA, undated). Despite the stringency, these discharge levels would still have introduced more oxygen demand into the river than allocated by the river's TMDL, thus requiring offsets to be achieved elsewhere in the service area. MPCA administered the federal permit and trades fundamental to the permit. Much of the nutrient loading into the basin, which drains 16,700 square miles, derives from NPSs. In particular, nearly three-quarters of the phosphorus loading into the river is from NPSs (MPCA, undated). In accordance with the permit, three approaches, including critical area set-asides and wetland restoration, erosion control, and livestock exclusion, controlled phosphorus discharge into the TMDL zone. The permit was issued in 1997 and offsets were all achieved within four years, more than a year less than the five years it was allowed for this goal. NPS controls must remain in effect thereafter as long as Rahr continued its discharge (Breetz *et al.*, 2004). Besides allowing Rahr to achieve growth and reduced costs, added benefits were the environmental and economic improvements to the NPS areas, including restored habitats and property upgrades.

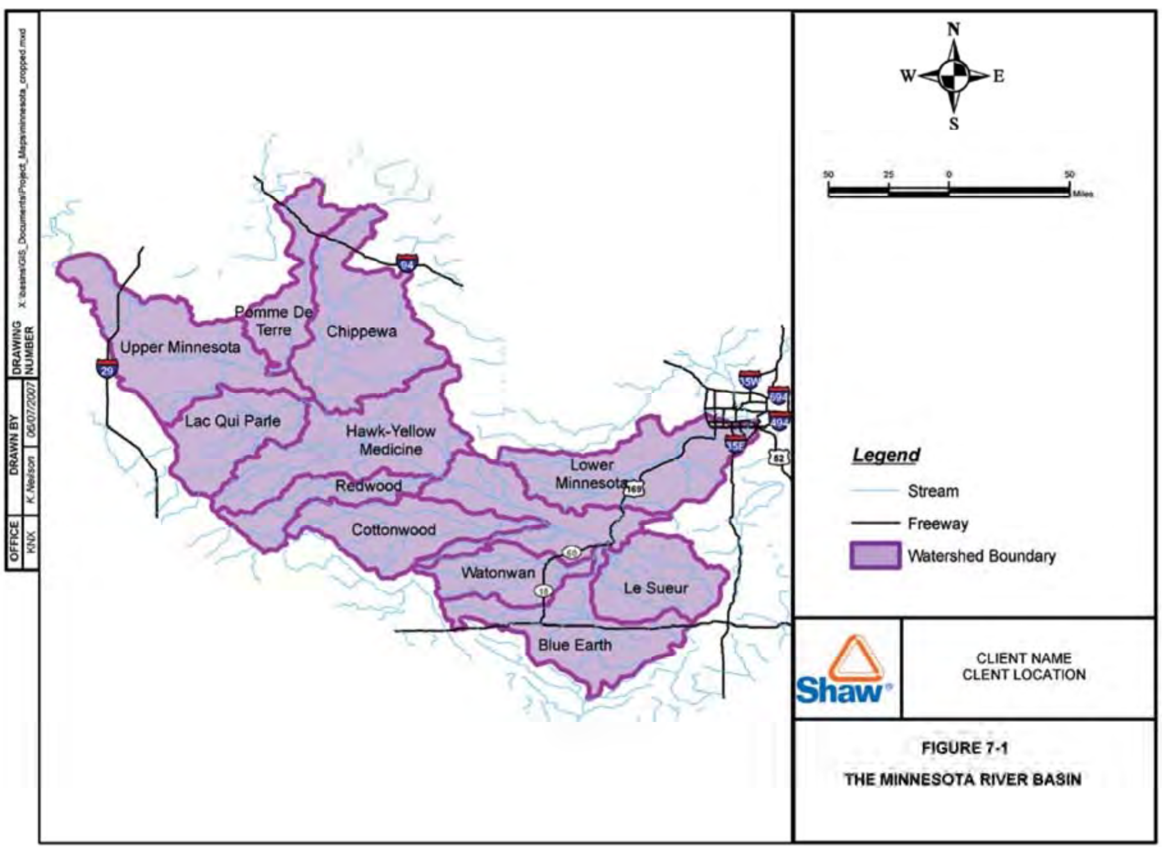

Figure 7-1 *The Minnesota River Basin (base map taken from http://wrc.coafes.umn.edu/lowermn/maps/mnbasin.htm)*

7.2 Background

Rahr initiated the program in an effort to increase its production by 20 percent, while gaining control and decreasing costs of its wastewater discharge. To do so, it proposed to build its own treatment facility. Until then, the company had sent its waste to the Blue Lake WTF in Shakopee, Minnesota, located 25 miles upstream from the con uence of the Minnesota and Mississippi Rivers. The Metropolitan Council Environmental Services operated the WTF. Significant stress to dissolved oxygen levels to below acceptable levels due to nutrients in the lower Minnesota River, below mile 25, led to the implementation in 1988 of the TMDL for five-day CBOD ($CBOD_5$).[20] The TMDL had allocated 53,400 pounds per day of CBOD at mile 25 and downstream. This allocation was based on the 7-day, 10-year low ow in 1988 because low- ow periods are when dissolved oxygen levels are most vulnerable (Faeth, 2000; Jaksch, 2000). Excessive oxygen demand results in dissolved oxygen levels that do not adequately support aquatic life. Phosphorus loads contribute to the CBOD. Additional stress to the dissolved oxygen levels result from nitrogen and sediment loads, which deplete oxygen from the river water via nitrogenous biochemical oxygen demand (NBOD)[21] and sediment oxygen demand.[22] The TMDL obligated MPCA to prohibit new oxygen demanding loads into the river. Therefore, any new discharges would require an existing source to be eliminated.

The key impetus for implementing the program was the infeasibility of Rahr to reduce down to zero the pollutant loads in the ef uent from its planned WTF. Therefore, Rahr needed to somehow reduce other loads into the river to offset its own. Blue Lake WTF would not agree to trade any of its allocated loading because it was needed to accommodate growth. The company negotiated an agreement with MPCA to offset $CBOD_5$ discharge from its new WWTP by funding upstream NPS phosphorus reductions. Under this agreement, Rahr developed the program to treat its process wastewater to within specified levels and reduce upstream loading by an amount equal to its resulting discharges (Fang and Easter, 2003).

The resulting trade included four NPSs upstream of the TMDL zone. Rahr was the sole PS. While nitrogen and sediment were also included in the trades prescribed in the permit, phosphorus is the nutrient traded in the chosen BMP.

7.3 Program Performance

The trading program was a multifaceted success due to diligent efforts by all those involved to maximize and balance efficiency, equivalency, additionality, and accountability (Fang and Easter, 2003). These four criteria are fundamental to a successful trading program involving NPSs.

The first criterion is one of economics. Efficiency mandates the trade proceed only when one source is able to more cost-effectively reduce its discharges than another source. This condition is critical to making the program financially attractive, and thus marketable. Although Rahr had no alternative but to buy credits from NPSs, in contrast to market-based systems where there is a choice of whether or not to trade at all, it had to optimize cost-effectiveness in the types and locations of NPS controls. NPSs, which are not presently regulated, typically have little incentive to control their discharges with the high costs involved in trading. Indeed, there may be disincentives in participating in such trades. In particular, by agreeing to a quantified load reduction, an NPS discharger may unintentionally facilitate future regulation of that discharge. Rahr was fortunate to have found the trading partners that it did. This good fortune was the result of actively involving the community and environmental organizations throughout the process, promoting Rahr's position to fund the BMPs, financially compensating the NPSs, and avoiding quantified validation of load reductions. So while the NPSs were not driven by regulation, they recognized the opportunity to improve their property free of charge without acknowledging measurability of their loads.

The other three criteria address technical and administrative issues necessary to evaluate efficiency. Equivalency is a measure of how pollutant loads from various sources relate to the pollutant of concern to be offset. Ensuring that offsets are equivalent to or greater than the permitted load is vital to avoid exceeding the TMDL. Conversion ratios multiply the offsets to account for uncertainties associated with temporal, spatial, and/or chemical differences in the sources. Such differences are often complex, so this criterion is fraught with uncertainties, which must also be factored into the trade. Additionality stipulates that any NPS offset that would have occurred regardless of the trading program cannot count toward a trade. This prevents double-counting actions simultaneously applied to more than one objective. Finally, accountability mandates appropriate monitoring and oversight to ensure proper implementation of all program requirements. Performance and design monitoring and reporting may satisfy this criterion. Otherwise, conservatively setting

20 *CBOD is the amount of dissolved oxygen that is needed for the breakdown of carbon-based organic molecules into CO_2 and water.*

21 *NBOD is the amount of dissolved oxygen that is needed for the breakdown of nitrogen-based protein molecules and ammonia into nitrate and nitrite. Nitrogen conversions use four times as much oxygen as carbon conversions.*

22 *Sediment oxygen demand is the amount of dissolved oxygen that is needed for biological and chemical processes in the sediment.*

the conversion and trading ratios could satisfy this criterion by overshooting expected requirements to offset uncertainty in performance (Fang and Easter, 2003; Jaksch, 2000).

The following sections describe how, the four criteria for a successful WQT program were optimized through scientific research, cooperation by all those involved and assurances of financially viability, this laid the foundation for the program's success. A quasi-independent five-person board was set up to select sites for trading consideration. A technical consultant with a member on the board calculated trading units. For a trade to be pursued, MPCA needed first to approve it, followed by a positive vote by the board, followed again by final MPCA approval (Jaksch, 2000). Common objectives to conservatively protect and even improve the environment, reliable science, and the social and financial commitment by Rahr and MPCA supported the WQT program. Rahr offset the wastewater load that it planned to add to the river by funding BMPs to decrease NPS loads upstream of the facility. After careful consideration of several types of BMPs, four trades were chosen for their ability to achieve the four criteria, particularly equivalence and accountability.

Despite the overall success of the program, some challenges were encountered. As demonstrated in the following sections, complexities involved in the determination of conversion and trading ratios hindered the certainty of equivalency. Furthermore, efforts to develop scientifically-based ratios burdened the program, particularly MPCA, with transaction costs. Another limitation was the lack of necessity of NPSs, which are generally not regulated, to work within set credits. Although they did not have the market-based incentives to trade with Rahr, they were motivated by financial compensations and improvements to their property. Still, Rahr was fortunate to have contracted with those that it did. However, future trading partners, either to allow for growth or if further reductions are necessary, may be more challenging to convince. Finally, being one of the first in the nation to trade nutrients, and the first to do so trading pollutants other than that targeted by the TMDL, made additional research and negotiation necessary which added another obstacle, and thus time and money.

7.4 Technical Performance

MPCA and Rahr agreed on a trading credit system where one credit unit is equivalent to one pound per day of CBOD5. A critical component of the trading program was the determination of reasonable effluent levels from their planned PS. The concentrations of CBOD5, phosphorus, nitrogen, and TSS in 24-hour composite samples of their treated waste were analyzed three times per week. Monthly concentrations of CBOD5 for average (1 million gallons per day [mgd]) and maximum (2.5 mgd) flows could not exceed 12 mg/L and 18 mg/L, respectively. These limits were enforced year-round, more stringent than the typical increase during October through May. Also more stringent was the limit for phosphorus, set at 2 mg/L, compared to the more common limit of 3 mg/L. Effluent limits were 30 mg/L and 45 mg/L of TSS for average and maximum flows. Effluent limits for nitrogen depended not on flows but on the time of year, decreasing in warmer months, and with a yearly average of 9 mg/L. So for every unit discharged by Rahr, BMPs had to control an equal number of units of NPS discharges upstream of the facility. After treating its waste, Rahr would still need to discharge 54,750 pounds of CBOD5 per year into the TMDL zone (Jaksch, 2000), equivalent to 150 units.

The permit specifies that BMPs use soil erosion control; livestock management to exclude cattle from stream or riparian zones either with or without rotational grazing; critical area set-asides; and/or constructed/restored wetlands (MPCA, 1997). The nature of CBOD challenges the certainty of equivalency in that nutrient and sediment loads relate according to site-specific factors to the oxygen demand. To select the appropriate BMPs to pursue, the permit prescribes the relationships between loads of phosphorus, nitrogen, sediment, and CBOD5. Furthermore, the program incorporated several safety factors to provide accountability by reducing risks to equivalency. Conservative ratios used to determine equivalency made it unnecessary to monitor BMP load reductions, thereby saving MPCA time and money. Equation 7-1 calculates the number of units traded to offset the PS discharge.

$$\text{trade\_unit}_{\text{CBOD}_5} = \text{pounds\_per\_day}_{\text{pollutant\_reduced}} \frac{\text{CR}}{\text{TR}} \tag{7-1}$$

where $\text{trade\_unit}_{\text{CBOD5}}$ = trading units (defined as pounds of CBOD5 per day)

$\text{pounds\_per\_day}_{\text{pollutant\_reduced}}$ = pounds per day of the pollutant reduced by BMPs

CR = conversion ratio

TR = trading ratio

Conversion ratios for phosphorus relied on research relating phosphorus with chlorophyll concentrations, which in turn relate to CBOD. Therefore, calculated ratios of phosphorus loads to CBOD determine the trading ratios. This ratio varies with biological activity, flow rate, turbidity, phosphorus bioavailability, and concentrations of other nutrients. Approximately 15 miles upstream of the facility, at Jordan, 1 pound of phosphorus reduced from the NPS was worth 8 pounds of CBOD5 per day, i.e., 8 units. Although this ratio varied between 1:8 and 1:17, as determined presumably by measured concentrations of phosphorus and chlorophyll and an average stream correlation between chlorophyll and CBOD, the ratio was conservatively established as 1:8 (Jaksch, 2000). Unfortunately, this conversion does not directly address the differences in phosphorus bioavailability of loads from various sources, i.e., dissolved or bound to sediment. The impacts on oxygen demand and river conditions differ according to complex dynamics that conservative assumptions may not always manage. It was assumed that use of the most conservative ratio would adequately offset uncertainty associated with site-to-site differences. This assumption was not explicitly validated through performance monitoring. Some critics consider this failure to validate the performance a critical fault in the program, while others worry that overly conservative assumptions eliminate otherwise viable potential NPS trading participants. In all fairness, WQT should not be required to satisfy a higher degree of technical rigor, in terms of modeling and monitoring than was originally applied in the first place during development of the TMDL and individual load allocations.

Conversion ratios for nitrogen relied on stoichiometry, which dictates 4.6 pounds of oxygen for every pound of TN. However, nitrogen exerts oxygen demand more rapidly than does phosphorus. Additionally, nitrogen leaves the system through volatilization, leaving less to demand oxygen. Therefore, nitrogen upstream of mile 25 trades for less than it does downstream of mile 25. Conservatively, the ratio was established as 1:4 downstream and 1:1 upstream, i.e., 1 pound per day of reduced nitrogen was worth four units downstream and one unit upstream (Jaksch, 2000).

Sediment was related to $CBOD_5$ on a 1:0.5 ratio. Reducing the sediment load by 1 pound per day counted as reducing 0.5 pounds of $CBOD_5$ (Jaksch, 2000). This conversion re ects that sediment demands much less oxygen than do the nutrients.

Finally, measured $CBOD_5$ was traded variably depending on the location along the river, with a 1:1 ratio at mile 25 and downstream, decreasing to 1:0.01 at mile 107 (Jaksch, 2000). The decrease is justified by the CBOD upstream exerting its oxygen demand before the TMDL zone.

Load reductions for each BMP proposed for implementation were not measured but were instead estimated according to several assumptions. Safety factors aim to counter the uncertainty that these assumptions bring. Trades defaulted to a trading ratio of 2:1, so that two units of NPS reduction were needed for every unit that the PS discharged (Kieser and Fang, 2005). As appropriate, additional safety factors were multiplied into the trading ratios. Phosphorus reductions from soil erosion were estimated based on analyses of phosphorus contents of soil and measured soil loss reductions. This estimation incorporated an additional safety factor of 0.75 for samples that indicated relatively high phosphorus concentrations, thus reducing the amount of $CBOD_5$ that would be credited for each pound of offset phosphorus. For livestock exclusion approaches, pollutant loadings into the river are calculated as the product of the area's delivery ratio, the time livestock spend on the land, and the size of the herd. The offset is thus the difference of these estimates from before and after the controls are implemented. Typically, depending on the time of year, cattle spend 25 percent to 36 percent of their time in the riparian zone. Delivery ratios are 100 percent within the riparian zone, 20 percent outside the riparian zone but within 0.25 miles of the stream, and 10 percent beyond that (Jaksch, 2000). Rahr and MPCA agreed through negotiation to use conservative conversion and trading ratios to provide accountability, supplanting the need to validate these load reductions through onsite monitoring of $CBOD_5$ load reductions.

Based on an optimization of the four criteria, the board identified and MPCA verified four NPSs for trading: (1) Cottonwood River, (2) Minnesota River, (3) the Fruhwirth site along Eight Mile Creek, and (4) the Hathaway site along Rush River (Fang and Easter, 2003). Figure 7-2 identifies approximate locations of these sites relative to the Rahr facility.

BMP approaches included critical area set-asides with revegetation, erosion control, and livestock management. The chosen BMPs at these sites would not have been implemented were it not for the trades, satisfying the additionality criterion. A contract with Rahr for long-term commitment to these BMPs, the ability to monitor these sites, and oversight by the board and MPCA added a greater level of accountability. To assure accountability, Rahr must submit monthly monitoring reports, as well as annual reports of reductions of $CBOD_5$ from the NPSs.

While the permit stipulates the conversion and safety factors for nitrogen, sediment, and $CBOD_5$, the BMPs pursued for trading achieved all the necessary credits by reducing only phosphorus input to the TMDL zone. According to the 1:8 ratio for phosphorus:$CBOD_5$, the reduction of 97,730 pounds of phosphorus measured over five years is equivalent to reducing 781,830 pounds of $CBOD_5$ over the same time period, which averages to 428.4 pounds of $CBOD_5$ per day (Fang and Easter, 2003). Using the trading ratio of 2:1, this equates to 214.2 units, far exceeding the 150 units mandated in the permit. Table 7-1 itemizes the pounds of phosphorus and consequently $CBOD_5$ over the five-year permitted timeframe. Table 7-2 itemizes the resulting credits that these sources earned for Rahr within that period.

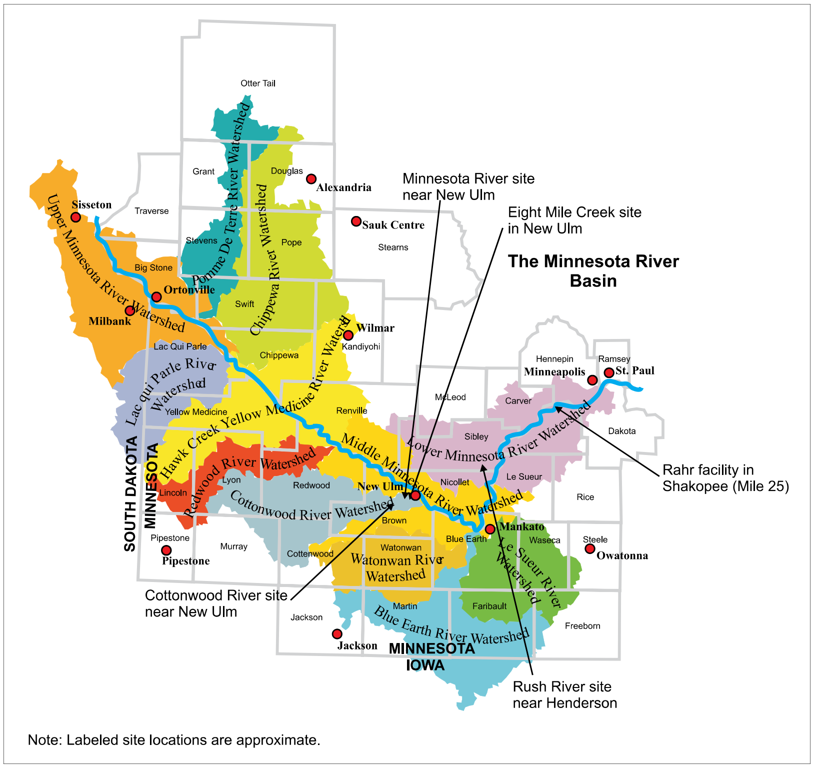

Figure 7-2 *The Minnesota River Basin with sites of NPS sellers identified (base map taken from http://wrc.coafes.umn.edu/lowermn/maps/mnbasin.htm).*

Along the Cottonwood River, which flows east to the confluence with the Minnesota River near New Ulm, Minnesota, and the Minnesota River at approximately mile 150, also near New Ulm, Minnesota, easements set aside approximately 105 acres of critical areas from crop production to prevent flood scouring. These areas were, in essence, 105 acres of restored wetlands. Plowing for crop production contributed to flooding, which resulted in the removal of several feet of soil (Jaksch, 2000). Restoring native wetland vegetation on farmland along the rivers protected these critical areas from further scouring. Together, these wetlands removed 45,944 pounds of phosphorus over five years, generating approximately 100 units of credit. Rahr ultimately donated these restored wetlands to the city of New Ulm to be used as a park, and to the Coalition for a Clean Minnesota River, a local environmental organization, to be used as an environmental education site (Breetz *et al*., 2004). Restoring these wetland sites also created habitat for wildlife. The effectiveness of these restored wetlands for reducing nutrient loading was assumed based on conservative performance ratios and was not validated by performance monitoring data (Fang and Easter, 2003).

Soil erosion controls restored stream banks along Eight Mile Creek at New Ulm, Minnesota, and along Rush River in Henderson, Minnesota. Controls included bioengineered banks with vegetation and J-hooks in the river to deflect flow energy. The former also managed livestock by re-grading the feedlot for wastes to flow away from the water, and fencing in the cattle to exclude them from the riparian zone, which had been overgrazed (Jaksch, 2000). Aerial photographs spanning 36 years and periods of high and low flows were used to estimate the average bank recession rate. The lifetime of the control structures is comparable to this duration, rendering the estimates of the credits more reliable. In addition to offsetting sediment loads, the landowners of these source control sites received the added benefit of preserving the land against erosion. Since 1988, they had unsuccessfully sought financial means to control bank erosion. The erosion was sometimes so extreme that it impacted adjacent land, destroying houses and barns (Breetz *et al*., 2004; Fang and Easter, 2003). The BMPs for Rahr's permit were able to stabilize the banks within two years for the Eight Mile Creek site and four years for the Rush River site.

Table 7-1 Pounds of Phosphorus and $CBOD_5$ Reduced over Five Years

	Cottonwood	Minnesota	8-Mile Creek	Rush River	Total
Pounds of $CBOD_5$	105,490	262,070	54,020	360,260	781,840
Pounds of phosphorus	13,190	32,760	6,750	45,030	97,730

Table 7-2 Traded Units From Each Controlled Nonpoint Source

	Cottonwood	Minnesota	8-Mile Creek	Rush River	Total
Traded units	28.9	71.8	14.8	98.7	214.2
$CBOD_5$ pounds per day	57.8	143.6	29.6	197.4	428.4
Phosphorus pounds per day	7.2	17.9	3.7	24.7	53.5

7.5 Economic Performance

At MPCA's instruction, Rahr established a trust fund of $250,000 to secure monies to develop and maintain BMPs. The five-person board charged with selecting sites also managed this fund, offering credibility and unbiased views to planning and implementation. However, the inclusion of one executive from Rahr communicated to the public the company's commitment to the environment while advancing the company's interests in decisions. The fund was to cover all expenses of designing and implementing the trades, barring transaction costs (Kieser and Fang, 2005). If costs exceeded the fund's capability, Rahr was responsible for the difference.

Transaction costs added an estimated $105,000, or 35 percent, to the cost of the controls, for a total cost of $405,100, most of which MPCA and Rahr incurred. The product of the median salary rates of Rahr and MPCA staff members and their estimated time spent on transaction activities provided an estimate of their respective transaction costs (Fang and Easter, 2003). Engineering, material, and consulting costs were not considered transaction costs and were instead covered by the trust fund. The relatively small number of trades, as compared to other trading programs, such as the Southern Minnesota Beet Sugar Cooperative in Minnesota, with over 100 trades, simplified the process somewhat. However, the complexities of trading ratios for equivalency and safety factors for accountability added significant costs.

The permit phase spanned from the initial negotiations to when the permit was issued. This phase also included the search for trading partners, administration, and communications between Rahr and state and federal authorities. As this was one of the first of its kind, this phase took about two years and amounted to approximately 65 percent of the transaction costs. Following permitting, implementation was the phase during which the trades occurred and credit requirements were fulfilled with implementation of nutrient control measures. Costs went to credit verification and project management. As MPCA took charge of the design on the BMP and trading structure, their transaction costs accounted for 81 percent of the total, leaving Rahr responsible for less than 20 percent of the total (Jaksch, 2000).

The cost of credits was estimated based on the capital and O&M costs of the project, the estimated pounds of offset nutrients it could deliver, trading ratios, and safety factors. Without transaction costs, the critical area set-asides with restored vegetation along the Cottonwood and Minnesota Rivers were most cost-effective. By reducing phosphorus loadings into the TMDL zone, these restored wetlands cost $4.44 per pound of phosphorus over the five years of the permit. The cost per pound of reduced phosphorus at the Fruhwirth site along Eight Mile Creek and the Hathaway site along Rush River were $5.28 and $4.49 per pound, respectively. Accounting for the 1:8 conversion ratio with $CBOD_5$, credits averaged $0.77 per pound of $CBOD_5$ removed. However, the BMPs will likely survive and remain effective far beyond the five years of the permit. Reasonably assuming a 20-year lifetime, with an 8 percent discount rate, the average cost of reduction decreases to $0.20 per pound of $CBOD_5$ and $1.56 per pound of phosphorus. Adding transaction costs, these reductions increase to $1.03 per pound of $CBOD_5$, equivalent to $0.26 per pound of $CBOD_5$ over 20 years, and $8.26 per pound of phosphorus, equivalent to $2.10 per pound of phosphorus over 20 years. The long-term measures such as easements and re-vegetation are the most efficient of the BMPs because they provide greater nutrient reduction with low investment. Furthermore, the lifetime of these controls is comparable to the lifetime of the nutrient reduction estimation, minimizing the uncertainties associated with the trade (Fang and Easter, 2003).

In contrast, a comparable municipal WWTP designed for permitted discharge of 1.5 mgd would have to meet 1 mg/L phosphorus if only PSs were responsible for phosphorus load reductions. Over 20 years, and at an 8 percent interest rate, the capital and operational costs associated with implementing these controls would be between $4 and $18 per pound of phosphorus. The NPS controls are thus more cost-effective than PS controls even when transaction costs are considered. In fact, the savings afforded to Rahr for not using Blue Lake's services, accounting for the cost of its new facility and the $250,000 to fund the trust, will amount to more than $300,000 per year over 30 years (Jaksch, 2000).

7.6 Administrative Performance

The five-person board was involved in every step of the process, from recommending preliminary NPSs for review to selecting the final projects to implement. MPCA framed the trade within the NPDES structure, thereby underscoring accountability. To ensure legal enforceability of the selected controls, the NPDES permit prescribed the types of BMPs, selection process, reporting, and goals. MPCA was charged with verifying each trade and confirming annual pollutant reductions prescribed in the permit (Breetz *et al.*, 2004). While the credits must be achieved within five years of permit issuance, Rahr must continue O&M of BMPs for as long as it discharges within the TMDL zone.

Administration of the trade provided flexibility to encourage success. Credits from the NPS controls were awarded on a partial basis as projects progressed (Breetz et al., 2004). Moreover, MPCA offered Rahr 30 units of credits from the yearly cumulative load reductions for $CBOD_5$ and another 30 units of credit for phosphorus for consenting to the more stringent point discharge effluents of each. These credits started with 2001, the year of permit expiration, and continued yearly thereafter, provided the point effluent levels were met. As such, if Rahr accepted all of these offered credits, NPS controls would only need to offset 90 units. Rahr was also offered 10 units of phosphorus credit to be used in 1998, 1999, or 2000 to make up for any deficit in those years. Finally, 20 units of credit were issued to Rahr for starting up its facility after 1997. The permit offered financial incentives to Rahr to efficiently achieve the mandated 150 units of credit through BMPs within the permit's five-year life. MPCA would give the company an additional five years to completely spend any of the remaining $250,000 (Fang and Easter, 2003).

7.7 Summary

According to the conservative assumptions, but not through validated monitoring, the program successfully reduced the NPS load by more and in less time than the permit required. Cooperation by farmers, landowners, grass-roots environmental organizations, and eagerness of Rahr to work with, not against, all stakeholders, contributed to the program's success. The nutrient offset achieved by the NPS controls allowed the Rahr facility in Shakopee to grow according to Rahr's original treatment facility design. Rahr has become the largest producer of malt at a single site in the world. In the process, it has earned the reputation of working with and for the community. The NPS controls also provided environmental and social benefits. The public became aware of the unregulated nutrients discharged by NPSs. Involving public interest groups early during the negotiation phase educated many on the challenges and significance of equivalency, additionality, and accountability. The controls also served to create wildlife habitat. The trading program benefited the financial and social standing of Rahr, water quality, and the community.

Even with its success, the program encountered some limitations. As one of the first of its kind, this trading program faced new challenges. Fortunately, lessons learned from Rahr's trade could be extrapolated to other programs. A primary gap hindering the full potential of NPS trades was the inability to accurately quantify differences in nutrient load reduction associated with dynamic complexities that vary from site to site. Such uncertainties were offset by increasing the scale of each BMP (e.g., restore a larger wetland area to offset uncertainty in performance). The expenses incurred in efforts to conservatively overcome these uncertainties further burdened the program. Another limitation is that NPSs typically lack regulatory incentive to engage in trading. Rahr will have to overcome this for any future reductions it may need. Nonetheless, the benefits far outweighed the limitations, rendering this trading case a success.

On December 1, 2005, MPCA issued a general NPDES permit (MNG420000) to all authorized parties within the Minnesota River Basin, which included Rahr, who may apply for a permit to discharge phosphorus. This permit aims to achieve the renewed TMDL there. Moreover, the permit specifically authorizes WQT according to specified units of credit. Individual permits must still be obtained and remain valid for another five years, through November 30, 2010 (MPCA, 2005). The general permit is consistent with the continued impairment for oxygen deficiency, albeit with indications of some improvement, and the significant blame that falls on phosphorus discharge (MPCA *et al.*, 2003). Moreover, it gives credence to the validity of trading for which Rahr was a pioneer.

8.0 Case Study – Lower Boise River, Idaho

8.1 Overview

The LBR Effluent Trading Demonstration Project is the first WQT project in the Pacific Northwest (USEPA, 2002c). The project is a start-up program for phosphorus trading in the LBR watershed in Idaho. The goal of the project is to create a business-like trading framework that can be implemented to help achieve the nutrient reduction goals set by CWA Section 303(d). The project is designed to be environmentally and legally sound, consistent with existing regulatory programs, allow trades to occur in a dynamic, market-based manner, and grounded in environmentally protective requirements. Furthermore, project participants hoped the WQT framework developed by the LBR project could guide similar programs in other areas in the region and throughout the country.

8.1.1 Location

The LBR Watershed is located in the southwestern part of Idaho and encompasses 1,290 square miles (Figure 8-1). The LBR flows through the watershed for 64 miles, crossing through Ada County, Canyon County, and the city of Boise. The river flows to the northwest from its origin at Lucky Peak Dam to its confluence with the Snake River near Parma, Idaho. Nine cities are located within the watershed, most adjacent to Boise River. The watershed is home to about one-third of Idaho's population and is growing rapidly (Ross and Associates, 2000). Major land uses in the subbasin include forestry, agriculture, gazing, and urban development. There are 15 subwatersheds within the watershed, and 4 stream segments are listed on the 303(d) list for pollutants of concern, including flow alteration, sediment, dissolved oxygen, oil and grease, nutrients, bacteria, and temperature. The trading demonstration project is designed to address one of the nutrient pollutants of concern - phosphorus. The project is proposed to help comply with the current policy of "no net increase" in TP established in the sediment and bacteria TMDL for LBR completed in 1998 and approved by USEPA in 2000 (IDEQ, 2005a). An LBR phosphorus TMDL is anticipated now that the downstream Snake River-Hells Canyon (SR-HC) TMDL has been issued (September 2004). This LBR phosphorus TMDL was expected to be completed by IDEQ for review by USEPA in March 2006 (Schary, 2005).

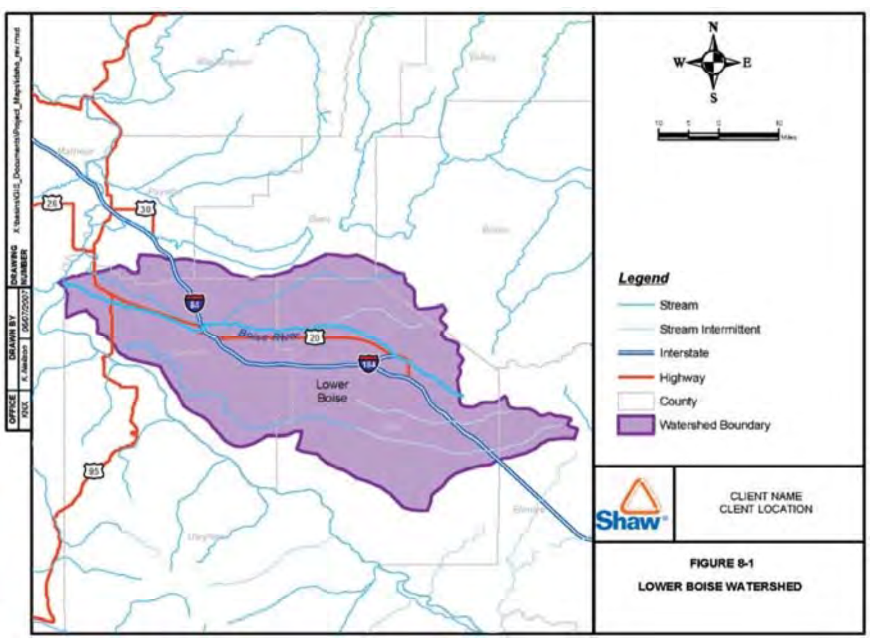

Figure 8-1. *Lower Boise, Idaho river watershed site map.*

8.1.2 Participants

USEPA started collaborating with Idaho, Oregon, and Washington in late 1997 to examine how WQT could reduce the cost of meeting TMDL requirements in the Pacific Northwest USEPA Region 10 (excluding Alaska) (Ross and Associates, 2000). USEPA worked with IDEQ to launch the LBR Ef uent Trading Demonstration Project as the first pilot project for the region (Breetz *et al.*, 2004). IDEQ assumed responsibility for the project from USEPA on April 21, 2000 by signing an interagency agreement (IDEQ, 2001). Other agencies participating in the interagency agreement included USEPA, ISCC, NRCS, Ada Soil and Water Conservation District (ASWCD), Canyon Soil and Water Conservation District (CSCD), Southwest Idaho Resource Conservation & Development Council, and the US Bureau of Reclamation. This interagency agreement outlined the various responsibilities of the agencies for continuing to support the demonstration project.

Idaho LBR was selected as the first demonstration project based on several criteria and support from interested parties (Ross and Associates, 2000). The project began in January 1998 with the assessment of the market feasibility of phosphorus trading. Starting in August 1998, the trading structure and protocols were developed and tested on two trading simulations. The results of this development and testing were summarized in September 2000 (Ross and Associates, 2000). Trading is scheduled to begin following completion of the LBR phosphorus TMDL and issuance of new NPDES permits, which are still pending.

8.1.3 Administration

The trading project is set up to be administered by the Idaho Clean Water Cooperative (ICWC), a newly created non-profit association (ICWC, 2000). The concept for giving administrative responsibility to a non-profit non-governmental group was generated to reduce the fears of trading partners of government intervention (Kieser and Fang, 2005). A Memorandum of Understanding (MOU) between USEPA, IDEQ, and ISCC signed April 27, 2001 also governs the project. This MOU defines the roles of the agencies in verifying credits purchased and used by NPDES-permitted sources that choose to participate in the WQT project.

8.2 Background

The LBR is highly enriched with phosphorus, especially at the downstream cities of Middleton and Parma. Water high in nutrients such as phosphorus can cause eutrophication. This condition can lead to algal blooms, which can harm fish by reducing oxygen levels within the water when the algae dies and decomposes. This reduction in oxygen is caused by the heavy oxygen demand from microorganisms as they decompose the organic material. Algal blooms can also interfere with water use for recreation as the vegetation disrupts equipment and swimming. The foul smell of decomposition also disrupts recreation. Consequently, nutrients like phosphorus contained in runoff and erosion from NPSs, such as agriculture, create a resource management concern. In general, phosphorus bound to sediment contributes 60 to 90 percent of the phosphorus in runoff from most cultivated land (NRCS, 2001).

Recent analysis by IDEQ indicated that the phosphorus level is not currently high enough in LBR to cause algal blooms, but contributes to the high phosphorus loads downstream in the Snake River (IDEQ, 2005b). The phosphorus loads in Snake River are problematic and require reduction by more than 78 percent. Because LBR is the largest contributor of phosphorus to the Snake River, phosphorus loads in LBR will need to be reduced by the same amount (IDEQ, 2005b). The SR-HC TMDL targets each tributary to contribute less than or equal to 0.070 mg/L phosphorus as measured at the mouth of the tributary between May and September. Studies in the LBR watershed found that phosphorus concentrations along LBR increase by more than 10-fold, from over 0.02 mg/L near Boise to 0.26 mg/L near the LBR's con uence with the Snake River (IDEQ, 2005b).

8.2.1 Phosphorus Movement

Within the LBR and Snake River, phosphorus is the limiting nutrient, and any increase can result in greater growth of aquatic vegetation. The amount of phosphorus in the system depends on the transport of phosphorus to the water body; the source and form of phosphorus; and management factors such as application, timing, and placement in the landscape. Dissolved phosphorus is readily available to plants, while particulate phosphorus (attached to sediment) can be a long-term source of phosphorus within a system (NRCS, 2001). The ability of a water body to handle inputs of phosphorus depends on the volume of water present, the temperature of the water to promote algal blooms, and the turbidity of water (phosphorus tends to bind to sediment particles). Typically highest concentrations of phosphorus happen during low- ow conditions, which typically occur during the winter when aquatic plant growth is less of a concern. However, in the LBR and Snake River low- ow conditions can also occur during summer droughts, allowing algae to thrive.

The LBR is the greatest contributor of phosphorus to the Brownlee Reservoir via the Snake River. This reservoir suffers from excessive nutrient loading and nuisance aquatic growth. Idaho law requires surface waters of the state to be free from excess nutrients that can cause visible slime growths or other nuisance aquatic growths, impairing designated beneficial uses (Idaho Administrative Procedures Act [IDAPA] 16.01.02.200.06). The nutrient data of Boise River and productivity in the lower Snake River indicate that a cap on phosphorus is needed for the LBR. Thus, the LBR sediment and bacteria TMDL established a policy of “no net increase” of TP as an interim measure until the Snake River basin-wide nutrient goals are set (IDEQ, 1999). Now that the phosphorus TMDL is completed for SR-HC, the phosphorus reduction goal for a LBR’s phosphorus TMDL will be adjusted and finalized (Breetz *et al*., 2004). This goal is expected to be approximately an 80 percent reduction in phosphorus at the mouth of LBR (Schary, 2005).

8.2.2 Trading

Exploring a WQT program as a water quality management tool was jointly supported by USEPA and by Idaho, Oregon, and Washington water quality programs. Motivation for this innovative tool was generated by the considerable challenges produced during the development and implementation of TMDLs on court-order schedules (Ross and Associates, 2000). WQT was considered a exible and cost-effective option to meet the policy of “no net increase” in phosphorus established by the LBR sediment and bacteria TMDL and expected in the LBR phosphorus TMDL.

8.2.3 Regulations

There are several regulatory drivers for the LBR WQT project. In addition to the CWA and Idaho law mentioned before, Idaho state rules call for “no net increase” in phosphorus for the LBR (IDAPA 16.01.02.054). These rules also specifically allow WQT as a tool for meeting the “no net increase” requirement. The rules establish a source-specific cap on phosphorus discharges to the Boise River. PSs are allocated phosphorus reductions based on TMDL requirements within their NPDES permit. Since Idaho is not a delegated state for NPDES permits, these permits are issued by USEPA Region 10. It is expected that NPSs may also be subject to a load allocation for phosphorus in the future (Ross and Associates, 2000).

8.2.4 Trading Framework

The Idaho LBR Ef uent Trading Demonstration Project is an example of interagency collaboration to produce a trading framework that can be used for WQT in LBR. The lessons learned during this framework development and the framework itself can apply to other areas of Idaho, the Pacific Northwest, and the United States, although local and regional conditions, regulations, needs, and acceptance will affect its applicability.

The LBR project participants agreed on several objectives during the process of developing a trading framework for LBR. These objectives were to create a framework that:

- Is legally defensible and enforceable;
- Protects water quality;
- Maximizes market exibility and minimizes transaction costs;
- Ensures trading activities are apparent to the public;
- Does not create or exacerbate other environmental problems; and
- Supports robust participation.

The project also developed a set of design principles that promoted trade and cost-effective implementation of TMDL reductions. These principles are as follows:

- Avoid trade-by-trade changes to the TMDL;
- Avoid trade-by-trade changes to the NPDES permits;
- Minimize trades through private contracts;
- Create environmentally equivalent (or better) reductions;
- Work with existing programs and processes; and
- Provide clear and predictable permit compliance and enforcement.

Features of the Idaho LBR trading framework and demonstration project include:

- Regulatory guidance by USEPA’s Final Water Quality Trading Policy (2003);
- Regulatory guidance by IDEQ’s Pollutant Trading Guidance (2003);
- Trading project administration by non-profit association: ICWC;
- Preparation of TMDLs, implementation plans, and trading ratios by IDEQ;
- Issuance of NPDES permits and approval of TMDLs by USEPA;

- Approved list of BMPs with effectiveness calculations and uncertainty discounts by ISCC (2002);
- Guidance for ICWC provided by council from NRCS; and
- Purchasers include seven POTWs, three industrial dischargers, and eight irrigation districts.

No trades have yet been made using the LBR Effluent Trading Project because of delays in finalizing the LBR phosphorus TMDL. Therefore, no information is available yet on what portion of the project is composed of PS or NPS trades. The expected purchasers and the abundance of agriculture create an environment favorable for producing trading partners. Furthermore, the stringent target set by the SR-HC phosphorus TMDL will be difficult for PSs to meet without seeking trades, especially for the final portion of phosphorus reduction (Schary, 2005). Consequently, once the regulatory drivers are in place, trading should commence relatively quickly.

8.3 Program Performance

The LBR Effluent Trading Demonstration Project set up a framework for trading pollutant discharges among sources. The framework allows for trades among point and nonpoint pollutant generators. Elements of a trading process were developed by the project team, including permit conditions, necessary forms, agencies' roles, and generation of credits. To understand the estimated cost savings of implementing a trading program, municipalities were asked to consider the impacts of phosphorus reductions on their programs and estimated a unit cost of $12 to $178 per pound of phosphorus reduction. Project participants estimated the cost for NPSs to reduce phosphorus through BMPs ranged from $2 to $20 per pound. Thus, the estimated cost savings from implementing the trading project in LBR are estimated to be $10 to $158 per pound of phosphorus reduction.

8.3.1 Trading Process

The framework established by the demonstration project generated a straightforward process to complete a trade. Steps for PS to NPS trade include:

1. Trading parties are identified;
2. Water quality contribution is calculated or measured for NPS participants;
3. Trading parties negotiate and sign trade contract;
4. Seller installs phosphorus reduction measure (if not already in place);
5. NPS BMP installation inspection/buyer signs and submits first "Reduction Credit Certificate;"
6. Buyer and seller parties sign and submit official "Trade Notification Form;"
7. Trade information is entered into Trade Database (monthly); and
8. The ICWC tracks trading activity and USEPA audits trades though NPDES permits.

The ISCC inspects BMPs installed by NPSs to document proper design, monitoring, and maintenance. These inspection reports are reviewed by USEPA and IDEQ to verify the BMP implementation. The agencies may also visit BMP sites to confirm their performance. NPDES permit holders are ultimately responsible for ensuring proper implementation of BMPs. Consequently, they inspect the BMP installation and receive copies of ISCC's inspection reports. USEPA and IDEQ take up any compliance matters or enforcement actions with the NPDES permit holder, not the BMP installer (USEPA, 2002c).

The ICWC is responsible for tracking trading activity and maintaining a trade tracking database (USEPA, 2002c). The major functions of the ICWC are to:

- Set a submittal time for trade notification forms and reduction credit certificates;
- Accept and review trades to ensure completeness and consistency with trading project requirements, and not accept trades that do not meet the project requirements;
- Track all trades in a central database and determine how trades impact effluent limits and account balances of buyers and sellers;
- Reconcile all trades in the market area to ensure credits are not used more than once;
- Make trading information and adjusted effluent limits readily available to regulatory agencies and the public; and
- Produce Trade Summary Reports required for NPDES permit compliance and provide them to the PSs involved in trades.

8.3.2 BMPs

The ISCC, in collaboration with IDEQ, developed eligible BMPs for the LBR Pollution Trading Project (ISCC, 2002). The BMPs listed in the state-level Idaho Pollutant Trading Guidance were broken down by region because the "effectiveness" of the BMP would be different in each region (IDEQ, 2001). Several NPS BMPs are eligible for offsetting a PS discharge. Eligible BMPs available to trading contracts are listed in Table 8-1:

Table 8-1 Currently Eligible BMPs for Trading in LBR WQT Project[a]

BMP	Effectiveness (%)[b]	Uncertainty Discount (%)[b]	Life span
Sediment basins	65-85[c]	10-15[c]	20 years
Filter strips	55	15	1 season
Underground outlet	85-65[d]	15-25[d]	20 years
Straw in furrows	Not listed	Not listed	1 season
Crop sequencing	90	10	1 season
Polyacrylamide	95	10	1 irrigation
Sprinkler irrigation	100	10	15 years
Microirrigation	100	2	10 years
Tailwater recovery	100	5	15 years
Surge irrigation	50	5	15 years
Nutrient management	NA	NA	1 years
Constructed wetland	Not recommended – 90[e]	Not recommended-5[e]	15 years

a Source: http://www.envtn.org/docs/boise_bmp_manual_DRAFT.doc.

b These discounts are applied during calculation of WQT credits; the uncertainty is subtracted from the effectiveness. Effectiveness is a measure of the efficiency of a BMP at improving water quality by removing phosphorus.

c Range depends on scale (field, farm, or watershed).

d This BMP's effectiveness drops off after two years.

e This BMP is not recommended for calculating credit at the watershed scale; the number listed is for a farm-scale BMP.

This is the current list of BMPs, but additional BMPs may be incorporated over time or can be proposed by sources (ISCC, 2002). At the first annual meeting in May 2001, it was decided that wetlands, individually or in combination, would be added to the initial BMP list generated by ISCC and IDEQ (IDEQ, 2001). Ross and Associates (2000) state that wetlands are the best "natural system" method to remove phosphorus. This BMP list was finalized during 2002 (IDEQ, 2002). The life span for BMPs eligible for trading varies depending on effectiveness and endurance.

Agricultural NPSs desiring to develop credits are encouraged to work with either the ASWCD or the CSCD, depending on which county (Ada or Canyon) the source is located in. By working with the appropriate district, farmers develop a conservation plan in cooperation with NRCS and ISCC. BMPs are designed as part of these conservation plans to address water quality concerns. After the BMPs are installed and included in the plan, they can be certified as installed according to NRCS and meeting applicable laws and regulations. Once the BMP is certified and operational, phosphorus reduction credits can be generated and traded. Typically, within the LBR, the BMPs will operate to reduce phosphorus during the irrigation season (April 15 through October 15); thus, credits are available for trade during this season. Fortunately, the beneficial reduction during the irrigation season coincides with the needed phosphorus reductions required by the SR-HC TMDL. BMPs must be inspected prior to their seasonal operation and periodically during the monitoring period throughout the life span of the BMP.

The BMP list developed by ISCC also includes procedures for generating credits. To generate credits that can be traded in a market, there must be an equal and beneficial reduction in phosphorus beyond the regulatory requirements of the source. This reduction is calculated or measured in pounds of phosphorus by either of two methods. The reduced poundage of phosphorus is then converted to credits for trading purposes.

The selection of the method used to generate the amount of phosphorus reduction depends on data availability. The amount of phosphorus reduced by a BMP is calculated if adequate data are available or measured if data is limiting. Calculated phosphorus reduction is the estimated average reduction with a BMP, discounted due to the potential uncertainty in the effectiveness of the BMP and other management factors (discussed below). Measured reductions are quantified from grab samples taken during implementation of the BMP to quantify actual reductions, which requires an inflow and outflow for comparison.

8.3.3 Discount Factors

The calculated reduction of phosphorus from eligible BMPs must be discounted based on the effectiveness of the BMP and uncertainties in the effectiveness determination. These discounts are provided at the field, farm, and watershed scale. The nutrient management BMP does not have efficiency data, but use of this BMP in combination with other BMPs allows the other BMPs' uncertainty discounts to be reduced by 50 percent. Currently, constructed wetlands are lacking sufficient data to determine efficiency or uncertainties and, therefore, are not recommended by ISCC for calculating credits. Consequently, use of constructed wetland BMPs requires actual measurement of phosphorus reduction to determine credits.

To determine the actual credit given for reducing phosphorus by employing BMPs, three factors have been developed to adjust the reduction calculation: site location, drainage delivery ratio, and river location ratio. Factors were developed to address the net impacts at Parma of a trade between sources elsewhere in the watershed. These trades have the potential to cause local water quality impacts in the areas where trading occurs. The localized impacts are smallest when the BMP implementor is upstream of the PS generator because water quality is improved by the BMP before it reaches the PS generator. However, water diversions between the trading parties may produce impacts in the river far below the PS generator if the irrigation diversion of water containing high levels of phosphorus is returned to the river. This would result in a net increase in phosphorus between the diversion and the returned irrigation drain.

A site location factor is included because of the transmission loss that may occur between the location where the phosphorus reduction takes place and the location of the discharge to a water body. To account for this transmission loss, three site location factors were developed using common scenarios as follows:

- Site factor of 0.6 for when land runoff flows to a canal that is likely to be reused by a downstream canal user;
- Site factor of 0.8 for when land runoff does not flow directly to a drain, but through or around other fields prior to entering drain;
- Site factor of 1.0 for when land runoff flows directly to a drain or stream through a culvert or ditch.

In addition to transmission loss between the source and the receiving water body, transmission loss can occur within the water body. However, no data are currently available to develop local transmission models. In the absence of data, a simpler linear calculation that represents this loss was developed. This equation is:

Drainage delivery ratio = (100 – distance in miles to the mouth of drain from the project's point of discharge to drain) ÷ 100

Distance is estimated using a GIS.

The third discount ratio, river location ratio, attempts to take into account the influence of diversions that prevent phosphorus from reaching the LBR mouth. This ratio provides a means to determine equivalent loads between sources along the LBR (Ross and Associates, 2000). Ratios are calculated and provided for each source of hydrologic input (municipality or tributary/drain) flowing into LBR.

8.3.4 Calculating Credits

Calculating credits begins with determining the amount of phosphorus produced at a location. To estimate the current phosphorus loads from a cropland, the SISL tool is currently the most accurate and simple method to estimate soil loss from surface-irrigated croplands. This tool is used to calculate the tons per acre of soil loss per irrigation season. The SISL uses a baseline soil loss. ISCC established agricultural baseline loads for the project using 1996 as the base year (IDEQ, 2001). Phosphorus reduction is compared against the phosphorus loads in 1996 because this is the baseline used for the TMDL (ISCC, 2002). The total amount of phosphorus load is calculated by multiplying the soil loss by the amount of acres being irrigated.

The amount of soil loss can be converted to phosphorus loads by multiplying soil loss by 2 pounds of applied phosphorus per ton of soil. Phosphorus loads with irrigation vary by season. Typically, more phosphorus is generated during the beginning of the irrigation season (April 15 through October 15) due to erosion and less uptake by crop plants. The phosphorus reduction from the calculated loads is based on the effectiveness of the BMP selected, minus the uncertainty factor. Because NPS would also be assigned a share of the nutrient reduction under the TMDL, the nutrient reduction generated, and available for sale, is calculated by subtracting the individual NPS share of nutrient reduction from the total nutrient reduction created by a BMP (baseline load multiplied by the BMP effectiveness ratio. "Parma Pounds," which are the unit of credit available for the trading project can then be calculated by multiplying the “saleable” the nutrient reduction by the site location factor, drainage delivery ratio, and river location ratio. The concept of “Parma Pounds” recognizes that all pounds are not equal due to water reuse within the basin. The Parma Pounds are allocated over the months of the irrigation season to reflect the phosphorus load variability over the season. This season coincides with the seasonal TMDL reduction requirements.

8.3.5 Example Trade

The LBR Effluent Trading Demonstration Project conducted a trading simulation for a PS-to-NPS trade. This simulation used a combination of two eligible BMPs—sediment basin and constructed wetland—installed in sequence. The model included a conceptual design, sample permit conditions, completed forms documentation, cost estimates, and performance evaluation (Ross and Associates, 2000).

The conceptual design for the sediment basin and wetland system consisted of running phosphorus-containing water though the several treatment features by percent of total area (Table 8-2). Designs differ for treatment of continuous agricultural runoff versus treatment of intermittent stormwater runoff and for phosphorus removal versus removal of other pollutants. Conventional constructed wetland wastewater systems have tertiary treatment and polishing of municipal or industrial effluent. Vegetation in these wetlands helps facilitate nutrient uptake and transformation into basic elements, compost, and plant biomass.

Table 8-2 Example Design of Sediment Basin and Wetland System

Design Feature	Percent of Total Area
Sediment basin	3
Primary Grass filter	23
Vegetated wetland	23
Deep Water pond	41
Polishing filter	10

The conceptual design took into account the maintenance requirements, such as roads for accessing portions of the system. The wetlands depth was designed to provide for accumulation of biomass and the sediment basins could store six years of sediment at 2 feet of depth. More than one sediment basin was provided in the design to allow for one basin to be shut down for maintenance while the other continued to treat flows. Plants used for the design consisted of wetland grasses like redtop (*Agrostis spp.*) for the primary filter, emergent plants like bulrush (*Schoenoplectus spp.*) for the vegetated wetland, and herbaceous and woody species for the polishing filter. The system was designed to function with minimal flows through the operation of control gates to keep plants alive and minimize decay, which can lead to remobilization of phosphorus. Finally, the conceptual design had inlets and outlets to allow for the measurement of phosphorus concentrations and flows.

The performance of wetlands in removing phosphorus depends on the design, maintenance, and the concentration and flow rate of effluent phosphorus through the wetland. The efficiency of wetlands to remove phosphorus depends on the flow rate. Based on mass balance models, the fraction of TP removal is approximately 90 percent at 1 cubic foot per second (cfs) and 15 percent at 15 cfs. However, the amount of phosphorus removal in pounds increases with the flow rate, with diminishing returns at higher flow rates (Ross and Associates, 2000). Analysis of the LBR simulated design showed that phosphorus removal can be optimized for a site by increasing flow rates, without regards to the efficiency of the removal process (i.e., fraction of phosphorus removed). The ability of the system to remove phosphorus was based on the equations developed by Kadlec and Knight (1996) (Ross and Associates, 2000).

The design used in the simulation predicted phosphorus removal at a different amount for each BMP using a flow rate of 15 cfs and concentration of 0.366 mg/L. Over a 30-year life span, the sediment basins would remove 1,040 pounds of TP per season; the constructed wetland would remove 980 pounds of TP per season; and the combined sediment basins and constructed wetland BMPs would remove 2,020 pounds of TP per season, or 60,600 pounds over 30 years. This removal rate would vary within an expected SD derived from other studies. The Shop Creek facility in the Cherry Creek Reservoir study showed an SD of 22 to 25 percent for annual average phosphorus removal. The LBR simulated design was expected to perform better (i.e., 20 percent SD) than the Shop Creek facility because the LBR design would not be subject to storms and increased flow variability, which reduces TP removal due to the controlled flows. A compilation of data from 60 studies of 57 natural wetlands in 16 countries reported a mean SD of 27 percent for nitrogen and an SD of 23 percent for phosphorus (Fisher and Acreman, 2004). Analysis of 44 wetlands in 17 locations throughout the United States concluded an SD of 30 percent for phosphorus (USEPA, 1999).

The simulated design provided a detailed estimate of probable cost for the proposed system. The cost estimate was based on a public bid process and included material, equipment, and labor in year-2000 dollars, assuming a 30-year operation. The estimate was broken down into capital, including engineering, construction, contingency (20 percent), and land acquisition ($10,000 per acre), and O&M. Capital and O&M were estimated at $3,004,000 and $145,800, respectively. The cost for O&M was composed of $71,800 for annual O&M and $74,000 for harvesting wetlands plants every five years. Using these costs and a 3 percent in ation rate, annualized cost for removal of TP was $118 per pound. If public funds were borrowed through issued bonds, then the cost would be $161 per pound. The cost for constructing wetland systems for treating stormwater has been estimated at $10,000 to $30,000 per acre (Zentner, 1995; Reed, 1991). This simulation, based in year-2000 dollars, is close to $67,000 per acre. Because of the high cost of using a constructed wetland BMP, the value of the phosphorus reduction (i.e., “Parma Pound”) will need to be high to justify implementing this BMP practice. A stringent TMDL and/or other mechanisms to partially recover costs would be necessary for use of this BMP to be cost-effective. The high cost of using a constructed wetland BMP represented by this simulation emphasizes the need to find lower cost engineering solutions to construction wetland design and maintenance.

A summary of the features and results of the simulated scenario that combined the sediment basin and constructed wetland BMPs is provided in Table 8-3.

Table 8-3 Summary of Sediment Basin and Wetland System Simulation

Simulation Feature	Quantity
Amount of wetland	54 acres
Life span	30 years
Flow rate	15 cfs
Ef uent concentration	0.366 mg/L
Capital cost	$3,004,000
O&M cost	$145,800
TP removed by the wetlands per irrigation season	980 lbs
TP removed per irrigation season	2,020 lbs
TP removed per life span	60,600 lbs
Annualized cost per pound of TP removed	$118

Credits are generated on a monthly basis. However, the life span of a BMP varies depending on the BMP. Life spans for BMPs provide assurance to credit buyers that credits will be available and to credit sellers that opportunities to market their credits will persist for at least the designated life span of the BMP they choose to implement. In the LBR case study, the life span assigned to BMPs re ected the professional judgments of scientists, regulators, and field practitioners. Constructed wetlands were originally assigned a 5-year life span, but this was increased to 15 years based on discussion within a technical focus group (Koberg, 2006). Therefore, the NPS could implement this BMP and sell credits for 15 years following the completion of the BMP, assuming maintenance and monitoring was carried out and demonstrated effectiveness. Because the TMDL reduction goals are seasonal (May through September), the credits would only be needed and available during these seasonal periods.

Monitoring is required to determine if a BMP is operating properly and actually reducing phosphorus. In the BMP guidance, constructed wetlands require evaluation from an inspection before and during the middle of the season of use. Consequently, during the 15 year life span of a wetland, a minimum of 30 evaluations would be necessary to continue generating tradable credits. Monitoring is the responsibility of the NPDES permit holder who is involved in WQT. The permit holder documents the monitoring on trade tracking forms and uses this documentation to comply with his NPDES permit.

8.4 Summary

It is too early to determine whether the LBR Ef uent Trading Demonstration Project is a success. The framework has been established, but no trades have occurred because of delays in providing the phosphorus reductions required by an LBR phosphorus TMDL. The project simulation generated a scenario using a constructed wetland that could be duplicated by sources along LBR. This simulation produced a total of 2,020 pounds of TP removal using a combination of two BMPs: sediment basins and constructed wetlands. Theoretically, these pounds could be converted to tradable “Parma Pounds” following discounts applied based on the location of the BMPs and trading partners. The approach the LBR Project took towards the application of the TMDL facilitates NPS participation because they are not required to satisfy their assigned share of the phosphorus load reduction for their entire property before they are able to participate in trading.

The experiences recovered from the LBR Ef uent Trading Demonstration Project highlight keys to success for a WQT project as well as some limitations to this approach to water quality improvement. These successes and limitations can be applied to other trading programs within the United States.

One of the fundamental components of a successful trading program is the need to have drivers for trading. These drivers include: regulatory requirements within a defined water body, high costs for PS to reduce pollutant levels, and the ability of NPSs or other PSs to reduce pollutants more cost-effectively than certain PSs (Kramer, 2000). It is critical that a trading program generate sufficient publicity that sources are aware the program exists and how they can benefit from participating. The parties involved in trades must be able to find each other and execute a meaningful agreement or contract. Effective BMPs need to be identified, and must be practical and cost-effective to implement. The framework for trading credits needs to be established and simple to use. This includes being able to calculate the credit, complete required documentation, and effectively monitor and audit performance. Estimation techniques for calculating NPS nutrient reductions must be reliable. A trading market should enable PS and NPS reductions to be achieved at a lower cost than the individual PSs could accomplish within their own operations (ISCC, 2002; Kramer, 2000). Additionally, there are spatial components to a successful trading program. This geographic issue consists of the need for a larger number of PSs and NPSs within the drainage basin requiring nutrient reductions (Kramer, 2000). There must be enforcement and penalties for non-compliance to ensure that BMPs are installed and performing as expected and trades are occurring equitably. Finally, the trading approach must result in a reduction in pollutants that is measurable and meets the objectives of the TMDL.

There are several limitations or challenges to a successful WQT program. Trading could be hampered by the lack of an established or known trading framework. Additionally, trading would fail to be effective if it is viewed as, or in practice actually is, too cumbersome for traders to use or regulators to evaluate. Similarly, transaction costs must be minimized to ensure utility of the program (Kramer, 2000). Trading needs to avoid hot spots or localized areas in a watershed with high levels of nutrients (Kieser and Fang, 2005); otherwise, the local water loads could become worse instead of improving. Ultimately, WQT is unsuccessful if it fails to create environmentally equivalent nutrient reductions. Equivalency can be difficult to demonstrate or calculate when there are uctuations in phosphorus generation within a given timeframe. For example, irrigation produces more phosphorus earlier in the irrigation season due to erosion and less uptake by crops (ISCC, 2002). This variability may not necessarily coincide with variable or constant phosphorus loading by PSs.

Obstacles to developing the trading program include incurring high expenses and intensive use of resources to develop the trading framework. Furthermore, the irrigation districts (PSs) and farmers (NPSs) in the LBR demonstration project were leery about losing water rights by participating in a program. NPSs are also wary that their participation in generating credits by reducing phosphorus loads might encourage or facilitate their being subjected to regulations, requiring them to reduce their phosphorus loads to the LBR (King, 2005; Environomics, 1999). Currently, NPSs are not regulated and trading is voluntary. Public comments by environmental interest groups on pollutant trading expressed concerns about the ability to hold PSs fully accountable for trades, the verifiability of NPS trades, and the need to obtain trade-by-trade regulatory approval. The participants in the demonstration project felt that the LBR framework established highly effective and locally tailored solutions to CWA liabilities.

The LBR Ef uent Trading Demonstration Project identified several additional data and investigational needs of trading programs and use of constructed wetlands as BMPs to remove phosphorus. For example, the forms used for documenting trading activity generated in a trading program need to conform to the Paper Reduction Act. A simple but formal audit plan is necessary for a trade tracking system. In the LBR case study, there were no deadlines by which a trade must be completed in order for it to be included in a given month's monitoring report. This relationship needs to be explicit. The support for discounts developed to generate credits is incomplete. For example, the transmission losses and the fate and transport of nutrient uptake capacity between the trading partners need additional study to refine discounts. Further watershed analysis on the effects of diversion on localized water quality impacts could strengthen the discount relationships. Additionally, more evaluation is needed on the use of "total mass" caps for PSs to prevent localized impacts. These analyses could be part of ongoing review and evaluation of an operating program, this would distribute the study and analysis costs over a period of years and would leverage the additional BMP monitoring and verification requirements required to validate credits.

The ISCC determined there is insufficient data for deriving efficiency or uncertainty values for calculating phosphorus removal of constructed wetlands. Consequently, phosphorus reduction from constructed wetlands must be measured, which requires incorporation of in ow and out ow structures in wetland design, which creates a design limitation for the use of constructed wetland BMPs. Wetland design, including the way water ows into and out of a wetland, is critical to the effectiveness of a constructed wetland at removing phosphorus. For example, ow delivery or departure could be by sheet ow or infiltration, which makes measuring phosphorus content more difficult. The variability in designs and their ability to remove phosphorus from PSs or NPSs needs additional investigation. Through this investigation, various scenarios and calculated credits could be generated to guide sources in the selection of this BMP.

Another area needing investigation is the appropriate life span assigned to BMPs. In the LBR BMP list, the life span for a constructed wetland BMP is 15 years based on a technical focus group decision among participants during development of the WQT project (Koberg, 2006). However, the example simulation used a 30-year BMP life span. Due to the high cost of constructing a wetland for phosphorus treatment, it is more cost-effective for these BMPs to be used for trading programs for as long as they are functional. This would be similar for any BMP that is maintained and performs phosphorus removal. Adjustments in the life span of BMPs or a discount for the age of the BMP should be considered as a part of WQT program review and evaluation. This would avoid the necessity of making long-range assumptions during the initial stage of program implementation.

Finally, information and planning are lacking on the long-term fate of phosphorus removed using BMPs such as constructed wetlands. If sediment or plants are harvested containing large concentrations of phosphorus, the ultimate disposition of this harvested material may only transfer the environmental problem to another location or medium, such as groundwater used for drinking water.

9.0 Case Study – Tar-Pamlico River and Neuse River, North Carolina

The Tar-Pamlico and Neuse rivers ow parallel to each other approximately 50 miles apart and empty into the Pamlico Sound, an estuary in which the circulation of water is slowed by a string of islands between it and the Atlantic Ocean. In the mid-1980s, fish kills and algal blooms in the Tar-Pamlico and Neuse River Estuaries due to eutrophication created public concern regarding water quality. Subsequently, the NCEMC declared the upper portion of the Neuse River Basin NSW in 1983, the entire Neuse River Basin NSW in 1988, and the entire Tar-Pamlico Basin NSW in 1989. In addition, each river basin was added to the state's 303(d) list for chlorophyll a (USEPA, 2005b). As required by North Carolina state law, the NSW designation initiated a process to develop and implement nutrient management strategies for each river basin.

The strategies developed over the next decade included measures to address both PSs and NPSs of nutrients, including WQT programs. The trading model for both these programs can best be described as an exceedance tax or a group cap-and-trade program. PSs are assigned a baseline maximum nutrient load and nutrient reduction goals, which cumulatively set the overall nutrient loading goals for the water body. PS entities are provided the option to form an association so that they are able to collaborate to meet those goals. In the event that the collective exceeds the nutrient limits, each program developed a nutrient offset fee for each additional pound of nutrient discharged that is paid to a state-administered fund for implementing BMPs to reduce the nutrient load from NPSs.

In this case study, the Tar-Pamlico Nutrient Reduction Trading Program and the Neuse River Basin Sensitive Waters Management Strategy are described in separate sections and then compared.

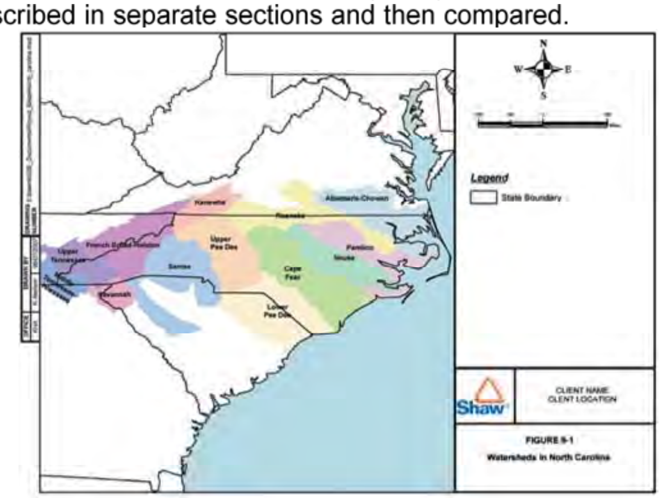

Figure 9-1 *Watersheds in North Carolina.*

9.1 Tar-Pamlico Nutrient Reduction Trading Program

The Tar-Pamlico Nutrient Reduction Trading Program was initiated in 1990. During Phase I (1990-1994) of the program, the Association was assigned an interim cap for combined discharges, which required a 44,092-lb/yr reduction in TN and phosphorus (Kerr *et al.*, 2000), and a 20 percent reduction in nutrients over five years. In addition, the Association was tasked with the following: (1) develop an estuarine model; (2) perform an optimization study for capital improvements to WWTPs; (3) fund the initial design and administration of the WQT program ($150,000 was provided over a two-year period); (4) make minimum payments into the offset fund if cap was not exceeded (these payments amounted to $850,000 at the end of Phase I); and (5) perform water quality monitoring to document compliance with the cap (Breetz *et al.,* 2004; Kerr *et al.*, 2000). The offset fee was set at $25.40 per pound, and credits expire after 10 years. The fees are paid to the North Carolina Agriculture Cost Share Program, administered by the DSWC, a pre-existing program that funds 75 percent of the capital costs associated with voluntary implementation of agricultural BMPs.

Throughout Phase I, the association was able to meet the nutrient reduction goals collectively through improvements in operational efficiencies.

During Phase II (1995 through 2004), the focus of the nutrient management strategy shifted to include NPSs based on the recognition that NPSs contribute the majority of nutrient loading to the watershed. The modeling completed by the Association in Phase I estimated that NPSs accounted for 92 percent of the nutrient loads (Gannon, 2005b). A goal of 30 percent reduction was set for both PSs and NPSs and the limit for discharge of phosphorus was set at 1991 levels. An interim target of 60 percent progress towards these goals by 1999 was set. If progress was inadequate, the NCDWQ and NCEMC would evaluate whether additional regulatory requirements were necessary (Kerr *et al*., 2000). When adequate progress had not been made, mandated rules on riparian buffers, fertilizer application, stormwater, and agriculture were adopted by the NCEMC and went into effect in 2000 and 2001 (Gannon, 2005b). The Phase II agreement reduced the price of NPS credits to $13 per pound. Throughout Phase II, the Association has maintained discharges well below the caps assigned without needing NPS offsets (Breetz *et al.,* 2004).

The Phase III agreement spans an additional 10 years (2005 through 2014), with an amendment after 2 years to address potential needs for improvements. The Phase III Agreement updates Association membership and maintains the nutrient caps established in Phase II. It also proposes actions over the first two years that will improve the offset rate, resolve related temporal issues (life span of offset credits), and evaluate alternative offset options. The offset credit life span, what happens after 10 years when the credits expire, and how to handle credits that have been banked by the Association, but not used within 10 years, are issues that participants in the Phase III agreement are currently working to resolve (Huisman, 2006). It also establishes 10-year estuary performance objectives and alternative management options. If water quality in the estuary worsens by 2008, a process to re-model the estuary and revise TMDLs will be initiated (Gannon, 2005b).

9.1.1 Background

The Tar-Pamlico River Basin is located north of Neuse River Basin and encompasses 5,400 square miles (Figure 9-2). When the NCEMC designated the Tar-Pamlico basin NSW in 1989, the DENR developed an initial management strategy, as required by state law, which focused reductions of nutrients in the discharges from PSs. The Water Quality Control Commission proposed discharge limits of 2 mg/L TP and 6 mg/L TN (4 mg/L TN in summer and 8 mg/L TN in winter); total nutrient (e.g., tons of TN) load reductions were not specified. It was estimated that to meet these standards, it would cost PSs between $50 and $100 million in capital costs for technology upgrades. PSs opposed the strategy due to the costs and because they believed that discharges from NPSs were also responsible for eutrophication. Environmental groups also opposed the strategy because of the lack of a strategy for NPS reductions and the lack of a goal for PS reductions. Phase I of the NSW implementation strategy, which includes the WQT program, was adopted in December 1989 and was the result of a cooperative stakeholder process with the Association, the state, and the North Carolina Environmental Defense Fund (NCEDF) (Kerr *et al.,* 2000).

Partners involved in the effort were NCDWQ, Soil and Water Conservation Districts, North Carolina DSWC, North Carolina Cooperative Extension, USDA's NRCS, North Carolina Department of Agriculture, North Carolina Farm Bureau, North Carolina State University, the Association, the agricultural community, and commodity groups. Fourteen dischargers equaling about 90 percent of all PS ows to the river joined the Association (Gannon, 2005b). The NCEMC brought together stakeholder groups of affected parties and provided the participants with a chance to express differing viewpoints. Stakeholders involved in the process included environmental groups, municipalities, developers, businesses, and the public (USEPA, 2005c).

A TMDL for nitrogen and phosphorus was developed late in Phase I, assisted by the estuarine modeling initiative conducted as a part of the Phase I agreement, and approved in 1995 (Environomics, 1999). The model predicted that a 45 percent reduction would be necessary to meet in-stream water quality goals; however, due to the uncertainty associated with the modeling, a 30 percent reduction in nitrogen loading for all sources was established by the Phase II agreement (Kerr et al., 2000). The trading program is one element of the implementation strategy of the Tar-Pamlico nutrient TMDL; as previously described, it also charged NPSs with a 30 percent reduction. The environmental organizations Environmental Defense and Pamlico-Tar River Foundation (PTRF) were participants in the Phase I and III agreements (Gannon, 2005b). However; they chose to not participate in the Phase II agreement because they disagreed with the 30 percent reduction goal that was established.

Phase III of the NSW implementation strategy was adopted as a continuation and update of the Phase II strategy with specific goals to improve and refine the program.

Two years into the implementation of the Phase II agreement, regulations modeled after the Neuse nutrient reduction regulation were developed in conjunction with stakeholder consultation (Gannon, 2005b). These regulations include: buffer protection rules (15A North Carolina Administrative Code [NCAC] 2B.0259, .0260 and .0261); nutrient management rule (15A NCAC 2B.0257); stormwater rule (15A NCAC 2B.0258); and agriculture rules (15A NCAC 2B.0255 and .0256) (NCDWQ, 2005).

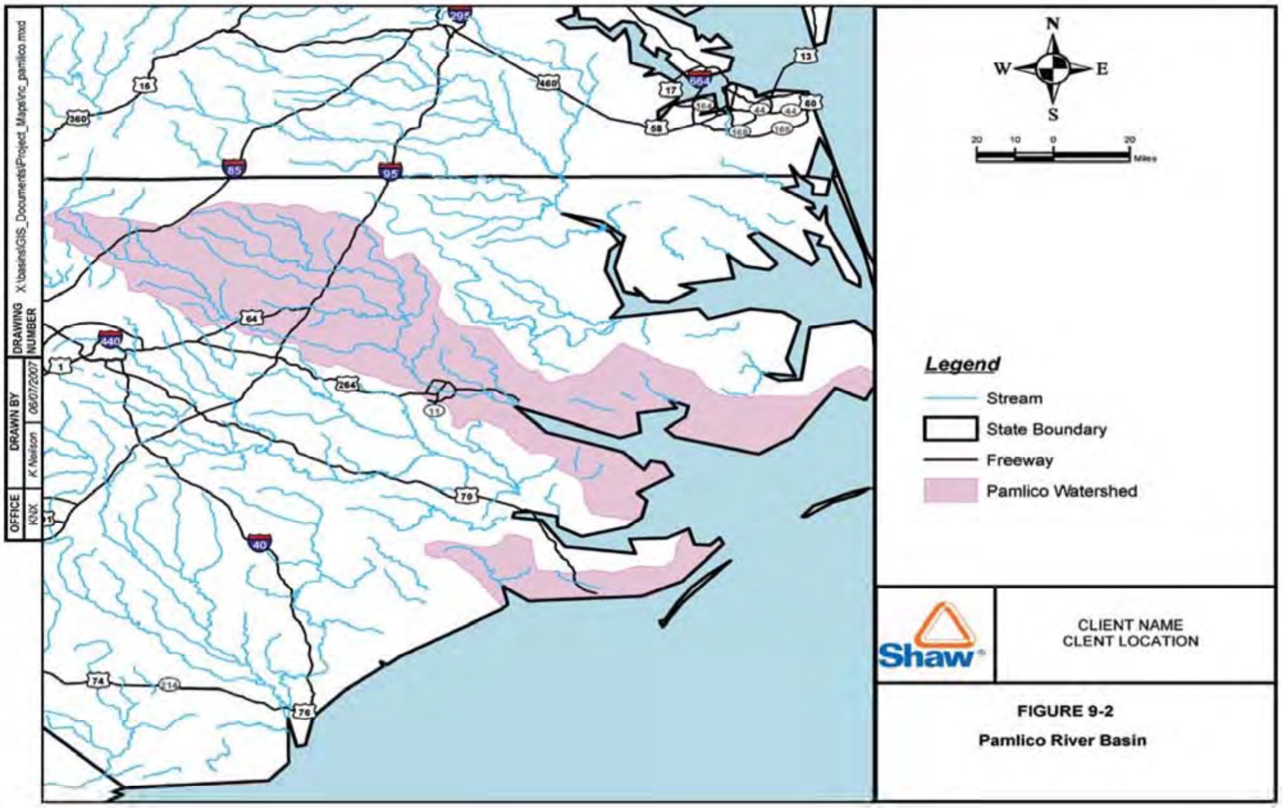

Figure 9-2 *Tar-Pamlico River Basin.*

The trading program was designed so that fees for offset credits would be paid to the NC Agriculture Cost Share Program. The NC Agriculture Cost Share Program is responsible for allocating those funds to the Tar-Pamlico Basin, targeting projects geographically for the most cost-effective nutrient reductions to the estuary. Once PSs have purchased credits, they are no longer liable for ensuring NPS BMPs are implemented and successful. The state assumes responsibility for the monitoring and verification of BMPs. The DSWC has final authority over BMP implementation and the NCDWQ has final authority over nutrient tradeoffs and allocations (Breetz et al., 2004). The primary focus of the Agriculture Cost Share Program is to provide farmers with assistance implementing agricultural BMPs aimed at reducing nutrients (Research Triangle Institute & USEPA, undated).

9.1.2 Program Performance

The Tar-Pamlico Nutrient Trading Program has been part of a successful strategy to reduce nutrients in the Tar-Pamlico Basin although, to date, no trades have occurred. Thanks to the exibility of the collective discharge goals afforded the Association, members of the Association have been able to improve treatment efficiencies and time technology upgrades with planned expansions so that improvements in treatment efficiency are cost-effective (Allen and Taylor, 2000). As opportunities for cost-effective technology upgrades are exhausted, trading will likely occur in the future.

The Association also provided up-front funding of almost $1 million worth of agricultural BMPs, in large part through a federal USEPA grant, and have been able to bank the credits toward future cap exceedances (Gannon, 2005b).

By the end of Phase II, the Association successfully met the nutrient reduction goals and by 2003 had decreased nitrogen and phosphorus discharges by 45 percent and 60 percent, respectively, even though ows increased by 30 percent. The agriculture community was also successful in meeting its nutrient reduction goals; it collectively reduced nitrogen discharges by 45 percent by 2003 (Gannon, 2005b), as estimated by land-based accounting methods that estimate TN and TP percentage reduction with implementation of BMPs. The land-based accounting methods are discussed further in Section 9.1.3.2.

As a result of watershed-wide efforts, impaired acreage in the estuary has been reduced by 90 percent (from 36,200 to 3,450 acres) (Gannon, 2005a), and one segment of the Pamlico estuary has been removed from the 303(d) list for chlorophyll a (USEPA, 2005b). Trends in nutrient loading in the Tar-Pamlico Basin from 1991 to 2002 were evaluated using the Seasonal Kendall test, a nonparametric trend test that is a generalization of the Mann-Kendall test (Kennedy, 2003). The results indicate significant, negative trends in ow-adjusted concentrations for both TP and TN. Over the selected study period of 1991 through 2002, the estimated decreases in TP and TN concentration over the 12 years are 0.046 mg/L and 0.203 mg/L, respectively. This represents a reduction of TP and TN through 2002 of 33 percent and 18 percent, respectively (see Figure 9-3 and Figure 9-4) (Kennedy, 2003).

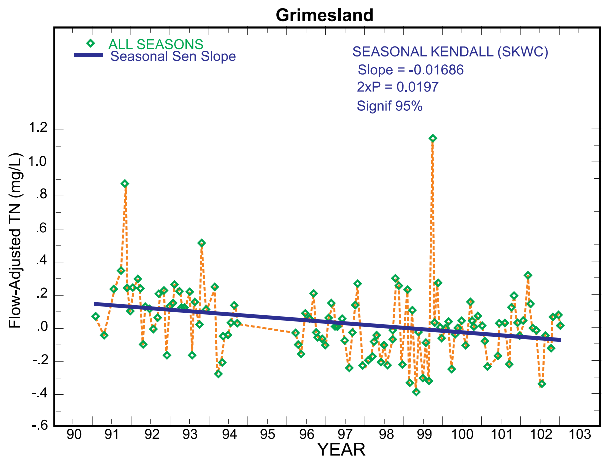

Figure 9-3 *Estimated TN concentration decrease using Seasonal Kendall test.*

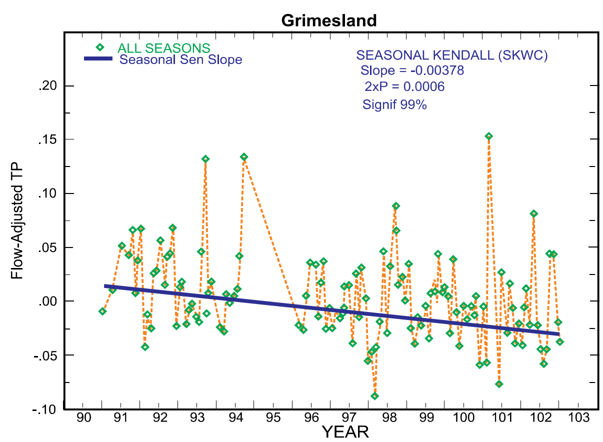

Figure 9-4 *Estimated TP concentration decrease using Seasonal Kendall test.*

A key factor that hampered the progress of NPS nutrient reduction activities during the early part of Phase II was limited funding/lack of resources to facilitate accounting for progress on NPS BMP implementation (NCDWQ, 1999). In addition, unknowns associated with atmospheric deposition of nitrogen make it difficult to address this source of NPS nutrients (Gannon, 2005b).

9.1.3 Technical Performance

The NSW implementation strategy established a fixed fee per pound of TN discharged above the discharge limit. A nutrient source budget (an accounting of all nutrient sources in the watershed) was prepared for the Tar-Pamlico basin in 1986 and revised in 1988 to re ect significant changes in the watershed. The researchers who developed the budget determined that nitrogen was likely the limiting factor in plant growth. There were uncertainties in the estimates, but with ongoing development in the basin it was crucial that initial goals be established. The NCDWQ projected the 1994 ow for all the Association members at 30.55 mgd. Assuming no nutrient reductions from pre-strategy conditions, NCDWQ estimated that total nutrient loading in 1994 would reach 1,278,000 lb/yr. Under the original NSW proposal, which required mandatory phosphorus and nitrogen limits for PSs, projected loadings for 1994 would decrease to an estimated

936,965 lb/yr, a reduction of 440,924 lb/yr. Subsequently, NCDWQ, the Association, NCEDF, and the PTRF together established 440,924 lb/yr as the nutrient reduction goal for Phase I of the WQT program. Of this, 396,832 lb/yr is for nitrogen and 44,092 lb/yr is for phosphorus (Research Triangle Institute & USEPA, undated).

9.1.3.1 Methods for Defining Caps and Measuring Baseline Nutrient Loading

During Phase I, HydroQual developed a two-dimensional, laterally averaged hydrodynamic water quality model to predict the impacts of nutrient loading in the estuary. The model extends from Greenville to Pamlico Point, a distance of approximately 60 miles. 1991 was chosen as the calibration year for the model because it represented when typical impairment of the estuary was evident. It was also the baseline year when PSs in the Association were required to perform nutrient monitoring (Gannon, 2005b).

A water quality station near the town of Washington was chosen as the point at which management strategies would be evaluated because modeling results indicated that this was where the greatest number of chlorophyll a and dissolved oxygen violations occur, and the magnitude of the violations was the greatest. Thus, it is the critical portion of the river (Gannon, 2005b).

TMDL targets were set in Phase II at 2,778,000 lb/yr of TN and 397,000 lb/yr of TP at Greenville based on the relatively low flow year 1991. Given that Washington is downstream and additional loading would occur between those points, TN load delivered to Washington was calculated to be 4,280,000 lb/yr. Therefore, the 30 percent TN reductions goal for all sources was set at 1,285,000 lb/yr (Gannon, 2005b). PSs were allocated 8 percent of the total nutrient load reductions, and NPSs 92 percent. For Phase III, these load reductions translate to a cap of 891,271 lb/yr for TN and 161,070 lb/yr for TP for PSs (Gannon, 2005b), and a cap of 2,109,220 lb/yr TN and approximately 1,851,883 lb/yr TP for NPSs.

The modeling results predicted that a 30 percent reduction in TN would significantly reduce the frequency and severity of algal blooms in the estuary. To prevent exceedances of the chlorophyll a standard of 40 µg/L, the model predicted that a 45 percent reduction in TN would be needed. However, given that the level of uncertainty in the modeling increases the further conditions are from baseline conditions, 30 percent was selected at the target for reducing TN. There were plans to recalibrate the model to lower nutrient loading conditions after 30 percent reductions were achieved in order to more accurately determine whether additional reductions are needed. However, recalibration has been postponed pending the results of other estuary evaluations (Gannon, 2005b).

9.1.3.2 Methods for Quantifying Nutrient Load Reductions

Point Sources. Assessing compliance of PSs within the trading program is relatively simple. Since July 1991, Association facilities have been performing weekly effluent monitoring for TP, TN, and flow. The Association reports monitoring data to NCDWQ annually. NCDWQ has developed a set of guidelines for estimating flow and concentration if this information is not provided. Water quality monitoring is performed according to monitoring protocols defined or referenced in their NPDES permits (Gannon, 2005b).

Nonpoint Sources. Although wetlands have not been a primary method used to reduce nutrient loads, the methodologies developed for assessing the progress of NPSs towards nutrient reduction goals are applicable to assessing the effectiveness of constructed and restored wetlands as NPS BMPs. This is relevant to a general discussion of how to account for the reductions in NPS nutrients. The NCDWQ determined that measuring compliance with instream loading targets would have required a combination of complex modeling of processes occurring between edge of management unit (e.g., a given property or unit area of land bordering a body of water) and the water column instream (which would have significant uncertainty), and a substantial amount of quantitative water quality monitoring to support that modeling (Gannon, 2005b). As a result, they have developed methods to assess compliance with load reduction targets based on land-based accounting methods that estimate nitrogen and phosphorus percentage reduction based on BMP implementation.

The NCDWQ has developed estimates of nutrient removal efficiencies based on "model local stormwater programs" developed under the Neuse and Tar-Pamlico stormwater rules and agency research. Table 9-1 is the latest table developed by NCDWQ of typical nutrient removal efficiencies. It is being used to calculate NPS nutrient reductions for both of these programs (Bennett and Gannon, 2004).

Two other tools have been developed; the Nitrogen Loss Evaluation Worksheet (NLEW) and the Phosphorus Loss Assessment Tool (PLAT). Both tools were developed for nitrogen and phosphorus accounting under the Tar-Pamlico agriculture rule. The NLEW was developed by a multi-agency task force to meet the need for a scientifically valid nitrogen loss accountability method for use in the Neuse and Tar-Pamlico nutrient strategies. It is an empirically-derived spreadsheet model that estimates nitrogen export from agricultural management units. It was developed to estimate relative reduction in nitrogen export through a pre- and post-BMP implementation calculation, rather than estimating delivery to surface waters (Gannon, 2003). The NLEW uses crop and soil acreages, fertilization rates, and areas of BMP implementation to estimate nutrient fluxes from agricultural land. To estimate BMP implementation before implementation of the Agriculture Rule, the Local and Basin Committees (LAC)[23] used cost-share records, if they existed, and relied on best professional judgment where unassisted BMP implementation was significant (Gannon, 2003).

Table 9-1 New Nutrient Removal Efficiencies for Stormwater BMPs Used Under the Neuse and Tar-Pamlico Stormwater Rules

Practice	TN efficiency (%)	TP efficiency (%)
Wet pond	25	40
Stormwater wetland	40	35
Sand filter	35	45
Bioretention	35	45
Grass swale	20	20
Vegetated filter strip with level spreader	20	35
50-foot restored riparian buffer with level spreader	30	30
Dry detention	10	10

From Bennett and Gannon (2004).

9.1.4 Economic Performance

9.1.4.1 Calculating Offset Credit Value

When the Phase I agreement was developed, the estimated cost of achieving the 440,925 lb/yr nutrient reduction goal using agricultural BMPs alone was $11.8 million: $10 million on the ground and $1.8 million in administration. These values were determined by multiplying the reductions by a factor of $25.40 per lb/yr, the estimated cost for removing 1 pound of nutrient per year using BMPs. The rate was drawn from BMP funding experience in the adjoining Chowan River basin. The calculation of the cost factor included a margin of safety by multiplying by a factor of three for cropland BMPs and by a factor of two for animal BMPs (Research Triangle Institute & USEPA, undated).

The offset fee was refined when the Phase II agreement was developed. The base offset fee takes into account farmers' capital costs, maintenance costs, BMP effectiveness, area affected, and BMP life expectancy. BMP effectiveness values were based on a literature review that included empirical studies of conservation tillage, terracing, and buffer strip BMPs in the Chesapeake Bay. The fee also includes a trading ratio that re ects a 10 percent increase for administrative costs and a 200 percent margin of safety. Credits for structural BMPs have a useful life of 10 years, while non-structural BMPs have a credit life of 3 years (Breetz *et al.,* 2004; Gannon, 2005b). The type of BMP eligible for generating nutrient reduction credits was left broad: any BMP included within the NC Agriculture Cost Program that is associated with nutrient reduction can be used to generate credits (Huisman, 2006). The key limitation is that nutrient reductions from BMP projects designed to satisfy the 30 percent TN reduction required of all agricultural operations cannot also be used to generate nutrient offset credits.

The following equation illustrates how the offset fee was calculated.

$$2(\$5.90/\text{lb N}) + 0.1[2(\$5.90/\text{lb N})] = \$13/\text{lb N}$$

Where 2 accounts for uncertainty in BMP effectiveness, $5.90/lb N high-end cost effectiveness for nitrogen removing BMPs, and 0.1 adds in administration costs (Gannon, 2005a).

The offset payments made by the Association to the Agriculture Cost Share Program are used to fund voluntary BMP implementation (75 percent state/25 percent producer) and pay for staff resources to track and target contracts and verify compliance.

The NCDWQ plans to work to refine the offset credit calculations further during the first two years of Phase III, and NCDWQ plans to work in consultation with signatories to the Phase II agreement to develop improvements to the offset rate that address the following issues:

- Develop an offset rate for exceedances of the phosphorus cap.
- Update cost-effectiveness data developed in the 1995 RTI report.
- Add current BMPs not addressed in the 1995 RTI report.

23 *LACs were established as a part of the agriculture rules to develop plans for meeting the 30 percent reduction goal, and provide technical assistance to farmers reporting on progress to the EMC.*

- Project BMP implementation for the foreseeable future, including relative numbers and geographic distribution if possible.
- Include uncertainty estimates with all cost effectiveness values.
- Replace the current value with single nitrogen and phosphorus values weighted for projected BMP implementation. Include spatial weighting if possible to account for differences in estuary delivery due to BMP distribution within the basin. Evaluate the use of uncertainty bounds to replace the current safety factor.
- Revisit the administrative cost factor.
- Resolve understanding on payment longevity and credit life initiation (Gannon, 2005b).

As a part of this work, NCDWQ determined the cost-effectiveness of implementing various BMPs in reducing nutrient loads (Table 9-2).

Table 9-2 Nitrogen Removal Cost-Effectiveness Comparison

Practice	$ per Pound (30-year life equivalent)
Agriculture	
• Water control structure	$1.20
• Nutrient management	$7 - $9
• Vegetated filter strip	$7 - $8
• Conservation tillage	$20 - $80
Stormwater/bioretention	$57 - $86
Riparian wetland restoration	$11 - $20

Source: Gannon, 2005a.

9.1.4.2 Program Costs

The trading program has yielded substantial savings for the Association, which originally estimated costs for technology upgrades at $50 – 100 million, although a revised estimate of costs to the Association without trading puts potential costs at $7 million to achieve a comparable level of nutrient reduction that a $1 million investment in NPS controls yielded (DeAlessi, 2003).

According to the USEPA Office of Water (2005), in addition to costs to the Association, the overall costs of the NSW implementation strategy[24] have been as follows:

- The North Carolina Agriculture Cost Share Program, administered by the DSWC, contributed $12.5 million between 1992 and 2003.
- Another DSWC-administered program, the federal Conservation Reserve Enhancement Program, has obligated approximately $33.1 million in the Tar-Pamlico River Basin since 1998.
- Between 1995 and 2003, approximately $2.67 million in CWA section 319 expenditures supported a variety of NPS projects in the Tar-Pamlico Basin, including BMP demonstration and implementation, technical assistance and education, GIS mapping, development and dissemination of accounting tools, and monitoring.

9.1.5 Administrative Performance

PSs and NPSs are required to achieve environmental goals and provide sufficient information to document compliance. The NCEMC, NCDWQ, and Soil and Water are the key administrative bodies for the NSW management strategy. The government agencies retain the ability to take enforcement actions against PSs and NPSs in the event that they are not able to demonstrate compliance.

9.1.5.1 Point Source Accountability

The Agreement signed by the Association, NCEMC, NCDWQ, and Soil and Water is the primary mechanism used to assure accountability. The NPDES permits of the Association members do not contain limits for nitrogen, which means that if they overperform, they are not subject to the antibacksliding requirements in the federal CWA (which would result

24 The trading program is just one part of the overall strategy developed for the Basin.

in adjustments in permit limits if association members showed they could meet more stringent requirements).[25] This would effectively penalize environmental performance. The NPDES permits do, however contain a "reopener" clause stating that if conditions in the agreement are violated, then permits would be revised to impose new discharge limits (Kerr *et al.,* 2000). The Association documents its nitrogen loading for the year in an annual report (Gannon, 2005b).

Non-Association members (the remaining 10 percent of the PS dischargers) are subject to slightly different rules. They are regulated by traditional PS permitting requirements. In addition, they are required to offset new nutrient loading by funding BMPs at an offset ratio of 1.1:1 (Kerr *et al.,* 2000).

9.1.5.2 Nonpoint Source Accountability

The performance of NPSs on nutrient reduction goals is tracked using three methods: tracking activities, computer modeling, and sampling.

Tracking Activities. The NCDWQ and EMS use annual reports submitted by LACs to verify progress of NPSs on BMP implementation plans developed by LACs. LACs were created to develop agriculture BMP implementation strategies. LACs are required to submit annual reports on progress (Gannon, 2005a).

Modeling. Computer modeling efforts have included improving the Tar-Pamlico Estuarine Water Quality Model used to develop the basin-wide strategy. In addition to the NLEW and PLAT modeling tools developed for agriculture, an Excel-based model was developed to calculate nitrogen and phosphorus loading associated with stormwater runoff from new developments before and after BMP implementation (Gannon, 2005a).

Monitoring. The Soil and Water Conservation Districts perform compliance monitoring on BMP implementation; they inspect 5 percent of all contracts for cost share projects per year and all animal waste systems twice per year; and review all local programs every five years (Gannon, 2005a). The NLEW is also used to track progress.

9.2 Neuse River Basin Nutrient Sensitive Waters Management Strategy

The 1997 Neuse River Basin NSW Management Strategy (Neuse NSW Strategy) established nitrogen allocations and control options to improve water quality in the Neuse River Basin. The strategy included elements of PS-NPS trading for nitrogen allocations and PS-NPS offsets for nitrogen loading (Breetz *et al.,* 2004). It set a 30 percent TN reduction target for all sources (including PSs and NPSs) that would need to be achieved within five years, by 2003 (15A NCAC 2B.0234). The strategy also established a group compliance option, which PS dischargers over 5.0 mgd have the option to join. In 2004, the NRCA included 22 members. It issued a single, collective NPDES permit for nitrogen based on the sum of the members' individual nitrogen allocations. PS-PS transactions for nitrogen allocations can occur either internally within the NRCA or between members of the NRCA and non-members (Breetz *et al.,* 2004).

The system established for PS-NPS trades is similar to that of the Tar-Pamlico Nutrient Reduction Program and can best be described as an exceedance tax, rather than a traditional trading program. Potential trading parties include: members of the NRCA, any discharger holding an allocation, and landowners. Trades with NPSs are conducted indirectly through the North Carolina Wetlands Restoration Fund. Landowners receiving grants from the Wetlands Restoration Fund are indirect trading partners. As with the Tar-Pamlico Program, responsibility rests with the state for ensuring nutrient offset projects are implemented and successful (Breetz *et al.,* 2004).

A fixed, per-pound price has been established for the purchase of TN offset credits. Credits may be purchased if new or expanding dischargers cannot secure nitrogen allocations from other PSs or if the NRCA exceeds its annual nitrogen allocation. In addition to the offset payments, the NRCA is subject to penalties and other enforcement action for any exceedance. In that event, the NRCA members are also subject to enforcement if they exceed their individual allocations as listed in the NRCA's permit. Non-members with TN limits are not required to make offset payments, but are subject to enforcement for any exceedance of their TN limits (15A NCAC 2B.0234) (Breetz *et al.,* 2004).

The Neuse NSW Strategy also created a mechanism for NPS-NPS trades. The Neuse NSW Stormwater Requirements (15A NCAC 2B.0235) set a nitrogen export standard for local governments identified within the regulation based on population and growth rate. Local governments subject to this regulation are required to develop stormwater management program plans and have them approved by the NCEMC. Local governments that do not submit stormwater management program plans or fail to implement them will be subject to NPDES permitting requirements. The plans are tailored to help the local government ensure nutrient reduction goals are met. A key component of the plans is review and approval of stormwater management plans of new developments to ensure they will comply with a nitrogen export standard of 3.6 pounds per acre per year. Developers have the option of installing stormwater BMPs to satisfy this standard or may

25 *The* USEPA Water Quality Trading Policy (2003) *has since addressed this issue directly, stating*, *"antibacksliding provisions will also generally be satisfied where a point source generates pollution reduction credits…and it later decides to discontinue generating credits, provided that the total pollutant load to the receiving water is not increased, or is otherwise consistent with state or tribal antidegradation policy."*

choose to implement stormwater BMPs that will attain maximum allowable nitrogen export rates and purchase offsets for the remainder of the nitrogen export rate above the rate set for local governments.

An initial focus on education is another aspect of Neuse NSW Strategy that is different than the Tar-Pamlico Program. At the outset of the 1997 strategy, the Neuse River Education Team (NRET) was created (and funded) with a mandate to educate NPSs of nutrients (agricultural producers, homeowners, and cities) (Newport, 2004).

9.2.1 Background

The Neuse River Basin is located directly to the south of the Tar-Pamlico River Basin and covers 6,192 square miles (Figure 9-5).

It was not until 1997 that a WQT program was included in the Neuse River Basin NSW Management Strategy. When the NCEMC developed the original Nutrient Management Strategy (Neuse NSW Strategy) for the Neuse River Basin in 1988, most of the nutrient problems in the lower Neuse region were occurring in the lower freshwater portion of the river near Street's Ferry, and phosphorus was considered the most important nutrient (NCDENR, 1998); thus the focus of the Strategy was on reducing TP. The strategy gave PS dischargers with ows greater than 0.5 mgd and all new facilities a TP limit of 2.0 mg/L. Specific goals were not established for TN, although the NCDWQ also stated that nitrogen loading from NPSs should be controlled. The Agricultural Cost Share Program was identified as the primary mechanism for reducing nitrogen from NPSs.

The first Basin Wide Plan for the Neuse River was developed in 1993. At this point, TN was becoming a concern in the Neuse because monitoring and modeling in the Tar-Pamlico Basin were showing that nitrogen appeared to be the more important nutrient for brackish estuarine waters. The plan recommended that the Neuse NSW Strategy be reevaluated before it was updated in 1998 (NCDENR, 1998). Major fish kills in 1995 provided further impetus to revise and update nutrient controls. In 1997, the Neuse NSW Strategy was updated by the NCDWQ. It focused on nitrogen and established the Neuse NSW Rules, which were crafted to meet and maintain a 30 percent nitrogen reduction goal within five years, and retained the technology-based concentration limits for TP. Nutrient impacts also led to listing the basin on the 303(d) list and to the development of TMDLs, which USEPA Region 4 approved in 2001 (USEPA, 2002b and Environomics, 1999).

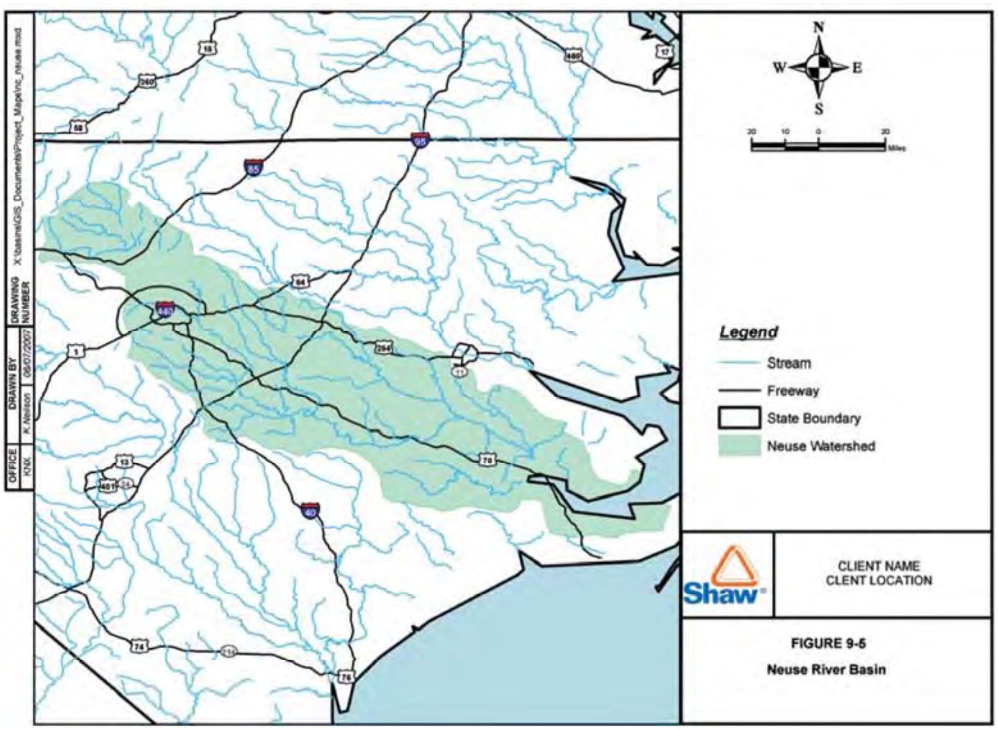

Figure 9-5 *Neuse River Basin.*

The Neuse NSW Rules (Rules .0232, .0234, and .0240 of 15A NCAC 2B) were developed by the state in an effort to address the major known sources of nutrients in a exible, fair, and reasonable fashion (NCDENR, 1998). PSs were estimated to contribute approximately 24 percent of the nitrogen and phosphorus loading to the estuary (Brookhart, 2003, Gannon, 2006). There were 111 dischargers in 1995 (the baseline year); it was estimated the largest 32 dischargers accounted for over 95 percent of the TP loading from PSs to the estuary (Breetz *et al.*, 2004). Thus, more than 600 people participated in the public hearing process. The group compliance option came about as a result of suggestions from PSs. They were concerned that stringent nutrient allocations would have been burdensomely expensive, and they were interested in more cost-effective and exible regulatory structures (Breetz *et al.,* 2004). The Tar-Pamlico Nutrient Trading Program, which had entered into Phase II at that point, was used as a template for the Neuse Trading Program. The draft rules were brought to the public for comment before being adopted in December 1997.

According to Breetz *et al.* (2004), participants in the Neuse NSW Implementation Strategy include the following organizations:

- NCDWQ: issues NPDES permits to individual dischargers and a group NPDES permit to the NRCA; provides regulatory oversight for the group nitrogen allocation.
- NCEMC: responsible for developing and adopting the Neuse River Nutrient Management Strategies and associated rules.
- NRCA: association of PS dischargers, primarily large municipal WWTPs, with a common nutrient cap.
- Lower Neuse Basin Association (LNBA): a nonprofit coalition of dischargers that conducts instream monitoring; preceded the NRCA by several years and served as the starting point for the development of the NRCA. Many LNBA members became NRCA members.
- Wetlands Restoration Fund (administered by the Ecosystem Enhancement Program [EEP]).
- USEPA, Region IV.
- Neuse River Foundation and Neuse Riverkeepers: environmental advocates.

NCDWQ oversees compliance with the group nitrogen cap. The NRCA manages the individual nitrogen discharge of members through an internal fee system.

The NRCA has been successful at meeting the nutrient discharge limits and has not needed to purchase any offsets. However, approximately $5 million in offset fees has been collected from Neuse stormwater projects (Gannon, 2005a). Payments to the Wetlands Restoration Fund are allocated to wetland construction and restoration projects. There are currently numerous projects in design; most are constructed wetlands (Gannon, 2005a). Currently, the focus of the Wetlands Restoration Fund is shifting to include stormwater BMPs, including constructed wetlands. Since 1999, the EEP has struggled to find good wetland sites for restoration (Rich Gannon, telephone interview Dec. 9, 2005). These difficulties are reminiscent of the challenges encountered by wetland mitigation banking fee-in-lieu programs.

9.2.2 Program Performance

The Neuse NSW Strategy has been a success and has produced results similar to the Tar-Pamlico Program. The goal of the trading program was to provide another option for achieving compliance with nitrogen allocations (Breetz *et al.,* 2004). As shown in Figure 9-6, the NRCA has been able to surpass the 30 percent TN reduction goal by more than 100 percent. NPS TN loads from agriculture have been reduced by 37 percent and 177 acres of riparian buffers have been preserved (Gannon, 2005b).

One PS-PS trade that would raise the NRCA's nitrogen cap was considered in 2004, but was rejected because it was found that the trade could potentially result in a hot spot (localized water quality problems) in Falls Lake, which is the major drinking water supply for the City of Raleigh (Breetz *et al.,* 2004; Gannon 12/2005).

9.2.3 Technical Performance

The Neuse Rules established a fixed fee-per-pound of TN discharged above the discharge limit allocated to the NRCA and municipalities. In 1998, PSs were discharging 4.1 million pounds of nitrogen per year into the Neuse River Estuary. In order to achieve a 30 percent reduction, PSs had to reduce their nitrogen contribution by 2.8 million lb/yr. Nitrogen allocated to individual dischargers was based on the ratio of their permitted ow to the total permitted ow of all PSs (NCDENR, 1998).

NPS loading for the Neuse River Basin was originally estimated using export coefficients[26] for different land cover types. Land cover classifications were interpreted from LANDSAT imagery for 1993 – 1995 (NCDENR, 1998). The modeling and

26 Export coefficient refers to the amount of substance, such as nitrogen, expected to be transported from land by stormwater runoff. Expressed as amount of loading per acre per year (e.g., pounds/ac/yr).

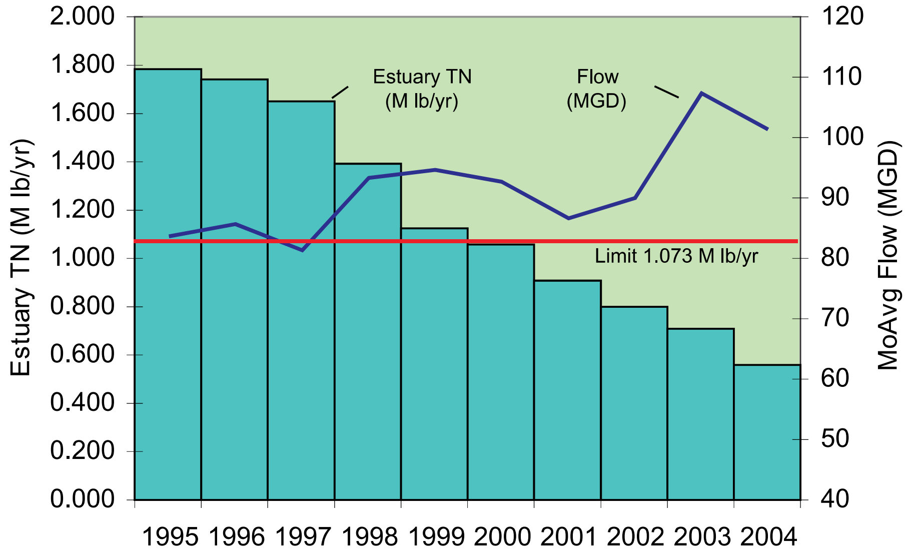

Figure 9-6 *Neuse River NRCA performance, 1995 - 2004.*

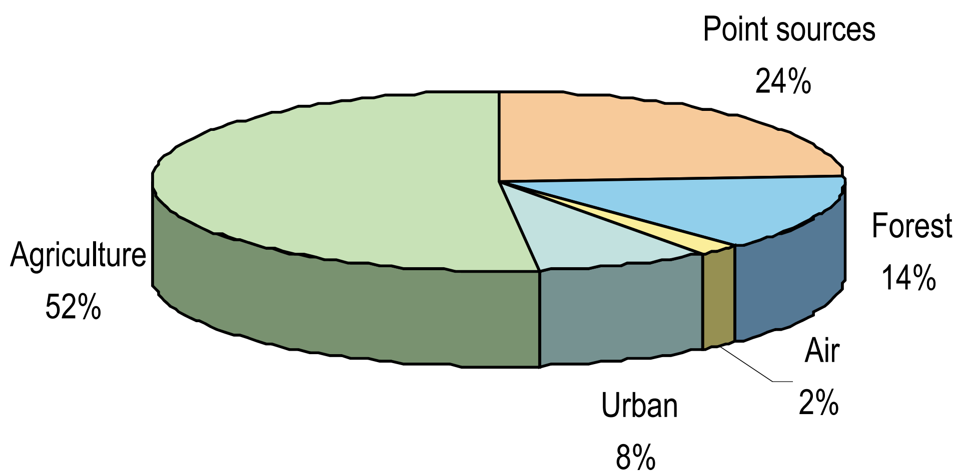

Figure 9-7 *Sources of Nitrogen in the Neuse River Basin (1995).*

information on PS loading determined that nutrient loads from agricultural operations account for more than 50 percent of the nutrient load in the Neuse River Basin and PSs account for 24 percent; the remaining nutrient sources include forest land, air, and urban areas (Figure 9-7).

The 30 percent nitrogen reduction goal was established before the TMDL process was concluded. Modeling to evaluate the effects of various nutrient reduction scenarios was completed during the TMDL process to determine whether an adjustment needed to be made to the 30 percent TN reduction target established by the Neuse Rules. Three models were developed:

1. Neuse Estuary Eutrophication Model, a CE-Qual W2 application to the Neuse estuary;
2. Neuse Estuary Bayesian Ecological Response Network, a probability network model; and
3. Water Analysis Simulation Program, application to the Neuse Estuary. Two scenarios of this model were run (NCDENR, 2001).

The results of these models confirmed that a 30 percent reduction in nitrogen from the 1995 baseline for TN is a reasonable initial target (NCDENR, 2001).

Based on the 30 percent reduction target, local governments were assigned a nitrogen export standard of 3.6 pounds/acre/year. As previously discussed, new developments are required to implement on-site stormwater controls at least to assure that nitrogen export from residential and commercial/industrial developments does not exceed 6 and 10 pounds/acre/year, respectively. Offset payments are required to meet the remainder of the requirement (Shabman and Scodari, 2004; and Rules .0232, .0234, and .0240 of 15A NCAC 2B).

9.2.3.1 Nutrient Removal by Constructed Wetlands

Wetlands are recognized as playing a valuable role in the removal of nutrients from stormwater runoff in the Neuse NSW program. As shown in Table 9-1, the standard TN and TP removal efficiencies of stormwater wetlands (also known as constructed wetlands) developed by the NCDWQ for the purpose of monitoring progress toward nutrient reduction goals is 40 and 35 percent, respectively. The Neuse NSW program has also generated several case studies on the performance of constructed wetlands in various types of conditions.

In one such example, the NRET and Smithfield-Selma High School built a demonstration stormwater wetland to treat runoff from parking lots, buildings, and the soccer field on the 70-acre school property in 1999. The created wetland covers ⅓ acre in an area that was once a ditch. Students from the school participated in planting wetland plants and continue to be involved in monitoring the performance of the wetland. The project cost $14,280 (NRET, 2004). Water quality was tested using grab samples each August and December and following every storm event for a year and a half. (An automatic monitoring system was not installed due to concerns regarding the potential for vandalism.) The wetland has been very effective at removing nutrients and lowering water temperature: TN was lowered 85 percent, TP was lowered by 93 percent, and average temperature decreased 3 degrees Fahrenheit. No seasonal variability was observed in the level of nutrients removed from the wetland (Bill Lord, telephone interview December 9, 2005).

Assuming a linear relationship between construction costs and size of wetland, the unit cost of this wetland was $42,840 per acre.

Another example provided by the NRET illustrates nutrient removal efficiencies and also other factors that need to be included in the selection of constructed wetlands versus other stormwater BMPs. This project was developed in conjunction with a plant nursery in Johnston County. A constructed wetland was built to reduce nutrients reaching the Neuse River in 1998 and 1999. Because there was a growing demand for wetland plans, the constructed wetland was built to double as a nursery for wetland plants. Preliminary water tests showed that the wetland was removing approximately 50 percent of the nitrate-nitrogen (NO_3-N) (NRET, undated); however, the wetland attracted snakes and the project was discontinued (Bill Lord, telephone interview December 9, 2005).

Demonstration projects have also revealed that constructed wetlands can have mixed results. Prior to the adoption of the 1997 Neuse NSW Strategy, a pilot project was completed in the South River, located near the mouth of the Neuse River. Residential, forestry, and agricultural land uses are dominant in the watershed. A constructed wetland was developed on a 10-acre parcel of converted cropland adjacent to Southwest Creek. Blocked in ow ditches were opened and an out ow structure put in place to reestablish the wetland hydroperiod and raise water tables of approximately 300 acres of upgradient cropland.[27] The restored wetland removed more than 90 percent of the NH_4-N and 97 percent of the NO_3-N from the field out ow; however, phosphate phosphorus increased by 30 percent, possibly due to a reduction in pH (NCDENR, 1998).

Similar results were observed in another wetland project in the Chowan River Basin in the northeastern part of North Carolina (Figure 9-1), in the Town of Edenton. A two-year study was conducted by Kristopher Bass (2000) as a part of a Masters thesis to quantify impacts of an in-stream constructed wetland on water quality. The 2.4-acre in-stream wetland was built to intercept drainage waters from approximately 600 acres of agricultural and urban watershed, which resulted in a wetland-to-watershed area ratio of 0.004:1. During the project, NO_3-N concentrations were reduced through the wetland by 60 percent; NH_4-N concentrations by 30 percent, and TKN levels by 9.5 percent. This resulted in a 20 percent drop in TN concentration. TP levels increased 55 percent between the wetland inlets and outlet. Seasonality of wetland performance was also evaluated. Bass (2000) found that NH_4-N concentrations decrease by 10 percent more during the growing season; TKN concentrations decreased 15 percent during the winter and not at all during the summer; and TP was higher during the summer than in winter. In summary, he found that nutrient reductions were generally associated with temperature changes, and higher temperatures resulted in greater NH_4-N and NO_3-N reductions and larger increases in TKN and TP (Bass, 2000).

The results reported by Bass (2000) indicate a relationship between nutrient removal efficiencies and temperature/seasonality. However, seasonality in nutrient removal efficiencies was not observed at the Smithfield-Selma High School. An evaluation in the relationship between the effects of seasonality/temperature and the wetland-to-watershed areas ratio may provide insight into design of more effective constructed wetlands.

27 If 300 acres is the total area serviced by the wetland, the ratio of area to wetland is 1:0.033.

9.2.4 Economic Performance

The unit offset payment adopted by the Neuse Rules was originally set at $11 per pound (15A NCAC 2B.0240). Offset payments are required to include money for 30-year O&M, which is undertaken by a government entity such as a local government or community college (Gannon, 2005a). In addition, new or expanding PSs or offsets purchased by the NRCA are multiplied by 200 percent to account for uncertainty (15A NCAC 2B.0240). However, under the urban stormwater rules, developers are not required to multiply offset payments by 200 percent. As a result, a discharger needing to purchase an offset for 1 pound of nitrogen would pay an effective fee of $660 per pound, and a developer would pay $363 per pound.

The $11-per-pound offset was based on the cost of restoring degraded wetlands. However, revisions to the offset rate, which would raise it to $57 per pound, are currently being made to 15A NCAC 2B.0240. The change in the offset fee is due to a shift in the focus of the EEP to stormwater BMPs. Over the past years, the EEP has struggled to find appropriate sites for wetland restoration. The $57-per-pound offset rate re ects the higher price of this sort of BMP (Table 9-2). In addition to the revision to the offset rate, the applicability of the regulation will be expanded to apply to the entire state (including Tar-Pamlico), and the Neuse River Basin nutrient reduction goal (15A NCAC 2B.0232) will be expanded to include a reduction target for TP (Rich Gannon, telephone interview, December 9, 2005). The draft revisions to the regulations also proposed revisions in calculating the total offset fee. The revised offset fee calculation is presented below:

EEP Offset Rate:

N offset (Fee) = [$57/lb (lb/yr)(30 years) + $/ac(1/35)(ac developed)] x 1.1

Where $57 is stormwater BMP cost (?)-effectiveness, (lb/yr) is reduction needed, 30 years is the BMP life span, $/acre is cost of developed land, 1/35 is the BMP/drainage ratio, and 1.1 is an administrative cost factor.

Phosphorus (Fee) = $45/0.1 lb x same as above

Note: for wastewater load offsets, the land cost factor = 0 (Gannon, 2005a)

There is no trading ratio for PS-PS trades, nor is the NPS offset fee paid to the Wetlands Restoration Fund (Breetz et al., 2004).

9.2.4.1 Constructed Wetland Construction Costs

Wetland construction costs fall into three main categories: land, construction, and maintenance. Land cost is, of course, the most variable, depending on location, but is often the largest single cost associated with wetlands in North Carolina, especially in urbanizing areas. (Hunt and Doll, 2000). Research completed by Hunt and Doll (2000) and Wossink and Hunt (2003a) developed the following cost estimates for various components of wetland construction based on a series of case studies:

- **Excavation and grading:** this category of costs for wetlands constructed in the Piedmont and Coastal Plain of North Carolina have ranged from $4 to $9 per cubic yard, with a tendency toward economies of scale. Hauling costs dramatically increase with the distance the excavated soil needs to be carried (Hunt and Doll, 2000).
- **Land:** (1) undeveloped land for commercial use with an average opportunity cost of $5 per square feet ($217,800 per acre); (2) undeveloped land for residential use with an average opportunity cost of $50,000 per acre; and (3) undeveloped land with zero opportunity cost because of the requirement for open space (Wossink and Hunt, 2003a).
- **Vegetation:** the species of wetland vegetation can greatly affect costs. Costs have ranged from as low as $0.30 per square foot where plants came from selective harvesting and natural establishment to $1 per square foot where nursery vegetation was used (Hunt and Doll, 2000).
- **Outlet and drawdown structures:** costs of the principal outlet and drawdown device depend on the size of the wetland and have ranged from $0.25 to $1 per square foot of wetland area (Hunt and Doll, 2000).

Costs for constructing wetlands and other stormwater BMPs in North Carolina are compared in Table 9-3.

Table 9-3 Summary of Construction Cost Curves, Annual Maintenance Cost Curves, and Surface Area for Five Stormwater BMPs in North Carolina

	Wet ponds	Constructed wetlands	Sand filters	Bioretention in clay soils	Bioretention in sandy soils
Range of BMP size (acres)	0.75 – 67	4 – 200	0.5 – 9	0.3 – 9.2	0.3 – 9.2
Cost					
Construction	$C = 13,909\ x^{0.672}$	$C = 3,852\ x^{0.484}$	$C = 47,888\ x^{0.882}$	$C = 10,162\ x^{1.088}$	$C = 2,861\ x^{0.438}$
20-year maintenance	$C = 9,202\ x^{0.269}$	$C = 4,502\ x^{0.153}$	$C = 10,556\ x^{0.534}$	$C = 3,437\ x^{0.152}$	$C = 3,437\ x^{0.152}$
Surface area					
Residential development:					
• Piedmont	SA = 0.015 x	SA = 0.020 x		SA = 0.025 x	SA = 0.025 x
• Coastal Plain	SA = 0.0075 x	SA = 0.01 x		SA = 0.015 x	SA = 0.015 x
Highly impervious area (CN80)					
• Piedmont and Coastal Plain	SA = 0.02 x	SA = 0.03 x		SA = 0.03 x	SA = 0.03 x
100% impervious	SA = 0.05 x	SA = 0.065 x	SA = 0.017 x	SA = 0.070 x	SA = 0.070 x

Source: Wossink and Hunt (2003a). Note: C = cost in $. x = size of watershed in acres. SA = surface area in acres.

This table illustrates that stormwater wetlands are less expensive to construct and maintain than wet ponds, but wet ponds require a much smaller surface area to effectively treat stormwater runoff. Bioretention is the least expensive option for treating stormwater from smaller sized watersheds. The cost curves do not include land costs; as the cost of land increases, wet ponds would become more cost-effective than stormwater wetlands.

Table 9-4 provides a cost comparison for four stormwater BMPs for a 10-acre watershed and the nutrient removal efficiencies of each BMP.

Table 9-4 Cost Comparison of Four BMPs for 10-Acre Watershed (CN 80[a])

Practice	Wet pond	Wetland	Bioretention in clay soils	Bioretention in sandy soils
Construction cost	$ 65,357	$ 11,740	$ 124,445	$ 7,843
Annual maintenance cost	$ 4,411	$ 752	$ 583	$ 583
Opportunity cost of land ($217,800/acre)	$ 43,560	$ 65,340	$ 65,340	$ 65,340
Present value of total cost	$ 146,474	$ 83,486	$ 194,751	$ 78,137
Annualized cost per acre watershed	$ 1,721	$ 981	$ 2,288	$ 918
Annualized cost per 1 percent of pollutant removal				
TSS	$26	$15	N/A	N/A
TN	$61	$45	$51	$20

Source: Wossink and Hunt (2003b). N/A = not applicable.

[a] *Curve Number (CN) reflects the ability of a watershed to store water through initial storage and subsequent infiltration. A high CN indicated a watershed with limited storage capacity.*

9.2.4.2 *Program Costs*

There is incomplete information available on the total costs of the Neuse NSW Strategy. Aside from the initial funding of $500,000 annually for the NRET, which has been reduced in recent years, information on other costs associated with the program is not readily available. The state, rather than the NRCA, assumes most of the transaction costs associated with NPS offsets (Breetz *et al*., 2004). The $11-per-pound offset payment can be compared to the $25- to $30-per-pound nitrogen control costs estimated for PSs elsewhere in North Carolina (Environomics, 1999); however, the requirement that credits be purchased for a 30-year period pushes the total cost higher than state-wide average costs.

9.2.5 Administrative Performance

The NCDWQ, NCEMC, and EEP administer the Neuse NSW Strategy. As with the Tar-Pamlico, it is the responsibility of PSs and NPSs to demonstrate compliance with the Neuse Rules. The NPDES permits of PSs within the NRCA do not contain a discharge limit for TN; the TN limit for the NRCA is specified in the group compliance NPDES Permit (USEPA, 2002b).

Each co-permittee has been assigned a TN allocation, but that is subject to change due to purchases, sales, trades, leases, and other transaction among the NRCA members. Furthermore, if the membership of the NRCA changes, the group TN allocation is changed in the group compliance NPDES permit accordingly. Members of the NRCA monitor discharges and report results to the NCDWQ, as specified in their NPDES permits, and to the NRCA. The NRCA compiles the co-permittee reports for its own reporting. As a group, the NRCA submits mid-year, year-end, and five-year reports (USEPA, 2002b).

Offset payments are paid to the EEP and tracked by an "In-Lieu Fee Coordinator," a staff position created to administer the program. North Carolina State University and local governments assist the EEP in identifying potential projects. The offset BMP projects are located no farther from the estuary than the loading being offset (Gannon, 2005a). Offset BMP projects are awarded to an on-call EEP contractor pool. The contractors are responsible for design, construction, and one year of performance monitoring (Gannon, 2005a). There are currently numerous projects in design (Gannon, 2005a).

9.3 Summary

The Tar-Pamlico and Neuse River Basin NSW implementation strategies were both successful at reducing nutrient loads. By 2003, nitrogen had been reduced in the Tar-Pamlico and Neuse River basins by 34 percent over 10 years and 37 percent over 7 years, respectively (Gannon, 2003). Furthermore, the associations of PSs created by both programs have successfully attained nutrient reduction targets. Although no PS-NPS trades have occurred, the structure is in place so that this option is available if needed in the future. As a result of these efforts, water quality has been improving in the Pamlico Estuary.

The Neuse NSW Strategy may have been successful at reducing nutrient loads faster than the Tar-Pamlico due to two key factors.

1. By the end of 2002, the target year for full implementation of the Neuse Rules was nearing (the rules were adopted in 1997). NPSs had been legally required to meet nutrient reduction goals for over four years, whereas the Tar-Pamlico Rules did not take effect until 2000-2001.
2. From the outset, the Neuse was allocated significant new resources in the form of field staff to facilitate BMP implementation and NPS education programs. It also received significant new cost-share funding for the entire period. No new resources were allocated to the Tar-Pamlico program between 1997 and 2002 (Gannon, 2003). Education of the agricultural community on their role in NPS nutrients was important in both programs.

The NSW strategies for both basins were developed concurrently and relied heavily on public and stakeholder input. The key goals of both strategies were to reduce eutrophication and to provide sources of nutrients with exible options for achieving nutrient reduction goals. Each program developed innovations that the other adapted: Tar-Pamlico developed the WQT program for PSs first and Neuse developed regulations to address NPSs of nutrients first.

There are several key differences between the two programs:

- The Tar-Pamlico has not adopted rules to allow NPS-NPS trading.
- Tar-Pamlico targeted agricultural BMPs for offset projects to reduce NPS nutrient loads. Neuse River Basin targeted wetland restoration and (recently) stormwater BMPs. Adoption of the Tar-Pamlico Agriculture Rule likely raised the stakes with respect to the potential offset BMPs projects – the rules do not allow double counting of nutrient reduction, so agricultural offset projects would need to be in addition to what agricultural producers were already required to do. Given that the least expensive BMPs are likely to be implemented first, this is likely one of the reasons the offset rate paid to the EEP is being increased.
- The methods used to calculate offset fees and the estimated life span of BMPs is very different between the two programs. A 10-year life span is assigned in the Tar-Pamlico program compared to a 30-year life span in the Neuse. There appears to be a need for further research into the life span of the nutrient removal BMPs and how they change over time. Work is currently being done in the Tar-Pamlico program to address uncertainty regarding the life span of credits and how to deal with temporal issues related to when credits are generated versus when they are used.

The one failed PS-PS trade between an NRCA member and a non-NRCA member in the Neuse River Basin demonstrates the strength of regulatory checks and balances, but a potential weakness in both programs. The trade was not approved due to the potential for localized water quality impacts. However, trading among NRCA members does not require NCDWQ approval. This may be resulting in localized water quality impacts that neither program seems to address.

Other lessons learned from the Tar-Pamlico Program relate to development of the initial baseline estimates of nutrient loads from various sources and program funding. Farmers perceived that the baseline for Phase II reductions did not adequately account for BMPs that had already been implemented voluntarily. Some believed better documentation of voluntary progress might have precluded the need for regulations (Breetz *et al*., 2004). Administering trades through the Cost-Share Program streamlined the program in many ways, but Cost-Share staff ran into difficulty predicting available funds and staffing needs in Phase II, when the NRCA was no longer required to make minimum payments for these purposes (Breetz *et al*., 2004).

9.3.1 Unanswered Questions

- Seasonality and the nutrient removal efficiency of wetlands: The Bass study (2000) provided some information on the effects of season; however, given that the constructed wetland monitored during this study was undersized, it is unclear whether the same results would have been observed in a wetland that was appropriately sized.
- Nutrient removal efficiency of wetlands over time: wetland monitoring data available for this case study spanned short time periods (approximately two years), but the information is inconclusive regarding how wetland nutrient removal changes over time.
- What is the life span of the nutrient removal BMPs?
- What is the effect of BMP maintenance on nutrient removal efficiencies?
- Does nutrient removal efficiency of a BMP change as the concentration of nutrients in the in owing water increases or decreases? Are some BMPs better than others for removing nutrients at higher or lower concentrations?
- How were the land-based accounting methods developed? How accurate are they?[28]

28 This has a much broader application than just WQT.

10.0 Synthesis/Summary of Findings

The information provided by the literature review and case studies is summarized here into key observations illustrated by comparisons among the case studies. These observations integrate the scientific, economic, and regulatory elements of trading to identify opportunities, potential hurdles, and unknowns for a very select set of trading pilot projects and programs attempted to date in the United States.

10.1 Performance Monitoring versus Conservatism

Most of the evaluated trading programs bypass performance monitoring for quantifying NPS load reductions and instead use conservative estimates (i.e., underestimates) of effectiveness to determine the amount of wetland required to achieve the desired nutrient load reduction. Safety factors are used to increase confidence in performance. The Cherry Creek trading program, a notable exception, requires direct measurement of nutrient load reduction, but creating an in ow point and an out ow point for the constructed wetland accommodates this. For the other program examples, implementation of BMPs was documented, but actual performance in reducing nutrient loads was presumed based on estimates and safety factors not substantiated with monitoring data. The rationale for using this approach stated that monitoring was either not feasible or prohibitively costly to the degree that it was more cost-effective to grossly oversize the wetlands to overcome uncertainty about performance.

While there is a wealth of scientific information on the function of various types of wetlands in removing nutrients, the literature does not report that anyone has yet compiled the available information into a comprehensive tool that can be used to assess the many interrelated factors affecting wetland performance that makes each wetland unique. Such a tool would provide confidence in designing or determining the performance of constructed wetlands in reducing nutrient loads. In Idaho, for example, the ISCC recommended against using constructed wetlands for calculated credit because currently there are not enough data to determine efficiency or uncertainties at a scale larger than a single site (ISCC, 2002). A primary challenge is to quantify baseline conditions, i.e., the site load prior to BMP application. The degree to which headwater wetlands may treat pollutants and contribute to the baseline should be considered. Many interrelated parameters, including seasonality, changes in retention rates with varying loads and over time, drainage patterns, relative location of a wetland within the watershed, and type of wetland, drive wetland performance according to system dynamics.

The incorporation of safety factors, which increase the amount of wetland required to produce the necessary performance, may mitigate the limitations due to these uncertainties. Therefore, in the absence of monitoring data, performance is presumed based on gross conservatism. Unfortunately, not only is this approach potentially cost-prohibitive, it also fails to manage uncertainty regarding non-target pollutants. Specifically, the management of one stressor affects the fate and transport of other contaminants, potentially releasing them from wetlands. For example, a wetland's role as a greenhouse gas and methyl mercury sink or source affects its benefit to the ecosystem.

There may be an opportunity to reduce uncertainty and increase program potential by establishing objective and reliable means of determining performance of constructed wetlands. One approach would be to develop more cost-effective and adaptable guidelines for collecting monitoring data. Another solution would use a combination of existing information and new research to develop general performance data to inform the creation of generalized calculation guidelines for estimating performance. For this strategy to succeed, it must acknowledge the wetland's dynamics and resulting changes in retention rates within the context of the larger geographic scale. Establishing baseline nutrient levels and mapping the wetlands in the watershed will serve to more accurately quantify these rates. Finally, historical contamination in the wetland may also justify monitoring of non-target pollutants.

10.2 Motivations for Nonpoint Source Participation

NPS contributors are difficult to regulate due to the challenges in isolating and quantifying the contributions of individual parties. Nevertheless, for many watersheds, NPS nutrient load contributions exceed PS contributions, as illustrated by the case studies documented in this report. WQT programs may be used to create an economic incentive for NPSs to control their contributions through trading the load reductions for a profit. This is feasible in certain circumstances based on the significant difference in costs.

NPS contributors have a subtle disincentive to participate in trading programs. While they may benefit financially by reducing nutrient loads, the financial gains may be offset by potential liabilities associated with new compliance requirements, or strict enforcement of existing compliance requirements they currently do not meet. "Additionality" stipulates that any offset that would have occurred regardless of the trading program cannot count toward a trade—e.g., BMPs that are already required of farmers cannot be used to create trade value. Presumably, if reliable methods are developed to isolate and quantify NPS load reductions, those same methods may be used to facilitate more effective regulation of NPSs. Ultimately, a thorough understanding of nutrient loading on a watershed scale is necessary to align the right incentives for NPS contributors to participate. WQT programs may provide a viable mechanism to increase the participation of NPSs in implementing BMPs to improve water quality. Trading programs may provide a platform for education and means by which landowners receive outside funds to make improvements to their properties by implementing BMPs and to generate more valuable data for better scientific assessment of water quality conditions.

Ancillary benefits to property owners may be enough to motivate participation in NPS load reduction actions. In the Rahr nutrient trade, bank stabilization and riparian habitat restoration were used to reduce nutrient and sediment loads. The property owners received the benefit of a stabilized riverbank that protected their property from future loss.

Cooperation among stakeholders is essential to success. Rahr established collaborative relationships with environmental organizations, MPCA, and the NPSs so that everyone perceived that all parties were working together for the best interest of the environment.

10.3 Effects of Compliance Thresholds and Enforcement

The "maturity" of the trading market is a strong determinant for the feasibility of trades. The Cherry Creek trading program illustrates this point clearly. The load allocations were assigned to PSs allowing for projected growth capacity. Since the PSs are, at current capacity, easily able to operate within their compliance limits, there is no demand for trades. As PSs grow and increase their capacity, it will become more difficult for them to operate within the same load allocation limits. At some future point, nutrient trades will become economically preferable in comparison to facility upgrades. In contrast, Rahr was unable to obtain a permit to discharge into the Minnesota River unless its contribution was entirely offset by trades. Based on the success of the Rahr trade, a general permit was established following the same form to guide future applicants. Enforcement of discharge limits will also affect participation in trading. If the discharge limits are strict enough they necessitate trading, but if the likelihood of enforcement when limits are not met is remote, dischargers may decide to game the system instead of participating in trading. Therefore, stringent permit limits with strict enforcement significantly motivates PS demand for trading. The four case studies suggest that NPS participation eventually follows, matching supply to the demand.

10.4 Comparison of Program Structure

Trading programs vary among the case studies in terms of how the structure guides and regulates trades. The Rahr example in Minnesota illustrates how a single set of trades can be incorporated into the terms of an NPDES permit for a single PS. The Tar-Pamlico program in North Carolina established an association of PS and NPS contributors who were collectively regulated and allowed to trade among themselves to achieve group compliance. No trades have occurred in either of the North Carolina case studies. The exibility afforded by the group compliance option has allowed members within the Tar-Pamlico and Neuse compliance associations to informally trade amongst themselves (Breetz *et al.*, 2004). As opportunities for cost-effective technology upgrades are exhausted, trading will likely occur in the future. The Cherry Creek program in Colorado establishes two entities that accomplish NPS reductions and build up a credit bank for sale. The LBR program in Idaho allows for trades to occur freely between trading partners required to report the trade to the regulatory authority for review, monitoring, and approval.

10.5 Credit Life

Considerable work has been completed evaluating time limits or the useful life of BMPs. In general, a life span of 10 years for structural and 3 years for nonstructural BMPs has been the norm in trading programs; however, the Idaho and Neuse River programs extend credit life beyond that to 15 and 30 years, respectively. There are still questions regarding what happens after credits expire; how to deal with temporal differences between when the credits were generated and when they are applied; what happens if credits are generated and not used; and how to better understand and predict the short- and long-term assimilative capacities for a given wetland considering seasonal variation in performance.

10.6 Economic Challenges to Trading

As discussed in Section 4.0, efficiency requires that at least one source be able to more cost-effectively reduce its discharges than another source; otherwise, the program would not be financially attractive nor marketable (Fang and Easter, 2003; Jaksch, 2000).

It is essential that economic considerations support WQT for it to be a viable tool to achieve water quality standards. Economic trading challenges suppress WQT by making net economic value of trading less attractive than alternate compliance management strategies due to risks and uncertainties. Four economic challenges threaten the development of robust, sustainable WQT programs because they reduce the DCFROI, the future return on investment in relation to capital costs associated with generating credits, of trading. These are: (1) simplified modeling of natural system impacts which leads to overly conservative trading ratios, (2) costly environmental protection, (3) high transaction costs, and (4) ill-defined property rights. These challenges hinder efficient and fair deal making, usually because they make the risk and/or return on investments in WQT high to the buyer, the seller, or both.

There are a number of potential solutions to address the economic gaps and challenges that complicate the value and risks associated with trading, such as:

- ***Improving the efficiency of regulatory activities***: this could include special training for agency staff, dedicated WQT agency staff, clarification of legal issues that reduce disputes, improved system modeling, and simplified data management. Implementing these measures is both technically and economically feasible. However, it would require upfront investment by regulatory agencies in improving staff, policies, practices and equipment. Some of these costs could be recaptured by administrative costs built into offset fees. Limiting regulatory involvement to setting the minimum rules of engagement would maximize regulatory efficiency.
- ***Increase the command and control compliance liability for PS***: stricter PS discharge limits should increase the economic attractiveness of WQT, encouraging more trades and better environmental protection. However, very careful consideration and justification would be required before selecting this option. PSs and other stakeholders could potentially argue these changes are unfair in light of the NPS contribution to watershed nutrients in many watersheds.
- ***Market and non-market economic valuation of natural systems:*** establishing market and non-market economic valuation of a natural system, such as a watershed, would take into account the economic value of the system or system components (e.g., flood control, drinking water, fisheries) and the parties that derive value from those components (municipal government, commercial fishermen, tourism industry, etc.). The outcome of this analysis would furnish a more comprehensive understanding of the economic values of these systems and the key stakeholders, yielding more informed decisions. For example, the analysis could provide potential traders with an understanding of how else they benefit directly from implementing a BMP. In addition, this analysis could identify other potential markets for the ecological services delivered by wetlands. Suppliers would realize a greater return for their investment, thereby encouraging their participation. Methods for determining economic values are well established and can be useful in informing long-term policy, and they could provide potential traders with additional information on the benefits that they may derive from participation in trading. Other than the generated credits for sale, other returns may also add value for the seller, thereby promoting WQT. Ironically, the non-market value of ecosystem components is considered less important unless and until natural events occur that make value more "real" to residents within a watershed. For example, fish kills in the Neuse and Tar-Pamlico provided the impetus for bringing about changes in how those watersheds are managed. Likewise, flooding in the wake of hurricanes Katrina and Rita raised the profile of the utility of levees and dikes and coastal wetlands that protect the shores of Louisiana.
- ***Economic Analysis Tools:*** Many economic analysis tools already exist and they could be applied specifically to WQT. These tools include: economic investment decision methods, which could employ techniques for calculating DCFROI to demonstrate long-term value of WQT and support decisions of potential WQT participants; and probabilistic analysis, which would allow a thorough evaluation of risk. For example, World Resource Institute's "Nutrient Net" allows PS and NPSs to evaluate cost-benefits of trading specific to their watershed application. Such analyses could be used to compare the value of wetlands versus other BMPs. If regulators develop platforms for performing this type of analysis, then individuals can use them to perform their own analyses of the risks and opportunities associated with participation.

With respect to risk, credit prices in WQT programs have not tended to be structured to compensate sellers for their risk in implementing BMPs and engaging in WQT, presumably because the opportunity to create private value is substantial relative to the risk to engage in activities for the purpose of improving water quality. For example, in Idaho, while the NPSs were not driven by regulation, they recognized the opportunity to improve their property free of charge without acknowledging measurability of their loads. In ideal markets, investors build their cost of risk into the price of their goods and services. Not pricing credits to include the cost of investor risk might be an important reason that WQT supply and trading are suppressed if the NPS feel they are not getting enough of a return for their risk. Likewise, not pricing credits to include the opportunities associated with investor risk might also suppress WQT supply. At a minimum, efforts to increase the awareness of the value generated beyond credit prices, e.g., market and non-market economic valuations, may increase the attractiveness of participating in trading to potential credit sellers. Complicating matters, credit prices are also affected by investor risk, and opportunities on the supply curve will influence the intersection with the demand curve.

Prices of credits will re ect risk if the market is allowed to function without too many restrictions.

10.7 Property Rights and Transfer of Liability

WQT programs have taken different approaches to issues associated with property rights and transfer of liability. In all cases, NPDES liability remains with the PS discharger. However, the question of who would be contractually liable if a BMP project fails is addressed slightly differently in each of the WQT programs included in the case studies. In the Cherry Creek, Rahr, and Idaho programs, the credit purchaser is not offered a release from liability if the mitigation is ineffective and may be faced by the need to continuously monitor and maintain the mitigation measures implemented to generate credits. In the Tar-Pamlico and Neuse programs, a third party takes on the liability for BMP maintenance.

The transfer of liability from the credit purchaser to the third-party mitigator was identified as critical to making wetland mitigation banking work: credit purchasers are interested in rapid permitting and avoidance of liability if a mitigation site fails; creating healthy wetlands is secondary to the decision to purchase nutrient credits from the mitigation bank. The lingering liability attached to trades in the first three programs exposes the buyer to risk. Making a nutrient trade does not eliminate the possibility that the same discharge issue could arise again some time in the future. As a result, the unknown risk associated with trading plus additional costs and logistics associated with monitoring BMPs implemented on the credit seller's property make WQT less attractive to PSs.

As previously discussed, many trading programs put time limits on the useful life of credits. If a wetland has been restored or enhanced to generate credits for a WQT trading program, there may be regulatory implications associated with what happens to the wetland after the credits expire. The wetland could become regulated under the CWA, thereby limiting potential uses of the land. This could serve as a deterrent to using constructed wetlands as a BMP in WQT programs. There may also be implications to drinking water supply issues. If the USEPA and states would like to encourage the use of constructed wetlands in WQT programs, then the long-term regulatory implications of building constructed wetlands to generate credits for WQT programs will need to be clarified.

11.0 Research Recommendations

The literature review and case studies in this report illustrate the need for additional research for WQT programs to successfully integrate NPS nutrient load reduction through the use of constructed wetlands. Specific research topics are grouped into three categories that mirror the structure of the study: (1) technical research needs, (2) economic research needs, and (3) regulatory and administrative research needs. Many of the specific recommendations integrate components across the range of these categories.

11.1 Technical Research Needs

While several examples illustrate the feasibility of WQT programs involving wetland creation for NPS trades, there are several elements of such programs where uncertainty is mitigated by applying conservative factors of safety. The case studies illustrate that in practice, program participants presume it is more cost-effective to create larger wetlands than to directly measure the effectiveness of the constructed wetland. These areas of uncertainty present opportunities for improving trading program efficiency and economic viability.

There are two distinct areas of uncertainty associated with the performance of wetlands in reducing NPS nutrient loads. The first involves the ability to quantify the performance of a discrete wetland in reducing nutrient load. Many factors influence nutrient removal efficiency, and these factors relate to one another in complex ways. The dynamic nature of the system compounds these complexities. The second area of uncertainty involves the ability to translate nutrient load reductions spatially throughout a watershed.

11.1.1 Individual Wetland Performance

Some trading programs concluded that performance monitoring was either not feasible or prohibitively costly to the degree that it was more cost-effective to grossly oversize the wetlands to overcome uncertainty about performance. Literature does not reflect a compilation of the abundance of scientific information pertaining to the function of various types of wetlands in removing nutrients into a comprehensive tool that can be used to consistently and confidently design or determine the performance of constructed wetlands in reducing nutrient loads. This limitation does not prevent NPS nutrient trades involving wetlands. Instead of precisely determining the load reduction associated with wetland creation, the uncertainty associated with estimating techniques is mitigated by incorporating safety factors. This approach greatly multiplies the amount of wetland required to ensure the necessary performance. Several possible research topics emerge to address uncertainty in wetland performance:

- Define the minimum performance monitoring data requirements to determine water quality credits and determine the optimum distance downstream of the wetland for monitoring. Accordingly, collect data to satisfy these data requirements for a few pilot projects to validate presumed load reductions.
- Collect performance data documenting the effect of various maintenance activities on prolonging optimal performance in removing nutrients. Determine the deterioration of performance with time in the absence of maintenance.
- Gather additional data on the cyclical and long-term trajectory of nutrient removal by various types of constructed and restored wetlands.
- Compile scientific information pertaining to the function and effectiveness of various types of wetlands in removing nutrients and the long-term trajectory of nutrient removal over time. Use these data to create a comprehensive tool that can be used to assess the many interrelated factors affecting wetland performance. Such a tool would provide confidence in designing or determining the performance of constructed wetlands in reducing nutrient loads. This information would also facilitate nutrient removal modeling and aid calculation of nutrient credits.
- Perform additional literature review and analysis focused on the effects of seasonality on the nutrient removal efficiency of wetlands. Consider the reliability of annual nutrient removal to suitably reflect wetland performance.
- Perform additional literature review and analysis to comprehensively assess the variability of nutrient removal by ecoregion.

- Research effects of atmospheric deposition of nutrients, particularly NOx, and how to incorporate them into wetland design.
- Determine the effect of inflow nutrient concentration on removal efficiency of various BMPs. Does nutrient removal efficiency of a BMP change as the concentration of nutrients in the inflowing water increases or decreases? How do upland land uses affect pollutant inputs? Are some BMPs better than others for removing nutrients at higher or lower concentrations?
- Develop better models, methods, and tools to cost-effectively predict and monitor performance of nutrient removal BMPs to eliminate having to measure performance to generate credits and to allow for design flexibility.
- Gain insight into how to optimally locate a wetland within the landscape and into how an existing wetland's location affects its utility as a nutrient reducer with which to trade credits and thus the value of those credits. Administrators could then assemble a list of potential sites from which PSs seeking an NPS trading partner could choose. Additionally, the design and performance would benefit from this insight.
- Conduct research on the long-term fate of nutrients removed using constructed wetlands.
- Refine the current body of knowledge on transmission losses and uptake capacity of nutrients between the trading partners. Develop standard methods for discounting credits as the distance between the buyer and seller increases and as the distance of the BMP from the water body increases. This would help administrative bodies to ensure that localized water quality impacts do not occur as a result of a trade and determine whether "total mass" caps for PSs need to be set to prevent localized impacts.
- Refine methods to accurately account for differences in constituent speciation or even the type of constituent. The inability to do so results in overwhelmingly conservative safety factors, which can stifle trading or at least limit trading participants.
- Review how land-based accounting methods were developed and assess their relative accuracy compared to direct measurement. Determine the key areas of uncertainty and design research programs to address them.
- Establish quality assurance/quality control of monitoring.

11.1.2 Watershed-Scale System Dynamics

Describing the integration of multiple PSs and NPSs and transport processes requires sophisticated tools. Characterization of spatial and temporal effects on nutrient loads is necessary to evaluate and document the effectiveness of transferring load reductions in time and space. Such comprehensive evaluations on system performance should consider the effects on other stressors and their impacts, e.g., the fate and transport of residual contaminants in the wetlands. Likewise, performance should assess the sensitivity of operational and engineering parameters on nutrient removal and, more generally, on ecosystem integrity. This knowledge is necessary to ensure that WQT contributes to meeting watershed-scale water quality management objectives without unduly compromising local water quality or introducing undesirable temporal effects.

SDA can facilitate the success of WQT by reducing uncertainty and quantifying risk. The capabilities of this tool to evaluate the complex events and phenomena inherent in many systems are critical to achieving a thriving WQT market that is protective of the environment. SDA provides the platform to account for risk by (1) thoroughly modeling and analyzing complexity, (2) minimizing assumptions and simplistic functions, (3) allowing flexibility in time and space, (4) allowing a stress test of baseline conditions, (5) facilitating sensitivity analyses, (6) modeling complicated feedback relations, and (7) allowing model upgrades to best available science, as better knowledge and information become available. This approach establishes expected values for each model input and the expected value of a given strategy. With SDA, conservative contingency factors and trading ratios are minimized or obsolete. For example, trading ratios are replaced with analyzed values that represent break-even values; i.e., ratios which realistically balance nutrient loads into a watershed, for regulators. SDA is a very effective tool for evaluating how complex systems will behave as a result of change. This tool can provide insight into how factors interrelate. Ultimately, data for specific watersheds could be inputted, with literature values substituting for unknown data, into a general SDA model.

11.2 Economic Research Needs

The following economic research recommendations focus on determining value and risk associated with strategies that use wetlands to reduce nutrient loads.

- Perform complete economic valuations of strategic alternatives that involve WQT and develop tools that potential trading participants could use to quantify the value of investing in WQT as a nutrient management strategy of choice. Include environmental uncertainties in economic models for such valuations.

- Determine the interaction of factors hindering participation in a WQT market; e.g., cost-prohibitive discount ratios, unlikelihood of enforcement, lack of incentives, or fear of future liability. Use comprehensive understanding of the system and clearer guidelines to overcome these challenges.
- Quantify supply-demand curves and factors affecting them. Use this information to determine whether a WQT market is a viable solution in a de-regulated environment.
- Search for evidence of free market applications of WQT. If available, compare benefits and challenges with regulated case studies reviewed for this report.
- Identify additional economic incentives for BMPs when credits are not available (e.g., budgeting payments during seasonal needs for nutrient reduction) that would foster NPS participation.
- Assess viability of designing wetlands in advance and banking credits to meet daily and monthly needs.
- Investigate the feasibility of making trading credits available for multiple environmental amenities (e.g., water quality, endangered species, ood control) provided by BMPs such as restored or constructed wetlands. This would need to be supported by thorough public market valuations for the functioning BMPs over time. Integrating multiple concurrent ecological values enhances the opportunity to improve the returns credit sellers are able to make by building BMPs on their property and the opportunity costs associated with not using that land for other purposes. The implementation of the 2007 Farm Bill will test the feasibility of using Federal funds towards BMPs for credit generation.
- Evaluate cost effectiveness of the wetlands design. Compare the effectiveness of more, but smaller, wetlands versus fewer, but larger, wetlands. Include among the various costs, those associated with monitoring and maintaining the wetlands.
- Research how considerations of scale affect economic decisions and how related uncertainties can be addressed.
- Probe the sociological drivers affecting entry into the market and evaluate the feasibility of incorporating these into economic models.
- Identify lower-cost engineering solutions for constructed and restored wetland design and maintenance.

11.3 Regulatory and Administrative Research Needs

Regulations and policies steer the administration and performance of WQT programs, sometimes in unforeseen or undesirable ways. The following research recommendations anticipate some such effects and target administrative steps or tools that could contribute to the success of WQT programs.

- Optimize models for the administration of WQT programs to conform to the Paper Reduction Act and investigate opportunities to minimize transaction costs.
- Provide protocol for minimum rules of engagement to specify interaction between programs and organizations. Develop guidelines based on science and lessons learned.
- Develop a simple, but rigorous audit plan to formally track WQT and BMP implementation and compliance.
- Assess federal and state compliance-based and voluntary programs to control NPS nutrient loads and evaluate program performance, participation levels, and overall success. Develop recommendations for how to improve NPS participation in WQT and quantitatively track existing BMPs in TMDL settings. Currently, the level of NPS regulation and enforcement shifts WQT from being a true market and forces buyers to provide some other incentive (e.g., financial compensation, improved property) to encourage participation of NPSs.
- Perform additional research on gaming risks and how watershed management plans in general and WQT programs specifically can be designed to significantly increase the potential cost of this compliance strategy.
- Investigate the regulatory feasibility of sharing liability between PS, NPS, and/or a third party, and the impact that may have on entry into the WQT market.

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Appendix A
Annotated Bibliography

#	Title	AAA Author	Pub. Date	Type	Publisher	Comments
1	Managing the Brisbane River and Moreton Bay: An Integrated Research/Management Program to Reduce Impacts on an Australian Estuary.	Abal, E.G., W.C. Dennison, and P.F. Greenfield	2001	Paper	Water Sci Technol. 2001;43(9):57-70. PMID: 11419140	This report describes results of an interdisciplinary study of Moreton Bay to examine the link between sewage and diffuse loading with environmental degradation. The study includes examination of runoff and deposition of fine-grained sediments, sewage-derived nutrient enrichment, blooms of a marine cyanobacterium, and seagrass loss. The study framework illustrates a unique integrated approach to water quality management whereby scientific research, community participation and the strategy development were done in parallel with each other. This collaborative effort resulted in a water quality management strategy which focuses on the integration of socioeconomic and ecological values of the waterways.
2	Biomass Production and NPK Retention in Macrophytes from Wetlands of the Tingitan Peninsula	Abdeslam Ennabili, Mohammed Ater and Michel Radoux	Sep-98		Aquatic Botany; 62(1): 45-56. Sept. 1, 1998.	
3	Hydrologic Performance of a Large-Scale Constructed Wetland: The Everglades Nutrient Removal Project	Abtew, Wossenu and Tim Bechtel	Aug-01	Conference Proceeding Paper Abstract	Wetlands Engineering & River Restoration 2001, Proceedings of the 2001 Wetlands Engineering & River Restoration Conference, August 27-31, 2001, Reno, Nevada. Section 36, Chapter 1 .	This paper summarizes the hydrologic performance, mass balance and treatment efficiency of one of the largest constructed wetlands in the world.
4	Ecological Issues Related to N Deposition to Natural Ecosystems: Research Needs	Adams, Mary Beth	Jun-03		Environment International; 29(2-3): 189-199. June 2003.	
5	Nutrient Partitioning in a Clay-based Surface Flow Wetland	Adcock, P.W., G. L. Ryan and P. L. Osborne	1995		Water Science and Technology; 32(3): 203-209. 1995.	
6	Hydrologic Regime Controls Soil Phosphorus Fluxes in Restoration and Undisturbed Wetlands	Aldous, Allison, Paul McCormick, Chad Ferguson, Sean Graham, and Chris Craft	Jun-05	Abstract	Restoration Ecology; 13(2): 341. June 2005.	Many wetland restoration projects occur on former agricultural soils that have a history of disturbance and fertilization, making them prone to phosphorus (P) release upon ooding. We conclude that maintaining moist soil is the means to minimize P release from recently ooded wetland soils. Alternatively, prolonged ooding provides a means of liberating excess labile P from former agricultural soils while minimizing continued organic P mineralization and soil subsidence.
7	Framework for Surface Water Quality Management on a River Basin Scale: Case Study of Lake Iseo, Northern Italy	Al-Khudhairy, D. H. A., A. Bettendrof-fer, A. C. Cardoso, A. Pereira, and G. Premazzi	Jul-01	Paper	Lakes and Reservoirs: Research and Management: 6(2): 103-115. July 2001.	
8	South Nation Watershed Phosphorus Algorithm Report Phase II	Allaway, Chris (B.Sc.)	Jan-03	Paper	South Nation Conservation Clean Water Committee	
9	Proceedings of a Conference on Wetlands for Wastewater Treatment and Resource Enhancement	Allen, G.H. and R.H. Gearheart	1988		Humbolt Sate University, Arcata, CA	

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10	Treatment of Domestic Wastewater by Subsurface Flow Constructed Wetlands in Jordan	Al-Omari, Abbas and Manar Fayyad	May-03		Desalination; 155(1): 27-39. May 30, 2003.	
11	South Nation River Conservation Authority: What has 57 years of Watershed Management and Multi-Million Dollar Watershed Plans Taught Us?	American Society of Agricultural and Biological Engineers, St. Joseph, Michigan www.asabe.org	2004		American Society of Agricultural and Biological Engineers, St. Joseph, Michigan. www.asabe.org	http://asae.frymulti.com/abstract.asp?aid=16399&t=2
12	The Effects of Bird Use on Nutrient Removal in a Constructed Wastewater-Treatment Wetland	Andersen, Douglas C., James J. Sartoris, Joan S. Thullen, and Paul G. Reusch	Sep-02	Abstract	Wetlands; 23(2): 423-425. September 2002.	This case study supports the concept that a constructed wetland can be designed both to reduce nutrients in municipal wastewater and to provide habitat for wetland birds.
13	Temporal and spatial development of surface soil conditions at two created riverine marshes	Anderson, C.J., W.J. Mitsch, R.W. Nairn	Nov-Dec-05		Journal of Environmental Quality; 34(6): 2072-2081. Nov-Dec 2005.	
14	Temporal Export of Nitrogen from a Constructed Wetland: In uence of Hydrology and Senescing Submerged Plants	Ann-Karin Thorén, Catherine Legrand, and Karin S. Tonderski	Dec-04		Ecological Engineering; 23(4-5): 233-239. Dec 30, 2004.	
15	Modelling Nitrogen Removal in Potential Wetlands at the Catchment Scale	Arheimer, Berit and Hans B. Wittgren	Jul-02		Ecological Engineering; 19(1): 63-80. July 2002.	
16	Oxygen diffusion from the roots of some British bog plants	Armstrong, W.	1964		Nature 204:801-802. 2004	
17	SWRRB: A Basin Scale Simulation Model for Soil and Water Resources Management	Arnold, J.G., J.R. Williams, A.D. Nicks, and N.B. Sammons	1990		Texas A&M Univ. Press. College Station, TX.	
18	Latitudinal characteristics of below- and above-ground biomass of Typha: a modelling approach	Asaeda, T., D.N. Hai, J. Manatunge, D. Williams, and J. Roberts	Aug-05		Annals of Botany; 96(2): 299-312. Aug 2005.	
19	Microbial Ecology: Fundamentals and Application	Atlas, R.M. and R. Bartha	1981		Addison-Wesley, Reading, MA.	
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21	Update on the Tradable Loads Program in the Grassland Drainage Area	Austin, S.	Aug-99	Paper		
22	Treatment of Wastewater by Natural Systems	Ayaz, Selma Ç. and Lütfi Akça	Jan-01		Environment International; 26(3): 189-195. January 2001.	
23	Denitrification in Constructed Free-water Surface Wetlands: I. Very High Nitrate Removal Rates in a Macrocosm Study	Bachand, Philip A.M. and Alex J. Horne	Sep-99		Ecological Engineering; 14(1-2): 9-15. September 1999.	

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24	Denitrification in Constructed Free-water Surface Wetlands: II. Effects of Vegetation and Temperature	Bachand, Philip A.M. and Alex J. Horne	Sep-99		Ecological Engineering; 14(1-2): 17-32. September 1999.	
25	Holding the Line: Tampa Bay's Cooperative Approach to Trading	Bacon, E. and H. Greening	May-98	Presentation	Watershed '98 – Moving from Theory to Implementation. Denver, CO.	
26	Nutrients and Zooplankton Composition and Dynamics in Relation to the Hydrological Pattern in a Confined Mediterranean Salt Marsh (NE Iberian Peninsula)	Badosa, Anna, Dani Boix, Sandra Brucet, Rocío López-Flores, and Xavier D. Quintana	Feb-06		Estuarine, Coastal and Shelf Science; 66(3-4): 513-522. February 2006.	
27	Nitrogen mineralization processes of soils from natural saline-alkalined wetlands, Xianghai National Nature Reserve, China	Bai, J., W. Deng, Q. Wang, H. Chen, C. Zhou	Aug-05		Canadian Journal of Soil Science; 85(3): 359-367. Aug 2005.	
28	Spatial variability of nitrogen in soils from land/inland water ecotones	Bai, J., W. Deng, Y. Zhu, and Q. Wang	2004		Communications in Soil Science and Plant Analysis; 35(5-6): 735-749. 2004.	
29	Spatial Distribution Characteristics of Organic Matter and Total Nitrogen of Marsh Soils in River Marginal Wetlands	Bai, Junhong, Hua Ouyang, Wei Deng, Yanming Zhu, Xuelin Zhang, and Qinggai Wang	Jan-05		Geoderma; 124(1-2): 181-192. Jan 2005.	
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32	Potential nitrification and denitrification on different surfaces in a constructed treatment wetland	Bastviken, S.K., P.G. Eriksson, I. Martins, J.M. Neto, L. Leonardson, and K. Tonderski	Nov-Dec-03		Journal of Environmental Quality; 32(6): 2414-2420. Nov-Dec 2003.	
33	GLTN Comments to the EPA on Proposed Changes to the NPDES Program	Batchelor, David J. (Chair)	Jan-99	Letter to Comment Clerk		
34	Growth of Phragmites australis (Cav.) Trin ex. Steudel in Mine Water Treatment Wetlands: Effects of Metal and Nutrient Uptake	Batty, Lesley C. and Paul L. Younger	Nov-04		Environmental Pollution; 132(1): 85-93. Nov 2004.	

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36	Progress in the Research and Demonstration of Everglades Periphyton-based Stormwater Treatment Areas	Bays, J.S., R.L. Knight, L. Wenkert, R. Clarke, and S. Gong	2001		Water Science Technology; 44(11-12):123-30. 2001.	
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38	Incentives For Environmental Improvement: An Assessment Of Selected Innovative Programs In The States And Europe	Beardsley, Daniel P.	Aug-96	Report	Global Environmental Management Initiative	http://www.gemi.org/IDE_003.pdf
39	Feasibility of Using Ornamental Plants (Zantedeschia aethiopica) in Subsurface Flow Treatment Wetlands to Remove Nitrogen, Chemical Oxygen Demand and Nonylphenol Ethoxylate Surfactants: A Laboratory-Scale Study	Belmont, Marco A. and Chris D. Metcalfe	Dec-03		Ecological Engineering; 21(4-5): 233-247. Dec 31, 2003.	
40	Treatment of Domestic Wastewater in a Pilot-scale Natural Treatment System in Central Mexico	Belmont, Marco A., Eliseo Cantellano, Steve Thompson, Mark Williamson, Abel Sánchez, and Chris D. Metcalfe	Dec-04		Ecological Engineering; 23(4-5): 299-311. Dec 30, 2004.	
41	Updates to Stormwater BMP Efficiencies	Bennett, Bradley and Rich Gannon	Sep-04	Memo	Memorandum to Local Programs, Neuse and Tar-Pamlico Stormwater Rules, NC Division of Water Quality	Memo notifying the Neuse and Tar-Pamlico Stormwater Programs of new nutrient removal efficiencies for Stormwater BMPs.
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44	pH, redox, and oxygen microprofiles in rhizosphere of bulrush (Scirpus validus) in a constructed wetland treating municipal wastewater	Bezbaruah, A.N.and T.C. Zhang	Oct-04		Biotechnology and Bioengineering; 88(1): 60-70. Oct. 5, 2004.	

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46	N storage and cycling in vegetation of a forested wetland: implications for watershed in processing	Bischoff, J.M., P. Bukaveckas, M.J. Mitchell, and T. Hurd	May-01		Water, Air, and Soil Pollution; 128(1-2): 97-114. May 2001.	
47	Evaluation of Past and Potential Phosphorus Uptake at the Orlando Easterly Wetland	Black, Courtney A. and William R. Wise	Dec-03		Ecological Engineering; 21(4-5): 277-290. Dec 31, 2003.	
48	The effects of varied hydraulic and nutrient loading rates on water quality and hydrologic distributions in a natural forested treatment wetland	Blahnik, T. and J. Day, Jr.	Mar-00		Wetlands : the journal of the Society of the Wetlands Scientists. Mar 2000. v. 20 (1) p. 48-61.	
49	Nitrogen as a Regulatory Factor of Methane Oxidation in Soils and Sediments	Bodelier, Paul L. E. and Hendrikus J. Laanbroek	Mar-04		FEMS Microbiology Ecology; 47(3): 265-277. Mar 15, 2004.	This paper summarises and balances the data on the regulatory role of nitrogen in the consumption of methane by soils and sediments with the intent of stimulating the scientific community to embark on experiments to close the existing gap in knowledge regarding the role of nitrogen in methan oxidation in soils and sediments. http://www.blackwell-synergy.com/doi/abs/10.1016/S0168-6496(03)00304-0
50	Hydraulic tracer study in a free-water surface ow constructed wetland system treating sugar factory wastewater in Western Kenya	Bojcevska, H.	2005		IFM/Department of Biology, University of Linköping, Linköping, Sweden.	http://www.ifm.liu.se/~inuita/researchproposal_tracerstudy.doc
51	Pollutant Removal Capability of a Constructed Melaleuca Wetland Receiving Primary Settled Sewage	Bolton, Keith G.E. and Margaret Greenway	Mar-99		Water Science and Technology; 39(6): 199-206. March 1999.	
52	Metabolism of Compounds with Nitrofunctions by Klebsiella pnuemoniae Isolated from a Regional Wetland	Boopathy, Ramaraj and Earl Melancon	Dec-04		International Biodeterioration & Biodegradation; 54(4): 269-275. Dec 2004.	
53	Controlled drainage and wetlands to reduce agricultural pollution: a lysimetric study	Borin, M., G. Bonaiti, and L. Giardini	Jul-Aug-01		Journal of environmental quality. July/Aug 2001. v. 30 (4) p. 1330-1340.	
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55	Nutrient Removal from Ef uents by an Artificial Wetland: In uence of Rhizosphere Aeration and Preferential Flow Studied Using Bromide and Dye Tracers	Bowmer, Kathleen H.	May-87		Water Research, Volume 21, Issue 5, May 1987, Pages 591-599	
56	Salinity & Nutrient Trading in Australia	Brady, Katy	3/16-18/2004	Presentation	New South Wales Environment Protection Authority, Australia	http://www.inece.org/emissions/brady.pdf

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57	Factors Affecting Nitrogen Retention in Small Constructed Wetlands Treating Agricultural Non-Point Source Pollution	Braskerud, B.C.	Jan-02		Ecological Engineering; 18(3): 351-370. January 2002.	
58	The impact of hydraulic load and aggregation on sedimentation of soil particles in small constructed wetlands	Braskerud, B.C., H. Lundekvam, and T. Krogstad	Nov-Dec-00		Journal of environmental quality. Nov/Dec 2000. v. 29 (6) p. 2013-2020.	
59	Restoration of Lake Borrevannet - Self-purification of Nutrients and Suspended Matter through Natural Reed-belts	Bratli, J.L., A. Skiple and M. Mjelde	1999		Water Science and Technology, Volume 40, Issue 3, 1999, Pages 325-332	
60	A Mass Balance Method for Assessing the Potential of Artificial Wetlands for Wastewater Treatment	Breen, Peter F.	Jun-90		Water Research, Volume 24, Issue 6, June 1990, Pages 689-697	
61	Water Quality Trading and Offset Initiatives in the U.S.: A Comprehensive Survey*	Breetz, Hanna L. and Karen Fisher-Vanden, Laura Garzon, Hannah Jacobs, Kailin Kroetz, Rebecca Terry	Aug-04	Paper	http://www.dartmouth.edu/~kfv/waterqualitytradingdatabase.pdf	*This research was supported by the US Environmental Protection Agency and the Rockefeller Center at Dartmouth College. Corresponding author: 6182 Steele Hall, Hanover, NH 03755; phone: 603-646-0213; email: kfv@dartmouth.edu Summarizes waterquality trading and offset initiatives in the U.S., including state-wide programs and recent proposals. The document provides background information on each program and provides specific information on each program for the following categories: trade structure (determination of credit, trading ratios and other mechanisms to deal with uncertainty, liabilities/penalties for non-complinace, approval process, ex post-verification/auditing, machanisms for trade identification and communication, market structure and types of trades allowed); outcomes (types and volumes of trades that have occured, adminiatrative costs, transaction costs, cost savings, program goals achieved, program obstacles, MPS inolvement and incentives to engage in trading, and other); and program/information references.
62	A comparison of nutrient availability indices along an ombrotophic-minerotrophic gradient in Minnesota wetlands	Bridgham, S.D., K. Updegraff, and J. Pastor	Jan-Feb-01		Soil Science Society of America journal. Jan/Feb 2001. v. 65 (1) p. 259-269.	
63	Application of Wastewater to Wetlands	Brinson, M.M. and F.R. Westall	1983	Report	Rept. #5, Water Research Inst., Univ. of North Carolina, Raleigh, NC	
64	Nutrient Assimilative Capacity of an Alluvial Floodplain Swamp	Brinson, M.M., H.D. Bradshaw, and E.S. Kane	Dec-84		Journal of Applied Ecology Vol. 21, No. 3, p 1041-1057, December, 1984. 9 Fig, 2 Tab, 45 Ref. OWRT project B-114-NC.	The capacity of the swamp for nutrient removal was highest for nitrate, intermediate for ammonium, and lowest for phosphate. Annual drydown of sediments would be required for sustained ammonium removal in swamps with prolonged ooding, as in this case. It appears that swamps of this type could be managed for inorganic nitrogen removal from sewage ef uent, but their usefulness for tertiary treatment of phosphate is limited by the capacity of sediments for phosphorus storage.
65	Gas Exchange through the Soil-atmosphere Interphase and through Dead Culms of Phragmites australis in a Constructed Reed Bed Receiving Domestic Sewage	Brix, H.	Feb-90		Water Research, Volume 24, Issue 2, February 1990, Pages 259-266	

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66	Treatment of Wastewater in the Rhizosphere of Wetland PlantsùThe Root Zone Method	Brix, H.	1987		Water Sci Technol., 19:107-118	
67	Root-zone acidity and nitrogen source affects Typha latifolia L. growth and uptake kinetics of ammonium and nitrate	Brix, H., K. Dyhr-Jensen, and B. Lorenzen	Dec-02		Journal of experimental botany. Dec 2002. v. 53 (379) p. 2441-2450.	
68	The Use of Vertical Flow Constructed Wetlands for On-site Treatment of Domestic Wastewater: New Danish Guidelines	Brix, Hans and Carlos A. Arias	Dec-05		Ecological Engineering; 25(5):491-500.Dec. 1, 2005.	
69	Denitrification in a Natural Wetland Receiving Secondary Treated Ef uent	Brodrick, Stephanie J., Peter Cullen and W. Maher	Apr-98		Water Research, Volume 22, Issue 4, April 1988, Pages 431-439	
70	Watershed Permitting in North Carolina: NPDES Permit NCC000001 Became Effective Jan 1, 2003, Neuse River Compliance Association	Brookhart, Morris	2003	Powerpoint	Presented at the National Forum on Water Quality Trading, Chicago, IL, July 22-23, 2003. Retrieved Dec. 12, 2005 from www.epa.gov/owow/watershed/trading/brookhart.ppt	
71	Watershed Permitting to Increase Efficiency and Facilitate Trading	Brookhart, Morris	Jul-03	PowerPoint		2003 National Forum on Water Quality Trading
72	Evaluating Constructed Wetlands Through Comparisons with Natural Wetlands	Brown, M.T.	1991		EPA/600\3-91-058. EPA Environmental Research Lab., Corvallis, OR	
73	A Simulation Model of Hydrology and Nutrient Dynamics in Wetlands	Brown, Mark T.	1988		Computers, Environment and Urban Systems, Volume 12, Issue 4, 1988, Pages 221-237	
74	Nutrient Removal and Plant Biomass in a Subsurface Flow Constructed Wetland in Brisbane, Australia	Browning, K. and M. Greenway	2003		Water Science Technology. 2003;48(5): 183-9.	
75	Spatial variability of soil properties in created, restored, and paired natural wetlands	Bruland, G.L. and C.J. Richardson	Jan-Feb-05		Soil Science Society of America journal. 2005 Jan-Feb, v. 69, no. 1, p. 273-284.	
76	Treatment of Potato Processing Wastewater with Engineered Natural Systems	Burgoon, Peter S., Robert H. Kadlec and Mike Henderson	1999		Water Science and Technology, Volume 40, Issue 3, 1999, Pages 211-215	
77	Nitrogen and Phosphorus Removal by Wetland Mesocosms Subjected to Different Hydroperiods	Busnardo, Max J., Richard M. Gersberg, René Langis, Theresa L. Sinicrope and Joy B. Zedler	Dec-92		Ecological Engineering, Volume 1, Issue 4, December 1992, Pages 287-307	

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78	Riparian Alder Fens - Source or Sink for Nutrients and Dissolved Organic Carbon? - 2. Major Sources and Sinks	Busse, Lilian B. and Günter Gunkel	May-02		Limnologica - Ecology and Management of Inland Waters; 32(1): 44-53. May 2002.	
79	The Nitrogen Abatement Cost in Wetlands	Byström, Olof	Sep-98		Ecological Economics, Volume 26, Issue 3, 1 September 1998, Pages 321-331	
80	Economic Criteria for Using Wetlands as Nitrogen Sinks Under Uncertainty	Byström, Olof, Hans Andersson, and Ing-Marie Gren	Oct-00		Ecological Economics, Volume 35, Issue 1, October 2000, Pages 35-45	
81	Defining the Mercury Problem in the Northern Reaches of San Francisco Bay and Designing Appropriate Regulatory Approaches	California Environmental Protection Agency, San Francisco Bay Regional Water Quality Control Board	Jun-98	Draft Staff Report	California Environmental Protection Agency, San Francisco Bay Regional Water Quality Control Board	
82	Pollutant Removal from Municipal Sewage Lagoon Ef uents with a Free-surface Wetland	Cameron, Kimberly, Chandra Madramootoo, Anna Crolla, and Christopher Kinsley	Jul-03		Water Research; 37(12): 2803-2813. July 2003.	
83	Proposed BMPs to be Applied in Trading Demonstration	Carter, David L. (Ph. D., CPAgSSc)	Feb-02	BMP Proposal		
84	Stream Assessment and Constructed Stormwater Wetland Research in the North Creek Watershed	Carter, Melanie Dawn	Mar-05	Ph.D. Dissertation	North Carolina State University, Biological and Agricultural Engineering, URN: etd-03142005-103836	Based on stormwater runoff concerns, two constructed stormwater wetlands (0.3 ac) were designed and installed on the North Creek oodplain. The purpose of this study was to measure stormwater treatment of sediment and nutrients during initial stabilization (three months). Suspended sediment was generated in both wetlands (W1 and W2) during the first two weeks. Total suspended sediment loads were reduced in W2 but not in W1 by the end of the study. Nutrients (TKN, NH_4, NO_3, TP) were all reduced in W1 throughout the study. Ammonium and total phosphorus were generated in W2 throughout the study. Differences between the two wetlands were due to several variables, including the larger sediment and nutrient concentrations entering W2. Polyacrylamide (PAM) was applied to W1 only (15 lb/ac) during hydromulching after construction. The in uence of PAM was not clear, however, due to the numerous different variables between the two wetlands. http://www.lib.ncsu.edu/theses/available/etd-03142005-103836/
85	Mechanisms of nutrient attenuation in a subsurface ow riparian wetland	Casey, R.E., M.D. Taylor, S.J. Klaine	Sep-Oct-01		Journal of environmental quality. Sept/Oct 2001. v. 30 (5) p. 1732-1737.	
86	Effects of static vs. tidal hydrology on pollutant transformation in wetland sediments	Catallo, W.J. and T. Junk	Nov-Dec-03		Journal of environmental quality. 2003 Nov-Dec, v. 32, no. 6, p. 2421-2427.	

#	Title	AAA Author	Pub. Date	Type	Publisher	Comments
87	Developing an Ef uent Trading Program to Address Nutrient Pollution in the Providence and Seekonk Rivers Master's Thesis	Caton, Patricia-Ann	May-02		Center for Environmental Studies Brown University	http://envstudies.brown.edu/Thesis/2002/caton/ includes multiple case studies at the following link: http://envstudies.brown.edu/Thesis/2002/caton/FRAMES/Case%20Study%20Frame.htm
88	Effects of sediment deposition on fine root dynamics in riparian forests.	Cavalcanti, G.G., B.G. Lockaby	May-Jun-05		Soil Science Society of America Journal. 2005 May-June, v. 69, no. 3, p. 729-737.	
89	The Humber Catchment and Its Coastal Area: From UK to European Perspectives	Cave, R.R., L. Ledoux, K. Turner, T. Jickells, J.E. Andrews, and H. Davies	Oct-03	Paper	Sci Total Environ. 2003 Oct 1;314-316:31-52. Review. PMID: 14499525	This paper provides an overview of the current environmental and socio-economic state of the Humber catchment and coastal zone, and broadly examines how socio-economic drivers affect the uxes of nutrients and contaminants to the coastal zone, using the driver-pressure-state-impact-response (DPSIR) approach.
90	The Practice of Watershed Protection: Techniques for Protecting and Restoring Urban Watersheds	Center for Watershed Protection	2000		Center for Watershed Protection	Compilation by the Center for Watershed Protection of 150 articles on all aspects of watershed protection and represents a broad interdisciplinary approach to restoring and maintaining watershed health. Indexed for easy reference, this massive volume is an invaluable reference for anyone interested in the whys and hows of watershed protection practices. http://www.cwp.org/PublicationStore/practice.htm
91	The Performance of a Multi-stage System of Constructed Wetlands for Urban Wastewater Treatment in a Semiarid Region of SE Spain	Cerezo, R. Gómez, M.L. Suárez, and M.R. Vidal-Abarca	Feb-01		Ecological Engineering; 16(4): 501-517. February 1, 2001.	
92	Sewage ef uent discharge and geothermal input in a natural wetland, Tongariro Delta, New Zealand	Chague-Goff, C., M. R. Rosen, and P. Eser	Jan-99		Ecological Engineering, Volume 12, Number 1, January 1999, pp. 149-170(22).	
93	The Use of Wetlands for Water Pollution Control	Chan, E., T.A. Bunsztynsky, N. Hantzsche, and Y.J. Litwin	1981		EPA-600/S2-82-086. EPA Municipal Environmental Research Lab., Cincinnati, OH	
94	Water Quality Impacts of Climate and Land Use Changes in Southeastern Pennsylvania	Chang, Heejun	May-04	Paper	The Professional Geographer, Volume 56, Issue 2, Page 240-257, May 2004	
95	Removal of Endocrine Disruptors by Tertiary Treatments and Constructed Wetlands in Subtropical Australia	Chapman, H.	2003		Water Science Technology. 2003;47(9): 151-6.	
96	Syntrophic-methanogenic associations along a nutrient gradient in the Florida Everglades	Chauhan, A., A. Ogram, and K.R. Reddy	Jun-04		Applied and environmental microbiology. 2004 June, v. 70, no.6, p. 3475-3484.	

#	Title	AAA Author	Pub. Date	Type	Publisher	Comments
97	Chesapeake Bay Program Nutrient Trading Fundamental Principles and Guidelines	Chesapeake Bay Program	Mar-01	Report	Chesapeake Bay Program	This document presents fundamental principles and guidelines for nutrient trading in the Chesapeake Bay Watershed. This document is not a regulation. Rather, it is intended to be used on a voluntary basis as a guide for those Bay jurisdictions that choose to establish nutrient trading programs. The document is based on the Negotiation Team's comprehensive consideration of numerous other trading programs and approaches, substantial research, and corresponding lengthy negotiations.
98	Nutrient Trading in the Chesapeake Bay Watershed, Public Workshop Proceedings (361 KB)	Chesapeake Bay Program	Apr-01	Report	Chesapeake Bay Program	The Chesapeake Bay Program completed a document delineating nutrient trading guidelines entitled Nutrient Trading Fundamental Principles and Guidelines - Draft and made this document available to the public for review on September 8, 2000. A series of public meetings were held during the months of September and October in a variety of locations around the Chesapeake Bay watershed for the purpose of providing the public with an explanation of the meaning and purpose of the trading guidelines, and to give the public a chance to comment on them. This document is a compilation of the public meeting proceedings prepared for each of the 16 public meetings.
99	Nutrient Trading to Maintain the Nutrient Cap in the Chesapeake Bay Watershed (128 KB)	Chesapeake Bay Program	Dec-98	Report	Chesapeake Bay Program	This is the workshop proceedings held on December 14, 1998. Its purpose, as delineated on the agenda (see Appendix I) was to initiate a process to develop nutrient trading policies and guidelines to achieve and maintain the Nutrient Cap in the Chesapeake Bay Watershed.
100	Nutrient Trading for the Chesapeake Bay (109 KB)	Chesapeake Bay Program	Apr-01	Report	Chesapeake Bay Program	This paper addresses the need for nutrient trading in the Chesapeake Bay, the process to develop baywide guidelines, and activities taken elsewhere in the Bay region.
101	Nutrient Trading in the Chesapeake Bay Watershed, Public Comments Summary (286 KB)	Chesapeake Bay Program	Apr-01	Report	Chesapeake Bay Program	Following the release of the Nutrient Trading Fundamental Principles and Guidelines - Draft, sixteen public meetings were collectively held throughout the watershed in each of the signatory jurisdictions. All jurisdictions received numerous public comments during the meetings as well as written comments during the review period. This document is a summary of the comments (both during the public meetings as well as those written) received by the jurisdictions.
102	Endorsement of the Nutrient Trading Fundamental Principles and Guidelines (555 KB)	Chesapeake Bay Program	Mar-01	Executive Council Action	Chesapeake Bay Program	
103	Watershed Risk Analysis Model for TVA's Holston River Basin	Chew, C. W., J. Herr, R. A. Goldstein, F. J. Sagona, K. E. Rylant, and G. E. Hausers	Jul-96	Paper	Water, Air, & Soil Pollution (Historical Archive), Springer Science+Business Media B.V., Formerly Kluwer Academic Publishers B.V. ISSN: 0049-6979 (Paper) 1573-2932 (Online), Volume 90, Numbers 1-2 Pages: 65 - 70	

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104	Seasonal changes of shoot nitrogen concentrations and 15N/14N ratios in common reed in a constructed wetland	Choi, W.J., S.X. Chang, H.M. Ro	2005		Communications in Soil Science and Plant Analysis. 2005, v. 36, no. 19-20, p. 2719-2731.	
105	Nutrient Trading Advocated to Improve Water Quality	Christen, K.	Feb-02	Paper	Environ Sci Technol. 2002 Feb 1;36(3):53A-54A. PMID: 11871571	No abstract available.
106	Dissolved organic nitrogen in contrasting agricultural ecosystems	Christou, M., E.J. Avramides, J.P. Roberts, D.L. Jones	Aug-05		Soil Biology & Biochemistry. 2005 Aug., v. 37, no. 8, p. 1560-1563.	
107	Dimensionless Volatilization Rate for Two Pesticides in a Lake	Ciaravino, Giulio and Carlo Gualtieri	Dec-01	Paper	Lakes and Reservoirs: Research and Management, Volume 6, Issue 4, Page 297-303, Dec 2001	
108	Chemical Characteristics of Soils and Pore Waters of Three Wetland Sites Dominated by Phragmites australis: Relation to Vegetation Composition and Reed Performance	Cikova, Hana, Libor Pechar, t pán Husák, Jan Kv t, Václav Bauer, Jana Radová, and Keith Edwards	Apr-01		Aquatic Botany; 69(2-4): 235-249. April 2001.	
109	Role of Macrophyte Typha latifolia in a Constructed Wetland for Wastewater Treatment and Assessment of Its Potential as a Biomass Fuel	Ciria, M.P., M.L. Solano, and P. Soriano	Dec-05		Biosystems Engineering; 92(4): 535-544. Dec 2005.	
110	Role of macrophyte Typha latifolia in a constructed wetland for wastewater treatment and assessment of its potential as a biomass fuel	Ciria, M.P., M.L. Solano, P. Soriano	Dec-05		Biosystems Engineering. 2005 Dec., v. 92, no. 4, p. 535-544.	http://www.sciencedirect.com/science/journal/15375110
111	Nitrogen Pools and Soil Characteristics of a Temperate Estuarine Wetland in Eastern Australia	Clarke, P.J.	Dec-85		Aquatic Botany, Volume 23, Issue 3, December 1985, Pages 275-290	
112	Water quality changes from riparian buffer restoration in Connecticut	Clausen, J.C., K. Guillard, C.M. Sigmund, and K.M. Dors	Nov-Dec-00		Journal of environmental quality. Nov/Dec 2000. v. 29 (6) p. 1751-1761.	
113	Thermal Load Credit Trading Plan at Rock Creek and Durham wastewater treatment facilities, OR, Clean Water Services	Clean Water Services	Oct-03	Temperature Management Plan	Clean Water Services	
114	Ammonium Oxidation Coupled to Dissimilatory Reduction of Iron Under Anaerobic Conditions in Wetland Soils	Clément, Jean-Christophe, Junu Shrestha, Joan G. Ehrenfeld, and Peter R. Jaffé	Dec-05		Soil Biology and Biochemistry; 37(12): 2323-2328. Dec 2005.	

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115	Search for the Northwest Passage: The Assignation of NSP (non-point source pollution) Rights in Nutrient Trading Programs	Collentine, D.	2002	Paper	Water Sci Technol; 45(9):227-34. 2002. PMID: 12079107	Paper from the Department of Economics, Swedish University of Agricultural Sciences, Uppsala that analyzes the lack of success in nutrient trading programs. Tradable permit solutions are based on an assumption that the assignation of quantifiable rights to both point and nonpoint sources, based on some predetermined ambient water quality measure, is possible. The conclusion here is that there are significant features particular to NSP that hinder the introduction of rights and significantly decrease the utility of tradable permit solutions.
116	Including Non-point Sources in a Water Quality Trading Permit Program	Collentine, D.	2005	Paper	Water Sci Technol; 51(3-4):47-53. 2005. PMID: 15850173	A paper that analyzes the problems with Transferable Discharge Permit (TDP) systems and describes a composite market system that may solve some of the common problems. Problems with TDP systems are transaction costs and in the case of non-point sources (NPS), undefined property rights. The composite market design specifically includes agricultural NPS dischargers and addresses both property rights and transaction cost problems.
117	Setting Permit Prices in a Transferable Discharge Permit (TDP) System for Water Quality Management	Collentine, D.	2005		Paper prepared for presentation at the 99th seminar of the EAAE (European Association of Agricultural Economists), Copenhagen, Denmark August 24-27, 2005	http://www.eaae2005.dk/CONTRIBUTED_PAPERS/S11_250_Collentine.pdf
118	Including Non-point Sources in a Water Quality Trading Permit	Collentine, Dennis	2003		Diffuse Pollution Conference, Dublin 2003	This paper proposes an innovative design for a Transferable Discharge Permit (TDP) system, a composite market system. The composite market design is a proposal for a TDF system, which specifically includes agricultural non-point source (NPS) dischargers and addresses both property rights and transaction cost problems.
119	Economic Modelling of Best Management Practices (BMPs) at the Farm Level	Collentine, Dennis	2002		In Steenvoorden, J.(ed.), Agricultural Effects on Ground and Surface Waters. IAHS Publication no. 273, 17-22.	http://www.envtn.org/docs/EMM_WHITE_PAPERApril04.pdf
120	Restoration of Wetlands from Abandoned Rice Fields for Nutrient Removal, and Biological Community and Landscape Diversity	Comín, Francisco A. , José A. Romero, Oliver Hernández, and Margarita Menéndez	Jun-01	Paper	Restoration Ecology, Volume 9, Issue 2, Page 201-208, Jun 2001	A number of experimental freshwater wetlands with different ages since they were abandoned as rice fields, were used to analyze the prospects of multipurpose wetland restoration for such degraded areas. Nitrogen and phosphorus removal rate of the wetlands was determined monthly during the ooding season to estimate their efficiency as filters to remove nutrients from agricultural sewage. Both the temporal dynamics and changes in the spatial pattern of land use cover during the last 20 years were determined from aerial photographs and field analysis. All the wetlands appeared to be very efficient in the removal of nitrogen and phosphorus exported from rice fields.
121	Nitrogen Removal and Cycling in Restored Wetlands Used as Filters of Nutrients for Agricultural Runoff	Comín, Francisco A., Jose A. Romero, Valeria Astorga and Carmen García	1997		Water Science and Technology, Volume 35, Issue 5, 1997, Pages 255-261	

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122	Comparison of Created and Natural Freshwater Emergent Wetlands in Connecticut (USA)	Confer, S.R. and W.A. Niering	1992		Wetlands Ecology & Management. 2(3):143-156	
123	Watershed Economic Incentives Through Phosphorous Trading and Water Quality, Innovations in Watershed Stewardship	Conservation Authorities of Ontario	Jun-05		Conservation Authorities of Ontario	
124	Reducing Diffuse Pollution through Implementation of Agricultural Best Management Practices: A Case Study	Cook, M.G., P.G. Hunt, K.C. Stone and J.H. Canterberry	1996		Water Science and Technology, Volume 33, Issues 4-5, 1996, Pages 191-196	
125	The Use of a Constructed Wetland for the Amelioration of Elevated Nutrient Concentrations in Shallow Groundwater	Cook, Michael J. and Robert O. Evans	2001		Paper number 012102, 2001 ASAE Annual Meeting . @2001	
126	Anthropogenic landscapes and soils due to constructed vernal pools	Cook, T.D. and K. Whitney	2002		Soil Survey Horizons. Fall 2002. v. 43 (3) p. 83-89.	
127	Use of Constructed Wetland to Protect Bathing Water Quality	Coombes, C. and P. J. Collett	1995		Water Science and Technology, Volume 32, Issue 3, 1995, Pages 149-158	
128	Constructed Wetlands in Water Pollution Control	Cooper, P.F. and B.C. Findlater	1990		IAWPRC. Pergamon Press, Inc., Maxwell House, NY	
129	Water Quality: Implementing the Clean Water Act	Copeland, Claudia (Resources, Science, and Industry Division)	Apr-05	Briefing	CRS Issue Brief for Congress Order Code IB89102	http://www.ncseonline.org/nle/crsreports/05apr/IB89102.pdf
130	Stormwater Permits: Status of EPA's Regulatory Program	Copeland, Claudia (Specialist in Resources and Environmental Policy Resources, Science, and Industry Division)	Feb-05	Briefing	CRS Report for Congress 97-290 ENR	http://www.ncseonline.org/nle/crsreports/05Feb/97-290.pdf
131	Response of biogeochemical indicators to a drawdown and subsequent re ood	Corstanje, R. and K.R. Reedy	Nov-Dec-04		Journal of environmental quality. 2004 Nov-Dec, v. 33, no. 6, p. 2357-2366.	
132	Introduction: Assessing Non-point Source Pollution in the Vadose Zone with Advanced Information Technologies	Corwin, D.L., K. Loague, and T.R. Ellsworth	1999		pg. 1-20. In D.L. Corwin, K. Loague, and T.R. Ellsworth (ed.). Assessment of non-point source pollution in the vadose zone. AGU. Washing ton, D.C.	
133	Removal of Municipal Solid Waste COD and NH4-N by Phyto-reduction: A Laboratory-scale Comparison of Terrestrial and Aquatic Species at Different Organic Loads	Cossu, Raffaell, Ketil Haarstad, M. Cristina Lavagnolo, and Paolo Littarru	Feb-01		Ecological Engineering; 16(4): 459-470. February 1, 2001.	

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134	Preliminary Investigation of an Integrated Aquaculture-wetland Ecosystem Using Tertiary-treated Municipal Wastewater in Los Angeles County, California	Costa-Pierce, Barry A.	Jul-98		Ecological Engineering, Volume 10, Issue 4, July 1998, Pages 341-354	
135	Nutrient Removal from Eutrophic Lake Water by Wetland Filtration	Coveney, M.F., D.L. Stites, E.F. Lowe, L.E. Battoe, and R. Conrow	Aug-02		Ecological Engineering; 19(2): 141-159. Aug 2002.	
136	Rehabilitation of Freshwater Fisheries: Tales of the Unexpected?	Cowx, I. G., M. van Zyll de Jong	Jun-04	Paper	Fisheries Management and Ecology, Volume 11, Issue 3-4, Page 243-249, Jun 2004	
137	Forms and amounts of soil nitrogen and phosphorus across a longleaf pine-depressional wetland landscape	Craft, C.B. and C. Chiang	Sep-Oct-02		Soil Science Society of America journal. Sept/Oct 2002. v. 66 (5) p. 1713-1721.	
138	Removal of metals in constructed wetlands	Crites, R.W., R.C. Watson, and C.R. Willams	1995		In: Proceedings of WEFTEC 1995, Miami, FL. Water Environment Federation, Alexandria, VI.	
139	Comparative Changes in Water Quality and Role of Pond Soil After Application of Different Levels of Organic and Inorganic Inputs	Das, Pratap Chandra, Subanna Ayyappan, and Joykrushna Jena	Jun-05	Paper	Aquaculture Research, Volume 36, Issue 8, Page 785-798, Jun 2005	Changes in water parameters were studied in a yard experiment for 7 weeks after application of cow dung, poultry manure, feed mixture and inorganic fertilizers. To study the role of soil in the mineralization process, each treatment was divided into two groups - one with and the other without soil substrate. Higher degree of changes in water parameters was observed at higher input levels. Both organic amendment and inorganic fertilization caused significant reduction ($P<0.05$) in dissolved oxygen and increase in free CO_2, dissolved organic matter, total ammonia, nitrite, nitrate and phosphorus contents of water. Organic inputs significantly decreased ($P<0.05$) water pH and increased total alkalinity and hardness. In contrast, inorganic fertilization caused a significant increase in pH; alkalinity and hardness increased significantly in the presence of soil, but reduced in its absence. In organic input, presence of soil substrate caused significantly lower value of pH, dissolved oxygen, dissolved organic matter and phosphate-phosphorus and significantly higher free CO_2, alkalinity, hardness, ammonia, nitrite and nitrate contents, compared with those in the absence of soil, revealing enhanced microbial mineralization in the presence of soil.
140	The in uence of organic carbon on nitrogen transformations in five wetland soils	Davidsson, T.E. and M. Stahl	May-Jun-00		Soil Science Society of America journal. May/June 2000. v. 64 (3) p. 1129-1136.	
141	Temporally Dependent C, N, and P Dynamics Associated with the Decay of Rhizophora mangle L. Leaf Litter in Oligotrophic Mangrove Wetlands of the Southern Everglades	Davis, Stephen E., III, Carlos Corronado-Molina, Daniel L. Childers, and John W. Day, Jr.	Mar-03		Aquatic Botany; 75(3): 199-215. March 2003.	

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142	The Use of Wetlands in the Mississippi Delta for Wastewater Assimilation: A Review	Day, J.W., Jr., Jae-Young Ko, J. Rybczyk, D. Sabins, R. Bean, G. Berthelot, C. Brantley, L. Cardoch and W. Conner, et al.	2004		Ocean & Coastal Management; 47(11-12): 671-691. 2004.	
143	Nutrient uxes at the river basin scale. I: the PolFlow model	De Wit, M.	2001		Hydrological Processes 15:743-759.	
144	Nutrient uxes in the Rhine and Elbe basins	De Wit, M.	1999	PhD thesis	Faculty of Geographical Sciences, Utrecht University, Netherlands Geographical Studies:259. The Netherlands.	
145	Nutrient Fluxes in the Po Basin	de Wit, M. and G. Bendoricchio	2001	Paper	Sci Total Environ. 2001 Jun 12;273(1-3):147-61. PMID: 11419598	
146	Removing Muck With Markets: A Case Study on Pollutant Trading for Cleaner Water	DeAlessi, M.	Aug-03	Policy Brief	Reason Foundations	http://rppi.org/pb24.pdf
147	Nitrogen Cycling in Wetlands	DeBusk, W.F.	1999		University of Florida, Institute of Food and Agricultural Science, Gainesville, FL.	
148	Nonpoint Source Pollution Reductions-Estimating a Tradable Commodity	Dedrick, Allen	Jul-03	PowerPoint		2003 National Forum on Water Quality Trading
149	Benefits to Downstream Flood Attenuation and Water Quality As a Result of Constructed Wetlands in Agricultural Landscapes	DeLaney, T.A.	1995		American Farmland Trust	http://www.aftresearch.org/researchresource/caepubs/delaney.html (January 2006).
150	A Screening of the Capacity of Louisiana Freshwater Wetlands to Process Nitrate in Diverted Mississippi River Water	DeLaune, R.D., A. Jugsujinda, J.L.West, C.B. Johnson, and M. Kongchum	Nov-05		Ecological Engineering; 25(4): 315-321. Nov 1, 2005.	
151	The Banking Experience: Environmental Performance Standards & Credit Release	Denisoff, Craig Wildlands, Inc.	7/11-12/2005	Presentation	Audio Recording	
152	The Banking Experience: Environmental Performance Standards & Credit Release	Denisoff, Craig Wildlands, Inc.	7/11-12/2005	Presentation	PowerPoint Presentation	Presented at National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking. Describes framework for establishing banks, including outlines of performance standards, credit release, and monitoring. Draws on information from existing mitigation banks in CA. - http://www2.eli.org/research/wqt_main.htm
153	Economic Instruments for Water Pollution	Department for Environment, Food & Rural Affairs	Sep-99	Report	Department for Environment, Food & Rural Affairs	http://www.defra.gov.uk/environment/water/quality/econinst2/index.htm

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154	Water Pollution Discharges: Economic Instruments	Department for Environment, Food & Rural Affairs	Jan-98	Report	Department for Environment, Food & Rural Affairs	http://www.defra.gov.uk/environment/water/quality/econinst1/index.htm Note: Annex 3 International experience (http://www.defra.gov.uk/environment/water/quality/econinst1/eiwp09.htm)
155	Nitrate dynamics in relation to lithology and hydrologic ow path in a river riparian zone	Devito, K.J., D. Fitzgerald, A.R. Hill, and R. Aravena	Jul-Aug-00		Journal of environmental quality. July/Aug 2000. v. 29 (4) p. 1075-1084.	
156	Submerged Aquatic Vegetation-based Treatment Wetlands for Removing Phosphorus from Agricultural Runoff: Response to Hydraulic and Nutrient Loading	Dierberg, F.E., T.A. DeBusk, S.D. Jackson, M.J. Chimney, and K. Pietro	Mar-02		Water Resources. 2005 Mar;36(6): 1409-22.	
157	Geographic Distribution of Endangered Species in the United States	Dobson, A.P., J.P. Rodrigues, W.M. Roberts, and D.S. Wilcove	1997		Science, 275: 550-555	
158	Economic Analysis as a Basis for Large-Scale Nitrogen Control Decisions: Reducing Nitrogen Loads to the Gulf of Mexico.	Doering O.C., M. Ribaudo, F. Diaz-Hermelo, R. Heimlich, F. Hitzhusen, C. Howard, R. Kazmierczak, J. Lee, L. Libby, W. Milon, M. Peters, and A. Prato	Oct-01	Paper	ScientificWorldJournal. 2001 Oct 23;1 Suppl 2:968-75. PMID: 12805894 [PubMed - indexed for MEDLINE]	Economic analysis can be a guide to determining the level of actions taken to reduce nitrogen (N) losses and reduce environmental risk in a cost-effective manner while also allowing consideration of relative costs of controls to various groups. The biophysical science of N control, especially from nonpoint sources such as agriculture, is not certain. Widespread precise data do not exist for a river basin (or often even for a watershed) that couples management practices and other actions to reduce nonpoint N losses with specific delivery from the basin. The causal relationships are clouded by other factors in uencing N ows, such as weather, temperature, and soil characteristics. Even when the science is certain, economic analysis has its own sets of uncertainties and simplifying economic assumptions. The economic analysis of the National Hypoxia Assessment provides an example of economic analysis based on less than complete scientific information that can still provide guidance to policy makers about the economic consequences of alternative approaches. One critical value to policy makers comes from bounding the economic magnitude of the consequences of alternative actions. Another value is the identification of impacts outside the sphere of initial concerns. Such analysis can successfully assess relative impacts of different degrees of control of N losses within the basin as well as outside the basin. It can demonstrate the extent to which costs of control of any one action increase with the intensity of application of control.
159	Great Lakes Commission Point-Counterpoint on USEPA's Trading Policy	Donahue, Michael J.(Ph.D.)	Mar-Apr 2003		Advisor, Great Lakes Trading Network, March/April 2003Volume 16, No.2	
160	HSPFParm: An Interactive Database for HSPF Model Parameters, Version 1.0	Donigian, A.S., Jr., J.C. Imhoff, and J.L. Kittle, Jr.	1999		EPA-823-R-99-004. U.S. EPA, Washington DC 38pp.	

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161	Modelling Nitrogen Transformations in Freshwater Wetlands: Estimating Nitrogen Retention and Removal in Natural Wetlands in Relation to their Hydrology and Nutrient Loadings	Dørge, Jesper	Sep-94		Ecological Modelling, Volumes 75-76, September 1994, Pages 409-420	
162	Pollution Diffuse et Gestion du Milieu Agricole: Transferts Compares de Phosphore et d'Azote dans un Petit Bassin Versant Agricole: Non-Point Pollution and Management of Agricultural Areas: Phosphorus and Nitrogen Transfer in an Agricultural Watershed	Dorioz, J.M. and A. Ferhi	Feb-94		Water Research, Volume 28, Issue 2, February 1994, Pages 395-410	
163	Phosphorus saturation potential: a parameter for estimating the longevity of constructed wetland systems	Drizo, A., Y. Comeau, C. Forget, R.P. Chapuis	Nov-02		Environmental Science & Technology. Nov 1, 2002. v. 36 (21) p. 4642-4648.	
164	Evaluation of Total Nitrogen Pollution Reduction Strategies in a River Basin: A Case Study	Drolc, A., J.Z. Kondan, and M. Cotman	2001	Paper	Water Sci Technol. 2001;44(6):55-62. PMID: 11700664	In this paper, the methodology of the material ow analysis is presented and applied to develop a nitrogen balance in a river basin and to evaluate different scenarios for total nitrogen pollution reduction. Application of the methodology is illustrated by means of a case study on the Krka river, Slovenia. Different scenarios are considered: the present level of sewerage and treatment capacities, different stages of wastewater treatment and management of agricultural activities on land. The results show that beside ef uents from wastewater treatment plants, agriculture contributes significantly to the total annual nitrogen load. Therefore, in order to protect river water quality and drinking water supply, strategies to manage agricultural nitrogen will be needed in addition to reduction of point sources by means of wastewater collection and implementation of nutrient removal technology.
165	Phosphorus retention and sorption by constructed wetland soils in southeast Ireland	Dunne, E.J., N. Culleton, G. O'Donovan, R. Harrington, K. Daly	Nov-05		Water Research. 2005 Nov., v. 39, issue 18, p. 4355-4362.	
166	The Three Rivers Project--Water Quality Monitoring and Management Systems in the Boyne, Liffey and Suir Catchments in Ireland	Earle, J.R.	2003	Paper	Water Sci Technol. 2003;47(7-8):217-25. PMID: 12793683	
167	Phosphorus Trade Credits for Non-Point Source Projects	Earles, T. Andrew, Wayne F. Lorenz, and Wilbur L. Koger	2005		World Water Congress 2005 Impacts of Global Climate Change World Water and Environmental Resources Congress 2005 Raymond Walton - Editor, May 15–19, 2005, Anchorage, Alaska, USA	http://scitation.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=ASCECP000173040792000214000001&idtype=cvips&gifs=yes Available for purchase
168	Design methdology of free water surface constructed wetlands	Economopoulou, M.A. and V.A. Tsihrintzis	Dec-04		Water Resources Management. 2004 Dec., v. 18, no. 6, p. 541-565.	http://www.kluweronline.com/issn/0920-4741/contents

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169	DUFLOW, a microcomputer package for simulation of one-dimentional unsteady ow and water quality in open channel systems	EDS.	1998		Leidchendam, The Netherlands.	
170	Effective Enforcement and Compliance in the EU ETS: A View from the Financial Sector	Edwards, Rupert	3/16-18/2004	Presentation	Climate Change Capital	http://www.inece.org/emissions/edwards.pdf
171	Performance of Constructed Wetland System for Public Water Supply	Elias, J.M., E. Salati Filho, and E. Salati	2001		Water Science Technology. 2001;44(11-12):579-84.	
172	The Impact of a Riparian Wetland on Streamwater Quality in a Recently Afforested Upland Catchment	Emmett, B.A., J.A. Hudson, P.A. Coward and B. Reynolds	Nov-94		Journal of Hydrology, Volume 162, Issues 3-4, November 1994, Pages 337-353	
173	Nonpoint Source Pollution Control: Breaking the Regulatory Stalemate	Environmental Defense			Environmental Trading Network	
174	Background Information on Water Quality Trading and Wetland Mitigation Banking by the Environmental Law Institute	Environmental Law Institute		Web page	Environmental Law Institute	
175	Water Quality Trading Nonpoint Credit Bank Model	Environmental Trading Network	2003	Paper	National Association of Conservation Districts	http://www.envtn.org/docs/TradingBankModelPaper.doc CREDIT SALE REVENUE SCENARIOS: http://www.envtn.org/docs/TradingBankModel-CreditScenarios.doc
176	Great Lakes Protection Fund - Final Report Market-Based Approach to Ecosystem Improvement - Grant #609	Environmental Trading Network			Environmental Trading Network	http://www.envtn.org/docs/finalGLPFreport.pdf
177	Fertile Ground: Nutrient Trading's Potential to Cost-effectively Improve Water Quality.	Environmental Trading Network	2000	Paper	World Resources Institute, Washington, DC.	Background information for the National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking - http://www2.eli.org/research/wqt_main.htm
178	2002 Cost for Connecticut Nitrogen Trades	Environmental Trading Network	Accessed Jan. 31, 2006	Attachment	Environmental Trading Network	
179	Stormwater Trading Articles	EPA National Risk Management Research Laboratory		Articles	EPA National Risk Management Research Laboratory	
180	Using Tradable Credits to Control Excess Stormwater Runoff	EPA National Risk Management Research Laboratory		Report	EPA National Risk Management Research Laboratory	
181	Prevention of Mosquito Production at an Aquaculture Wastewater Reclamation Plant in San Diego, California using an innovative sprinkler system	Epibare, R., E. Heidig, and D.W. Gibson	1993		In: Bulletin of the Society for Vector Ecology 18(1):40-44.	

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182	Concept Paper for a Nutrient Trading Policy, Revision 5	Eskin, R. and V. Kearney	Aug-97	Paper	Maryland Department of the Environment	
183	Ecological Engineering for Wastewater Treatment	Etnier, C. and B. Guterstam	1991		Bokskogen, Gothenburg, Sweden	
184	Cypress Swamps	Ewel and Odum	1985		University of Florida Press, Gainesville, FL. 1985.	
185	The Potential for Nutrient Trading in Minnesota: The Case of the Minnesota River Valley	Faeth, P.	Feb-98	Draft Report	World Resources Institute	
186	Market-Based Incentive and Water Quality	Faeth, P.	1999	Paper	World Resources Institute	http://www.igc.org/wri/incentives/faeth.html
187	The Use of Water Quality Trading and Wetland Restoration to Address Hypoxia in the Gulf of Mexico	Faeth, Paul World Resources Institute	7/11-12/2005	Presentation	PowerPoint Presentation	
188	Nutrient Runoff Creates Dead Zone	Faeth, Paul and G. Tracy Mehan, III	Jan-05	Paper	WRI Features, Vol. 3, No. 1. World Resources Institute, Washington, DC.	Background information for the National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking - http://www2.eli.org/research/wqt_main.htm
189	A Climate and Environmental Strategy for U.S. Agriculture	Faeth, Paul and Greenhalgh, Suzie	Nov-00	Paper	WRI Issue Brief, World Resources Institute, Washington, DC.	Background information for the National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking - http://www2.eli.org/research/wqt_main.htm
190	Stable Isotope Dynamics of Nitrogen Sewage Ef uent Uptake in a Semi-arid Wetland	Fair, Jeanne M. and Jeffrey M. Heikoop	Oct-05		Environmental Pollution, In Press, Corrected Proof, Available online 4 October 2005	
191	Pollution Trading to Offset New Pollutant Loadings--A Case Study in the Minnesota River Basin	Fang, F. and K.W. Easter	Jul-03	presentation	American Agricultural Economics Association Annual Meeting in Montreal, Canada, July 27-30, 2003	This paper provides a detailed overview of two water pollution trading projects in Minnesota and tries to answer the question: have these two projects been cost-effective and environmentally beneficial? Specific objectives of this paper include: (1) to provide an in-depth examination of the two point-nonpoint source trading projects, (2) to conduct cost effectiveness analysis of the nonpoint source loading reduction practices used in the two projects for trading, (3) to evaluate the role of scientific uncertainty played in these two projects, and (4) to look for other social benefits that such offsetting pollution trading efforts can offer to a watershed.
192	Preliminary Analysis of Water Quality Trading Opportunities in the Great Miami River Watershed, Ohio	Fang, F., M. S. Kieser, D. L. Hall, N. C. Ott, and S. C. Hippensteel	unknown	Paper	American Society of Agricultural and Biological Engineers, St. Joseph, Michigan www.asabe.org	http://asae.frymulti.com/abstract.asp?aid=18044&t=2
193	Point-Nonpoint Source Water Quality Trading: A Case Study in the Minnesota River Basin	Fang, Feng (Andrew), K. William Easter, and Patrick L. Brezonik	2005	Journal Article	Journal of the American Water Resources Association (JAWRA) 41(3):645-658.	

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194	Physical and chemical characteristics of freshwater wetland soils	Faulkner, S.P. and C.J. Richardson	1989		In: Constructed Wetlands for Wastewater Treatment – Municipal, Industrial, and Agricultural. Lewis Publishers, Chelsea, MI.	
195	Wetlands: the lifeblood of wildlife	Feierabend, J.S.	1989		In: D.A. Hammer (ed.) Constructed Wetlands for Wastewater Treatment, Municipal, Industrial and Agricultural. Lewis Publishers, Chelsea, MI.	
196	Seasonal and Storm Event Nutrient Removal by a Created Wetland in an Agricultural Watershed	Fink, Daniel F. and William J. Mitsch	Dec-04		Ecological Engineering; 23(4-5): 313-325. Dec 30, 2004.	
197	Wetland nutrient removal: a review of the evidence	Fisher, J. and M.C. Acreman	Aug-04		Hydrology and earth system sciences. 2004 Aug., v. 8, no. 4, p. 673-685.	http://www.copernicus.org/EGU/hess/published_papers.html
198	Phosphorus ux from wetland soils affected by long-term nutrient loading	Fisher, M.M. and K.R. Reddy	Jan-Feb-01		Journal of environmental quality. Jan/Feb 2001. v. 30 (1) p. 261-271.	
199	Capped and Non-capped Emissions Trading: Applying Lessons from Water Quality Trading	Fisher-Vanden, K. and H. Jacobs, C. Schary	2002	Working paper		
200	The potential role of ponds as buffer zones	Fleischer, S; Joelsson, A; Stibe, L			Quest Environmental, PO BOX 45, Harpenden, Hertfordshire, AL5 5LJ (UK). pp. 140-146. 1997.	Governmental programmes and international agreements to counteract eutrophication have largely not attained agreed goals (e. g. reduction by half of the anthropogenic nitrogen load on Swedish coastal waters, to be carried out between 1985 and 1995). To attain the agreed goal of a 50 percent reduction of the nitrogen transport in streams, decreased agricultural leaching must be combined with extensive pond and wetland construction.
201	Balancing Wildlife Needs and Nitrate Removal in Constructed Wetlands: The Case of the Irvine Ranch Water District's San Joaquin Wildlife Sanctuary	Fleming-Singer, Maia S. and Alexander J. Horne	Nov-05		Ecological Engineering, In Press, Corrected Proof, Available online 28 November 2005	
202	Environmental Laws: Summaries of Statutes Administered by the Environmental Protection Agency	Fletcher, Susan (Coordinator Specialist in Environmental Policy Resources, Science and Industry Division)	Mar-05	Briefing	CRS Report for Congress	http://www.ncseonline.org/nle/crsreports/05mar/RL30798.pdf
203	Nitrate removal in a riparian wetland of the Appalachian Valley and ridge physiographic province	Flite, O.P. III., R.D. Shannon, R.R. Schnabel, and R.R. Parizek	Jan-Feb-01		Journal of environmental quality. Jan/Feb 2001. v. 30 (1) p. 254-261.	

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204	Nitrogen Removal from Domestic Wastewater Using the Marshland Upwelling System	Fontenot, Jeremy, Dorin Boldor, and Kelly A. Rusch	Jan-06		Ecological Engineering, In Press, Corrected Proof, Available online 6 January 2006	
205	Point-Nonpoint Pollutant Trading Study	Fordiani, R.	Jun-96	Presentation	Water Environment Federation and U.S. EPA	Published in Proceedings of Watersheds '96. http://www.epa.gov/owowwtr1/watershed/Proceed/fordiani.html
206	Basinlink	Fox-Wolf Basin 2000	2000	Newsletter	Vol. 2, No.3.	
207	Watershed-Based Trading & The Law: Wisconsin's Experience	Fox-Wolf Basin 2000	2000	Report		http://www.fwb2k.org/research/legalrpt/tradelaw.htm
208	A Test of Four Plant Species to Reduce Total Nitrogen and Total Phosphorus from Soil Leachate in Subsurface Wetland Microcosms	Fraser, Lauchlan H., Spring M. Carty and David Steer	Sep-04		Bioresource Technology; 94(2): 185-192. Sept 2004.	
209	Nitrate Removal by Denitrification in Alluvial Ground Water: Role of a Former Channel	Fustec, E., A. Mariotti, X. Grillo and J. Sajus	Mar-91		Journal of Hydrology, Volume 123, Issues 3-4, March 1991, Pages 337-354	
210	Detritus Processing and Mineral Cycling in Seagrass (Zostera) Litter in an Oregon Salt Marsh	Gallagher, John L., Harold V. Kibby and Katherine W. Skirvin	Oct-84		Aquatic Botany, Volume 20, Issues 1-2, October 1984, Pages 97-108	
211	Design and Construction of Demonstration/Research Wetlands for Treatment of Dairy Farm Wastewater	Gamroth, M.J. and J.A. Moore	Apr-93		EPA/600/R-93/105. EPA Environmental Research Laboratory, Corvallis, OR	
212	The Making of a Regulatory Crisis: Restructuring New York City's Water Supply	Gandy, Matthew	Sep-97	Paper	Transactions of the Institute of British Geographers, Volume 22, Issue 3, Page 338-358, Sep 1997	
213	Ecosystem Structure, Nutrient Dynamics, and Hydrologic Relationships in Tree Islands of the Southern Everglades, Florida, USA	Gann, Tiffany, G.Childers, Daniel L. Troxler, and Damon N. Rondeau	Aug-05		Forest Ecology and Management; 214(1-3):11-27. Aug 2005.	
214	Telephone Interview with Rich Gannon, North Carolina Division of Water Quality	Gannon, Rich	09-Dec-05			
215	WQC Item no. 3 EMC Item no. 03-38 Request for Approval of Local Nitrogen Strategies Tar-Pamlico Agriculture Rule: A Report to the NC Environmental Management Commission from the Tar-Pamlico Basin Oversight Committee	Gannon, Rich	October 8 - 9, 2003		North Carolina Division of Water Quality	Report to the N.C. Environmental Management Comission (EMC) from the the Basin Oversight Committee (BOC) on the progress of the Nitrogen Reduction Program and to obtain EMC approval of fourteen local strategies for achieving the Agriculture rule's basinwide nitrogen goal of a 30% reduction in loading from baseline 1991 levels by 2006. http://h2o.enr.state.nc.us/nps/EMCRpt-LocStrtgs10-03prn.pdf
216	Nutient Enrichment of Wetland Vegetation and Sediments in Subtropical Pastures	Gathumbi, S.M., P.J. Bohlen, and D.A. Graetz	2005		Soil Science Society of America Journal; 69: 539-548. 2005.	

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217	The use of mangrove wetland as a biofilter to treat shrimp pond ef uents: preliminary results of an experiment on the Caribbean coast of Colombia	Gautier, D., J. Amador, and F. Newmark	Oct-01		Aquaculture research. Oct 2001. v. 32 (10) p. 787-799.	
218	The Use of Free Surface Constructed Wetland as an Alternative Process Treatment Train to Meet Unrestricted Water Reclamation Standards	Gearheart, R.A.	1999		Water Science and Technology, Volume 40, Issues 4-5, 1999, Pages 375-382	
219	Suitability of a Treatment Wetland for Dairy Wastewaters	Geary, P.M. and J.A. Moore	1999		Water Science and Technology, Volume 40, Issue 3, 1999, Pages 179-185	
220	Horizontal Subsurface Flow Systems in the German Speaking Countries: Summary of Long-term Scientific and Practical Experiences; Recommendations	Geller, Gunther	1997		Water Science and Technology, Volume 35, Issue 5, 1997, Pages 157-166	
221	Nitrogen Transformations in a Wetland Receiving Lagoon Ef uent: Sequential Model and Implications for Water Reuse	Gerke, Sara, Lawrence A. Baker, and Ying Xu	Nov-01		Water Research; 35(16): 3857-3866. November 2001.	
222	Nitrogen Removal in Artificial Wetlands	Gersberg, R.M., B.V. Elkins and C.R. Goldman	1983		Water Research, Volume 17, Issue 9, 1983, Pages 1009-1014	
223	Role of Aquatic Plants in Wastewater Treatment by Artificial Wetlands	Gersberg, R.M., B.V. Elkins, S.R. Lyon and C.R. Goldman	Mar-86		Water Research, Volume 20, Issue 3, March 1986, Pages 363-368	
224	The Removal of Heavy Metals by Artificial Wetlands	Gersberg, R.M., S.R. Lyon, B.Y. Elkins, and C.R. Goldman	1984		EPA-600/D-84-258. Robt. S. Kerr Env. Research Lab., Ada, OK	
225	Mass Loss, Fungal Colonisation and Nutrient Dynamics of Phragmites australis Leaves During Senescence and Early Aerial Decay	Gessner, Mark O.	Apr-01		Aquatic Botany; 69(2-4): 325-339. April 2001.	
226	Environmental Flows and Water Quality Objectives for the River Murray	Gippel, C., T. Jacobs, and T. McLeod	2002	Paper	Water Sci Technol. 2002;45(11):251-60. MID: 12171360 [PubMed - indexed for MEDLINE]	This paper considers a plan for managing ows in the River Murray to provide environmental benefits. Described are four key aspects of the process being undertaken to determine the objectives, and design the ow options that will meet those objectives: establishment of an appropriate technical, advisory and administrative framework; establishing clear evidence for regulation impacts; undergoing assessment of environmental ow needs; and filling knowledge gaps.
227	A Comparison of Rain-related Phosphorus and Nitrogen Loading from Urban, Wetland, and Agricultural Sources	Glandon, R.P., F.C. Payne, C.D. McNabb and T.R. Batterson	1981		Water Research, Volume 15, Issue 7, 1981, Pages 881-887	

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228	Ecological Considerations in Wetlands Treatment of Municipal Wastewaters	Godfrey, P.J., E.R. Kaynor, S. Pelczarski and J. Benforado (eds)	1985		Van Nostrand Reinhold Co., New York, NY	
229	Surmounting the Engineering Challenges of Everglades Restoration	Goforth, G.F.	2001		Water Science Technology. 2001;44(11-12):295-302.	
230	Symbiont Nitrogenase, Alder Growth, and Soil Nitrate Response to Phosphorus Addition in Alder (Alnus incana ssp. rugosa) Wetlands of the Adirondack Mountains, New York State, USA	Gökkaya, Kemal, Todd M. Hurd, and Dudley J. Raynal	Jan-06		Environmental and Experimental Botany; 55(1-2): 97-109. Jan 2006.	
231	Freshwater Wetlands: Ecological Processes and Management Potential	Good, R.E., D.F. Whigham, and R.L. Simpson (eds)	1978		Academic Press, New York, NY	
232	The Origins and Practice of Emissions Trading	Gorman, H.S. and B.D. Solomon	2002	Paper	Journal of Policy History, 2002	
233	Modelling drainage practice impacts on the quantity and quality of stream ows for an agricultural watershed in Ohio	Gowda, P.H., A.D. Ward, D.A. White, D.B. Baker, and T.J. Logan	1998		In: Proceedings of the Seventh International Symposia of the ASAE, Orlando, FL.	
234	Rule Enforcing Selenium Load Allocation and Establishing a Tradable Loads Program for Water Year 1999	Grassland Basin Drainage Steering Committee	Jan-99	Draft rule	Grassland Basin Drainage Steering Committee	
235	The Nutrient Assimilative Capacity of Maerl as a Substrate in Constructed Wetland Systems for Waste Treatment	Gray, Shalla, John Kinross, Paul Read, and Angus Marland	Jun-00		Water Research: 34(8): 2183-2190. June 2000.	
236	Second Semi-Annual Report to the Great Lakes Protection Fund	Great Lakes Trading Network	Dec-98	Report	Great Lakes Trading Network	http://www.deq.state.mi.us/swq/trading/htm/GLTNrept2.htm
237	2nd Semi-Annual Report	Great Lakes Trading Network	Dec-98	Report	Great Lakes Trading Network	Includes a summary of trading programs in the Appendices
238	Categorization of Issues	Great Lakes Trading Network			Great Lakes Trading Network	
239	List of Issues Encountered	Great Lakes Trading Network			Great Lakes Trading Network	
240	Differences in wetland plant community establishment with additions of nitrate-N and invasive species (Phalaris arundinaceae and Typha xglauca)	Green, E.K. and S.M. Galatowitsch	Feb-01		Canadian journal of botany = Journal canadien de botanique Feb 2001. v. 79 (2) p. 170-178.	
241	Constructed Wetlands for River Reclamation: Experimental Design, Start-up and Preliminary Results	Green, Michal, Iris Safray and Moshe Agami	Feb-96		Bioresource Technology, Volume 55, Issue 2, February 1996, Pages 157-162	

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242	Standard Methods for the Examination of Water and Wastewater	Greenberg, A.E., L.S. Clescer, and A.D. Eaton, eds.	1992		18th ed. American Public Health Association. Water Environment Federation.	
243	A Potential Integrated Water Quality Strategy for the Mississippi River Basin and the Gulf of Mexico	Greenhalgh S, and P. Faeth	Nov-01	paper	Scientific World Journal; 1(2):976-83. Nov 22, 2001.	http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db =PubMed&list_uids=12805841&dopt=Citation
244	Awakening the Dead Zone: An Investment for Agriculture, Water Quality, and Climate Change	Greenhalgh, Suzie and Amanda Sauer	Feb-03	Paper	WRI Issue Brief, World Resources Institute, Washington, DC.	Background information for the National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking - http://www2.eli.org/research/wqt_main.htm
245	Suitability of Macrophytes for Nutrient Removal from Surface Flow Constructed Wetlands Receiving Secondary Treated Sewage Ef uent in Queensland, Australia	Greenway, M.			Water Sci Technol. 2003;48(2):121-8.	
246	The Role of Constructed Wetlands in Secondary Ef uent Treatment and Water Reuse in Subtropical and Arid Australia	Greenway, Margaret	Dec-05		Ecological Engineering; 25(5): 501-509. Dec. 1, 2005.	
247	Nutrient Content of Wetland Plants in Constructed Wetlands Receiving Municipal Ef uent in Tropical Australia	Greenway, Margaret	1997		Water Science and Technology, Volume 35, Issue 5, 1997, Pages 135-142	
248	Constructed Wetlands in Queensland: Performance Efficiency and Nutrient Bioaccumulation	Greenway, Margaret and Anne Woolley	1999		Ecological Engineering, Volume 12, Issues 1-2, January 1999, Pages 39-55	
249	Indigenous Sediment Microbial Activity in Response to Nutrient Enrichment and Plant Growth Following a Controlled Oil Spill on a Freshwater Wetland	Greer, C.W., N. Fortin, R. Roy, L.G. Whyte, and K. Lee	Apr-03		Bioremediation Journal; 7(1): 69-80. Apr 15, 2003.	
250	Wetland Functions and Values: The State of Our Understanding	Greeson, P.E., J.R. Clark and J.E. Clark (eds)	1979		Amer. Water Resources Assoc., Minneapolis, MN	
251	Cost-effective Nutrient Reductions to Coupled Heterogeneous Marine Water Basins: An Application to the Baltic Sea	Gren, I-M, and F. Wulff	Dec-04	Paper	Regional Environmental Change, ISSN: 1436-3798 (Paper) 1436-378X (Online), Issue: Volume 4, Number 4, pg 159-168	In this paper, the role of nutrient transports between marine basins is investigated for cost-effective solutions to predetermined marine basin targets. The interdependent advective nutrient transports as well as retentions among the seven major marine basins of the Baltic Sea are described by input-output analysis. This is in contrast to prior economic studies of transboundary water pollution that include only direct transport between the basins. The analytical results show that the difference in impacts between transport specifications depends mainly on the openness of the basins, that is, their transports with other basins. The application on Baltic Sea shows significant differences in costs and policy design between the nutrient transport specifications. The reason is that the Sea is characterized by long water and nutrient residence times, so relatively large parts of nutrients are transported among basins.

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252	The Advantages of a Constructed Reed Bed Based Strategy for Small Sewage Treatment Works	Griffin, P. and C. Pamplin	1998		Water Science and Technology, Volume 38, Issue 3, 1998, Pages 143-150	
253	Advanced Nitrogen Removal by Rotating Biological Contactors, Recycle and Constructed Wetlands	Griffin, P., P. Jennings and E. Bowman	1999		Water Science and Technology, Volume 40, Issues 4-5, 1999, Pages 383-390	
254	Hydraulic characteristics of a subsurface ow constructed wetland for winery ef uent treatment	Grismer, M.E., M. Tausendschoen, and H.L. Shepherd	Jul-Aug-01		Water Environment Federation. July/Aug 2001. v. 73 (4) p. 466-477.	
255	Nutrient Removal Processes in Freshwater Submersed Macrophyte Systems	Gumbricht, Thomas	Mar-93		Ecological Engineering, Volume 2, Issue 1, March 1993, Pages 1-30	
256	High nitrogen : phosphorus ratios reduce nutrient retention and second-year growth of wetland sedges	Gusewell, S.	May-05		New Phytologist. 2005 May, v. 166, no. 2, p. 537-550.	
257	Variation in Nitrogen and Phosphorus Concentrations of Wetland Plants	Güsewell, Sabine and Willem Koerselman	2002		Perspectives in Plant Ecology, Evolution and Systematics; 5(1): 37-61. 2002.	
258	Techniques of Water-resources Investigations of the United States Geological Survey: Laboratory Theory and Methods for Sediment Analysis	Guy, H.P.	May-05		U. S. Government Printing Office. Washington, DC	
259	Bank Review and Certification Requirements: A Third Party Auditor Perspective	Habicht, Hank Global Environment & Technology Foundation	Jul-11-12-05	Presentation	PowerPoint Presentation	
260	Nitrogen mineralization in marsh meadows in relation to soil organic matter content and watertable level	Hacin, J., J. Cop, and I. Mahne	Oct-01		Journal of Plant Nutrition and Soil Science = Zeitschrift für P anzenernährung und Bodenkunde. Oct 2001. v. 164 (5) p. 503-509.	http://www3.interscience.wiley.com/cgi-bin/jtoc?ID=10008342
261	Carbon Source Utilization Profiles as a Method to Identify Sources of Faecal Pollution in Water	Hagedorn, C., J.B. Crozier, K.A. Mentz, A.M. Booth, A.K. Graves, N.J. Nelson, and R.B. Reneau, Jr.	May-03	Paper	Journal of Applied Microbiology, Volume 94, Issue 5, Page 792-799, May 2003	
262	Where Did All the Markets Go? An Analysis of EPA's Emissions Trading Program	Hahn, R.W. and G.L. Hester	1989a	Journal Article	Yale Journal on Regulation, 6, 109-153	
263	Marketable Permits: Lessons for Theory and Practice	Hahn, R.W. and G.L. Hester	1989b	Article	Ecology Law Quarterly, 16, 361-406.	
264	Tar-Pamlico River Basin Program in North Carolina	Hall and Howett	1994	Paper		

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265	Guide to Establishing a Point/Nonpoint Source Reduction Trading System for Basinwide Water Quality Management: The Tar-Pamlico River Basin Experience.	Hall, J. and C. Howett, Kilpatrick & Cody	Jul-95	Paper	North Carolina Department of Health and Natural Resources, Division of Environmental Management, Water Quality Section EPA-904-95-900.	
266	Background: The History and Status of Wetland Mitigation Banking and Water Quality Trading	Hall, Lynda U.S. EPA	7/11-12/2005	Presentation	Audio Recording	Presented at National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking - http://www2.eli.org/research/wqt_main.htm
267	Background: The History and Status of Wetland Mitigation Banking and Water Quality Trading	Hall, Lynda U.S. EPA	7/11-12/2005	Presentation	PowerPoint Presentation	Presented at National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking - http://www2.eli.org/research/wqt_main.htm
268	Control of Denitrification in a Septage-treating Artificial Wetland: The Dual Role of Particulate Organic Carbon	Hamersley, M. Robert and Brian L. Howes	Oct-02		Water Research; 36(17): 4415-4427. Oct 2002.	
269	Nitrogen Balance and Cycling in an Ecologically Engineered Septage Treatment System	Hamersley, M. Robert, Brian L. Howes, David S. White, Susan Johnke, Dale Young, Susan B. Peterson, and John M. Teal	Oct-01		Ecological Engineering; 18(1): 61-75. October 2001.	
270	Creating Freshwater Wetlands	Hammer, D.A.	1992		Lewis Publishers, Inc. Boca Raton, FL.	
271	Constructed Wetlands for Wastewater Treatment - Municipal, Industrial & Agricultural	Hammer, D.A. (ed)	1989		Lewis Publ., Chelsea, MI	
272	Design Principles for Wetland Treatment Systems	Hammer, D.E. and R.H. Kadlec	1983		EPA- 600/S2-83-026. EPA Municipal Environmental Research Lab, Cincinnati, OH	
273	The Potential For Water Quality Trading To Help Implement The Cheat Watershed Acid Mine Drainage Total Maximum Daily Load In West Virginia	Hansen, E., M. Christ, J. Fletcher, J.T. Petty, P. Ziemkiewicz, and R.S. Herd	Apr-04	Report	Friends of the Cheat http://www.cheat.org/	http://downstreamstrategies.com/CheatReport.zip
274	Exploring Trading to Reduce Impacts from Acid Mine Drainage	Hansen, Evan	Jul-03	PowerPoint		2003 National Forum on Water Quality Trading
275	Methylmercury formation in a wetland mesocosm amended with sulfate	Harmon, S.M., J.K.King, J.B. Gladden, G.T. Chandler, and L.A. Newman	Jan-04		Environmental Science & Technology. 2004 Jan. 15, v. 38, no. 2, p. 650-656.	
276	Treatment at Different Depths and Vertical Mixing Within a 1-m Deep Horizontal Subsurface- ow Wetland	Headley, Thomas R., Eamon Herity, and Leigh Davison	Dec-05		Ecological Engineering; 25(5): 567-582. Dec. 2005.	

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277	The Role of Marsh Plants in the Transport of Nutrients as Shown by a Quantitative Model for the Freshwater Section of the Elbe Estuary	Heckman, Charles W.	1986		Aquatic Botany, Volume 25, 1986, Pages 139-151	
278	Agricultural Resources and Environmental Indicators, 2003, Agriculture Handbook No. (AH722)	Heimlich, Ralph	Feb-03	Report	Economic Research Service, U.S. Department of Agriculture. February, 2003.	This report identifies trends in land, water, and biological resources and commercial input use, reports on the condition of natural resources used in the agricultural sector, and describes and assesses public policies that affect conservation and environmental quality in agriculture. Combining data and information, this report examines the complex connections among farming practices, conservation, and the environment, which are increasingly important components in U.S. agriculture and farm policy. http://www.ers.usda.gov/publications/arei/ah722/dbgen.htm
279	Fate of Physical, Chemical, and Microbial Contaminants in Domestic Wastewater Following Treatment by Small Constructed Wetlands	Hench, Keith R., Gary K. Bissonnette, Alan J. Sexstone, Jerry G. Coleman, Keith Garbutt, and Jeffrey G. Skousen	Feb-03		The Science of The Total Environment, Volume 301, Issues 1-3, 1 January 2003, Pages 13-21	
280	Treatment of Primary-Settled Urban Sewage in Pilot-Scale Vertical Flow Wetland Filters: Comparison of Four Emergent Macrophyte Species Over a 12 Month Period	Heritage, Alan, Pino Pistillo, K. P. Sharma and I. R. Lantzke	1995		Water Science and Technology, Volume 32, Issue 3, 1995, Pages 295-304	
281	Nutrient Farming and Traditional Removal: An Economic Comparison	Hey, D., J. Kostel, A. Hurter, R. Kadlec	2005		Water Environmental Research Foundation doc#03-WSO-6C0	http://www.wetlands-initiative.org/images/03WSM6COweb.pdf
282	Nitrogen Farming: Using Wetlands to Remove Nitrogen From Our Nation's Waters	Hey, Donald The Wetlands Initiative	May-02	Report	The Wetlands Initiative, Chicago, IL.	Summary Report of Four Workshops. Background information for the National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking - http://www2.eli.org/research/wqt_main.htm
283	Stimulating Creation of a Point/Non-Point Source Trading System on a Watershed Scale	Hey, Donald The Wetlands Initiative	7/11-12/2005	Presentation	Audio Recording	
284	Nitrogen Farming: Harvesting a Different Crop	Hey, Donald L. (Ph. D.)	Mar-02		Restoration Ecology: The Journal of the Society for Ecological Restoration, Vol. 10, No. 1, March 2002	Introduces the concept of "nutrient farming" , which would create wetlands for their water quality improvement function in order to create nutrient trading credits. The paper describes a potential market for credits due to wetland losses and nitrogen fertilizer use in the Mississippi River Basin. A cost comparison between waste water plants and potential "nutrient farms" is provided. http://www.wetlands-initiative.org/images/pdfs_pubs/vol4n01.pdf
285	Water Quality Improvement by Four Experimental Wetlands	Hey, Donald L., Ann L. Kenimer and Kirk R. Barrett	Dec-94		Ecological Engineering, Volume 3, Issue 4, December 1994, Pages 381-397	

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286	Nutrient Farming: The Business of Environmental Management	Hey, Donald L., Laura S. Urban, and Jill A. Kostel	Apr-05	Paper	Ecological Engineering: The Journal of Ecosystem Restoration, Vol. 24, No. 4 (April 5, 2005), pp 279-287.	Available online at www.sciencedirect.com. http://www.wetlands-initiative.org/images/pdfs_pubs/EcoEng-Proof.pdf
287	Nutrient Farming: The Business of Environmental Management - Executive Summary	Hey, Donald L., Laura S. Urban, and Jill A. Kostel	Apr-05	Summary		http://www.wetlands-initiative.org/images/pdfs_pubs/nfarm.business-envimgmt.pdf
288	Removal Efficiency of Three Cold-climate Constructed Wetlands Treating Domestic Wastewater: Effects of Temperature, Seasons, Loading Rates and Input Concentrations	Hlum, Trond M. and Per Stlnacke	1999		Water Science and Technology, Volume 40, Issue 3, 1999, Pages 273-281	http://www.wetlands-initiative.org/images/pdfs_pubs/harvesting.diff.crop.pdf
289	The use of microbial tracers to monitor seasonal variations in ef uent retention in a constructed wetland	Hodgson, C.J., J. Perkins, and J.C. Labadz	Nov-04		Water Research. 2004 Nov., v. 38, issue 18, p. 3833-3844.	
290	Nitrogen removal from waste treatment pond or activated sludge plant ef uents with free-surface wetlands	Home, Alexander J.	1995		Water Science and Technology, Volume 31, Issue 12, 1995, Pages 341-351	
291	The Ecology and Management of Wetlands (2 vols.)	Hook, D.D. et. al.	1988		Croom Held, Ltd., London/Timber Press, Portland, OR	
292	Differences in Social and Public Risk Perceptions and Con icting Impacts on Point/Nonpoint Trading Ratios	Horan, R.D.	Nov-01	Paper	American Journal of Agricultural Economics; 83(4): 934. Nov 2001.	Most research on point–nonpoint trading focuses on the choice of trading ratio (the rate point source controls trade for nonpoint controls), although the first-best ratio is jointly determined with the optimal number of permits. In practice, program managers often do not have control over the number of permits—only the trading ratio. The trading ratio in this case can only be second-best. We derive the second-best trading ratio and, using a numerical example of trading in the Susquehanna River Basin, we find the values are in line with current ratios, but for different reasons than those that are normally provided. http://www.blackwell-synergy.com/links/doi/10.1111/0002-9092.00220?cookieSet=1
293	Policy Objectives and Economic Incentives for Controlling Agricultural Sources of Nnonpoint Pollution	Horan, R.D. and M.O. Ribaudo	1999	Journal Article	Journal of the American Water Resources Association, 35(5), 1023-1035.	
294	Point-nonpoint Nutrient Trading in the Susquehanna River Basin	Horan, R.D., J.S. Shortle, and D.G. Abler	2002		Water Resources Research, 38(5), 1-13.	

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295	Differences in Social and Public Risk Perceptions and Con icting Impacts on Point/Nonpoint Trading Ratios	Horan, Richard D.	Nov-01		American Journal of Agricultural Economics Volume 83 Issue 4 Page 934 - November 2001 doi:10.1111/0002-9092.00220	If stochastic nonpoint pollution loads create socially costly risk, then an economically optimal point/nonpoint trading ratio the rate point source controls trade for nonpoint controls is adjusted downward (a risk reward for nonpoint controls), encouraging more nonpoint controls. However, in actual trading programs, ratios are adjusted upward in response to nonpoint uncertainties (a risk premium for nonpoint controls). This contradiction is explained using a public choice model in which regulators focus on encouraging abatement instead of reducing damages. The result is a divergence of public and social risk perceptions, and a trading market that encourages economically suboptimal nonpoint controls.
296	When Two Wrongs Make a Right: Second-Best Point/Nonpoint Trading Ratios	Horan, Richard D. and James S. Shortle	May-05	Paper	American Journal of Agricultural Economics, Volume 87 Issue 2 Page 340 -	http://www.blackwell-synergy.com/links/doi/10.1111/j.1467-8276.2005.00726.x
297	Field Examination on Reed Growth, Harvest and Regeneration for Nutrient Removal	Hosoi, Y., Y. Kido, M. Miki and M. Sumida	1998		Water Science and Technology, Volume 38, Issue 1, 1998, Pages 351-359	
298	Background: The History and Status of Wetland Mitigation Banking and Water Quality Trading	Hough, Palmer U.S. EPA	7/11-12/2005	Presentation	Audio Recording	Presented at National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking - http://www2.eli.org/research/wqt_main.htm
299	Water Quality Study Feedstuffs	Howie, Michael	Jun-04			http://www.findarticles.com/p/articles/mi_go1470/is_200406/ai_n6534686
300	Nitrogen Removal in Constructed Wetlands Employed to Treat Domestic Wastewater	Huang, J., R.B. Reneau, Jr., and C. Hagedorn	Jun-00		Water Research; 34(9): 2582-2588. June 15, 2000.	
301	Effect of design parameters in horizontal ow constructed wetland on the behaviour of volatile fatty acids and volatile alkylsulfides	Huang, Y., L. Ortiz, P. Aguirre, J. Garcia, R. Mujeriego, J.M. Bayona	May-05		Chemosphere. 2005 May, v. 59, issue 6, p. 769-777.	
302	Assessment of Environmental and Economic Benefits Associated with Streambank Stabilization and Phosphorus Retention	Hubbard, Lisa C., David S. Biedenharn, and Steven L. Ashby	May-03		ERDC WQTN-AM-14	Techincal notes provide the results of a creek enhancement project in Mass. A summary of bank stabilization treatments and the conditions of the banks at Year 9 are provided. Erosion estimates are made using aerial photo interpretation. Total P and biologically available P are sampled in the bed, bank, and top of bank. Cost of bank stabilization and cost for total P removal are estimated. http://el.erdc.usace.army.mil/elpubs/pdf/wqtnam14.pdf
303	Use of oating vegetation to remove nutrients from swine lagoon wastewater	Hubbard, R.K., G.J. Gascho, G.L. Newton	Nov-Dec-04		Transactions of the ASAE. 2004 Nov-Dec, v. 47, no. 6, p. 1963-1972.	
304	Nitrogen and Phosphorus Removal from Plant Nursery Runoff in Vegetated and Unvegetated Subsurface Flow Wetlands	Huett, D.O., S.G. Morris, G. Smith, and N. Hunt	Sept-05		Water Resources, 39(14): 3259-72. Sept 2005.	

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305	Constructed Treatment Wetland System Description and Performance	Humboldt University	2000		Humboldt University	http://firehole.humboldt.edu/wetland/twdb.html (January 2006).
306	Denitrification potential and carbon quality of four aquatic plants in wetland microcosms	Hume, N.P., M.S. Fleming, and A.J. Horne	Sep-Oct-02		Soil Science Society of America journal. Sept/Oct 2002. v. 66 (5) p. 1706-1712.	
307	State of the Art for Animal Wastewater Treatment in Constructed Wetlands	Hunt, P.G. and M.E. Poach	2001		Water Science Technology. 2001;44(11-12):19-25.	
308	Denitrification in a coastal plain riparian zone contiguous to a heavily loaded swine wastewater spray field	Hunt, P.G., T.A. Matheny, and K.C. Stone	Nov-Dec-04		Journal of environmental quality. 2004 Nov-Dec, v. 33, no. 6, p. 2367-2374.	
309	Designing Stormwater Wetlands for Small Watersheds	Hunt, William F. and Barbara A. Doll	Apr-00		North Carolina Cooperative Extension, North Carolina State University	http://www.neuse.ncsu.edu/SWwetlands.pdf
310	Nitrogen, phosphorus, and organic carbon removal in simulated wetland treatment systems	Hunter, R.G., D.L. Combs, D.B. George	Oct-01		Archives of environmental contamination and toxicology. Oct 2001. v. 41 (3) p. 274-281.	
311	Perchlorate is Not a Common Contaminant of Fertilizers	Hunter, W. J.	Nov-01	Paper	Journal of Agronomy and Crop Science, Volume 187, Issue 3, Page 203-206, Nov 2001	The present study developed methods for improving the HPLC analysis of perchlorate and used these methods to survey 15 US fertilizers for perchlorate. The study found no perchlorate in any of the fertilizers investigated.
312	Nitrogen sources in Adirondack wetlands dominated by nitrogen-fixing shrubs.	Hurd, T.M., K. Gokkaya, B.D. Kiernan, D.J. Raynal	Mar-05		Wetlands : the journal of the Society of the Wetland Scientists. 2005 Mar., v. 25, no. 1, p. 192-199.	
313	Modeling of nitrogen sequestration in coastal marsh soils.	Hussein, A.H. and M.C. Rabenhorst	Jan-Feb-02		Soil Science Society of America journal. Jan/Feb 2002. v. 66 (1) p. 324-330.	
314	Open-air Treatment of Wastewater from Land-Based Marine Fish Farms in Extensive and Intensive Systems: Current Technology and Future Perspectives	Hussenot, Jérôme, Sébastien Lefebvre and Nicolas Brossard	Jul-Aug-98		Aquatic Living Resources, Volume 11, Issue 4, July-August 1998, Pages 297-304	
315	Methane Emission Rates from an Ombrotrophic Mire Show Marked Seasonality which is Independent of Nitrogen Supply and Soil Temperature	Hutchin, P.R., M.C. Press, J.A. Lee and T.W. Ashenden	Sep-96		Atmospheric Environment, Volume 30, Issue 17, September 1996, Pages 3011-3015	This paper reports methane uxes measured in an area of ombrotrophic mire at the Migneint in North Wales when nitrogen, in the form of ammonium and/or nitrate, was applied to plots on the mire surface. These applications of nitrogen had no effect on the methane emission rates at any date, with the exception of the measurement from November 1994. No correlation was found between methane ux and either soil temperature or water table. http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VH3-3Y45YRC-R&_coverDate=09%2F30%2F1996&_alid=375242647&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=6055&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=0ada691875c6f090e70e18e5bae684fe

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316	Technology Assessment of Wetlands for Municipal Wastewater Treatment	Hyde, H.C., R.S. Ross and F.C. Demgen	1984		EPA 600/2-84-154. EPA Municipal Environmental Research Lab., Cincinnati, OH	
317	Proceedings of Wetlands Downunder, An International Specialist Conference on Wetlands Systems in Water Pollution Control	IAWQ/AWWA	1992		Int'l. Assoc. of Water Quality/Australian Water & Wastewater Assoc., Univ. of New South Wales, Sydney, Australia	
318	Characterization of microbial communities and composition in constructed dairy wetland wastewater ef uent	Ibekwe, A.M., C.M. Grieve, S.R. Lyon	Sep-03		Applied and Environmental Microbiology. 2003 Sept., v. 69, no.9, p. 5060-5069.	
319	1st Annual Status Report: Lower Boise River Ef uent Trading Demonstration Project	Idaho Department of Environmental Quality	May-01	Report	Idaho Department of Environmental Quality	
320	2nd Annual Status Report: Lower Boise River Ef uent Trading Demonstration Project	Idaho Department of Environmental Quality	Jun-02	Report	Idaho Department of Environmental Quality	
321	Surface Water: Lower Boise River Subbasin Assessment and Total Maximum Daily Loads	Idaho Department of Environmental Quality	Accessed	Web-site	Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/data_reports/surface_water/tmdls/boise_river_lower/boise_river_lower.cfm
322	Surface Water: TMDL Implementation Plans	Idaho Department of Environmental Quality	Accessed	Web-site	Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/data_reports/surface_water/tmdls/implementation_plans.cfm
323	Surface Water: Snake River - Hells Canyon Subbasin Assessment and Total Maximum Daily Loads	Idaho Department of Environmental Quality	Accessed	Web-site	Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/data_reports/surface_water/tmdls/snake_river_hells_canyon/snake_river_hells_canyon.cfm
324	Best Management Practice (BMP) List for the Lower Boise River Pollution Trading Program	Idaho Soil Conservation Commission	May-02	BMP List Paper	Idaho Soil Conservation Commission	Selected nonpoint source BMPs used to offset a point source's discharge in the Lower Boise River are described in this paper. The procedure for generating credits, as well as other trading program requirements, are described as well. Evaluation and measurment requirements for BMP monitoring are discussed. This document will be updated periodically and new BMPs added to the list of those currently eligible for trading.
325	Pretreatment Market System Development	Illinois Environmental Protection Agency	Undated	Discussion Paper	Illinois Environmental Protection Agency	
326	Market-Based Trading of Categorical Pretreatment Limits	Illinois Environmental Protection Agency	Aug-96	Paper	Illinois Environmental Protection Agency	
327	Market-Based Approaches to Reduce Water Pollution: A Pre-Feasibility Study	Illinois Environmental Protection Agency, Bureau of Water and Environmental Policy Office	Nov-95	Report	Illinois Environmental Protection Agency, Bureau of Water and Environmental Policy Office	

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328	Discussion Paper: Conference on Compliance and Enforcement for Emissions Trading Schemes	INECE-Environment Agency (England and Wales), Worcester College, Oxford, England	3/16-18/2004	Presentation	INECE-Environment Agency (England and Wales), Worcester College, Oxford, England	
329	Periphyton tissue chemistry and nitrogenase activity in a nutrient impacted Everglades ecosystem	Inglett, P.W., K.R. Reddy, and P.V. McCormick	2004		Biogeochemsitry 67:213-233	
330	Hydrochemistry and Hydrology of Forest Riparian Wetlands	Jacks, G. and A.C. Norrström	Jul-04		Forest Ecology and Management; 196(2-3): 187-197. Jul 26, 2004.	
331	The Tar-Pamlico River Basin Nutrient Trading Program	Jacobcon, E.M., et al.	Apr-94	Paper	Applied Resource Economics and Policy, Department of Agricultural & Resource Economics, North Carolina State University.	http://www.bae.ncsu.edu/program/extension/arep/tarpam.html
332	The Tar-Pamlico River Basin Nutrient Trading Program	Jacobson, E.M., L.E. Danielson, and D.L. Hoag	1994		Applied Resource Economics and Policy Group, Department of Agricultural and Resource Economics	
333	Phosphorus adsorption characteristics of a constructed wetland soil receiving dairy farm wastewater	Jamieson, T.S., R. Gordon, A. Madani	Feb-02		Canadian Journal of Soil Science. Feb 2002. v. 82 (1) p. 97-104.	
334	Design and Performance of Experimental Constructed Wetlands Treating Coke Plant Ef uents	Jardinier, N., G. Blake, A. Mauchamp, and G. Merlin	2001		Water Science Technology. 2001;44(11-12): 485-91.	
335	Lessons Learned from the Neuse River Basin Education Program	Jennings, Greg, PhD. and Deanna Osmond, PhD. (NC State University)	Sep-05	Presentation	13th National Nonpoint Source Monitoring Workshop	http://www.bae.ncsu.edu/programs/extension/wqg/nmp_conf/presentations.html
336	The Potential of Natural Ecosystem Self-purifying Measures for Controlling Nutrient Inputs	Jenssen, Petter D., Trond Mæhlum, Roger Roseth, Bent Braskerud, Nina Syversen, Arnor Njøs and Tore Krogstad	1994		Marine Pollution Bulletin, Volume 29, Issues 6-12, 1994, Pages 420-425	
337	Evaluation of vegetation management strategies for controlling mosquitoes in a southern California constructed wetland	Jiannino, J.A. and W.E. Walton	Mar-04		Journal of the American Mosquito Control Association. 2004 Mar., v. 20, no. 1, p. 18-26.	
338	Removal of N, P, BOD5, and coliform in pilot-scale constructed wetland systems	Jin, G., T. Kelley, M. Freeman, M. Callahan	2002		International Journal of Phytoremediation. 2002. v. 4 (2) p. 127-141.	
339	Microcosm Wetlands for Wastewater Treatment with Different Hydraulic Loading Rates and Macrophytes	Jin, S.R., Y.F. Lin, T.W. Wang, and D.Y. Lee	2002		Journal of Environmental Quality. 2002 Mar-Apr;31(2): 690-6.	

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340	Nutrient Removal from Polluted River Water by Using Constructed Wetlands	Jing, S.R., Y.F. Lin, D.Y. Lee, and T.W. Wang	Jan-01		Bioresources Technology. 2001Jan;76(2):131-5.	
341	Methane emissions from a constructed wetland treating wastewater--seasonal and spatial distribution and dependence on edaphic factors	Johansson, A.E., A.M. Gustavsson, M.G. Oquist, B.H. Svensson	Nov-04		Water Research. 2004 Nov., v. 38, issue 18, p. 3960-3970.	In this paper the authors discuss the results of a study to determine the ux of methane from a constructed wetland over two growth seasons on a pilot scale wetland constructed to reduce nutrient levels in secondary treated wastewater. The emissions for the spring to autumn period averaged 141 mg CH4 m 2 d 1 (S.D.=187), ranging from consumption of 375 mg CH4 m 2 d 1 to emissions of 1739 mg CH4 m 2 d 1. The spatial and temporal variations were large, but could be accounted for by measured environmental factors. Among these factors, sediment and water temperatures were significant in all cases and independent of the scale of analysis (r2 up to 0.88). http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V73-4D5JSHK-2&_coverDate=11%2F01%2F2004&_alid=375244849&_rdoc=1&_fmt=&_orig=search&_qd=1&_cdi=5831&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=e5a42ee72c10f538ba0cfa882f815c75
342	Metamodelling Phosphorus Best Management Practices for Policy Use: A Frontier Approach	Johansson, R., P.H. Gowda, D.J. Mulla, and B.J. Dalzell	2004	Paper	Agricultural Economics, 2004 - ideas.repec.org	This article presents a modelling system for synthesising heterogeneous productivity and nutrient loading potentials inherent in agricultural cropland for policy use. Phosphorus abatement cost functions for cropland farmers in a southeastern Minnesota watershed are metamodelled using frontier analysis. These functions are used to evaluate policies aimed at reducing non-point phosphorus discharges into the Minnesota River. Results indicate an efficiently targeted policy to reduce phosphorus discharge by 40% would cost US$ $167,700 or $844 per farm.
343	Watershed Nutrient Trading Under Asymmetric Information	Johansson, R.C.	2002	Paper	Agricultural and Resource Economics Review, 2002.	This article presents a modelling system for synthesising heterogeneous productivity and nutrient loading potentials inherent in agricultural cropland for policy use. Phosphorus abatement cost functions for cropland farmers in a southeastern Minnesota watershed are metamodelled using frontier analysis. These functions are used to evaluate policies aimed at reducing non-point phosphorus discharges into the Minnesota River. Results indicate an efficiently targeted policy to reduce phosphorus discharge by 40% would cost US$ $167,700 or $844 per farm.
344	Reducing Hypoxia in Long Island Sound: The Connecticut Nitrogen Exchange	Johnson, Gary	Jul-03	PowerPoint		2003 National Forum on Water Quality Trading
345	Sediment and nutrient retention by freshwater wetlands: effects on surface water quality	Johnston, C.A.	1991		Critical Review in Environmental Control 12:491-565	
346	The cumulative effect of wetlands on stream water quality and quantity: a landscape approach	Johnston, C.A., N.E. Detenbeck, and G.J. Niemi	1990		Biogeochemistry 10:105-141.	

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347	Nutrient dynamics in relation to geomorphology of riverine wetlands	Johnston, C.A., S.D. Bridgham, and J.P. Schubauer-Berigan	Mar-Apr-01		Soil Science Society of America journal. Mar/Apr 2001. v. 65 (2) p. 557-577.	
348	Establishing a Framework for Nutrient Trading in Maryland – A Utility Perspective	Jones, C. and E. Bacon	May-98	Presentation	Watershed '98 – Moving from Theory to Implementation. Denver, CO. May 5, 1998.	
349	Trading Opportunities and Challenges for the Wastewater Management Community	Jones, Cyrus	Jul-03	PowerPoint		2003 National Forum on Water Quality Trading
350	Legal and Financial Liability – Issues in Mitigation Banking and Water Quality Trading: A Water Quality Trading Perspective	Jones, Cyrus Washington Suburban Sanitary Commission	7/11-12/2005	Presentation	Audio Recording	http://www2.eli.org/research/wqt_forum.htm
351	Legal and Financial Liability – Issues in Mitigation Banking and Water Quality Trading: A Water Quality Trading Perspective	Jones, Cyrus Washington Suburban Sanitary Commission	7/11-12/2005	Presentation	PowerPoint Presentation	Presented at National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking. Describes some of the challenges involved with implementing waste water trading programs in light of the Clean Water Act. http://www2.eli.org/research/wqt_forum.htm
352	Nutrient and Sediment Removal by a Restored Wetland Receiving Agricultural Runoff	Jordan, T.E., D.F. Whigham, K.H. Hofmockel, and M.A. Pittek	2003		Journal of Environmental Quality. 2003 Jul-Aug;32(4):1534-47.	
353	Nutrient Chemistry and Hydrology of Interstitial Water in Brackish Tidal Marshes of Chesapeake Bay	Jordan, Thomas E. and David L. Correll	Jul-85		Estuarine, Coastal and Shelf Science, Volume 21, Issue 1, July 1985, Pages 45-55	
354	Nutrient Flux in the Rhode River: Tidal Exchange of Nutrients by Brackish Marshes	Jordan, Thomas E., David L. Correll and Dennis F. Whigham	Dec-83		Estuarine, Coastal and Shelf Science, Volume 17, Issue 6, December 1983, Pages 651-667	
355	The Dead Zones: Oxygen-Starved Coastal Waters	Joyce, S.	Mar-00	Paper	Environ Health Perspect. 2000 Mar;108(3):A120-5. PMID: 10706539	
356	Domestic Wastewater Treatment through Constructed Wetland in India	Juwarkar, A.S., B. Oke, A. Juwarkar and S. M. Patnaik	1995		Water Science and Technology, Volume 32, Issue 3, 1995, Pages 291-294	
357	The inadequacy of first-order treatment wetland models	Kadlec, R. H.	2000		Ecological Engineering 15:105-119.	
358	Phosphorus Removal in Emergent Free Surface Wetlands	Kadlec, R.H.	2005		Journal of Environmental Science and Health Part A (2005) 40(6-7): 1293-306. 2005.	
359	Wetlands and Water Quality IN: Wetlands Functions and Values; The State of Our Understanding	Kadlec, R.H. and J.A. Kadlec	1979		American Water Resources Assoc., Bethesda, MD	

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360	Temperature Effects in Treatment Wetlands	Kadlec, R.H. and K.R. Reddy	Sep-Oct 2001		Water Environment Research. 2001 Sep-Oct;73(5):543-57.	
361	Wetlands Treatment Database	Kadlec, R.H., R.L. Knight., S.C. Reed, and R.W. Rubles (eds.).	1994		EPA/600/C-94/200. Office of Research and Development, Cincinnati, OH.	
362	Deterministic and Stochastic Aspects of Constructed Wetland Performance and Design	Kadlec, Robert H.	1997		Water Science and Technology, Volume 35, Issue 5, 1997, Pages 149-156	
363	Overview: Surface Flow Constructed Wetlands	Kadlec, Robert H.	1995		Water Science and Technology, Volume 32, Issue 3, 1995, Pages 1-12	
364	Modeling Nutrient Behavior in Wetlands	Kadlec, Robert H. and David E. Hammer	Jan-88		Ecological Modelling, Volume 40, Issue 1, January 1988, Pages 37-66	
365	Treatment Wetlands	Kadlec, Robert H. and Robert L. Knight	1996		CRC Press 893 pgs.	
366	Nitrogen Spiraling in Subsurface- ow Constructed Wetlands: Implications for Treatment Response	Kadlec, Robert H., Chris C. Tanner, Vera M. Hally, and Max M. Gibbs	Nov-05		Ecological Engineering; 25(4): 365-381. Nov 2005.	
367	Integrated Natural Systems for Treating Potato Processing Wastewater	Kadlec, Robert H., Peter S. Burgoon and Michael E. Henderson	1997		Water Science and Technology, Volume 35, Issue 5, 1997, Pages 263-270	
368	Wetland Use and Impact on Lake Victoria, Kenya Region	Kairu, J. K.	Jul-01	Paper	Lakes and Reservoirs: Research and Management, Volume 6, Issue 2, Page 117-125, Jul 2001	This article reports on a study of wetland use and impact on Lake Victoria conducted in March and April 1995. A field survey and interviews were used to study wetland use and their impact on Lake Victoria. This article identifies management issues and establishes a broad vision for the future. It also addresses the need to balance the competing demands for wetland use and development with the need to conserve a healthy and functional Lake Victoria. Investment proposals are made that would minimize destruction of the wetlands and negative impacts on the lake. General recommendations for planning and management issues, as well as suggestions of specific research needs that should form the basis of action and investment initiatives, are given.
369	Nitrogen Removal from a Riverine Wetland: A Field Survey and Simulation Study of Phragmites japonica	Kang, Sinkyu, Kang, Hojeong Walton, Dongwook Ko, and Dowon Lee	Mar-02		Ecological Engineering; 18(4): 467-475. March 1, 2002.	
370	Wastewater Treatment by Tropical Plants in Vertical- ow Constructed Wetlands	Kantawanichkul, S., S. Pilaila, W. Tanapiyawanich, W. Tikampornpittaya, and S. Kamkrua	1999		Water Science and Technology, Volume 40, Issue 3, 1999, Pages 173-178	

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371	Pollutant Sources Investigation and Remedial Strategies Development for the Kaoping River Basin, Taiwan	Kao, C.M., F.C. Wu, K.F. Chen, T. F. Lin, Y.E. Yen, and P.C. Chiang	2003	Paper	Water Sci Technol. 2003;48(7):97-103. PMID: 14653639	
372	Water Quality Management in the Kaoping River Watershed, Taiwan	Kao, C.M., K.F. Chen, Y.L. Liao, and C.W. Chen	2003	Paper	Water Sci Technol. 2003;47(7-8):209-16. PMID: 12793682	
373	An Information-theoretical Analysis of Budget-constrained Nonpoint Source Pollution Control	Kaplan, J.D., R.E. Howitt, Y.H. Farzin	2003	Paper	Journal of Environmental Economics and Management, 2003	This paper analyzes budget-constrained, nonpoint source (NPS) pollution control with costly information acquisition and learning, applied to the sediment load management program for Redwood Creek, which ows through Redwood National Park in northwestern California. We simulate dynamic budget-constrained management with information acquisition and learning, and compare the results with those from the current policy. The analysis shows that when information acquisition increases overall abatement effectiveness the fiscally constrained manager can reallocate resources from abatement effort to information acquisition, resulting in lower sediment generation than would otherwise exist. In addition, with learning about pollution generation occurring over time the manager may switch from a high intensity of data collection to a lower intensity to further reduce sediment generation. Also, as sediment control proceeds at upstream sources, at some time in the future the marginal reduction in sediment for a given expenditure will equalize across the sources such that uniform abatement effort may occur across all sources.
374	Constructed wetland technology and mosquito populations in Arizona	Karpiscak, M.M., K.J. Kingsley, R.D. Wass, F.A. Amalfi, J. Friel, A.M. Stewart, J. Tabor, and J. Zauderer	Mar-04		Journal of Arid Environments. 2004 Mar., v. 56, no. 4, p. 681-707.	
375	Multi-Species Plant Systems for Wastewater Quality Improvements and Habitat Enhancement	Karpiscak, Martin M., Charles P. Gerba, Pamela M. Watt, Kennith E. Foster and Jeanne A. Falabi	1996		Water Science and Technology, Volume 33, Issues 10-11, 1996, Pages 231-236	
376	Management of Dairy Waste in the Sonoran Desert Using Constructed Wetland Technology	Karpiscak, Martin M., Robert J. Freitas, Charles P. Gerba, Luis R. Sanchez and Eylon Shamir	1999		Water Science and Technology, Volume 40, Issue 3, 1999, Pages 57-65	
377	Performance of a sub-surface ow constructed wetland in polishing pre-treated wastewater--a tropical case study	Kaseva, M.E.	Feb-04		Water Research. 2004 Feb., v. 38, no. 3, p. 681-687.	
378	The Dillon Bubble	Kashmaniam et. al.	1986			

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379	Incentive Analysis for Clean Water Act Reauthorization: Point Source/Nonpoint Source Trading for Nutrient Discharge Reductions-Cherry Creek	Kashmanian, Richard and Mahesh Podar Apogee Research, Inc.	1992	Paper	(Besthesda, MD: Apogee Research, Inc., 1992), 24-26. Office of Policy, Planning, and Evaluation, U.S.Environmental Protection Agency http://yosemite.epa.	This report examines ef uent trading as one option to achieve water quality objectives at least cost. While several options are discussed, the paper focuses principally on trading schemes in which regulated point sources are allowed to avoid upgrading their pollution control technology to meet water quality-based ef uent limits if they pay for equivalent (or greater) reductions in nonpoint source pollution within their watersheds. The report identifies several conditions that appear necessary for an efficient and effective point/nonpoint source trading program. Reviews of three trading experiences to date--Cherry Creek and Dillon Reservoir in Colorado, Tar-Pimlico River Basin in North Carolina--indicate that the absence of one or more of these necessary conditions result in the delay of trading or will necessitate a shift in focus of the trading program to facilitate continued pollutant load reductions. The report also discusses the economic benefits and costs, the nationwide potential, and Clean Water Act implications of ef uent trading.
380	Contract-Based Trading Programs in Environmental Regulation	Keeler, A.G. Contemporary Economic Policy	Apr-04	Draft paper	http://aae.agecon.uga.edu/~akeeler/Keeler_home/Working%20papers/Contract-based%20trading.pdf	
381	Nitrogen and Bacterial Removal in Constructed Wetlands Treating Domestic Waste Water	Keffala, C. and A. Ghrabi	Nov-05		Desalination; 185(1-3): 383-389. Nov 2005.	
382	Adult Chloropidae (Diptera) associated with constructed treatment wetlands modified by three vegetation management techniques	Keiper, J.B., M. Stanczak, W.E. Walton	Sep-Oct-03		Entomological News. 2003 Sept-Oct, v. 114, no. 4, p. 205-210.	
383	Economic and Environmental Benefits of Nutrient Trading Programs	Keiser, M.S. and Feng Fang	undated	Paper	Environmental Trading Network and Keiser Associates	http://www.envtn.org/docs/Japan_paper.pdf
384	In situ ground water denitrification in stratified, permeable soils underlying riparian wetlands	Kellogg, D.Q., A.J.Gold, P.M. Groffman, K. Addy, M.H. Stolt, G. Blazejewski	Mar-Apr-05		Journal of environmental quality. 2005 Mar-Apr, v. 34, no. 2, p. 524-533.	
385	Indicators of nitrate in wetland surface and soil-waters: interactions of vegetation and environmental factors	Kennedy, M.P. and K.J. Murphy	Aug-04		Hydrology and earth system sciences. 2004 Aug., v. 8, no. 4, p. 663-672.	http://www.copernicus.org/EGU/hess/published_papers.html

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386	Trend Analysis of Nutrient Loading in the Tar-Pamlico Basin	Kennedy, Todd	May-23-03	Memo	Memorandum to Michelle Woolfolf, NC Division of Water Quality Planning Branch	This analysis evaluates the trends in nutrient loading in the Tar-Pamlico Basin from 1991 to 2002 using the Seasonal Kendall test, which tends to perform better than other parametric methods for data sets that are commonly non-normal, vary seasonally, and contain outliers and censored values. The results indicate significant, negative trends in ow-adjusted concentrations for both TP and TN. Over the selected study period of 1991-2002, the estimated decrease in TP and TN concentration over the 12 years are 0.046 mg/L and 0.203 mg/L, respectively. This represents a reduction of in TP and TN through 2002 of 33% and 18%, respectively. http://h2o.enr.state.nc.us/nps/TrendGrimesland91-02prn.pdf
387	Treatment of Domestic and Agricultural Wastewater by Reed Bed Systems	Kern, Jürgen and Christine Idler	Jan-99		Ecological Engineering, Volume 12, Issues 1-2, January 1999, Pages 13-25	
388	Market-based Approaches and Trading-Conditions and Examples	Kerns, W. and K. Stephenson		Paper		http://www.epa.gov/owowwtr1/watershed/Proceed/kerns.html
389	Nine Case Studies, Appendices A-I	Kerr, Robert L., Steven J. Anderson, and John Jaksch	Jun-00	Case Study	Kerr, Greiner, Anderson & April, and Battelle Pacific Northwest Division	
390	Cross Cutting Analysis of Trading Programs: Case Studies in Air, Water and Wetland Mitigation Trading Systems	Kerr, Robert L., Steven J. Anderson, John Jaksch (Kerr, Greiner, Anderson & April and Battelle Pacific Northwest Division)	Jun-00		Learning from Innovations in Environmental Protection, Research Paper Number 6	
391	Abundance of Alnus incana ssp. rugosa in Adirondack Mountain Shrub Wetlands and Its In uence on Inorganic Nitrogen	Kiernan, B.D., T.M. Hurd, and D. J. Raynal	Jun-03		Environmental Pollution; 123(3): 347-354. June 2003.	
392	Ecosystem Multiple Markets	Kieser & Associates	Apr-04	Draft white paper	Environmental Trading Network	http://www.envtn.org/docs/EMM_WHITE_PAPERApril04.pdf
393	Preliminary Economic Analysis of Water Quality Trading Opportunities in the Great Miami River Watershed, Ohio	Kieser & Associates	Jul-04	Report	Kieser & Associates	Prepared for the Miami Conservancy District, Dayton, Ohio
394	ETN Paper and Presentation Presented at the Workshop on Urban Renaissance and Watershed Management, Japan	Kieser, Mark and "Andrew" Feng Fang	Feb-04	Paper	Kieser & Associates	
395	Water Quality Trading in the United States: An Overview	Kieser, Mark S. and "Andrew" Feng Fang	Accessed	Web-site	The Katoomba Group's Ecosystem Marketplace	http://ecosystemmarketplace.com/pages/article.news.php?component_id=3954&component_version_id=5625&language_id=12
396	Economic and Environmental Benefits of Water Quality Trading- An Overview of U.S. Trading Programs	Kieser, Mark S. and "Andrew" Feng Fang			The Environmental Trading Network and Kieser & Associates	http://www.envtn.org/docs/Japan_paper.pdf mkieser@kieser-associates.com

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397	Point/non-point Source Water Quality Trading for Phosphorus in the Kalamazoo River Watershed: A Demonstration Project	Kieser, Mark S. and David J. Batchelor	1998		published in the proceedings for the Water Environment Research Foundation Conference Workshop #115: Watershed-based ef uent trading demonstration projects: Results achieved and lessons learned.	
398	The Challenges of Point/Non-Point Source Trading	King, Dennis University of Maryland	7/11-12/2005	Presentation	Audio Recording	Presented at National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking - http://www2.eli.org/research/wqt_main.htm
399	The Challenges of Point/Non-Point Source Trading	King, Dennis University of Maryland	7/11-12/2005	Presentation	PowerPoint Presentation	
400	Crunch Time for Water Quality Trading	King, Dennis M. and Peter J. Kuch	2005	Paper	Choices. 20(1): 71-75.	Background information for the National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking - http://www2.eli.org/research/wqt_main.htm
401	Will Nutrient Credit Trading Ever Work? An Assessment of Supply and Demand Problems and Institutional Obstacles	King, Dennis M. and Peter J. Kuch	2003	Paper	Environmental Law Reporter, 33 ELR 10352. Environmental Law Institute, Washington, DC.	Background information for the National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking - http://www2.eli.org/research/wqt_main.htm
402	Science, Technology, and the Changing Character of Public Policy in Nonpoint Source Pollution	King, J.L. and D.L. Corwin			pg 309-322. In D.L. Corwin, K. Loague, and T.R. Ellsworth (ed.). Assessment of non-point source pollution in the vadose zone. AGU. Washington, D.C.	
403	The Potential for Nitrification and Nitrate Uptake in the Rhizosphere of Wetland Plants: A Modelling Study	Kirk, G.J.D. and H.J. Kronzucker	Sep-05		Annals of botany. 2005 Sep., v. 96, no. 4, p. 639-646.	http://aob.oupjournals.org/
404	Seasonal Fluctuations in the Mineral Nitrogen Content of an Undrained Wetland Peat Soil Following Differing Rates of Fertiliser Nitrogen Application	Kirkham, F.W. and R.J. Wilkins	Jan-15-93		Agriculture, Ecosystems & Environment, Volume 43, Issue 1, 15 January 1993, Pages 11-29	
405	Constructed Treatment Wetland: A Study of Eight Plant Species Under Saline Conditions	Klomjeck, P. and S. Nitisoravut	Feb-05		Chemosphere, 58(5): 583-93. Feb 2005	
406	Nutrient dynamics of freshwater riverine marshes and the role of emergent macrophytes	Klopatek, J. M.	1978		In: Freshwater Wetlands: Ecological Processes and Management Potential. R.E. Good, D.F. Whigham, and R.L. Simpson, eds. Academic Press, New York, NY.	

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408	Constructed Wetlands for Livestock Wastewater Management	Knight, Robert L., Victor W. E. Payne, Jr., Robert E. Borer, Ronald A. Clarke, Jr., and John H. Pries	Jun-00		Ecological Engineering; 15(1-2): 41-55. June 2000.	
409	CREAMS: A Field Scale Model for Chemicals, Runoff and Erosion from Agricultural Management Systems	Knisel, W.G.	1980		USDA Conservation Research Rept. No. 26.	
410	Personal Communication with Scott Koberg, Idaho Association of Soil Conservation Districts	Koberg, Scott	31-Jan-06			
411	Nutrient, Metal, and Pesticide Removal During Storm and Nonstorm Events by a Constructed Wetland on an Urban Golf Course	Kohler, E.A., V.L. Poole, Z.J. Reicher, and R.F. Turco	Dec-04		Ecological Engineering; 23(4-5): 285-298. Dec 30, 2004.	
412	Role of Plant Uptake on Nitrogen Removal in Constructed Wetlands Located in the Tropics	Koottatep, Thammarat and Chongrak Polprasert	1997		Water Science and Technology, Volume 36, Issue 12, 1997, Pages 1-8	
413	Comparison of the Treatment Performances of Blast Furnace Slag-based and Gravel-based Vertical Flow Wetlands Operated Identically for Domestic Wastewater Treatment in Turkey	Korkusuz, E. Asuman, Meryem Bekliolu and Göksel N. Demirer	Feb-05		Ecological Engineering; 24(3): 185-198. Feb 20, 2005.	
414	Effectiveness of constructed wetlands in reducing nitrogen and phosphorus export from agricultural tile drainage	Kovacic, D.A., M.B. David, L.E. Gentry, K.M. Starks, and R.A. Cooke	Jul-Aug-00		Journal of environmental quality. July/Aug 2000. v. 29 (4) p. 1262-1274.	
415	Assessing Denitrification Rate Limiting Factors in a Constructed Wetland Receiving Landfill Leachate	Kozub, D.D. and S.K. Liehr	1999		Water Science and Technology, Volume 40, Issue 3, 1999, Pages 75-82	
416	The Role of Tradable Permits in Water Pollution Control	Kraemer, R.A., E. Kampa, and E. Interwies	Undated 2003+	Report	Ecologic, Institute for International and European Environmental Policy	This paper explores the use of market-based incentives such as tradable permits to improve water quality in Chile. http://www.iadb.org/sds/inwap/publications/Tradable_Permits_in_Water_Pollution_Control.pdf
417	Analysis of Phosphorus Control Costs and Effectiveness for Point and Nonpoint Sources in the Fox-Wolf Basin	Kramer, J., Resource Strategies, Inc.	Jul-99	Paper	Fox-Wolf Basin 2000	

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418	Analysis of Phosphorus Control Costs and Effectiveness for Point and Non-point Sources in the Fox-Wolf Basin	Kramer, Joseph M. Resource Strategies, Inc.	Jul-99	Report	Fox-Wolf Basin 2000	A report of a study of the P control costs for non-point (agricultural operations) and point source (municipal treatment plants) in the Fox-Wolf Basin, Wisconsin. Cost estimates made by MTP managers. For non-point source, current P loads are estimated, BMPs are described, and cost estimates are made for P load reductions. Trading zones recommended because of non-uniform mixing of P in water bodies. Favorable conditions for successful trading program include: wide variation in point source control costs, large number of point sources, availability of low cost non-point source reductions. http://www.rs-inc.com/FWB2K_Final_Report.pdf
419	Using a wetland bioreactor to remediate ground water contaminated with nitrate (mg/L) and perchlorate (m/L)	Krauter, P.W.	2001		International Journal of Phytoremediation. 2001. v. 3 (4) p. 415-433.	
420	Cost-Effective NOx Control in the Eastern United States	Krupnick, A., V. McConnell, M. Cannon, T. Stoessell, and M. Batz	2000	Discussion Paper	Resources for the Future	
421	Annual Cycle of Nitrogen Removal by a Pilot-scale Subsurface Horizontal Flow in a Constructed Wetland Under Moderate Climate	Kuschk, P., A. Wießner, U. Kappelmeyer, E. Weißbrodt, M. Kästner, and U. Stottmeister	Oct-03		Water Research; 37(17): 4236-4242. Oct 2003.	
422	Wetland Creation and Restoration: The Status of the Science	Kusler, J.A. and M.E. Kentula (eds)	1990		Island Press, Washington, DC	
423	A Comparative Study of Cyperus papyrus and Miscanthidium violaceum-based Constructed Wetlands for Wastewater Treatment in a Tropical Climate	Kyambadde, Joseph, Frank Kansiime, Lena Gumaelius, and Gunnel Dalhammar	Jan-04		Water Research; 38(2): 475-485. Jan 2004.	
424	Two Strategies for Advanced Nitrogen Elimination in Vertical Flow Constructed Wetlands	Laber, Johannes, Reinhard Per er and Raimund Haberl	1997		Water Science and Technology, Volume 35, Issue 5, 1997, Pages 71-77	
425	Application of Constructed Wetlands for Wastewater Treatment in Hungary	Lakatos, Gyula, Magdolna K. Kiss, Marianna Kiss and Péter Juhász	1997		Water Science and Technology, Volume 35, Issue 5, 1997, Pages 331-336	
426	Applying Lessons Learned from Wetlands Mitigation Banking to Water Quality Trading	Landry, Mark, Antje Siems, Gerald Stedge, and Leonard Shabman	Feb-05	White paper	Abt Associates Inc., Bethesda, MD.	Background information for the National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking - http://www2.eli.org/research/wqt_main.htm
427	Potential Nitrate Removal from a River Diversion into a Mississippi Delta Forested Wetland	Lane, Robert R., Hassan S. Mashriqui, G. Paul Kemp, John W. Day, Jason N. Day, and Anna Hamilton	Jul-03		Ecological Engineering; 20(3): 237-249. July 2003.	

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428	Changes in Stoichiometric Si, N and P Ratios of Mississippi River Water Diverted Through Coastal Wetlands to the Gulf of Mexico	Lane, Robert R., John W. Day, Dubravko Justic, Enrique Reyes, Brian Marx, Jason N. Day and Emily Hyfield	May-04		Estuarine, Coastal and Shelf Science; 60(1): 1-10. May 2004.	
429	The 1994 Experimental Opening of the Bonnet Carre Spillway to Divert Mississippi River Water into Lake Pontchartrain, Louisiana	Lane, Robert R., John W., Day, Jr., G. Paul Kemp, and Dennis K. Demcheck	Aug-01		Ecological Engineering; 17(4): 411-422. August 2001.	
430	The Role of Plant Uptake on the Removal of Organic Matter and Nutrients in Subsurface Flow Constructed Wetlands: A Simulation Study	Langergraber, G.	2005		Water Science and Technology, 51(9): 213-23. 2005	
431	Stormwater Quantity and Quality in a Multiple Pond-wetland System: Flemingsbergsviken Case Study	Larm, Thomas	Jun-00		Ecological Engineering; 15(1-2): 57-75. June 2000.	
432	Quantification of Biofilms in a Sub-Surface Flow Wetland and Their Role in Nutrient Removal	Larsen, E. and M. Greenway	2004		Water Science Technology. 2004; 49(11-12): 115-22.	
433	An Introduction to Water Quality Trading	Leatherman, J., C. Smith, and J. Peterson	Aug-04	Paper	Department of Agricultural Economics	Prepared for Agricultural Economics' "Risk and Profit" Conference http://www.agmanager.info/events/risk_profit/2004/Leatherman-Peterson.pdf
434	Surface Water Nutrient Concentrations and Litter Decomposition Rates in Wetlands Impacted by Agriculture and Mining Activities	Lee, A.A. and P.A. Bukaveckas	Dec-02		Aquatic Botany; 74(4): 273-285. Dec 2002.	
435	Performance of Subsurface Flow Constructed Wetland Taking Pretreated Swine Ef uent Under Heavy Loads	Lee, C.Y., C.C. Lee, F.Y. Lee, S.K. Tseng, and C.J. Liao	Apr-04		Bioresources Technology. 2004 Apr;92(2): 173-9.	
436	Effects of marshes on water quality	Lee, G.F., E. Bentley, and R. Amundson	1975		In: Coupling of Land and Water Systems. A.D. Hasler, Ed., Springer-Verlag, New York, NY.	
437	Chapter 5: The Pesticide Submodel	Leonard, R.A. and R.D. Wauchope	1980		p. 88-112. In W.G. Knisel (ed.). CREAMS: A field-scale model for chemicals, runoff and erosion from agricultural management systems. USDA Conservation Research Rept. No. 26.	
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439	Ocean Pollution from Land-based Sources: East China Sea, China	Li, D. and D. Daler	Feb-04	Paper	Ambio. 2004 Feb;33(1-2):107-13. PMID: 15083656	This paper describes the role that steady water discharge from the Yangtze River has on alleviating impacts from pollution in the East China Sea and that large-scale water transfer and dam constructions in the Yangtze River basin will change this process. The main challenge to restoring ecosystem balance is to integrate socioeconomic and environmental decision making in order to promote sustainable development.
440	Spatial Modeling on the Nutrient Retention of an Estuary Wetland	Li, Xiuzhen, Duning Xiao, Rob H. Jongman, W. Bert Harms, and Arnold K. Bregt	Sep-03		Ecological Modelling; 167(1-2): 33-46. Sept 1, 2003.	
441	Roles of Substrate Microorganisms and Urease Activities in Wastewater Purification in a Constructed Wetland System	Liang, Wei, Zhen-bin Wu, Shui-ping Cheng, Qiao-hong Zhou and Hong-ying Hu	Dec-03		Ecological Engineering; 21(2-3): 191-195. Dec 1, 2003.	
442	Comparison of Nutrient Removal Ability Between Cyperus alternifolius and Vetiveria zizanioides in Constructed Wetlands	Liao, X., S. Luo, Y. Wu, and Z. Wang	Jan-05		Ying Yong Sheng Tai Xue Bao, 16(1): 156-60. Jan 2005.	
443	Phosphorus removal in a wetland constructed on former arable land	Liikanen, A., M. Puustinen, J. Koskiaho, T. Vaisanen, P. Martikainen, and H. Hartikainen	May-Jun-04		Journal of environmental quality. 2004 May-June, v. 33, no. 3, p. 1124-1132.	
444	Temporal and Seasonal Changes in Greenhouse Gas Emissions from a Constructed Wetland Purifying Peat Mining Runoff Waters	Liikanen, Anu, Jari T. Huttunen, Satu Maaria Karjalainen, Kaisa Heikkinen, Tero S. Väisänen, Hannu Nykänen, and Pertti J. Martikainen	Dec-05		Ecological Engineering, In Press, Corrected Proof, Available online 15 December 2005	
445	The Effect of Heavy Metals on Nitrogen and Oxygen Demand Removal in Constructed Wetlands	Lim, P.E., M.G. Tay, K.Y. Mak, and N. Mohamed	Jan-03		The Science of The Total Environment; 301(1-3): 13-21. Jan 1, 2003.	
446	Oxygen Demand, Nitrogen and Copper Removal by Free-water-surface and Subsurface- ow Constructed Wetlands Under Tropical Conditions	Lim, P.E., T.F. Wong, and D.V. Lim	May-01		Environment International; 26(5-6): 425-431. May 2001.	
447	Removal of solids and oxygen demand from aquaculture wastewater with a constructed wetland system in the tart-up phase	Lin, Y.F., S.R. Jing, D.Y. Lee, T.W. Wang	Mar-Apr-04		Water Environment Federation. Mar/Apr 2002. v. 74 (2) p. 136-141.	
448	Performance of a constructed wetland treating intensive shrimp aquaculture wastewater under high hydraulic loading rate	Lin, Y.F., S.R. Jing, D.Y. Lee, Y.F. Chang, Y.M. Chen, K.C. Shih	Apr-05		Environmental Pollution. 2005 Apr., v. 134, no. 3, p. 411-421.	

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449	The Potential Use of Constructed Wetlands in a Recirculating Aquaculture System for Shrimp Culture	Lin, Ying-Feng, Shuh-Ren Jing, and Der-Yuan Lee	May-03		Environmental Pollution; 123(1): 107-113. May 2003.	
450	Nutrient Removal from Aquaculture Wastewater Using a Constructed Wetlands System	Lin, Ying-Feng, Shuh-Ren Jing, Der-Yuan Lee, and Tze-Wen Wang	Jun-02		Aquaculture; 209(1-4): 169-184. June 28, 2002.	
451	Effects of Macrophytes and External Carbon Sources on Nitrate Removal from Groundwater in Constructed Wetlands	Lin, Ying-Feng, Shuh-Ren Jing, Tze-Wen Wang, and Der-Yuan Lee	Oct-02		Environmental Pollution; 119(3): 413-420. Oct 2002.	
452	Air/water Exchange of Mercury in the Everglades II: Measuring and Modeling Evasion of Mercury from Surface Waters in the Everglades Nutrient Removal Project	Lindberg, S.E. and H. Zhang	2-Oct-00		Science of the Total Environment. 2000 Oct 2;259(1-3):135-43.	
453	Stimulation of microbial sulphate reduction in a constructed wetland: microbiological and geochemical analysis	Lloyd, J.R., D.A. Klessa, D.L. Parry, P. Buck, N.L. Brown	Apr-04		Water Research. 2004 Apr., v. 38, no. 7, p. 1822-1830.	
454	In uence of Harvesting on Biogeochemical Exchange in Sheet ow and Soil Processes in a Eutrophic Floodplain Forest	Lockaby, B.G., R.G. Clawson, K. Flynn, R. Rummer, S. Meadows, B. Stokes and J. Stanturf	Feb-97		Forest Ecology and Management, Volume 90, Issues 2-3, February 1997, Pages 187-194	
455	Telephone Interview with Bill Lord, Neuse River Eduction Team, North Carolina State University 12/9/2005	Lord, Bill				
456	Dissolved organic carbon and methane emissions from a rice paddy fertilized with ammonium and nitrate	Lu, Y., R. Wassamann, H.U. Neue, and C. Huang	Nov-Dec-00		Journal of environmental quality. Nov/Dec 2000. v. 29 (6) p. 1733-1740.	The effect of nitrogen fertilizers on methane (CH4) production and emission in wetland rice (Oryza sativa L.) is not clearly understood. Greenhouse pot and laboratory incubation were conducted to determine whether the effect of N type (NH4)-N and NO3-N) and rate (30 and 120 kg N ha super(-1)) were related to the availability of carbon for CH4 production in ooded rice soils. The inhibitory effect of NO3-N seemed not fully accountable for the prolonged reduction in CH4 production and emission in the fields. The root zone DOC that is enriched by plant-borne C appears to be a main source for CH4 production and the lower DOC concentrations with NO3-N application are accountable for the low CH4 emissions. http://www.csa.com/partners/viewrecord.php?requester=gs&collection=TRD&recid=0516433EN&q=Dissolved+organic+carbon+and+methane+emissions+from+a+rice+paddy+fertilized+with+ammonium+and+nitrate&uid=1025630&setcookie=yes
457	Early development of vascular vegetation of constructed wetlands in northwest Ohio receiving agricultural waters	Luckeydoo, L.M., N.R. Fausey, L.C. Brown, and C.B. Davis	Jan-02		Agriculture, ecosystems & environment. Jan 2002. v. 88 (1) p. 89-94.	

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458	Nutrient Removal Efficiency and Resource Economics of Vertical Flow and Horizontal Flow Constructed Wetlands	Luederitz, Volker, Elke Eckert, Martina Lange-Weber, Andreas Lange, and Richard M. Gersberg	Dec-01		Ecological Engineering; 18(2): 157-171. December 2001.	
459	Estimating Denitrification in a Large Constructed Wetland Using Stable Nitrogen Isotope Ratios	Lund, L.J., A.J. Horne, and A.E. Williams	Sep-99		Ecological Engineering; 14(1-2): 67-76. September 1999.	
460	Efficacy of a Subsurface- ow Wetland Using the Estuarine Sedge Juncus kraussii to Treat Ef uent from Inland Saline Aquaculture	Lymbery, Alan J., Robert G. Doupé, Thomas Bennett, and Mark R. Starcevich	Jan-06		Aquacultural Engineering; 34(1): 1-7. Jan 2006.	
461	Reducing Phosphorus Loads in Idaho's Lower Boise River: The Role of Trading from a State Perspective	Mabe, David	Jul-03	PowerPoint		2003 National Forum on Water Quality Trading
462	Importance of Compliance and Enforcement in International Emissions Trading Schemes	Mace, M. J. (Programme Director)	3/16-18/2004	Presentation	Foundation for International Law and Development	http://www.inece.org/emissions/mace.pdf
463	Cold-Climate Constructed Wetlands	Mæhlum, T., P.D. Jenssen and W. S. Warner	1995		Water Science and Technology, Volume 32, Issue 3, 1995, Pages 95-101	
464	The Use of Constructed Wetlands for the Treatment of Run-off and Drainage Waters: The UK and Ukraine Experience	Magmedov, Vyacheslav G., Michael A. Zakharchenko, Ludmila I. Yakovleva and Margaret E. Ince	1996		Water Science and Technology, Volume 33, Issues 4-5, 1996, Pages 315-323	
465	mpacts of sedimentation and nitrogen enrichment on wetland plant community development	Mahaney, W.M., D.H. Wardrop, R.P. Brooks	2004		Plant Ecology. 2004, v. 175, no. 2, p. 227-243.	http://www.kluweronline.com/issn/1385-0237/contents
466	Nitrogen and phosphorus ux rates from sediments in a southeastern US river estuary	Malecki, L.M., J.R. White and K.R. Reddy	2004		Journal of Environmental Quality	
467	Point/non-point Source Trading of Pollution Abatement: Choosing the Right Trading Ratio	Malick, A., D. Letson, and S.R. Crutchfield			American J. of Ag. Econ. 7:959-967.	
468	Constructed Wetlands for Wastewater Treatment in Estonia	Mander, Ulo and Tonu Mauring	1997		Water Science and Technology, Volume 35, Issue 5, 1997, Pages 323-330	
469	Nutrient Dynamics of Riparian Ecotones: A Case Study from the Porijõgi River Catchment, Estonia	Mander, Ülo, Valdo Kuusemets and Mari Ivask	Feb-95		Landscape and Urban Planning, Volume 31, Issues 1-3, February 1995, Pages 333-348	
470	Application of Constructed Wetlands for Domestic Wastewater Treatment in an Arid Climate	Mandi, L., K. Bouhoum and N. Ouazzani	1998		Water Science and Technology, Volume 38, Issue 1, 1998, Pages 379-387	

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471	Application of a Horizontal Subsurface Flow Constructed Wetland on Treatment of Dairy Parlor Wastewater	Mantovi, Paolo, Marta Marmiroli, Elena Maestri, Simona Tagliavini, Sergio Piccinini, and Nelson Marmiroli	Jun-03		Bioresource Technology; 88(2): 85-94. June 2003.	
472	Pollutant Monitoring of Ef uent Credit Trading Programs For Agricultural Nonpoint Source Control	March, D.J.	Nov-00	Masters Thesis	Virginia Polytechnic and State University	http://scholar.lib.vt.edu/theses/available/etd-02142001-091021/unrestricted/FinalFinalThesisVersion0202.PDF
473	The Role of the Submergent Macrophyte Triglochin huegelii in Domestic Greywater Treatment	Mars, Ross, Kuruvilla Mathew and Goen Ho	Jan-99		Ecological Engineering, Volume 12, Issues 1-2, January 1999, Pages 57-66	
474	Final Report: Results of Water-Based Trading Simulations	Marshall, C.	Sep-99	Report	Philip Services, Incorporated	
475	Results of Water-Based Trading Simulations	Marshall, Chuck QEP Philip Services	Sep-99	Report	EPA	
476	Estimating Erosion in a Riverine Watershed: Bayou Liberty-Tchefuncta River in Louisiana	Martin, A., J.T. Gunter, and J.L. Regens	2003	Paper	Environ Sci Pollut Res Int. 2003;10(4):245-50. PMID: 12943008	This study uses spatial analysis techniques and a numerical modeling approach to predict areas with the greatest sheet erosion potential given different soils disturbance scenarios.
477	The Use of Extended Aeration and In-series Surface- ow Wetlands for Landfill Leachate Treatment	Martin, Craig D. and Keith D. Johnson	Jun-05		Water Science and Technology, Volume 32, Issue 3, 1995, Pages 119-128	
478	Interaction and Spatial Distribution of Wetland Nitrogen Processes	Martin, Jay F. and K. R. Reddy	Dec-97		Ecological Modelling, Volume 105, Issue 1, 14 December 1997, Pages 1-21	
479	Fate of 15N-nitrate in Unplanted, Planted and Harvested Riparian Wetland Soil Microcosms	Matheson, F.E., M. L.Nguyen, A.B. Cooper, T.P. Burt, and D.C. Bull	Oct-02		Ecological Engineering; 19(4): 249-264. Oct 2002.	
480	Periodic draining reduces mosquito emergence from free-water surface constructed wetlands	Mayhew, C.R., D.R. Raman, R.R. Gerhardt, R.T. Burns, and M.S. Younger	Mar-Apr-04		Transactions of the ASAE. 2004 Mar-Apr, v. 47, no. 2, p. 567-573.	
481	Producing native and ornamental wetland plants in constructed wetlands designed to reduce pollution from agricultural runoff	Maynard, B.K.			Sustainable Agriculture Research and Education (SARE) research projects. Northeast Region. 2001, SARE PROJECT LNE98-100	
482	Effect of HRT on Nitrogen Removal in a Coupled HRP and Unplanted Subsurface Flow Gravel Bed Constructed Wetland	Mayo, A.W. and J. Mutamba	2004		Ecological Engineering, Volume 21, Issues 4-5, 31 December 2003, Pages 233-247	

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483	Nitrogen Transformation in Horizontal Subsurface Flow Constructed Wetlands I: Model Development	Mayo, A.W. and T. Bigambo	2005		Physics and Chemistry of the Earth, Parts A/B/C; 30(11-16): 658-667. 2005.	
484	Nitrogen Transformation in Horizontal Subsurface Flow Constructed Wetlands II: Effect of Biofilm	Mayo, A.W. and T. Bigambo	2005		Physics and Chemistry of the Earth, Parts A/B/C; 30(11-16): 668-672. 2005.	
485	Modelling Nitrogen Removal in a Coupled HRP and Unplanted Horizontal Flow Subsurface Gravel Bed Constructed Wetland	Mayo, A.W. and T. Bigambo	2005		Physics and Chemistry of the Earth, Parts A/B/C; 30(11-16): 673-679. 2005.	
486	Comparative treatment of dye-rich wastewater in engineered wetland systems (EWSs) vegetated with different plants	Mbuligwe, S.E.	Jan-Feb-05		Water Research. 2005 Jan-Feb, v. 39, issue 2-3 p. 271-280	
487	Habitat Quality Assessment of Two Wetland Treatment Systems in the Arid West--Pilot Study	McAllister, L.S.	Jul-92	Pilot Study Report	EPA/600/R-93/117. EPA Environmental Research Laboratory, Corvallis, OR	
488	Habitat Quality Assessment of Two Wetland Treatment Systems in Mississippi--A Pilot Study	McAllister, L.S.	Nov-92	Pilot Study Report	EPA/600/R-92/229. EPA Environmental Research Laboratory, Corvallis, OR	
489	Habitat Quality Assessment of Two Wetland Treatment Systems in Florida--A Pilot Study	McAllister, L.S.	Nov-93		EPA/600/R-93/222. EPA Environmental Research Laboratory, Corvallis, OR	
490	Modelling Biofilm Nitrogen Transformations in Constructed Wetland Mesocosms with Fluctuating Water Levels	McBride, Graham B. and Chris C. Tanner	Sep-99		Ecological Engineering; 14(1-2): 93-106. September 1999.	
491	Cost Effectiveness and Targeting of Agricultural BMPs for the Tar-Pamlico Nutrient Trading Program	McCarthy, M., R. Dodd, J.P. Tippett, and D. Harding	1996	Proceedings	Watersheds '96. Water Environment Federation and U.S. EPA.	This paper discusses some of the technical work that supports the Tar-Pamlico Nutrient Trading Program implementation. In order to help the Program participants set a reasonable cost for trading nitrogen or phosphorus between point and nonpoint sources and understand how cost effective different best management practices (BMPs) are, the authors developed cost-effectiveness estimates (expressed as $/kilogram of nutrient load reduced) for cost-shared agricultural BMPs in the Basin. The data represent BMPs that were implemented from 1985 to 1994. http://www.epa.gov/owowwtr1/watershed/Proceed/mccarthy.html
492	Nutrient Trading: Experiences and Lessons	McCatty, T.	Aug-99	Case Study	Massachusetts Institute of Technology	
493	A Guide to Hydrologic Analysis Using SCS Methods	McCuen, R.H.	1982		Printice-Hall, Inc. Englewood Cliffs, NJ.	
494	Multiple Credit Types for a Single Project Site	McElwaine, Andrew Pennsylvania Environmental Council	7/11-12/2005	Presentation	PowerPoint Presentation	

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495	Estimating Inorganic and Organic Nitrogen Transformation Rates in a Model of a Constructed Wetland Purification System for Dilute Farm Ef uents	McGechan, M.B., S.E. Moir, G. Sym, and K. Castle	May-05		Biosystems Engineering; 91(1): 61-75. May 2005.	
496	Modelling oxygen transport in a reed-bed-constructed wetland purification system for dilute ef uents	McGechan, M.B., S.E. Moir, I.P.J. Smit, and K. Castle	Jun-05		Biosystems Engineering. 2005 June, v. 91, no. 2, p. 191-200.	http://www.sciencedirect.com/science/journal/15375110
497	Watershed-based Pollution Trading Development and Current Trading Programs	McGinnis, S. L.	Feb-01	Paper	Springer-Verlag GmbH, ISSN: 1433-6618 (Paper) 1434-0852 (Online), DOI: 10.1007/s100220000018, Volume 2, Number 3, Pages: 161 - 170	This paper describes the diversity of existing pollution trading programs and the exibility that exists in trading programs to manage nearly any site-specific watershed pollution problem. Although the use of watershed-based pollution trading is relatively unproven, observation of the existing trading programs indicates that trading has the potential to improve water quality in heavily impaired watersheds. http://www.springerlink.com/app/home/contribution.asp
498	Relating Net Nitrogen Input in the Mississippi River Basin to Nitrate Flux in the Lower Mississippi River: A Comparison of Approaches	McIsaac, G.F., M.B. David, G.Z. Gertner, and D.A. Goolsby	Sept-Oct/ 2002	Paper	J Environ Qual. 2002 Sep-Oct;31(5):1610-22. PMID: 12371178	The objective of this study was to compare recently published approaches for relating terrestrial N inputs to the Mississippi River basin (MRB) with measured nitrate ux in the lower Mississippi River. Nitrogen inputs to and outputs from the MRB (1951 to 1996) were estimated from state-level annual agricultural production statistics and NOy (inorganic oxides of N) deposition estimates for 20 states that comprise 90% of the MRB. Modeling was used to analyze the data.
499	Soil Organic Matter and Nitrogen Cycling in Response to Harvesting, Mechanical Site Preparation, and Fertilization in a Wetland with a Mineral Substrate	McLaughlin, James W., Margaret R. Gale, Martin F. Jurgensen, and Carl C. Trettin	Apr-00		Forest Ecology and Management; 129(1-3): 7-23. April 17, 2000.	
500	Stakeholders' View of Watershed-Based Trading	McNew, Todd	Jul-03	PowerPoint		2003 National Forum on Water Quality Trading
501	The Use of Water Quality Trading and Wetland Restoration to Address Hypoxia in the Gulf of Mexico	Mehan, G. Tracy III, Cadmus Group	7/11-12/2005	Presentation	Audio Recording	Presented at National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking - http://www2.eli.org/research/wqt_main.htm
502	Mosquito (Diptera: Culicidae) development within microhabitats of an Iowa wetland	Mercer, D.R., S.L. Sheeley, E.J. Brown	Jul-05		Journal of Medical Entomology. 2005 July, v. 42, no. 4, p. 685-693.	
503	Water and Mass Budgets of a Vertical- ow Constructed Wetland used for Wastewater Treatment	Meuleman, Arthur F. M., Richard Van Logtestijn, Gerard B.J. Rijs, and Jos T. A. Verhoeven	Mar-03		Ecological Engineering; 20(1): 31-44. March 2003.	
504	Nutrients in salmon hatchery wastewater and its removal through the use of a wetland constructed to treat off-line settling pond ef uent	Michael, J.H., Jr.	Oct-03		Aquaculture. 2003 Oct. 31, v. 226, no. 1-4, p. 213-225.	http://www.elsevier.com/locate/issn/00448486

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505	Introduction to Market-Based Programs	Michigan Department of Environmental Quality, Surface Water Quality Division		Web site	Michigan Department of Environmental Quality, Surface Water Quality Division	http://www.deq.state.mi.us/swq/trading/htm/intro.htm
506	Market-Based Program Feasibility	Michigan Department of Environmental Quality, Surface Water Quality Division		Web site	Michigan Department of Environmental Quality, Surface Water Quality Division	http://www.deq.state.mi.us/swq/trading/htm/kzo.htm
507	Saginaw Basin Modeling	Michigan Department of Environmental Quality, Surface Water Quality Division		Modeling	Michigan Department of Environmental Quality, Surface Water Quality Division	http://www.deq.state.mi.us/swq/trading/htm/wrimod.htm
508	Water Quality Trading Workgroup Discussion Document. Part XXX. Water Quality Trading - Draft #20	Michigan Department of Environmental Quality, Surface Water Quality Division	Sep-99	Discussion	Michigan Department of Environmental Quality, Surface Water Quality Division	http://www.deq.state.mi.us/swq/trading/htm/Rule20.htm
509	Rahr Malting Company "Trading" Permit	Minnesota Pollution Control Agency	Mar-97	Fact sheet	Minnesota Pollution Control Agency	http://www.pca.state.mn.us/water/pubs/rahrtrad.pdf
510	Watershed-Based Permitting Case Study: Final Permit Rahr Malting Company National Pollutant Discharge Elimination System and State Disposal System Permit No. MN0031917	Minnesota Pollution Control Agency	Jan-97	Case Study	Minnesota Pollution Control Agency (MPCA)	
511	A Framework for Trading Phosphorus Credits in the Lake Allatoona Watershed	Minnesota Pollution Control Agency	2003	Project plan	River Basin Center Institute of Ecology, University of Georgia	
512	The Use of Wetlands for Water Pollution Control in Australia: An Ecological Perspective	Mitchell, D.S., A.J. Chick and G.W. Raisin	1995		Water Science and Technology, Volume 32, Issue 3, 1995, Pages 365-373	
513	Nitrogen Biogeochemistry in the Adirondack Mountains of New York: Hardwood Ecosystems and Associated Surface Waters	Mitchell, Myron J., Charles T. Driscoll, Shreeram Inamdar, Greg G. McGee, Monday O. Mbila, and Dudley J. Raynal	Jun-03		Environmental Pollution; 123(3): 355-364. June 2003.	

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514	Landscape design and the role of created, restored, and natural riparian wetlands in controlling nonpoint source pollution	Mitsch, W.J.	1992		Ecological Engineering [ECOL. ENG.]. Vol. 1, no. 1-2, pp. 27-47. 1992.	General design principles of wetland construction for nonpoint source (NPS) water pollution control emphasize self-design and minimum maintenance systems, with an emphasis on function over form and biological form over rigid designs. These wetlands can be located as instream wetlands or as oodplain riparian wetlands, can be located as several wetlands in upstream reaches or fewer in downstream reaches of a watershed, and can be designed as terraced wetlands in steep terrain. Case studies of a natural riparian wetland in southern Illinois, an instream wetland in a downstream location in a northern Ohio watershed, and several constructed riparian wetlands in northeastern Illinois demonstrate a wide range of sediment and phosphorus retention, with greater efficiencies generally present in the constructed wetlands (63-96% retention of phosphorus) than in natural wetlands (4-10% retention of phosphorus). By itself, this could be misleading since the natural wetlands have much higher loading rates and actually retain an amount of nutrients comparable to constructed wetlands (1-4 g P/ super(2)/year).
515	GLOBAL WETLANDS: OLD WORLD AND NEW	Mitsch, W.J. (ed.)	1994		Hardbound, ISBN: 0-444-81478-7, 992 pages, publication date: 1994	
516	Wetlands and Lakes as Nitrogen Traps : Kessler, E. and M. Jansson, eds. 1994. Special Issue of Ambio 23:319-386. Royal Swedish Academy of Sciences, Stockholm.	Mitsch, William J.	Oct-95		Ecological Engineering, Volume 5, Issue 1, October 1995, Pages 123-125	
517	Wetlands 3rd Edition	Mitsch, William J. and James G. Gosselink	21-Jul-00		John Wiley and Sons 936 pgs.	
518	Nitrate-nitrogen Retention in Wetlands in the Mississippi River Basin	Mitsch, William J., John W. Day, Li Zhang, and Robert R. Lane	Apr-05		Ecological Engineering; 24(4): 267-278. Apr 5, 2005.	
519	Creating Riverine Wetlands: Ecological Succession, Nutrient Retention, and Pulsing Effects	Mitsch, William J., Li Zhang, Christopher J. Anderson, Anne E. Altor, and Maria E. Hernández	Dec-05		Ecological Engineering; 25(5)1/19/2006 510-527. Dec. 1, 2005.	
520	Water Quality Trading in the United States	Morgan, Cynthia and Ann Wolverton	Jun-05	Working Paper	Working Paper # 05-07. U.S. EPA, National Center for Environmental Economics	Background information for the National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking - http://www2.eli.org/research/wqt_main.htm
521	Biogeochemical Considerations for Water Quality Trading in Canada	Morin, Anne	2005		Policy Research Initiative Working Paper, Ottawa.	
522	The Design and Performance of Avertical Flow Reed Bed for the Treatment of High Ammonia, Low Suspended Solids Organic Ef uents	Morris, Michael and Robert Herbert	1997		Water Science and Technology, Volume 35, Issue 5, 1997, Pages 197-204	

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523	Off-set Banking–A way Ahead for Controlling Non-point Source Pollution in Urban Areas	Morrison, M.	2003	Paper	School of Marketing and Management, Charles Sturt University	
524	Off-set Banking: A Way Ahead for Controlling Non-point Source Pollution in Urban Areas in Georgia	Morrison, Mark D.	Jun-02	Working Paper Draft	Georgia Water Planning and Policy Center	http://www.h2opolicycenter.org/pdf_documents/water_working-papers/2002_004.pdf
525	Constructed Wetland for Water Quality Improvement	Moshiri, G.A.	1993		CRC Press, Boca Raton, FL. 1993.	
526	Modelling Nutrient Fluxes from Diffuse and Point Emissions to River Loads: The Estonian Part of the Transboundary Lake Peipsi/Chudskoe Drainage Basin (Russia/Estonia/Latvia)	Mourad, D. and M. van der Perk	2004	Paper	Water Sci Technol. 2004;49(3):21-8. PMID: 15053095	
527	Do wetlands behave like shallow lakes in terms of phosphorus dynamics?	Moustafa, M.Z.	Feb-00		Journal of the American Water Resources Association / Feb 2000. v. 36 (1) p. 43-54.	http://www.awra.org/jawra/index.html
528	The Response of a Freshwater Wetland to Long-term "Low Level" Nutrient Loads - Marsh Efficiency	Moustafa, M.Z., M.J. Chimney, T.D. Fontaine, G. Shih and S. Davis	Sep-96		Ecological Engineering, Volume 7, Issue 1, September 1996, Pages 15-33	
529	Validation Approaches for Field-, Basin-, and Regional-scale Water Quality Models	Mulla, D.J. and T.M. Addiscott	1999		In D.L. Corwin and T.R. Ellsworth (ed.). Assessment of non-point source pollution in the vadose zone. American Geophsyical Union. Washington, D.C. pp. 63-78.	
530	Effect of NH4+/NO3? Availability on Nitrate Reductase Activity and Nitrogen Accumulation in Wetland Helophytes Phragmites australis and Glyceria maxima	Munzarova, Edita, Bent Lorenzen, Hans Brix, Lenka Vojtiskova, and Olga Votrubova	Jan-06		Environmental and Experimental Botany; 55(1-2): 49-60. Jan 2006.	
531	Information on Water Quality Parameters	Murphy, S.	2005		USGS Water Quality Monitoring, BASIN Project, City of Boulder, CO	http://bcn.boulder.co.us/basin/data/BACT/info/ (January 2006).
532	Simulation of Pollution Buffering Capacity of Wetlands Fringing the Lake Victoria	Mwanuzi, F., H. Aalderink, and L. Mdamo	Apr-03		Environmental International. 2003 Apr; 29(1): 95-103.	
533	Soil development in phosphate-mined created wetlands of Florida, USA	Nair, V.D., D.A. Graetz, K.R. Reddy, and O.G. Olila	Jun-01		Wetlands : the Journal of the Society of the Wetlands Scientists. June 2001. v. 21 (2) p. 232-239.	
534	Report of the Conservation Innovations Task Force (CITF), Dec. 2003, Appendix III - Water Quality Trading - Nonpoint Credit Bank	National Association of Conservation Districts	Dec-03	Report	National Association of Conservation Districts	http://www.nacdnet.org/resources/CITF/app3.htm

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535	Treatment of Freshwater Fish Farm Ef-uent Using Constructed Wetlands: The Role of Plants and Substrate	Naylor, S., J. Brlsson, M.A. Labelle, A. Drizo, and Y. Comeau	2003		Water Science Technology. 2003; 48(5): 215-22.	
536	Soil and Water Assessment Tool User's Manual	Neitsch, S.L., J.G. Arnold, J.R. Kiniry, and J.R. Williams	2001	Online	Available at http://www.brc.tamus.edu/swat/swat-2000doc.html.	
537	Market and Bargaining Approaches to Nonpoint Source Pollution Abatement Problems	Netusil, N.R. and John B. Braden	1993	Journal Article	Water Science and Technology, 28(3-5), 35-45.	
538	Watershed Based Permitting Case Study: Final Permit	Neuse River Compliance Association	2002	Case Study	US Environmental Protection Agency	http://www.epa.gov/npdes/pubs/wq_casestudy_factsht11.pdf
539	Wetland Project Teaches Students How To Protect Our Water Supply	Neuse River Eduction Team	winter 2004	Case study	Neuse River Eduction Team, North Carolina State University website. Viewed on 12/05/2005	http://www.neuse.ncsu.edu/neuse_letters/winter2004/story2.htm
540	Neuse Education Team Impacts: Agricultural Impacts 2: Novel Nursery	Neuse River Eduction Team	undated	Case study	Neuse River Eduction Team, North Carolina State University website. Viewed on 12/05/2005	http://www.neuse.ncsu.edu/impact2b.pdf
541	Guidance for Phosphorus Offset Pilot Programs	New York City Department of Environmental Protection, Bureau of Water Supply Quality and Protection	Mar-97	Guidance Doc	New York City Department of Environmental Protection, Bureau of Water Supply Quality and Protection	
542	Seasonal Performance of a Wetland Constructed to Process Dairy Milkhouse Wastewater in Connecticut	Newman, Jana Majer, John C. Clausen, and Joseph A. Neafsey	Sep-99		Ecological Engineering; 14(1-2): 181-198. September 1999.	
543	An Environmental Big Stick	Newport, Alan	Mar-04	Article	National Hog Farmer, PRIMEDIA Busienss Magazines and Media, Inc. 2004	
544	The Effects of Stormwater Surface Runoff on Freshwater Wetlands: A Review of the Literature and Annotated Bibliography	Newton, R.B.	1989		Publ. #90-2. The Environmental Institute, Univ. of Massachusetts, Amherst, MA	
545	Organic Matter Composition, Microbial Biomass and Microbial Activity in Gravel-bed Constructed Wetlands Treating Farm Dairy Wastewaters	Nguyen, Long M.	Nov-00		Ecological Engineering; 16(2): 199-221. November 2000.	
546	A Guide to Market-Based Approaches to Water Quality	Nguyen, T., R.T. Woodward, M.D. Matlock, and P. Faeth	Oct-04	Paper	World Resource Institute	

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547	Evidence of N2O emission and gaseous nitrogen losses through nitrification-denitrification induced by rice plants (Oryza sativa L.)	Ni, W.Z., and Z.L. Zhu	Aug-04		Biology and Fertility of Soils. 2004 Aug., v. 40, no. 3, p. 211-214.	
548	Inhibition kinetics of salt-affected wetland for municipal wastewater treatment	Nitisoravut, S. and P. Klomjek	Nov-05		Water Research. 2005 Nov., v. 39, issue 18, p. 4413-4419.	
549	Wetlands and Water Quality: A Regional Review of Recent Research in the U.S. on the Role of Freshwater and Saltwater Wetlands as Sources, Sinks, and Transformers of Nitrogen, Phosphorus, and Heavy Metals	Nixon, S.W. and V. Lee	1986	Abstract	Technical Rept. Y-86-2, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS	
550	Inactivation of Indicator Micro-organisms from Various Sources of Faecal Contamination in Seawater and Freshwater	Noble, R.T., I.M. Lee, and K.C. Schiff	Mar-04	Paper	Journal of Applied Microbiology, Volume 96, Issue 3, Page 464-472, Mar 2004	
551	A Pilot Study of Constructed Wetlands Using Duckweed (Lemna gibba L.) for Treatment of Domestic Primary Ef uent in Israel	Noemi Ran, Moshe Agami, and Gideon Oron	May-04		Water Research; 38(9): 2241-2248. May 2004.	
552	Report of the Proceedings on the Proposed Neuse River Basin Nutrient Sensitive Waters (NSW) Management Strategy	North Carolina Department of Environment and Natural Resources	Dec-97	Plan	Environmental Management Commission Meeting December 11, 1997. Printed November 26, 1997	
553	Phase II of the Total Maximum Daily Load for Total Nitrogen to the Neuse River Estuary, North Carolina	North Carolina Department of Environment and Natural Resources	Dec-01		North Carolina Department of Environment and Natural Resources, Dividion of Water Quality	
554	Neuse River Basinwide Water Quality Plan	North Carolina Department of Environment and Natural Resources (NCDENR)	1998		NC Division of Water Quality	http://h2o.enr.state.nc.us/basinwide/Neuse/neuse_wq_management_plan.htm
555	Report of the Proceedings on the Proposed Neuse River Basin Nutrient Sensitive Waters (NSW) Management Strategy. Environmental Management Commission Meeting	North Carolina Department of Environment, Health and Natural Resources.	Jun-97	Plan	Reprinted July 1997.	
556	Tar-Pamlico River Nutrient Management Plan for Nonpoint Sources of Pollution	North Carolina Division of Environmental Management, Water Quality Section	Dec-95	Plan	North Carolina Division of Environmental Management, Water Quality Section	

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557	Implementation of the Conservation Partnership's Neuse River Basin Initiative	North Carolina Division of Soil and Water Conservation		Website	North Carolina Division of Soil and Water Conservation, North Carolina Department of Environment and Natural Resources. Website accessed 11/26/2005	http://www.enr.state.nc.us/DSWC/pages/intitiative.html
558	Tar-Pamlico River Basinwide Water Quality Plan (July 1999)	North Carolina Division of Water Quality	1999		North Carolina Division of Water Quality	http://h2o.enr.state.nc.us/basinwide/tarpam_wq_management_plan.htm
559	North Carolina Division of Water Quality Nonpoint Source Management Program : Tar-Pamlico Nutrient Strategy Website	North Carolina Division of Water Quality	Date accessed: 12/06/05	Website	North Carolina Division of Water Quality	http://h2o.enr.state.nc.us/nps/tarpam.htm
560	Fiscal Analysis: Nonpoint Source Nutrient Rules Tar-Pamlico River Basin Nutrient Sensitive Waters Management Strategy	North Carolina Division of Water Quality	Jul. 1, 1999		North Carolina Division of Water Quality	
561	First Annual Status Report to the Environmental Management Commission. Tar-Pamlico River Nutrient Management Plan for Nonpoint Sources	North Carolina Division of Water Quality, Water Quality Section	Oct-97	Report	North Carolina Division of Water Quality, Water Quality Section	
562	Second Annual Status Report to the Environmental Management Commission. Tar-Pamlico River Nutrient Management Plan for Nonpoint Sources	North Carolina Division of Water Quality, Water Quality Section	Jul-98	Report	North Carolina Division of Water Quality, Water Quality Section	
563	Point/nonpoint Trading Program for the Green Bay Remedial Action Plan	Northeast Wisconsin Waters For Tomorrow (now called Fox-Wolf Basin 2000)	1994		Northeast Wisconsin Waters For Tomorrow (now called Fox-Wolf Basin 2000)	
564	The phosphorus index	NRCS	2001		NRCS. Agronomy Technical Note 26 (revised). Portland, OR.	
565	Evaluation of Phosphorus Retention in a South Florida Treatment Wetland	Nungesser, M.K. and M.J. Chimney	2001		Water Science Technology. 2001;44(11-12):109-15.	
566	Phosphorous Trading in the South Nation River Watershed, Ontario, Canada	O'Grady, D. and M.A. Wilson	2002		South Nation Conservation Authority.	http://www.envtn.org/wqt/programs/ontario.PDF.
567	Lessons Learned from Point-Nonpoint Source Trading Case Studies	O'Grady, Dennis South Nation Conservation	7/11-12/2005	Presentation	Audio Recording	Presented at National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking - http://www2.eli.org/research/wqt_main.htm
568	Lessons Learned from Point-Nonpoint Source Trading Case Studies	O'Grady, Dennis South Nation Conservation	7/11-12/2005	Presentation	PowerPoint Presentation	Presented at National Forum on Synergies Between Water Quality Trading and Wetland Mitigation Banking - http://www2.eli.org/research/wqt_main.htm

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569	Creating Markets for Nutrients and Other Water Pollutants	O'Sullivan, D.	2002		Coast-to-Coast 2002	
570	Distribution of Nutrients and Heavy Metals in a Constructed Wetland System	Obarska-Pempkowiak, Hanna and Katarzyna Klimkowska	Jul-99		Chemosphere; 39(2): 303-312. July 1999.	
571	Mineral nutrition of three aquatic emergent macrophytes in a managed wetland in Venezuela	Olivares, E., D. Vizcaino, and A. Gamboa	2002		Journal of plant nutrition. 2002. v. 25 (3) p. 475-496.	
572	Nonpoint Source-Stream Nutrient Level Relationships: A Nationwide Study	Omernik, J.M.	1997		EPA 600/3-79-105. Corvallis Environmental Research Laboratory, U.S. EPA, Corvallis, OR.	
573	Reducing Nitrogen from Agriculture at a River Basin Scale: Lessons Learned in the Neuse River Basin	Osmond, Deanna, Bill Lord, and Mitch Woodward (NC State University)	Sep-05	Presentation	13th National Nonpoint Source Monitoring Workshop	http://www.bae.ncsu.edu/programs/extension/wqg/nmp_conf/presentations.html
574	Microbial Characteristics of Constructed Wetlands	Ottová, Vlasta, Jarmila Balcarová and Jan Vymazal	1997		Water Science and Technology, Volume 35, Issue 5, 1997, Pages 117-123	
575	FerryMon: Using Ferries to Monitor and Assess Environmental Conditions and Change in North Carolina's Albemarle-Pamlico Sound System	Paerl, Hans and Thomas Gallo (Institute of Marine Science, UNC-Chapel Hill); Christopher P. Buzzelli (Hollings Marine Lab); Joseph S. Ramus, presenter (Duke University)	Sep-05	Presentation	13th National Nonpoint Source Monitoring Workshop	http://www.bae.ncsu.edu/programs/extension/wqg/nmp_conf/presentations.html
576	Phytoplankton Photopigments as Indicators of Estuarine and Coastal Eutrophication	Paerl, Hans W.	Oct-03		BioScience	http://www.findarticles.com/p/articles/mi_go1679/is_200310/ai_n9292643
577	Hydrologic In uence on Stability of Organic Phosphorus in Wetland Detritus	Pant, H.K. and K.R. Reddy	Mar-Apr 2001		Journal of Environmental Quality. 2001 Mar-Apr;30(2):668-74.	

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578	Planted Riparian Buffer Zones in New Zealand: Do They Live Up to Expectations?	Parkyn, Stephanie M., Rob J. Davies-Colley, N. Jane Halliday, Kerry J. Costley, and Glenys F. Croker	Dec-03	Paper	Restoration Ecology, Volume 11, Issue 4, Page 436-447, Dec 2003	Study that assessed nine riparian buffer zone schemes in New Zealand that had been fenced and planted (age range from 2 to 24 years) and compared them with unbuffered control reaches upstream or nearby. Included in the study were macroinvertebrate community composition and a range of physical and water quality variables within the stream and in the riparian zone. Generally, streams within buffer zones showed rapid improvements in visual water clarity and channel stability, but nutrient and fecal contamination responses were variable. Significant changes in macroinvertebrate communities toward "clean water" or native forest communities did not occur at most of the study sites. Improvement in invertebrate communities appeared to be most strongly linked to decreases in water temperature, suggesting that restoration of in-stream communities would only be achieved after canopy closure, with long buffer lengths, and protection of headwater tributaries. Expectations of riparian restoration efforts should be tempered by (1) time scales and (2) spatial arrangement of planted reaches, either within a catchment or with consideration of their proximity to source areas of recolonists.
579	Economic and Environmental Impacts of Nutrient Loss Reductions on Dairy and Dairy/poultry Farms	Pease, J. and D.E. Kenyon	1998	Paper	Pen State University and Virginia Tech	Study of potential N and P losses at edge of farm fields and root zones in Virginia. Describes details of existing farming practices. Simulates farm income effects under current practices and 3 possible nutrient management policies; manure incorporation, restrict N application, restrict P application. Estimates made by agricultural engineers.
580	Effect of different assemblages of larval foods on Culex quinquefasciatus and Culex tarsalis (Diptera: Culicidae) growth and whole body stoichiometry	Peck, G.W. and W.E. Walton	Aug-05		Environmental entomology. 2005 Aug., v. 34, no. 4, p. 767-774.	http://www.entsoc.org/pubs/periodicals/ee/index.htm
581	The use of design element in wetlands	Persson, J.	2005		Nordic Hydrology 36(2):113-120.	
582	Hydraulic efficiency of constructed wetlands and ponds	Persson, J., N. L. G. Somes, and T. H. F. Wong	1999		Water Science and Technology 40 (3): 291-300.	
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584	The Role of Plants in Ecologically Engineered Wastewater Treatment Systems	Peterson, Susan B. and John M. Teal	May-96		Ecological Engineering, Volume 6, Issues 1-3, May 1996, Pages 137-148	
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