ASSESSING THE FEASIBILITY OF NUTRIENT-RELATED WATER QUALITY TRADING IN TENNESSEE

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DEDICATION

This thesis is dedicated to my family.

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ABSTRACT

Continuous efforts have been made to restore and maintain water quality in the United States (U.S.) since the enactment of the "Clean Water Act" (CWA) in 1972. However, water quality impairment is still a prominent issue. Many water bodies in Tennessee remain impaired and unable to support their intended uses. Water Quality Trading (WQT) has been promoted as a flexible mechanism to reduce water quality impairment at lower cost. However, the results of trading programs, to date, are not encouraging. Given the inherent geographic restrictions of WQT programs, the spatial locations of impairments and of potential buyers and sellers of credits are keys to program success. Furthermore, trading is viable only if there is an economic incentive for buyers and sellers. This thesis identifies spatially feasible areas for nutrient-related WQT markets in Tennessee. This analysis updates and extends the stepwise screening technique used by Roberts et al. (2008). Fifty-nine potential "Market Zones" for nitrogen, forty-five zones for phosphorus and forty-eight zones for oxygen are identified.

The thesis also analyzes the cost of nutrient credit supply by agricultural non-point sources (NPS). Best management practices (BMPs) and land use (for BMP implementation) are selected based on their cost effectiveness using optimization technique. Abatement cost curves for NPS are derived for each Market Zone. Continuous no tillage is found to be the most cost-effective BMP for both nitrogen and phosphorus reduction. Marginal costs of nitrogen reduction range from $3.53 to $1643.42 per pound of nitrogen. Similarly, marginal costs of phosphorus reduction range from $10.07 to $6,694.68 per pound of phosphorus.

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CHAPTER 1 INTRODUCTION AND GENERAL INFORMATION

Background

Water bodies provide an array of benefits for humans, including serving as sources for recreation, sanitation, drinking water, commercial fisheries, navigation, agricultural production, and industrial use. In spite of their great value, waterbodies are often polluted by discharges from industrial, municipal, urban and agricultural sources. Regulatory efforts to control water pollution in the United States (U.S.) were initiated as early as 1899 (Freeman III, 1990). Since then, state, federal and local authorities have devoted billions of dollars and decades of experiments to improving water quality (Faeth, 2000). Despite these efforts, many waterbodies in the U.S. are impaired; i.e., they do not satisfy water quality standards established by regulatory authorities.

Like many other states, Tennessee is also experiencing water quality impairment. Approximately, thirty-two percent of reservoir and lake acres and fifty percent of stream miles among the assessed water bodies in Tennessee are impaired for one or more uses (TDEC, 2014). Agricultural activities, such as grazing animals and crop production, contribute to forty-four percent of the impaired river and stream miles in Tennessee (TDEC, 2014).

Hypoxic zones in the Gulf of Mexico are also of concern. These hypoxic zones are causing deleterious effects on the Gulf's aquatic ecosystem. Nutrient discharges (specifically nitrogen and phosphorus) from the Mississippi river are a major contributor to these hypoxic zones (Rabotyagov et al., 2010). Tennessee is among the top nine states in terms of the total nutrient flux delivered to the Gulf of Mexico, contributing an estimated 5.5 percent of the total nitrogen flux and 5.3 percent of the total phosphorus flux (Alexander et al., 2007; TDEC, 2015).

Water quality trading (WQT) has been suggested as a tool for achieving water quality

improvement at lower cost than other less flexible regulatory approaches (Faeth, 2000). WQT is a market-based approach to regulating water quality impairments. WQT reallocates pollution burdens among polluting sources to take advantage of existing differences in marginal abatement costs (Ramilan and Scrimgeour, 2006). For example, in a trading program, point sources (PS) facing regulatory requirements to abate pollutant discharges at ever-increasing costs could have the opportunity to buy pollution credits or reductions from point and/or non-point sources (NPS) with lower abatement costs (Ruppert, 2004). As a result, buyers will be able to meet their regulatory requirements at lower cost and sellers will get paid for the credits they generate, while improving water quality. Many WQT programs are structured on the belief that abatement by agricultural NPS is more cost-effective than abatement by PS and, thus, the agriculture sector is often viewed as the most likely supplier of pollution credits (Zhong et al., 2016).

Problem Identification and Research Objectives

WQT, especially the possibility of nutrient credit trading between PS and NPS, has been a focus of the US Environmental Protection Agency (USEPA) and US Department of Agriculture (USDA) (Ribaudo and Gottlieb, 2011). However, the results of such trading, to date, are not encouraging. Very few actual trades have occurred in many established WQT programs (King 2005; Ribaudo and Gottlieb, 2011; Shortle, 2013). The success of WQT is largely dependent on the spatial distribution of the demand for credits, supply of credits, and water quality impairments (Roberts et al. 2008). Furthermore, trading is viable only if there is an economic incentive to buyers and sellers. Thus, understanding the potential for WQT to allow Tennessee to cost-effectively address water quality impairments requires an analysis of the spatial and economic feasibility of WQT in Tennessee's watersheds.

This study has two objectives:

1) Identify potential nutrient related WQT markets in Tennessee by updating the work of Roberts et al. (2008); and
2) Quantify potential economic gains (i.e., abatement cost savings) associated with the introduction of a WQT program in Tennessee.

CHAPTER 2 LITERATURE REVIEW

Overview of Water Quality Regulation in the U.S.

The beginning of federal government involvement in protecting U.S. water quality is marked by the "Refuse act" of 1899. This act required polluters to obtain a federal permit to dump refuse into navigable waters of the U.S. (Freeman III, 1990). However, the first major comprehensive federal legislation to address water pollution was "The Federal Water Pollution Act" enacted in 1948. This act authorized states to implement programs for pollution control. The role of the federal government under the act was to provide technical advice and funding to states, municipalities and interstate agencies for the construction of sewer treatment plants. The act provided little effective federal control because federal review and enforcement efforts were limited to the pollution of interstate waters (waters that flow across or form a part of state boundaries) (Gaba, 1983) and there were no established standards for water quality (Freeman III, 1990).

The Water Quality Act of 1965 required states to adopt water quality standards and also authorized federal enforcement in case of the violation of these standards. States were required to set maximum discharges of various pollutants that would not violate established standards and distribute the total allowable discharges to major polluters through permits. Though this act was considered an improvement over previous acts, its effectiveness was limited by difficulty in monitoring violations and varying levels of commitment and enforcement among states (Freeman III, 1990; Gaba, 1983).

To address these limitations, congress significantly revised the "Federal Water Pollution Act" in 1972. This set of amendments became popularly known as "The Clean Water Act (CWA)". Since 1972, the CWA has been the primary regulatory framework for water pollution

control in the U.S. One objective of the CWA is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. Additional goals included i) the elimination of discharge of pollutants into navigable waters by 1985 and ii) attaining water quality that provides for recreation and the protection and propagation of fish, shellfish and wildlife and also recreation by 1983 as an interim goal (33 U.S.C. § 1251). The 1972 amendments authorized USEPA to issue federal permits based on technology-based effluent standards. The same effluent standards were to be applied within the same category of industries which eliminated the need for case-by-case determination of discharge limits. The CWA was again amended in 1977 and 1987 to, among other things, extend some of the deadlines (Freeman III, 1990).

The CWA defines "a point source as any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged" (USEPA, 2003a). PS discharges are relatively easy to monitor and quantify. NPS pollution refers to pollution caused by diffuse sources as opposed to a single identifiable point source. NPS pollution occurs when storm water picks up pollutants from various sources and deposits the pollutants into lakes, rivers, wetlands, coastal waters and ground waters (USEPA, 2003a). The diffuse nature of NPS pollution poses complications in monitoring actual NPS discharges. Discharge loadings for NPS cannot be measured accurately and the effectiveness of control efforts is more uncertain compared to PS (Malik et al., 1993).

To comply with the CWA, all PS discharging pollutants to U.S. waterbodies are required to obtain National Pollutant Discharge Elimination System (NPDES) permits assigned by either the state in which the PS is located or the appropriate USEPA regional office. NPDES permits

generally specify limits of specific pollutants a permit holder can discharge. NPDES permits provide two levels of control: technology-based effluent limitations (TBELs) and water-quality based effluent limitations (WBELs).

TBELs require a minimum level of treatment of pollutants for PS discharges based on available treatment technologies, while allowing the discharger to use any available control technique to meet the limits. If TBELs cannot sufficiently protect the impaired water body, the CWA provides for a more stringent level of control through the imposition of WBELs. Thus, WBELs are generally imposed on PS contributing to an impaired waterbody.

Under section 303(d) of the CWA, states are required to identify impaired waterbodies and set a Total Maximum Daily Load (TMDL) for each of them. A TMDL is the maximum amount of pollutant discharge a waterbody can assimilate without violating water quality standards, plus a margin of safety (33 U.S.C. § 1251, 2002). TMDLs also determine pollutant reduction targets and allocate those load reductions among PS and NPS in the form of waste load allocations (WLAs) and load allocations (LAs), respectively. WLAs assigned to PS through the TMDL process are generally implemented through WBELs (USEPA 1996).

After the passage of the CWA in 1972, efforts for improving water quality were concentrated on reducing PS discharges. Pollution from NPS discharges was largely overlooked. It eventually became clear that achieving the intended improvements in water quality would require reducing NPS pollution (Faeth 2000; Harington 1985). NPS is still a major contributor of water pollution in the U.S., and agriculture has been recognized as a major source of NPS pollution in many impaired waterbodies (TDEC, 2014). The nutrients (nitrogen and phosphorus) from commercial fertilizers and animal waste cause eutrophication leading to hypoxic zones in water bodies (Rabotyagov et al., 2010). The presence of high levels of nitrogen and phosphorus

doubles the chances of poor biological conditions for macro-invertebrates (USEPA, 2016). Similarly, pesticide run-off can pose a serious threat to aquatic habitat (Piper et.al., 1989).

However, NPS pollution remains largely unregulated and abatement is often voluntary (Stephenson and Shabman, 2013; Fisher-Vanden and Olmstead, 2013). The primary mechanism for emission control in the CWA is issuance of NPDES permit but NPS are excluded from NPDES permitting requirements (Rabotyagov et al., 2012). However, section 319 of the CWA requires each state to develop a management program to control NPS water pollution and it also authorizes USEPA to issue grants to states to assist in implementation of their conservation practices namely "best management practices" (BMPs) (TDA 2014).

Under a WQT program, the pollution-reduction credits generated from implementation of BMPs can be traded. One possible indicator of the potential for a WQT program is the presence of a potential for supply of credits in the form of NPS emissions. Thus, if an area has little or no agricultural activity there might be little to no trading in the absence of a sufficient supply of credits. While trading can occur between two PS, the difference between their abatement costs might not be as large compared to the cost differences between PS and NPS, which can be a limiting factor to WQT (Shabman and Stephenson, 2007).

Regulatory Context for Water Quality Trading

In May 1996, USEPA issued a "Draft Framework" document supporting WQT. The concept of using market mechanisms to control environmental externalities was not new. This concept started in the early 1960s when Coase described the cost savings associated with marketable property rights compared to the traditional taxation system (Coase, 1960). Dales pointed out the application of this concept to water quality issues in 1968 (Dales, 1968). The first theoretical foundation for marketing pollution permits is attributed to Montgomery (Montgomery, 1972).

The emissions trading concept was implemented to address air quality problems before applying the concept to water quality issues. The trading mechanism was accommodated into the legal framework of the "Clean Air Act (CAA)" in 1977 (Voß, 2007) and this experience suggested market-based mechanisms could be effective in achieving environmental policies (Bayon, 2004; Shortle 2013).

USEPA's 1996 Draft Framework endorsed WQT as an "offset program" rather than a watershed based "cap and trade" system (USEPA, 1996). In a cap and trade system, a maximum total allowable discharge of a pollutant in a particular watershed is determined and all polluting sources, including NPS, are allocated tradable permits to discharge, in total, up to the amount of the cap for the watershed. An offset program, on the other hand, allows PS facing stricter limits (imposed by WBELs) to purchase additional reduction credits from other polluting sources in the watershed (Russell and Clark 2006). USEPA continued its endorsement of offset trading in the "Final WQT Policy 2003" and asserted that such trading programs are within the regulatory framework of the CWA (USEPA, 2003b).

USEPA's 2003 "WQT Policy" and 2007 "WQT Toolkit for Permit Writers" provide guidance regarding WQT implementation. USEPA does not support trading for all types of pollutants. Trading is supported for nutrients (nitrogen and phosphorus) and sediments but not for persistent bio-accumulative toxics (PBTs). A case-by-case evaluation is suggested for other pollutants. USEPA also supports "cross-pollutant trading", i.e., trading between different pollutants, when equivalent amounts of each pollutant based on their impact to water quality are properly identified. The USEPA guidance identifies oxygen-related pollutants (e.g., low dissolved oxygen, biochemical oxygen demand, carbonaceous oxygen demand, etc.) as particularly suitable candidates for cross-pollutant trading. This type of trading could allow a PS

to purchase nitrogen or phosphorus reduction credits from other sources to fulfill their oxygen-related discharge limits (USEPA 2007). For example, the Rahr Malting facility in Minnesota used nutrient credits generated by upstream NPS to offset its 5-day carbonaceous biochemical oxygen demand (CBOD5) discharges (Breetz et al. 2004).

The USEPA does not support trading to fulfill TBEL requirements unless federal regulations expressly authorize trading (e.g., the effluent guidelines for the iron and steel PS category allows intra-plant trading of conventional, nonconventional and toxic pollutants between outfalls under certain circumstances). All PS have to use available treatment technologies to achieve a minimum level of pollutant control specified by their TBEL. Therefore, PS without a regulatory obligation to make additional reductions beyond their TBEL limits would have little or no incentive to participate in WQT.

Trading can be used to meet more stringent WBEL limits. If a waterbody is impaired and has a TMDL, each PS discharging to that waterbody is assigned WLAs which form the baseline water quality requirement for the PS. These baseline requirements are expressed in the PS's NPDES permit as WBELs (USEPA 2007). Under a WQT program, these PS have the flexibility to buy pollution-reduction credits from other PS or NPS to fulfill their WBELs. Thus, the need to fulfill WBELs acts as a regulation-driven demand for pollution-reduction credits. PS with WBELs might be willing to pay for credits from other sources if the price of credits are lower than their own marginal abatement costs.

WQT is often driven by TMDL development or the establishment of a pollutant cap. These limits and caps are generally calculated for an impaired waterbody. Therefore, WQT provisions within NPDES permits often address impaired waterbodies having a TMDL or pollutant cap.

However, the USEPA also supports pre-TMDL trading in impaired waters. Pre-TMDL trading can be done to improve the quality of a waterbody with a pending TMDL or to totally eliminate the need for a TMDL (USEPA 2007). Such trading cannot further degrade water quality. The Great Miami River Watershed Trading Pilot Program is an example of pre-TMDL trading (USEPA 2007).

Trading can also occur in unimpaired waters under certain conditions. States are authorized to allow increased discharge of pollutants in an unimpaired waterbody if the discharge is necessary for important economic and social development and if the lower water quality after discharge will still be adequate to fully protect existing uses. Trading in such high-quality waters can occur to mitigate the effects of new or increased discharges which can lower water quality in the absence of trading. However, states have to assure that there would be no net increase in pollutants discharged into the waterbody and no localized impairments as a result of trading (USEPA, 2007).

The USEPA encourages trading within hydrologic units or an area defined by a TMDL boundary. The purpose of trading within such an area is to ensure improved water quality in that area, and within downstream and contiguous waters. Trading can achieve water quality improvement if buyers and sellers discharge pollutants to the same impaired waterbody. Trading can occur across a wide geographic area if the impaired waterbody drains a large area (e.g., Chesapeake Bay or Gulf of Mexico). However, trading across geographic or hydrologic units where trading partners do not contribute to the same impairment are discouraged because they can deteriorate water quality downstream of the credit purchaser (USEPA, 2007).

Studies of the Feasibility of WQT

Several studies have focused on the spatial feasibility of WQT. Crutchfield et al. (1994) applied screening criteria based on the volume of PS and NPS loadings, the number and type of PS, and characteristics of land use to assess the feasibility of WQT in coastal waters of the U.S. They concluded that PS-NPS trading involving agriculture could not sufficiently protect costal water quality.

Ribaudo and Nickerson (2009) also used a screening criteria to assess the potential of WQT in the contiguous 48 U.S. states. The criteria used for screening were the presence of an impairment contributed by regulated PS and agricultural NPS; nutrient loadings from PS and agricultural NPS; and the degree of existing nutrient management practices which can limit the availability of low cost management practices. The study concluded that low demand for credits from PS in most watersheds limited the potential for WQT. Nutrient loadings from agricultural NPS were found to be higher compared to PS loadings which suggested that only a small fraction of potential NPS reductions could be used to offset PS demand. The overall potential for WQT to reduce nutrient impairments was limited from a national perspective.

Rowles (2005) assessed the feasibility of WQT in Georgia watersheds. The screening criteria used in the analysis were environmental suitability, regulatory incentive, economic incentive, availability of participants, and stakeholder response. The study identified six basins in Georgia with high potential for WQT. The study concluded that the opportunities for WQT were somewhat limited in Georgia by insufficient regulatory incentives. The study suggested the need for stricter loading limits in TMDLs to create opportunities for WQT.

Roberts et al. (2008) applied a screening technique based on the presence of tradable impairments, NPDES-permitted PS polluters, and agricultural NPS polluters to identify potential

WQT markets in Tennessee. Distance weighted PS and NPS scores were calculated based on impairment lengths and estimated nutrient loadings which were then used to rank the potential WQT markets. The results suggested that potential for WQT to help address water quality impairments in Tennessee is low because of the limited number of potential buyers. The lack of potential buyers was attributed to the location of impairments in or near the headwaters of streams and rivers, often upstream of PS. The study analyzed impaired rivers and streams, but excluded impaired lakes and reservoirs from the analysis. In addition, PS polluters with a phosphorus-related permit, phosphorus markets and the possibility of cross-pollutant trading were also overlooked, suggesting the study may have underestimated the potential for WQT markets.

Use of Physically-Based Models to Assess the Effects of Nutrient Loadings on Water Quality

Several studies have used Geographic Information System (GIS) based hydrology models to quantify nutrient loadings contributed by different polluting sources and assess the effect of these loadings on water quality. The Watershed Assessment Model (WAM) simulates the flow and quality of surface and ground waters based on land use, soil characteristics, weather and other factors. WAM is capable of simulating the environmental effects of land use management practices. It also represents nutrient transportation and attenuation process between polluting sources and nearby streams based on water flow and distance (SWET, 2011 quoted in Corrales et al., 2014). Corrales et al. (2014) used WAM to estimate phosphorus loadings generated, transported, and attenuated at various sites within the agricultural sub-basin of Lake Okeechobee watershed, Florida. The results from WAM were linked to an economic model to identify cost-minimizing nutrient management practices that achieve a required phosphorus reduction target.

The study showed the superiority (in terms of potential cost savings) of a "least cost abatement" approach over a "command and control" approach and concluded that credit trading should be considered for phosphorus abatement programs in the Lake Okeechobee watershed.

The Soil and Water Assessment Tool (SWAT) is widely used to assess the impact of various management practices on water quality (Gitau et al., 2004; Green et al., 2006; Chaubey et al., 2010). SWAT is a physically-based basin scale model designed to simulate the impact of management practices on water, sediment and agricultural chemical yields in large ungauged basins (Arnold et al., 1998). Even though SWAT operates on a daily time step, it can simulate long-term effects of management changes (Arnold et al., 1998). In SWAT, a watershed is categorized into multiple sub-watersheds or sub-basins. Sub-basins are further subdivided into hydrologic response units (HRUs) based on homogeneity of land use, management practices, and soil characteristics (Gassman et al., 2007). This framework provides site-specific outputs used for spatial analysis. SWAT has been used globally for various other applications including hydrologic analysis, pollutant load assessment, sensitivity analysis of input parameters and climate change impacts on hydrology (Gassman et al., 2007). Panagopoulos et al. (2015) used SWAT to study the impacts of implementing no tillage and cover crops in the Ohio-Tennessee River Basin under current and projected climate scenarios. The study found that no tillage was the most promising management practice for reducing sediment and phosphorus loads from agricultural land, whereas cover crops were the most effective in terms of nitrogen load reduction under current as well as projected climate scenarios. The study also highlighted SWAT's capabilities for simulating the effects of conservation practices on hydrologic-processes at the river basin scale.

Spatially Referenced Regressions on Watershed Attributes (SPARROW) is a regression-

based water-quality model that relates water-quality measurements at monitoring sites to spatially referenced watershed attributes (Smith et al. 1997). The regression model help correlates the in-stream pollutant load with polluting sources, landscape characteristics that determine the delivery of pollutants to the stream and stream properties that transform and assimilate the pollutants. The model quantifies the flux of contaminants delivered to streams from point and nonpoint sources (Ribaudo and Nickerson, 2009). The model has higher predictive accuracy and explanatory potential than non-spatially referenced models (Smith et al. 1997). The SPARROW model has been used to evaluate total nutrient loading in the Chesapeake Bay watershed (Preston and Brakebill, 1999) and New England watersheds (Moore et al., 2004). Ribaudo and Nickerson (2009) used the SPARROW model to compare the relative nutrient loadings from PS and NPS in the contiguous 48 states of the U.S and found predominance of NPS loadings over PS loadings. Lambert et al. (2016) also used SPARROW model to study the impact of switchgrass cultivation on water quality in the Southeastern-Atlantic, Eastern Gulf, and Tennessee (SAGT) River basin. The study concluded that conversion of land from cereals, soybean, and hay and pasture to switch grass significantly decreases nitrogen runoff.

Nutrient Loss from Agricultural Land Uses

Information on nutrient loss from various land uses is valuable for managing nutrient-related pollution. Nutrient loss information provides a baseline for comparing the effectiveness of various conservation practices and is also useful in evaluating various simulated water quality models (Harmel et al., 2006). Several studies report nutrient loss from agricultural land. Udawatta et al. (2004) examined the runoff samples from three watersheds planted with corn and soybean crop in northeastern Missouri for seven years (1991-1997). The study found that annual total phosphorus loss from the watersheds ranged from 0.29 to 3.59 kg/ha (0.26 to 3.2 lb/ac) with

an average of 1.36 kg/ha (1.21 lb/ac). The loss of total phosphorus was higher in fallow periods compared to other periods.

Chebud et al. (2010) used WAM to simulate NPS phosphorus loadings from Lake Okeechobee watershed, Florida. The results were validated using on-site monitoring data. The average simulated total phosphorus loads were 2.01 kg $ha^{-1}yr^{-1}$ (1.79 lb $ac^{-1}yr^{-1}$) from sod farms, 3.85 kg $ha^{-1}yr^{-1}$ (3.43 lb $ac^{-1}yr^{-1}$) from dairy, 0.86 kg $ha^{-1}yr^{-1}$ (0.77 lb $ac^{-1}yr^{-1}$) from row crop lands, and 0.23 kg $ha^{-1}yr^{-1}$ (0.21 lb $ac^{-1}yr^{-1}$) from citrus crop lands.

McDowell and McGregor (1980) examined the effect of tillage on soil and nutrient loss from soybean fields in North Mississippi and found that no tillage is effective in reducing soil as well as nutrient loss. Total nitrogen and phosphorus loss from no tillage soybeans were 4.7 kg ha^{-1} (4.19 lb ac^{-1}) and 2.8 kg ha^{-1} (2.5 lb ac^{-1}) respectively for year 1973. Whereas total nitrogen and phosphorus loss from conventional tillage soybeans for the same year were 46.4 kg ha^{-1} (41.4 lb ac^{-1}) and 17.6 kg ha^{-1} (15.7 lb ac^{-1}) respectively.

Beaulac et al. (1982) reported on extensive literature review of nutrient loss studies between 1970 and 1980 and reported total nitrogen and total phosphorus exports from a corn field ranging from 2.81 to 79.6 kg $ha^{-1}yr^{-1}$ (2.51 to 71.02 lb $ac^{-1}yr^{-1}$) and 0.4 to 18.6 kg $ha^{-1}yr^{-1}$ (0.36 to 16.59 lb $ac^{-1}yr^{-1}$) respectively. The total nitrogen and total phosphorus exports from cotton field were 4.99 to 14.84 kg $ha^{-1}yr^{-1}$ (4.45 to 13.24 lb $ac^{-1}yr^{-1}$) and 2.07 to 11.52 kg $ha^{-1}yr^{-1}$ (1.85 to 10.28 lb $ac^{-1}yr^{-1}$) respectively.

Bhaduri et al. (2000) reported annual average total nitrogen loadings from agricultural land as 26 kg $ha^{-1}yr^{-1}$ (23.2 lb $ac^{-1}yr^{-1}$) and from grass or pasture land as 6.2 kg $ha^{-1}yr^{-1}$ (5.53 lb $ac^{-1}yr^{-1}$). Similarly annual average total orthophosphorus loadings from agricultural land was reported as 1.05 kg $ha^{-1}yr^{-1}$ (0.94 lb $ac^{-1}yr^{-1}$) and from grass or pasture land as 0.5 kg $ha^{-1}yr^{-1}$

(0.45 lb $ac^{-1}yr^{-1}$).

Harmel et al. (2006) compiled 40 peer-reviewed publications that reported measured annual nitrogen and phosphorus load data from agricultural land uses to form a 163-record database. Median annual nutrient loads for various tillage practices, soil types and number of conservation practices were also reported. Table 2.1 presents the median annual total nitrogen and phosphorus load values for different land uses reported in Harmel et al. (2006), McDowell and McGregor (1980) and Bhaduri et al. (2000).

Effectiveness/Efficiency of BMPs

A BMP is a practice or combination of practices used to reduce the level of NPS pollution in watersheds. Information about the effectiveness of BMPs is useful for selection and placement of cost effective BMPs capable of achieving a desired water quality goal. A large number of studies have focused on the efficiency of BMPs in reducing pollutants (Evans et al., 2008).

Yagow et al. (2002) developed a database of published literature analyzing the effectiveness of BMPs in reducing nutrient loads and concentrations. For the study, the authors reviewed 596 articles, and used a screening technique to select articles reporting primary research and results from monitored field studies. A total of 168 articles meeting the criteria were incorporated into the final database.

Merriman et al. (2009) compiled a BMP efficiency database and developed a tool for estimating the effectiveness of BMPs. The study was an expanded form of the database generated by Gitau et al. (2005). The database was generated using a wide range of published and unpublished materials and, thus, represents effectiveness values over a wide range of conditions. The BMP tool calculates efficiency in reducing nutrient and sediment losses for agricultural as well as urban BMPs. Site specific estimates of efficiency can be obtained for

Table 2.1 Median Annual Total Nitrogen and Phosphorus Load Values for Different Land Use Type

Treatment	Total N (lbs/ac)	Dissolved N (lbs/ac)	Particulate N (lbs/ac)	Total P (lbs/ac)	Dissolved P (lbs/ac)	Particulate P (lbs/ac)
Corn	16.68	2.69	6.49	1.15	0.20	0.76
Cotton	7.03	2.20	8.15	4.47	0.61	5.00
Sorghum	2.69	0.27	0.00	1.05	0.00	0.00
Soybeans	4.19[a]	2.41	19.54	0.40, 2.5[a]	0.54	8.56
Oats/Wheat	5.90	1.17	5.26	1.96	0.27	3.08
Pasture/Range	0.87	0.29	0.55	0.21	0.13	0.00
Other Crops	23.2[b]			0.94[b]		

Source: Load values are from Harmel et al. (2006) unless otherwise mentioned; a: values from McDowell and McGregor (1980); b: values from Bhaduri et al. (2002)

agricultural BMPs but not for urban BMPs. The tool can also provide average values regardless of site characteristics.

Evans et al., (2008) determined baseline BMP efficiencies for "The Pollution Reduction Impact Comparison Tool (PRedICT)" based on a literature review. PRedICT is a tool for evaluating the impact of both agricultural and urban BMPs on water quality within a watershed.

Brosch et al. (2010) documented the efficiency of agricultural as well as urban BMPs in reducing total phosphorus, total nitrogen and sediments which were incorporated into a scenario builder tool for use in a watershed model for the Chesapeake Bay. Table 2.2 provides a summary of nutrient and sediment removal efficiencies of various BMPs reported in Merriman et al. (2009), Brosch (2010) and Evans et al. (2008). Average values from the BMP efficiency database compiled by Merriman et al. (2009) are reported in the table.

Uncertainties Associated with WQT

The literature suggests the existence of many obstacles and uncertainties that can hinder the performance of WQT (Ribaudo and Gottlieb, 2011; Walker and Selman, 2014). The geographic location of PS and NPS relative to impairments is one of the many recognized constraints (Roberts et al., 2008). The coexistence of buyers and sellers is a crucial factor for any market-based trading program. While there are a large number of NPS, there has often been a paucity of willing sellers (farmers) which prevents efficient trading (Caplan 2013). Apparently, some farmers fear that successful WQT programs might drive attention towards agriculture's contribution to water quality degradation thereby increasing their chance of being regulated in the future (Ribaudo and Gottlieb, 2011). The geographic location of buyers relative to sellers is important not only for the availability of potential market participants but also for water quality

Table 2.2. Nutrient and Sediment Reduction Efficiencies of BMPs

BMP type	Nitrogen reduction efficiency	Phosphorus reduction efficiency	Sediment reduction efficiency	Source
Conservation crop rotation	68%	53%		Merriman et al. 2009
Conservation Tillage general	53%	55%		Merriman et al. 2009
Constructed wetland	71%			Merriman et al. 2009
Cover crops general	10-45%	7-20%	70%	Brosch 2010; Merriman et al. 2009
Diversion	27%	50%	35%	Merriman et al. 2009
Grassed waterways			17%	Merriman et al. 2009
Mulching			77%	Merriman et al. 2009
No tillage	59%	69%	78%	Merriman et al. 2009
No tillage to critical areas	9%	9%	23%	Merriman et al. 2009
Pasture and hay planting	66%	67%		Merriman et al. 2009
Reduced tillage	55%	44%	55%	Merriman et al. 2009
Riparian Forest Buffers	47%	53%		Merriman et al. 2009
Sub-surface drain	-17%	4%		Merriman et al. 2009
Surface drainage, field ditch	-32%	-6%		Merriman et al. 2009
Terraces	37%	77%	85%	Merriman et al. 2009
Waste treatment lagoon	43%	62%		Merriman et al. 2009
Wetland Restoration	64%	74%		Merriman et al. 2009
Grass Buffers	13-46%	30-45%		Brosch 2010
Alternative Watering Facilities	5%	8%		Brosch 2010
Stream Access Control with Fencing	13-46%	30-45%		Brosch 2010
Precision Intensive Rotational Grazing	9-11%	24%		Brosch 2010
Prescribed Grazing	9-11%	24%		Brosch 2010
Strip cropping/Contour farming	23%	40%	41%	Evans et al. 2008
Nutrient management	70%	28%		Evans et al. 2008

Note: The single point values represent average values from BMP efficiency database compiled by Merriman et al. (2009)

improvement. Trading will improve water quality if buyers and sellers contribute to the same impairment. All sources that discharge pollutants of concern to an impaired waterbody are contributors to the impairment. The extent to which a source contributes to an impairment will vary based on the spatial heterogeneity of the area which defines the transferability of pollutants to the impaired waterbody. Sources far from the impairment would have relatively less contribution to the impairment. Failure to address spatial distribution increases the risk of hot spots (adverse local impacts) even if the aggregate pollutant loadings are decreased. If a PS buys pollution reduction credits from a downstream seller, pollutant-loads in the stream segment between these two sources will not be reduced. Buying pollution reduction credits from an upstream seller minimizes the risk of hot spots and improves water quality in the segment between the polluting sources (Rowles, 2005).

The difficulty of accurately measuring NPS discharges and the uncertainties associated with the impact of BMPs on water quality are other concerns. Spatial variability in weather, hydrology, soil and geologic factors affecting delivery of pollutant load to receiving waters, variable performance of land management practices, and time lag between implementation of BMPs and observed water quality benefits, all contribute to the uncertainty regarding the impact of BMPs on water quality (USEPA, 2010). Such uncertainties create lack of trust regarding the value of NPS nutrient credits and therefore PS prefer to either upgrade their nutrient removal technology or trade with other PS with similar limits (USGAO, 2017).

Other obstacles to implementing an effective WQT program include high transaction costs, delay in TMDL development, limits not stringent enough to induce trading, and the availability of cheaper alternatives for PS reductions. NPS are required to fulfill baseline (minimum level of conservation) before credit generation. Such requirements eliminate low-cost

credits and therefore discourage WQT (Morgan and Wolverton, 2005; Ribaudo and Gottlieb, 2011).

There are also some arguments which suggest WQT might not be effective in achieving its intended goal. According to Ribaudo and Nickerson (2009), in the present context of the U.S., the discharge from agricultural NPS relative to PS is so high that the discharge quotas for PS would be offset by only a fraction of potential NPS reductions. Therefore, anticipated improvements may not be achieved even if the trading ratio between PS and NPS is more than one (Fisher-Vanden and Olmstead, 2013). Higher trading ratios where PS have to buy more than one credit to offset one unit of discharge are expected to address riskiness of trading and improve water quality. Such ratios, however, increase the cost of purchasing credits making trading less attractive to PS (King and Kuch, 2003).

Existing WQT Programs

There were more than 70 WQT initiatives in the U.S. in 2005 (Breetz et al., 2004; Morgan and Woolverton, 2005). Morgan and Woolverton (2005) classified WQT initiatives into four categories: on-going offset/trading programs, one-time offset agreements, state and regional trading policies, and other proposed projects and also gave detailed information about 19 ongoing offset/trading programs and eight one-time offset agreements. The study found that WQT were often driven by more stringent discharge limits or TMDLs. Trading between PS and NPS was the most common type of trading and nutrients (nitrogen and phosphorus) were the most commonly-traded pollutants.

Ribaudo and Gottlieb (2011) assessed 15 active PS-NPS trading programs established between 1980 and 2008 which allowed trading for nutrients. Four programs, the Southern Minnesota Beet Sugar Cooperative Permit Program in Minnesota, the Red Cedar River Nutrient

Trading Pilot Program in Wisconsin", the Rahr Malting Company Permit in Minnesota and the Piasa Creek in Illinois, had some trades whereas 11 other programs had no trades as of 2008.

Greenhalgh and Selman (2012) updated the status of WQT programs through a combination of primary and secondary information. The study assessed 63 WQT programs within and outside the U.S., 33 of which were active. Table 2.3 summarizes the active WQT programs reported by Greenhalgh and Selman (2012). The trading programs were found to be diverse in terms of participants, pollutants traded, market drivers, baseline requirements for NPS, NPS nutrient-reduction calculation methods, trading ratios and types of market. However, a majority of the programs allowed PS to NPS trading and traded nutrients. Only one regulated NPS-NPS trading program, the Lake Taupo Nitrogen Trading Program in New Zealand was found to be active. The most common type of markets were bilateral negotiations followed by clearinghouses. Varying success levels were found for existing WQT programs. In terms of trading activity, the most active U.S. program (the Southern Minnesota Beet Sugar Cooperative Permit, Minnesota) reported 256 completed trades, while the second most active (Clean Water Services Permit, Oregon) only reported 25 completed trades. Internationally, the Hunter River Salinity Trading Scheme in Australia reported 980 completed trades, while the Lake Taupo Nitrogen Trading Program, New Zealand reported 26 completed trades. While some programs had numerous trades, some others e.g. "Cherry Creek Basin Trading Program" had very few trades (Greenhalgh and Selman, 2012). Factors that were found to discourage trading activity included the inadequacy of market drivers (PS allocated with higher caps than their existing discharge levels e.g. Cherry Creek trading program), PS lacking trust about NPS compliance (e.g. Rock River trading program), complex non-standardized credit and trade approval process resulting in high transaction costs (e.g. Chatfield Reservoir trading program), and insufficient

Table 2.3 Active Water Quality Trading Programs

Program name	State/Country	Participants[a]	Type of Market
Grassland Area Farmers Tradable Loads Program	California, U.S.	Irrigation districts	Bilateral
Lake Taupo Nitrogen Trading Program	New Zealand	NPS-NPS	Bilateral
South National Total Phosphorus Management Program	Ontario, Canada	PS-NPS	Clearing house
Dillion Reservoir Pollutant Trading Program	Colorado, U.S.	PS-NPS	Bilateral
Delaware Inland Bays	Delaware, U.S.	PS-NPS	Sole source
Rahr Malting Company Permit	Minnesota, U.S.	PS-NPS	Bilateral
Southern Minnesota Beet Sugar Cooperative Permit	Minnesota, U.S.	PS-NPS	Bilateral
Taos Ski Valley	New Mexico, U.S.	PS-NPS	Sole source/Bilateral
Sugar Creek (Alpine Cheese Trading Program)	Ohio, U.S.	PS-NPS	Third-party broker
Williamette Partnership (Rogue)	Oregon, U.S.	PS-NPS	Sole-source
Williamette Partnership (Williamette)	Oregon, U.S.	PS-NPS	Sole-source
Williamette Partnership (Lower Columbia)	Oregon, U.S.	PS-NPS	Sole-source
Red Cedar River Nutrient Trading Pilot Program	Wisconsin, U.S.	PS-NPS	Third-party broker
Hunter River Salinity Trading Scheme	New South Wales, Australia	PS-PS	Exchange
South Creek Bubble Licensing Scheme	New South Wales, Australia	PS-PS	Clearing house (bubble permit)
Long Island Sound Nitrogen Credit Exchange Program	Connecticut, U.S.	PS-PS	Clearing house
Minnesota River Basin Trading Program	Minnesota, U.S.	PS-PS	Bilateral
Las Vegas Wash	Nevada, U.S.	PS-PS	Clearing house (bubble permit)
Bear Creek Trading Program	Colorado, U.S.	PS-PS/NPS	Bilateral
Chatfield Reservoir Trading Program	Colorado, U.S.	PS-PS/NPS	Clearing house/Bilateral
Cherry Creek Basin Water Quality Authority Trading Program	Colorado, U.S.	PS-PS/NPS	Clearing house
Lower St Johns River Water Quality Credit Trading Program	Florida, U.S.	PS-PS/NPS	Bilateral
Maryland Nutrient Trading Program	Maryland, U.S.	PS-PS/NPS	Exchange/bilateral

Table 2.3 Continued

Program name	State/Country	Participants[a]	Type of Market
Fall Lake	North Carolina, U.S.	PS-PS/NPS	Sole source/bilateral
Jordan Lake	North Carolina, U.S.	PS-PS/NPS	Sole-source/bilateral
Tar-Pamlico Nutrient Reduction Trading Program	North Carolina, U.S.	PS-PS/NPS	Clearing house (bubble permit)
Great Miami River Watershed Water Quality Credit Trading Program	Ohio, U.S.	PS-PS/NPS	Third-party broker
Ohio River Basin Trading Program	Ohio, U.S.	PS-PS/NPS	To be determined
Clean Water Services Permit, Tualatin River	Oregon, U.S.	PS-PS/NPS	Third-party broker/Sole-source
Pennsylvania Nutrient Credit Trading Program	Pennsylvania, U.S.	PS-PS/NPS	Clearinghouse
Neuse River Basin Nutrient Sensitive Waters Management Strategy	North Carolina, U.S.	PS-PS/NPS	Clearinghouse
Virginia Water Quality Trading Program	Virginia, U.S.	PS-PS/NPS	Clearinghouse/ bilateral
Murray-Darling Basin Salinity Credits Scheme	South Eastern Australia	States	Bilateral

Note: a: PS- point source, NPS- nonpoint source
Source: Greenhalgh and Selman (2012)

stakeholder education (Greenhalgh and Selman, 2012). Thirty of the 63 WQT programs studied by Greenhalgh and Selman were either under consideration or development or inactive. Table 2.4 presents WQT programs in development, under consideration, or where trading was once considered or is now inactive as reported by Greenhalgh and Selman (2012).

The US Government Accountability Office (USGAO) (2017) reported 19 nutrient credit trading programs within 11 states (California, Connecticut, Florida, Georgia, Idaho, Minnesota, North Carolina, Ohio, Pennsylvania, South Carolina and Virginia) of the US in 2014. Pennsylvania Chesapeake Bay Trading Program (151 trades), Connecticut (Long Island Sound) Nitrogen Credit Exchange Program (39 trades), and Virginia General Permit for Nutrients (31 trades) were reported to have the highest number of trades in 2014. These programs also had the highest number of PS in the trading program. However, only 49 percent PS in Connecticut, 29 percent in Pennsylvania and 14 percent in Virginia trading program actually bought nutrient credits in 2014 (USGAO, 2017). The demand for nutrient credit was reported to be decreasing over time as more and more PS were upgrading their nutrient removal technologies (USGAO, 2017).

Economics of Water Quality Trading Analysis

Some studies related to economic analysis include willingness to pay for nutrient credits (Mc. Laughin, 2015) and willingness to implement BMPs (Zhong et al., 2016). Other studies (i.e. Zhang & Wang 2002; Wang et al. 2004; Zhao et al. 2009) have focused on minimizing the total abatement cost from PS and NPS using some form of optimization technique (e.g., chance constrained programming, linear programming, Kuhn-Tucker conditions, and watershed optimization model).

Table 2.4 Inactive or In Development Water Quality Trading Programs or Initiatives

Program name[a]	State/Country	Participants[b]	Type of Market
Moreton Bay Nutrient Trading Scheme	Queensland, Australia	PS-PS/NPS	TBD
Lake Simcoe Watershed	Ontario, Canada	TBD	TBD
Lake Winnipeg Basin	Manitoba, Canada	TBD	TBD
Lake Rotorua	Newzealand	NPS-NPS	TBD
Lower Colorado River	Colorado, U.S.	TBD	TBD
Lake Allatoona	Georgia, U.S.	PS-PS or PS-PS/NPS	TBD
Charles River Flow Trading Program	Massachusetts, U.S.	PS-PS	Bilateral
Vermillion River	Minnesota, U.S.	TBD	TBD
Upper Missippi River Basin	Minnesota, U.S.	PS-NPS	Clearinghouse
Passaic River	New Jersey, U.S.	PS-PS/NPS	TBD
Lake Tahoe	Nevada, U.S.	NPS-NPS	Third party broker
Truckee River Water Quality Settlement Agreement	Nevada, U.S.	PS-NPS	TBD
Sepherd Creek	Ohio, U.S.	PS-NPS	Third party broker
Upper Little Miami River Basin	Ohio, U.S.	PS-NPS	TBD
Portland Tradable Stormwater Credit Initiative	Oregon, U.S.	PS-PS	TBD
Bear River	Utah/Wyoming/Idaho, U.S.	TBD	TBD
West Virginia-Potomac Water Quality Bank and Trade Program	West Virginia, U.S.	PS-PS/NPS	Exchange
Clear Creek (I)	Colorado, U.S.	PS-PS	Sole-source
Boulder Creek Trading Program (I)	Colorado, U.S.	PS-NPS	Sole-source
Lower Boise River Effluent Trading Demonstration Project (I)	Idaho, U.S.	PS-NPS	Bilateral
Middle Snake River (I)	Idaho, U.S.	PS-PS	Bilateral
Upper Moquoketa and South Fork Moquoketa Watersheds Nutrient Trading Directory (I)	Iowa, U.S.	NPS-NPS	Bilateral
Sudbury River, Wayland (I)	Massachusetts, U.S.	PS-PS	Bilateral
Kalamazoo River (I)	Michigan, U.S.	PS-NPS	Third party broker
Passaic Valley Sewerage Commission Pretreatment Trading (I)	New Jersey, U.S.	PS-PS	Bilateral

Table 2.4 Continued

Program name[a]	State/Country	Participants[b]	Type of Market
New York City Watershed Phosphorus Offset Pilot Programs (I)	New York, U.S.	PS-PS	Sole-source
Lake Champlain (I)	New York/Vermont, U.S.	PS-PS	Sole-source
Cape Fear (I)	North Carolina, U.S.	PS-NPS	TBD
Fox-Wolf Basin (I)	Wisconsin, U.S.	PS-NPS	Bilateral
Rock River (I)	Wisconsin, U.S.	PS-NPS	Bilateral

Note: a: water quality trading programs in development, under consideration, or where trading was considered or is now inactive, (I) indicates program is inactive at present; b: PS- point source, NPS- nonpoint source, TBD- to be determined
Source: Greenhalgh and Selman (2012)

Alminagorta et al. (2012) used a linear program model to determine the cost-minimizing sets of BMPs for phosphorus reduction in the Echo Reservoir of north eastern Utah in order to meet the allocation required by a pending TMDL. Three sub-watersheds Chalk Creek, Weber River below and Weber River above Wanship were included in the study. The TMDL requirement was found to be fulfilled by protecting grazing land, stabilizing stream banks, and managing agricultural nutrients BMPs in all three sub-watersheds and conservation tillage in Chalk Creek. The annual cost associated with achieving the target phosphorus reduction (8,067 kg/yr) was estimated at $1 million.

Rabotyagov et al., (2010) combined results from the SWAT model with cost data using an evolutionary optimization algorithm to develop the least cost combination and location of conservation practices to achieve required nutrient reduction targets in the Upper Mississippi River Basin (a major contributor of nutrients to the Gulf of Mexico). A trade-off frontier between cost and nutrient reductions was developed. When nitrate-nitrogen reduction target was set at 30 percent, there was 36 percent simultaneous reduction in phosphorus and the annual cost was estimated as $1.4 billion. When a 30 percent phosphorus reduction target was set as the first strategy, the target was achieved at a lower annual cost ($370 million) but was only able to reduce nitrate-nitrogen by 9 percent.

Gitau et al. (2004) analyzed the optimal cost of reducing phosphorus loading at the farm level by using SWAT and a genetic algorithm (optimization procedure). The baseline discharge of 1,471 kg was reduced by 60 percent (target) through implementation of three BMP combinations: contour strip cropping, a nutrient management plan, and riparian forest buffer. A total of 884 kg phosphorus was reduced at a total cost of $1,430 per year. The annual cost of phosphorus abatement under this BMP scenario was $1.62/ kg.

The feasibility of WQT depends on the existence of abatement cost differentials between pollution sources. PS might not be willing to trade if they have cheaper alternatives available that can abate an equal amount of pollutant at the same or lower cost than trading (Morgan and Woolverton, 2005). Therefore, a comparison between PS and NPS abatement cost is essential for analyzing WQT feasibility. Khatri-Chhetri (2012) performed an economic analysis to assess the feasibility of WQT in the Greenbrier River watershed in West Virginia. The analysis included estimation of the cost of nutrient credit generation for NPS, cost of abatement for PS, aggregate demand and supply of nutrient credits and equilibrium prices. Mapshed, a water quality model (Evans and Corradini, 2012), was used for both the estimation of discharges from PS and NPS, and the effect of BMP implementation on emissions. A graphical method was used to find equilibrium price, producer surplus and consumer surplus. Net economic benefits were estimated as a sum of producer and consumer surplus minus treatment upgrade cost in absence of trading. Results indicated that all wastewater treatment plants (WWTPs) in the Greenbrier River had the potential for cost savings when they participated in nutrient trading compared to treatment plant upgrade costs. Cost savings were calculated for various baseline requirements, trading ratios and market (single nutrient or combined nutrient market) scenarios. WQT was found to be feasible in most of the scenarios. A 37 percent savings was reported from participation in a combined market under the existing BMPs baseline requirement and a trading ratio of two pounds of NPS pollutant for every pound of PS pollution.

CHAPTER 3 DATA AND METHODS

Identification of Potential Nutrient-Related WQT Markets

A GIS-based screening technique is used to identify potential WQT markets (Roberts et al. 2008). The market participants considered for the study are NPDES permitted PS with limits for nitrogen, phosphorus and/or oxygen-related pollutions (as potential buyers of credits) and agricultural NPS (areas with cultivated crops, hay and/or pasture production as potential sellers of credits). The criteria for selection of an area as a potential WQT market is based on:

i) the presence or absence of "tradable impairments" i.e., impairments due to nitrogen, phosphorus, nutrient eutrophication or low dissolved oxygen;

ii) the presence or absence of PS that contribute to, i.e. are upstream of, these impairments ("contributing PS"); and

iii) the presence or absence of NPS that contribute to, i.e. are upstream of, these impairments ("contributing NPS").

The area of study includes all 12-digit Hydrologic Unit Codes[1] (HUC 12s) that are located completely or partially within the state of Tennessee. HUC 12 boundaries together with their

[1] A hydrologic unit is a drainage area defined by hydrographic and topographic criteria that accepts surface water directly or indirectly from upstream drainage areas and drains to a single or multiple outlet points. The U.S. geological survey (USGS) classified watersheds in the U.S. into six types of hydrologic units using national standard hierarchical system based on surface hydrologic features. Each hydrologic unit is identified by a unique hydrologic unit code (HUC) ranging from two to twelve digits based on six levels of classification. Smaller HUCs are nested within a larger HUC and have relatively longer numeric codes. 8-digit HUCs (HUC 8s) and 12-digit HUCs (HUC 12s) are fourth and sixth level hydrologic units in the hierarchical classification of watersheds. HUC 8s are often called watersheds whereas HUC 12s are called sub-watersheds (USGS, 2017).

directional flow information were obtained from the "National Hydrography Dataset" (NHD) geodatabase[2] (USGS, 2016). To avoid the complications associated with involving multiple states, watershed boundaries are clipped with the Tennessee state boundary and only the portions of watersheds within Tennessee are analyzed. The analysis involves two major steps. The first step is to form different "impairment zones" by aggregating all of the HUC 12s that contribute to (i.e., are upstream of) a tradable impairment. The second step is to form WQT Market Zones by eliminating the impairment zones that do not have both contributing PS (i.e., buyers) and contributing NPS (i.e., sellers).

Formation of Impairment Zones

The shape files for impaired waterbodies listed in the Tennessee 303d (2016) list along with their causes and sources of impairment were obtained from the Tennessee Department of Environment and Conservation (TDEC) (TDEC, 2016). The first step in forming impairment zones is to identify the tradable impairments. All impairments are geo-located in ArcMap (Figure 3.1). Tradable impairments are retained for further analysis, while all other impairments are eliminated. The next step, is to identify contributing HUC 12s; i.e., HUC 12s that either contain a tradable impairment or are upstream of a tradable impairment. Upstream HUC 12s are determined on the basis of directional flow information for waterbodies provided by the NHD geodatabase. All HUC 12s that neither contain nor are upstream of a tradable impairment are eliminated from further consideration. This step fulfills the first criteria (presence or absence of tradable impairments).

The remaining HUC 12s are then aggregated into different impairment zones. All HUC-

[2] Available: https://nhd.usgs.gov/data.html

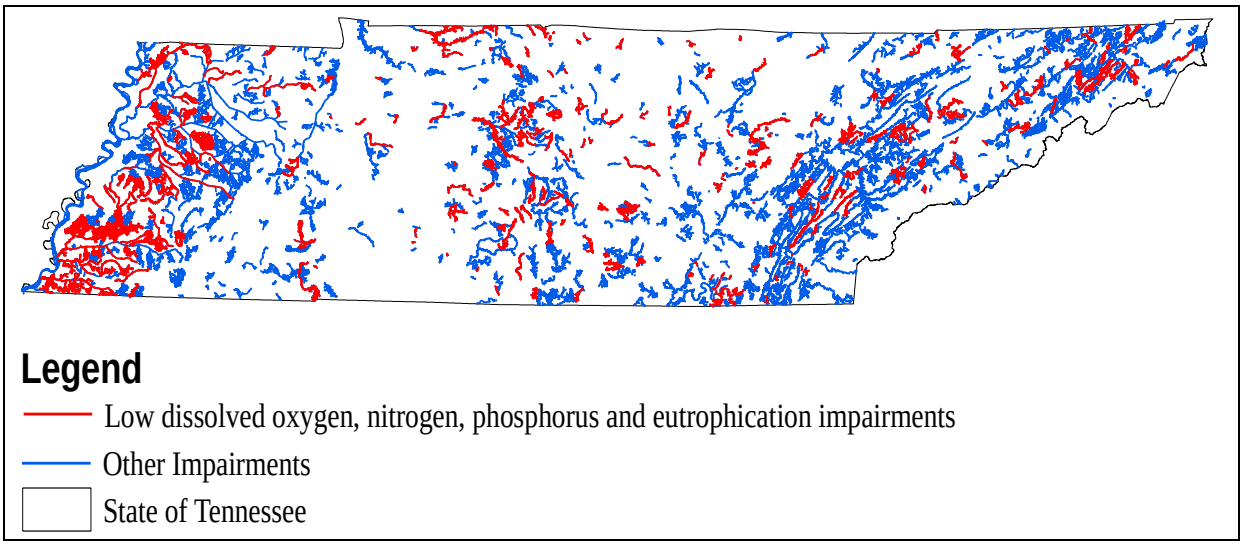

Figure 3.1 Water Quality Impairments in Tennessee (2016)

12s that contribute to the same impairment are categorized into one impairment zone given the USEPA's requirement that trades can only occur between contributors to the same impairment. Flow linkages between HUC 12s determine the impairment zone boundary. Using the Stones River watershed as an example, Figure 3.2 illustrates impairment zone formation where HUC 12s with the same color represent the same impairment zone. NHD flow lines indicate that five HUC 12s (yellow in color) contribute to the impairment labeled "a" in the figure. Therefore, these five HUC 12s are aggregated into a single impairment zone. Similarly, two HUC 12s (beige in color) contributing to impairment "b" are aggregated to form an impairment zone. Impairments "c", "d", and "e", have a single contributing HUC 12, therefore each of those HUC 12s formed a separate impairment zone.

In some cases, HUC 12s contribute to more than one impairment within the watershed. Polluting sources within these HUC 12s could conceivably trade in relation to each of these impairment zones. In such cases, the HUC 12s containing flow-linked impairments are

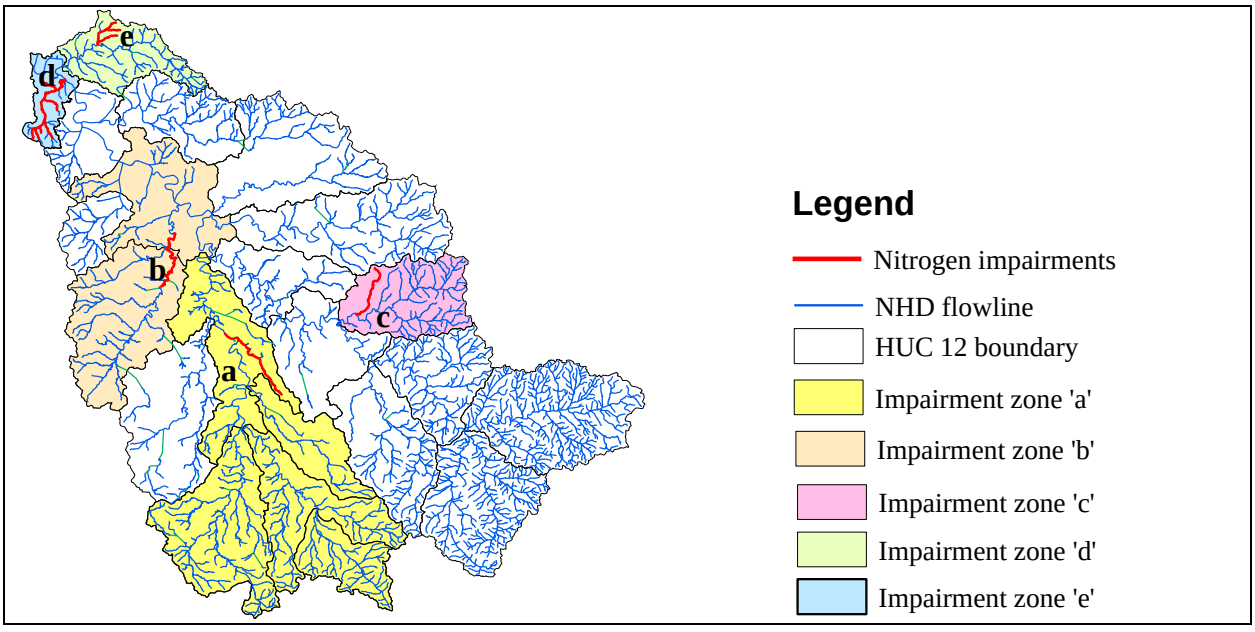

Figure 3.2 Example of Impairment Zone Formation in the Stones River Watershed (HUC 05130203)

aggregated to form a larger impairment zone. This aggregation is illustrated in Figure 3.3 where some HUC 12s contain an impairment and contribute to a downstream impairment while others only contribute to the downstream impairment. All HUC12s are aggregated into a single impairment zone.

In a few cases, the impairment zone boundary crossed an eight-digit HUC (HUC 8) boundary. Figure 3.4 presents an example of an impairment zone that lies in two different HUC 8 watersheds. Four HUC 12s within the Horn Lake-Nonconnah watershed contribute to an impairment in an adjoining HUC 12 in the Lower Mississippi-Memphis watershed. All 5 HUC12s are aggregated into a single impairment zone.

Formation of WQT Market Zones

The next step is to form "WQT Market Zones" by eliminating those impairment zones without either contributing PS or contributing NPS. Data on NPDES permitted PS along with their pollutant limits, and receiving water bodies were obtained from TDEC (TDEC, 2016). PS with individual NPDES permits that have either concentration or quantity limits for nitrogen (nitrate, nitrate, ammonia or total nitrogen as N), phosphorus (total phosphorus as P) and/or oxygen-related (level of dissolved oxygen, biochemical oxygen demand, chemical oxygen demand or carbonaceous oxygen demand) discharges are included, whereas PS that only need to report these discharges are not included for Market Zone formation. Appendix 1 shows summary information of all PS considered for this analysis. The geographic coordinates for these PS were downloaded from USEPA's integrated compliance information system (ICIS)[3]. All PS information is merged together and a shapefile created in ArcGIS based on the geographic coordinates of the PS. The directional flow information for waterbodies in NHD geodatabase and

[3] Available: https://www.epa.gov/enviro/pcs-icis-search

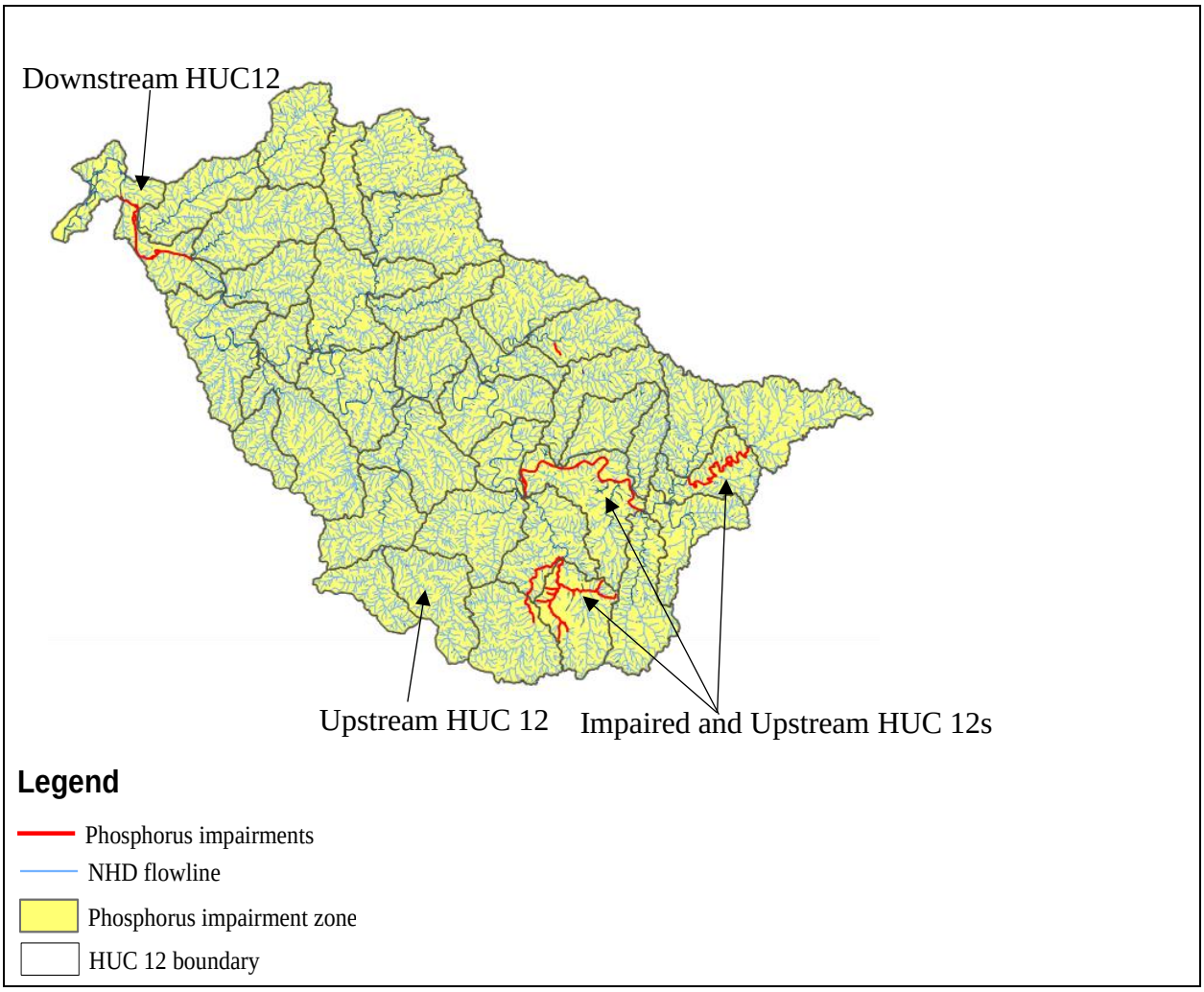

Figure 3.3 Impairment Zone in Lower Duck Watershed (HUC 06040003) with HUC 12s Contributing to More than One Impairment

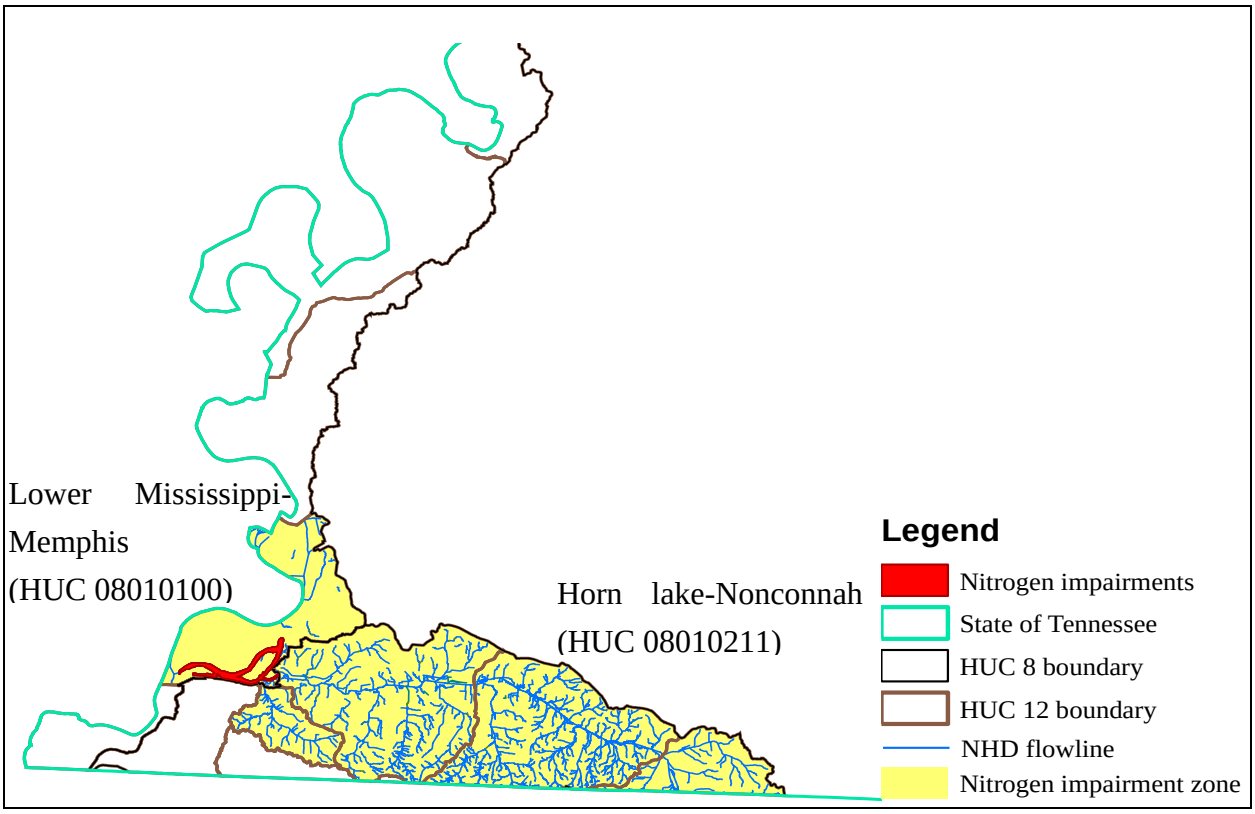

Figure 3.4 Impairment Zone with HUC 12s from Two Different HUC 8 Watersheds

information about receiving water for each PS helped in identification of contributing PS in an impairment zone. The impairment zones that have contributing PS are retained for further analysis while those without contributing PS are eliminated. This step fulfills the second criteria (presence or absence of contributing PS).

The presence or absence of contributing NPS (criteria 3) is equally important, because they are the potential sellers of nutrient reduction credits. This analysis focuses on agricultural NPS even though there are other NPS that could conceivably participate in some sort of trading program. The exclusive focus on agricultural NPS is based on the extent of the contribution of agricultural NPS to nutrient-related water quality impairment (TDEC, 2014). In addition, determining the nutrient discharges from various urban land uses would be exceedingly difficult without a detailed water quality model.

To identify agricultural NPS, the "National Land Cover Database (NLCD) 2011" shapefile for Tennessee was obtained from the Tennessee GIS Data Server[4] and located in ArcMap. Only impairment zones which have either cultivated crops, hay or pasture production are selected as final WQT Market Zones. Thus, all WQT Market Zones have at least one tradable impairment and at least one contributing PS (potential buyer) and one contributing NPS (potential seller). Individual WQT Market Zones for nitrogen, phosphorus and low dissolved oxygen are identified. Since nutrient eutrophication is often associated with low dissolved oxygen in waterbodies (Richardson and Jorgensen, 1996; Diaz and Rosenberg, 2008), impairment zones for nutrient eutrophication are included within oxygen WQT Market Zones. In addition, an aggregate set of WQT Market Zones are created using the same three criteria to accommodate the possibility of cross pollutant trading.

[4] Available: http://www.tngis.org/home.htm

Potential Point Source Demand for Nutrient Credits

One way to analyze the potential PS demand for nutrient credits would be to compare PS loadings, aggregated for each Market Zone, to applicable WLAs from TMDLs. However, the usefulness of this approach is limited by the scarcity of applicable TMDLs and mismatches between TMDL and Market Zone boundaries. Another way to analyze the PS demand is to compare PS loadings to another potential version of a regulatory driver-uniform discharge limits. Potential PS demand in this approach would be the difference between actual discharges and permitted uniform discharge limits. The use of these limits can provide a useful way of prioritizing among the potential trading zones. The disadvantage of this approach is that there are no such discharge limits in Tennessee and, to our knowledge, no plans to implement such limits. In this situation, 100 percent of actual PS discharges (considering 1:1 credit trading ratio) or 200 percent of actual PS discharges (considering 2:1 credit trading ratio) can act as an upper bound on potential PS demand. Comparison of a Market Zone's potential PS demand to NPS loading for that zone and to PS loads for other zones would be an appropriate route to analyzing the feasibility or relevance of WQT and is hence chosen for this study.

Actual nitrogen and phosphorus discharges from NPDES permitted PS for 2016 were obtained from USEPA's Discharge Monitoring Report (DMR) Pollutant Loading Tool[5]. The DMR data contains annual pollutant loads for each outfall of a facility. Pollutant loads from each facility's individual outfalls are summed to get total annual discharge for each facility. Appendix 2 shows DMR load values for all PS within the 73 aggregated nutrient Market Zones. Nutrient discharges for all PS within the Market Zones are aggregated to get total nutrient discharge from PS within the Market Zone. Proportions (0-200 percent at 5 percent increments) of Market

[5] Available at https://cfpub.epa.gov/dmr/adv_search_fields.cfm

Zone's nutrient discharges are set as possible PS nutrient demands and compared to estimated discharge loadings from NPS.

Potential Non-Point Source Supply of Nutrient Credits

The shapefile for Tennessee land use data was obtained from National Agricultural Statistics Service (NASS) cropland data layer 2016[6]. The cropland data layer is clipped in ArcMap by the Market Zone layer to obtain land use data for the Market Zones. The total area under various crops, including hay and pastureland, is calculated for each of the Market Zones using ArcMap (Appendix 3). Data on annual total nitrogen and phosphorus load values from agricultural land uses were obtained from Harmel et. al. (2006), McDowell and McGregor (1980), and Bhaduri et al. (2000). These loadings are summarized by land use in Table 2.1. Five types of BMPs (continuous no tillage, cover crops, filter strips, prescribed grazing and alternative watering) are included in the analysis. The average costs associated with implementation of BMPs were obtained from Shortle et al. (2013) and Environmental Quality Incentives Program (EQIP) (2017) and summarized in Table 3.1. Nitrogen and phosphorus reduction efficiencies of the five BMPs were obtained from a number of studies as shown in Table 3.2. Efficiency values varied across studies and some studies provided a range of efficiencies. These values are averaged and used for NPS credit supply estimation.

A linear programming model is built, and solved using the General Algebraic Modeling System (GAMS) to get least cost combinations of BMPs and land uses that fulfill the required nutrient (nitrogen and phosphorus) reduction targets for each Market Zone. Reduction targets for a Market Zone are set as proportions (0-200% at 5% increments) of aggregate nitrogen and

[6] Available at https://www.nass.usda.gov/Research_and_Science/Cropland/SARS1a.php

Table 3.1 Total Annual Cost of BMP Implementation in $/ac of BMP

Type of BMP	Average Cost ($/ac/yr)
Continuous no tillage	16.26 [b]
Cover crops	73.72 [a]
Filter strip	315.5 [b]
Prescribed grazing	19.32 [a]
Alternative watering	2028 [a]

Source: a-Shortle et al. 2013; b-EQIP 2017[7]

[7] Available at https://www.nrcs.usda.gov/wps/portal/nrcs/detail/tn/programs/financial/eqip/?cid=nrcs141p2_016426

Table 3.2 Total Nitrogen (TN) and Total Phosphorus (TP) Reduction Efficiencies of BMPs (Percentage of Total Loadings)

Type of BMP/ Source	Evans et al. 2008		Merriman et al. 2009		Shortle et al. 2013		Brosch 2010		Devlin et al. 2003		Wainger et al. 2013		Min		Max		Average	
	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN	TP
Continuous no tillage			59	69	10-15	20-40	10-15	20-40	25	40	10-15	20-40	10	20	59	69	20	36
Cover crops	25	36	66	67	34	0-15	10-45	7-20			34-45	15	10	0	66	67	37	23
Filter strip			54	57									54	57	54	57	54	57
Prescribed grazing					9-11	24	9-11	24					9	24	11	24	10	24
Alternative watering					5	8	5	8					5	8	5	8	5	8

phosphorus PS discharges within the Market Zone. The model is run for each Market Zone and is structured to minimize the total cost for BMP implementation subject to the nutrient reduction targets and a total available area constraint. The decision variable is the acres managed under each BMP in each Market Zone, which depends on nitrogen and phosphorus discharge from the different type of land uses within the Market Zone, the efficiency of the BMPs, the cost per acre of BMP implementation and the total acres available under each land use in the Market Zone.

It is important to consider the trading eligibility baseline in order to assure the additionality of nutrient credits. Baselines can either be the requirement to fulfill minimum level of conservation practices before actual credit generation or the existing level of management practices (Greenhalgh and Selman 2012). The latter is used for this study. Data for existing levels of no tillage in Tennessee was obtained from USDA-NASS[8] and deducted from available acres for no tillage. Cover crops, filter strips, and prescribed grazing have, to date, not been widely implemented in Tennessee (USDA-FSA[9]/NRCS[10]) and are therefore not considered for the purposes of this study. The model is run for each nutrient type (nitrogen and phosphorus) and each reduction target.

The optimization model minimizes the annual total cost of BMP implementation by selecting the total area for the implementation of BMPs under each land use.

$$\underset{S_{jk}}{\text{Min}}\, TC = \sum_{j=1}^{19}\sum_{k=1}^{5} S_{jk} * C_k \qquad (1)$$

Subject to:

[8]Available at https://www.nass.usda.gov/Statistics_by_State/Tennessee/Publications/Special_Surveys/tillage2016.pdf

[9]Available at https://www.fsa.usda.gov/news-room/efoia/electronic-reading-room/frequently-requested-information/crop-acreage-data/index

[10] Available at https://www.nrcs.usda.gov/Internet/NRCS_RCA/reports/cp_tn.html#wq

$$\sum_{j=1}^{19}\sum_{k=1}^{5} S_{jk} * D_j * E_k \geq x * R \qquad [\lambda_1] \qquad (2)$$

$$\sum_{k=1}^{5} S_{jk} \leq A_j \qquad \forall\, j \qquad [\lambda_2] \qquad (3)$$

Where,

TC =Annual total objective cost of BMP implementation (in $)

j =Set of 19 land use types within the Market Zones

k =Set of 5 BMPs that can be implemented

S_{jk} =Total area (in acres) for the implementation of 'kth' BMP in jth land use

C_k = Cost of kth BMP implementation (in $/ac/year)

D_j = Discharge of nutrient from land use *j* (in lb/ac/year)

E_k = Efficiency of kth BMP (in percent) in reducing nutrient

x = Percent of total PS loadings within the Market Zone (0-200% at 5% increments)

R =Reduction target for nutrient (in lb/year)

A_j =Total available area for land use *j* (in acres)

λ_1 =Shadow value of reduction target constraint

λ_2 = Shadow value of available area constraint

Shadow value for a constraint is the amount by which the value of objective function changes when the right hand side value of the constraint is increased by one unit. Shadow values represent marginal costs (Ragsdale, 2010). These marginal costs (shadow values) were obtained as output from the GAMS model. The marginal costs are then plotted against their corresponding nutrient reductions to generate nutrient credit supply curves for each Market Zone.

CHAPTER 4 RESULTS AND DISCUSSION

There are 1,151 HUC 12s partially or completely located in Tennessee (Figure 4.1). A total of 15,013 miles of streams and rivers in Tennessee are impaired by one or more causes. Similarly, 208,682 acres of lakes and reservoirs are impaired. Approximately 29 percent of impaired stream and river miles are impaired due to nutrients or low dissolved oxygen. Approximately 13 percent of impaired lake and reservoir acres are impaired due to nutrients or low dissolved oxygen. Phosphorus contributes to the most impaired stream and river miles whereas low dissolved oxygen contributes to the most impaired lake and reservoir acres. Table 4.1 presents the number of impaired segments and impaired miles or acres for each type of pollutant. Table 4.2 shows the number of HUC 12s that contain or are upstream of a nutrient-related impairment.

Nitrogen Market

Only 189 of the 1,151 HUC 12s contain or are upstream of a nitrogen impairment. These HUC 12s are aggregated into 125 impairment zones for nitrogen (Table 4.2). The impairment zones

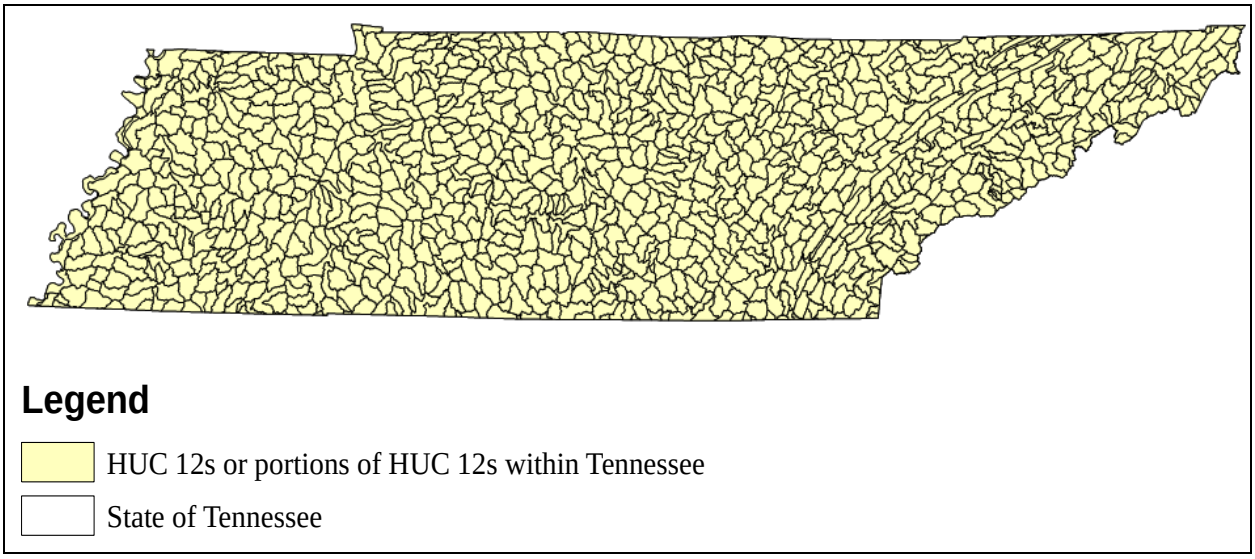

Figure 4.1 Portions of HUC 12s within Tennessee

Table 4.1 Waterbody Impairments Attributable to Nutrient-Related Causes in Tennessee, 2016

Cause of Impairment	Streams and Rivers Impairments		Lake and Reservoir Impairments	
	Count	Total impaired miles	Count	Total impaired acres
Tradable impairments				
Nitrogen	205	1767	4	78
Phosphorus	245	2657	13	6060
Low dissolved oxygen	169	1874	16	20952
Nutrient eutrophication	36	233	7	16733
Other impairments	1132	10692	82	200329
All impairments	1573	15013	87	208682

Source: TDEC 2016
Note: Column sums are greater than all impairments because waterbodies are often impaired by more than one cause.

Table 4.2 Number of HUC 12s Containing and/or Upstream of Nutrient-Related Impairments

Cause of Impairment	HUC12s			
	Impaired	Upstream	Total Impaired or Upstream	Not Impaired or Upstream
Nitrogen	161	28	189	962
Phosphorus	185	131	316	835
Low dissolved oxygen	155	285	440	711
Nutrient eutrophication	30	34	64	1087
Overall nutrients and low dissolved oxygen	301	291	592	559

for nitrogen are shown in Figure 4.2. A total of 66 of the 125 impairment zones do not have a contributing nitrogen PS and, thus, are eliminated, leaving 59 for further analysis. All of the 59 remaining impairment zones have some level of agricultural activity (cultivated crops, hay and pasture production) and, thus, application of the contributing NPS criteria does not eliminate any impairment zones. The 59 nitrogen WQT Market Zones contain a total of 115 HUC 12s. Figure 4.3 shows the nitrogen Market Zones, along with PS with nitrogen limits and cultivated crops, hay and pasture acres for all of Tennessee. Figure 4.4 presents the final nitrogen WQT Market Zones. These Market Zones include 57 percent of the stream and river miles and 99 percent of the lake and reservoir acres impaired due to nitrogen in Tennessee, 28 percent of the PS with nitrogen limits, and 14 percent of the cultivated crop, hay and pasture acres in the state. The coverage of different WQT Market Zones (percentage of impaired river and stream miles, percentage of impaired lake and reservoir acres, NPDES permitted PS with applicable limits and

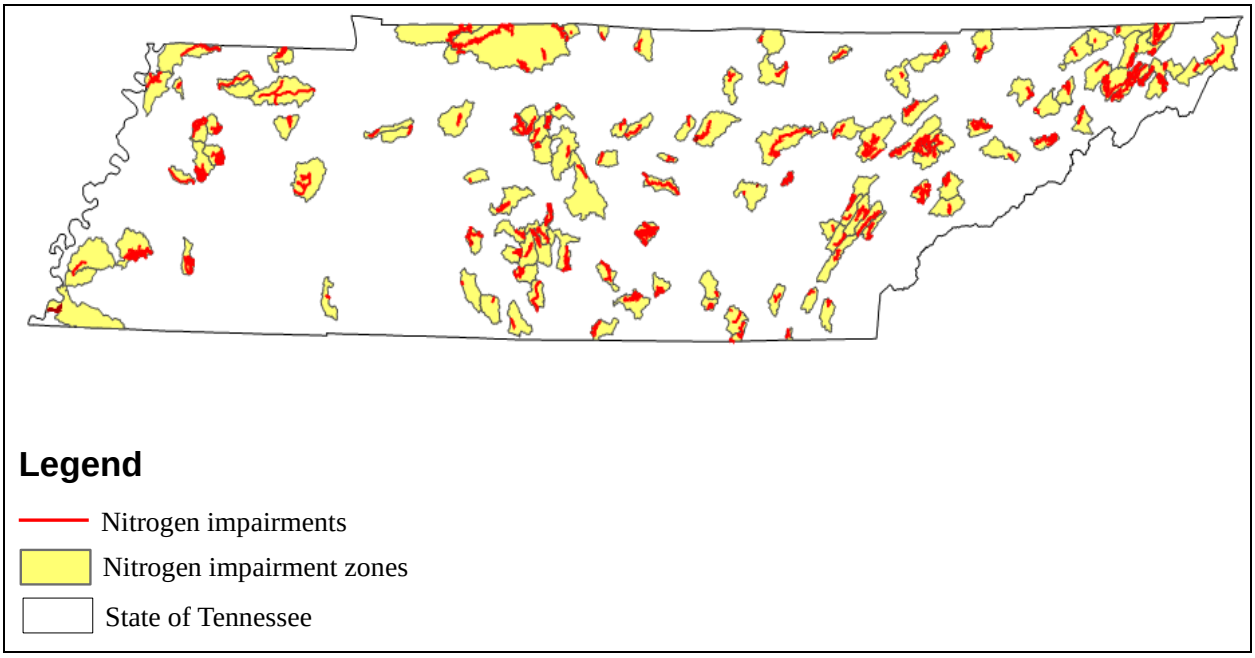

Figure 4.2 Nitrogen Impairment Zones

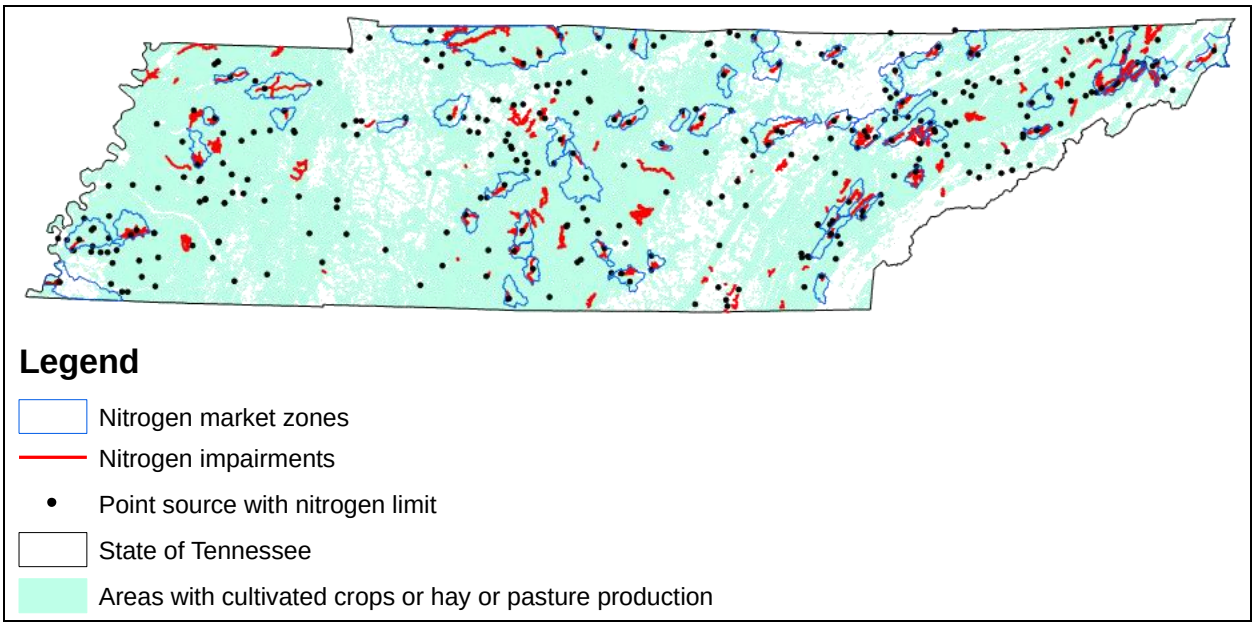

Figure 4.3 Nitrogen Impairments, PS with Nitrogen Limits, Agricultural NPS and Nitrogen Market Zones within Tennessee

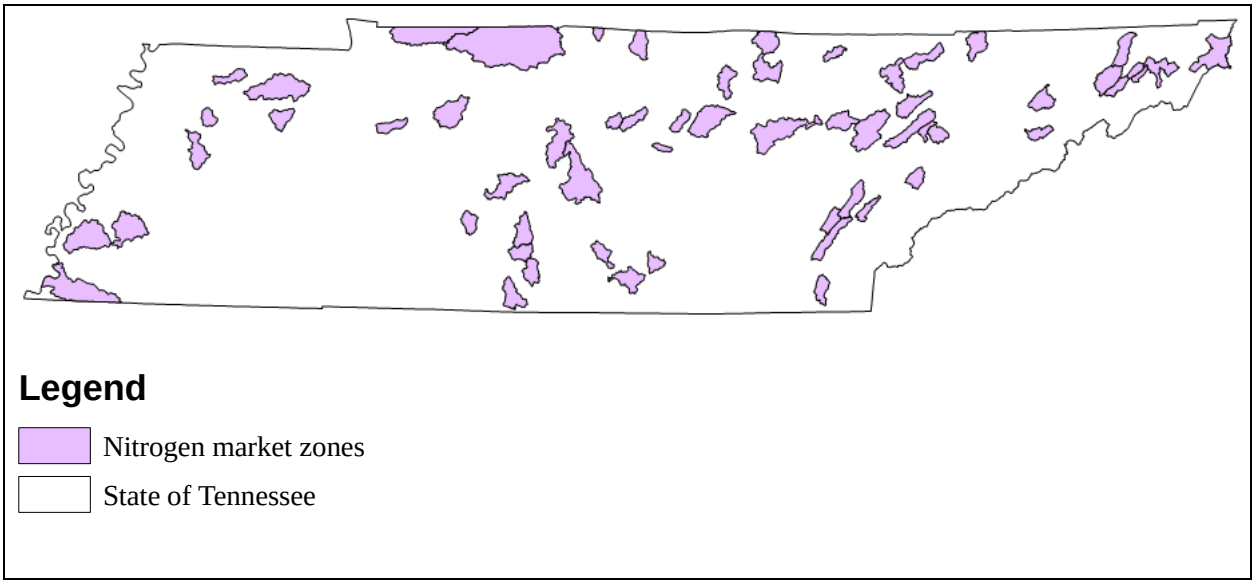

Figure 4.4 Nitrogen Market Zones

acres of cultivated crops, hay or pasture for each category of WQT Market Zones) are shown in Figure 4.5.

Phosphorus Markets

A total of 835 of the 1,151 HUC 12s neither contain nor are upstream of a phosphorus impairment (Table 4.2) and are therefore eliminated from consideration for a phosphorus WQT program. The remaining 316 HUC12s or portions of HUC 12s are aggregated into 99 phosphorus impairment zones (Figure 4.6). Fifty-four of the 99 impairment zones have no contributing PS and are thus eliminated, leaving 45 for further analysis. Again, all 45 of the remaining impairment zones have some level of cultivated crops, hay or pasture production. Thus, application of the last criteria does not eliminate any impairment zones and the 45 phosphorus WQT Market Zones contain a total of 233 HUC 12s. Figure 4.7 shows the location of the phosphorus Market Zones relative to all PS with phosphorus limits and all cultivated

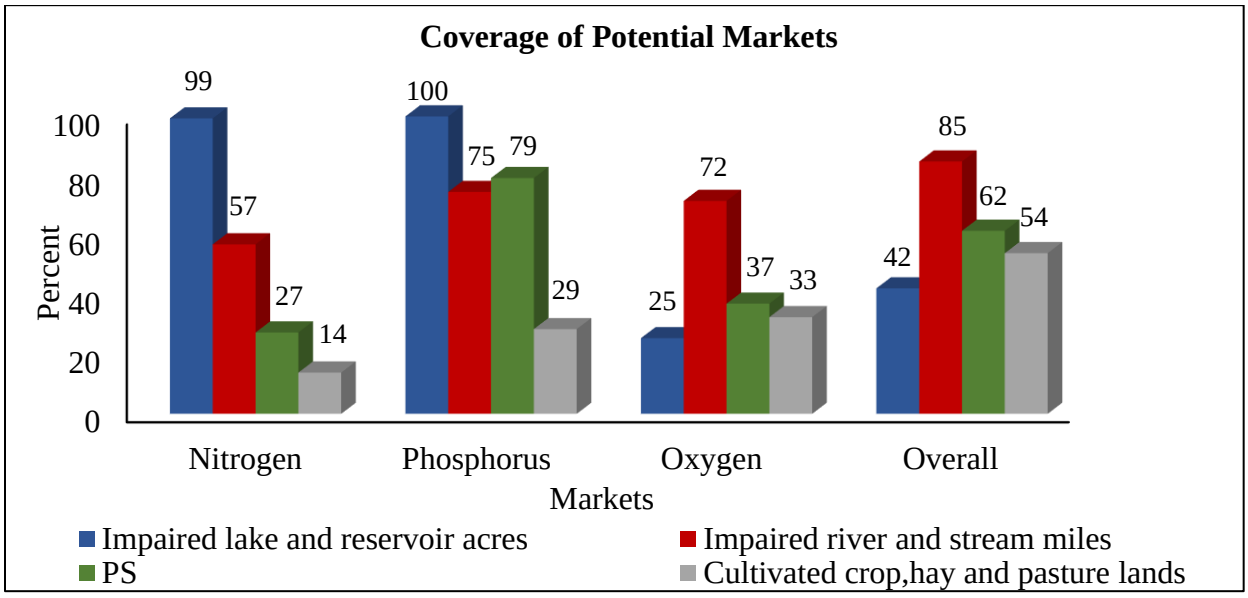

Figure 4.5 Percentage of Impaired River and Stream Miles, Percentage of Impaired Lake and Reservoir Acres, NPDES Permitted PS with Applicable Limits and Acres of Cultivated Crop, Hay and Pasture Lands) for Each Category of WQT Market Zones

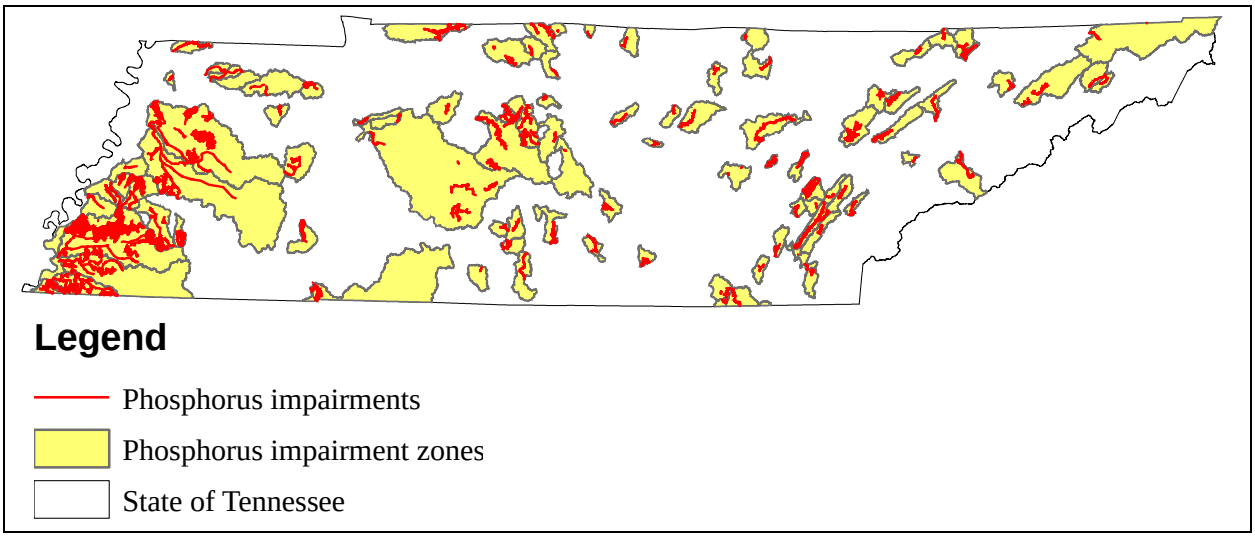

Figure 4.6 Phosphorus Impairment Zones

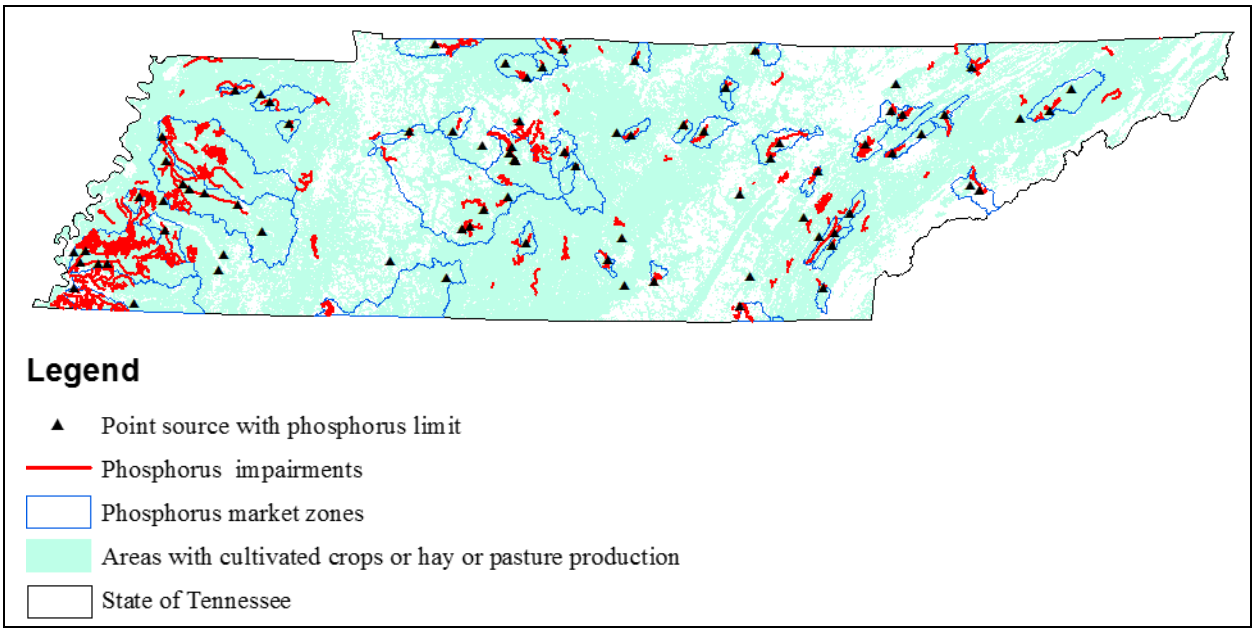

Figure 4.7 Phosphorus Impairments, PS with Phosphorus Limits, Agricultural NPS and Phosphorus Market Zones within Tennessee

crops, hay and pasture acres within Tennessee. Final phosphorus WQT Market Zones are presented in Figure 4.8. These Market Zones include 75 percent of the stream and river miles and 100 percent of the lake and reservoir acres impaired due to phosphorus in Tennessee, 79 percent of the PS with phosphorus limits in Tennessee, and 29 percent of the cultivated crop, hay and pasture acres in the state (Figure 4.5).

Oxygen Markets

Only 440 of the 1,151 HUC 12s either contain or are upstream of an oxygen impairment and 64 of the 1,151 HUC 12s either contain or are upstream of a nutrient eutrophication impairment (Table 4.2). Overlaying these HUC 12s together resulted into 466 unique (non-overlapping) HUC 12s or portions of HUC 12s which are aggregated into 97 oxygen impairment zones (Figure 4.9). Forty-nine of the 97 impairment zones have no contributing PS and are thus eliminated leaving 48 for further analysis. Again, all 48 of the remaining impairment zones have some level of cultivated crops, hay or pasture production. Thus, application of the last criteria does not eliminate any impairment zones and the 48 oxygen WQT Market Zones contain a total of 317 HUC 12s. Figure 4.10 shows the location of the oxygen Market Zones relative to all PS

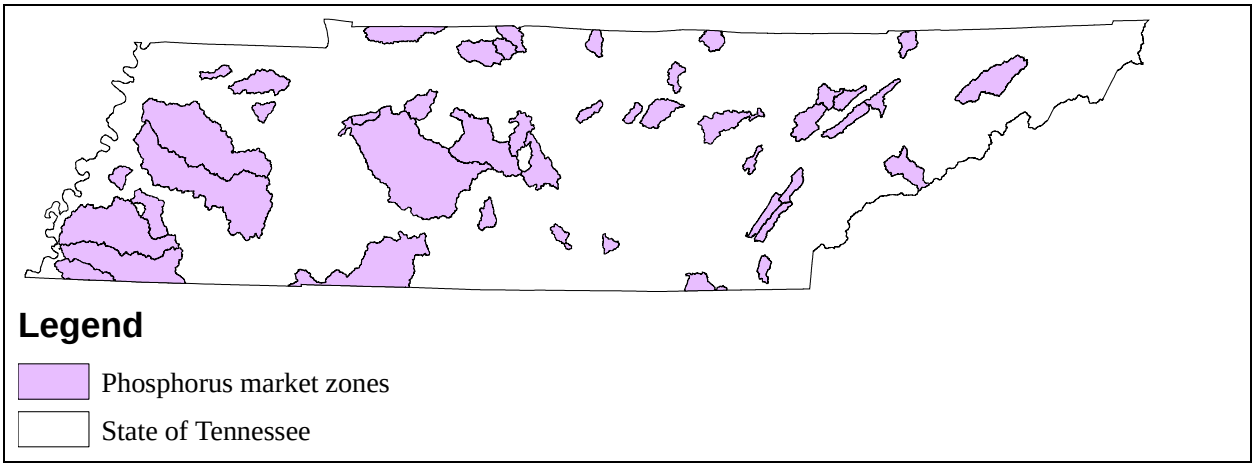

Figure 4.8 Phosphorus Market Zones

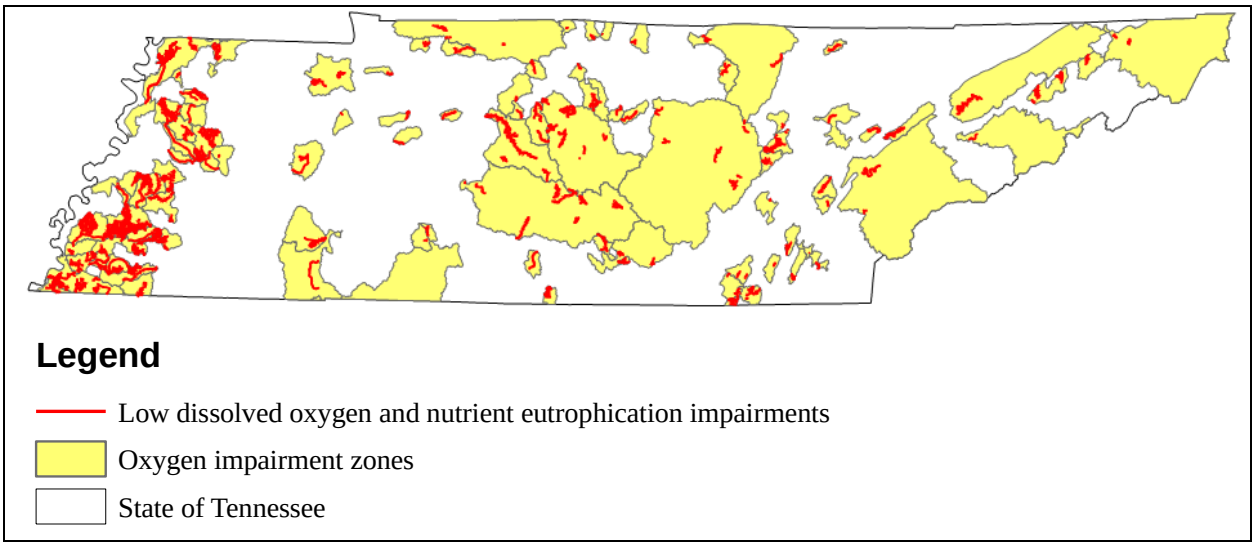

Figure 4.9 Oxygen Impairment Zones

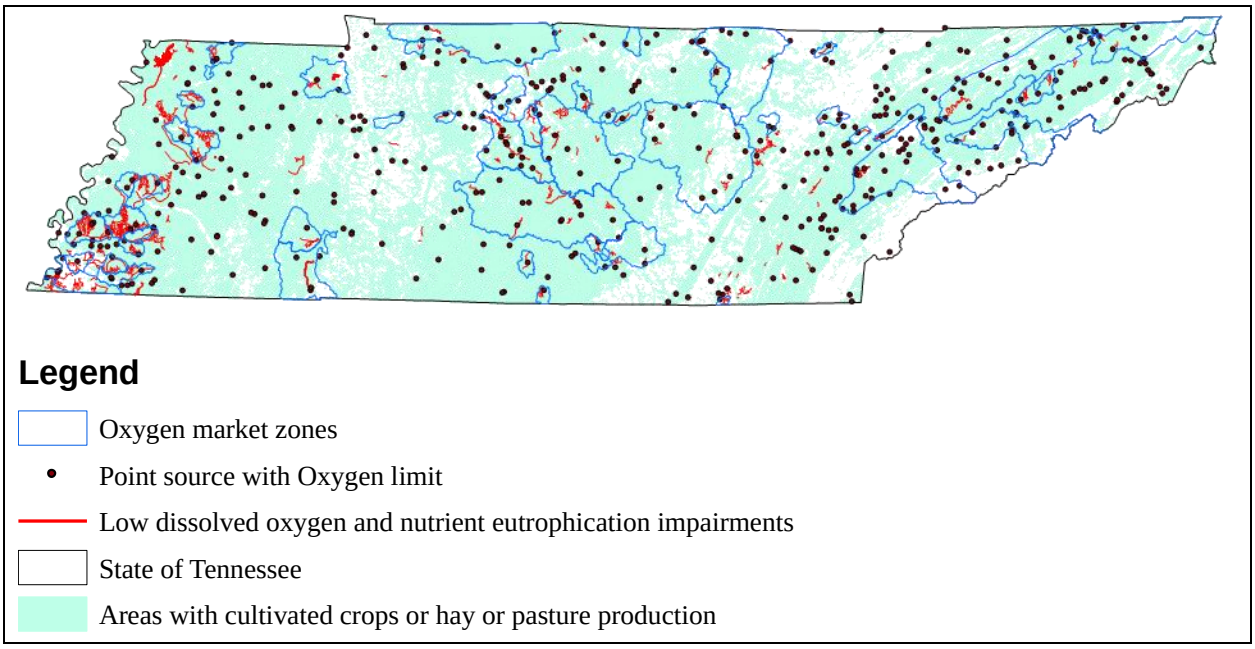

Figure 4.10 Low Dissolved Oxygen and Nutrient Eutrophication Impairments, PS with Oxygen Limits, Agricultural NPS and Oxygen Market Zones within Tennessee

with oxygen limits and all cultivated crops, hay and pasture acres within Tennessee. Figure 4.11 presents the final oxygen WQT Market Zones. These WQT Market Zones include 72 percent of stream and river miles and 25 percent of lake and reservoir acres impaired due to low dissolved oxygen or nutrient eutrophication, 37 percent of the PS with oxygen limits, and 33 percent of the State's cultivated crop, hay and pasture acres.

Aggregated Nutrient-Related Markets

A final aggregation is to consider the possibility of cross-pollutant trading among both nutrients and oxygen related impairments and pollutants. For this possibility, we treat all nutrient and oxygen related impairments as equivalent. A total of 559 of the 1,151 HUC 12s neither contain nor are upstream of a nutrient or low dissolved oxygen impairment (Table 4.2) and are therefore eliminated. The remaining 592 HUC12s or portions of HUC 12s are aggregated into 130 nutrient-related impairment zones (Figure 4.12). Fifty-seven of the 130 impairment zones have no contributing PS and are thus eliminated leaving 73 for further analysis. All 73 of the remaining impairment zones have some level of cultivated crops, hay or pasture production. Thus, application of the last criteria does not eliminate any impairment zones and the 73 nutrient-

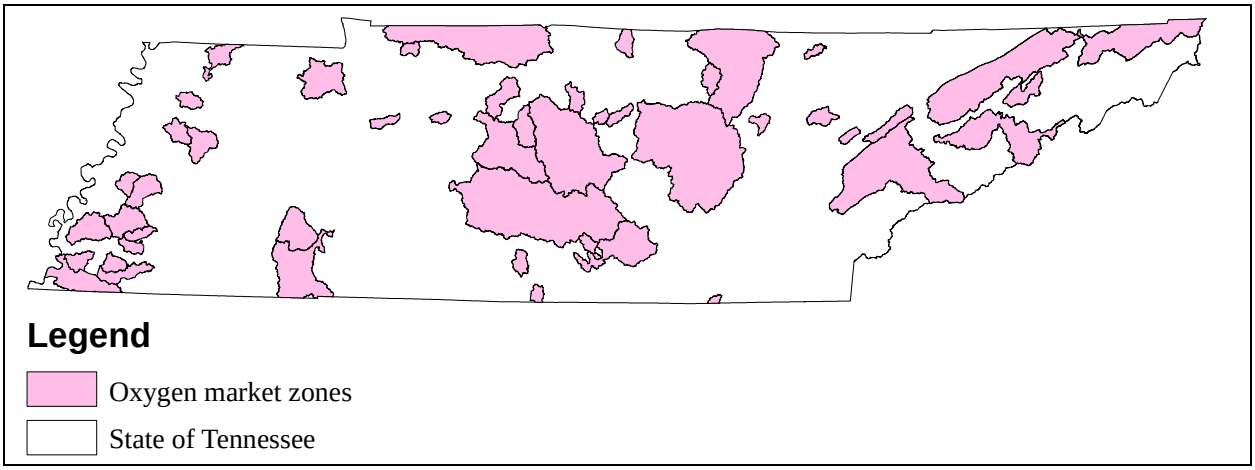

Figure 4.11 Oxygen Market Zones

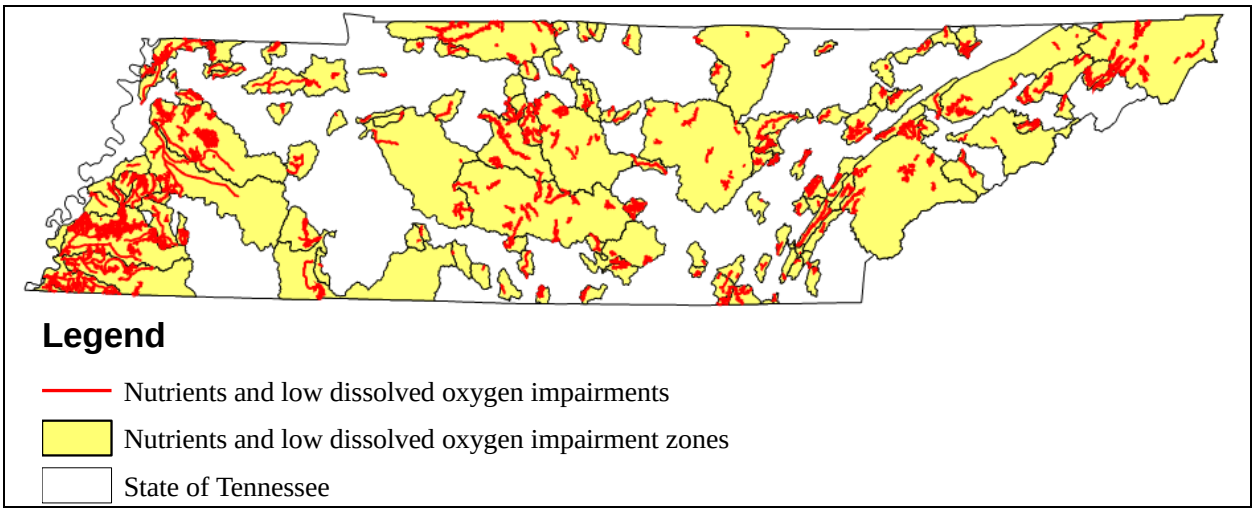

Figure 4.12 Nutrient-Related Impairment Zones

related WQT Market Zones contain a total of 528 HUC 12s. Figure 4.13 shows the location of the nutrient-related Market Zones relative to all PS with nutrient or low dissolved oxygen limits and all cultivated crops, hay and pasture acres within Tennessee. Figure 4.14 presents the final nutrient-related WQT Market Zones.

Non-Point Source Supply of Nutrient Credits

Based on total annual PS discharges, 60 Market Zones have positive nitrogen reduction targets and 56 Market Zones have positive phosphorus reduction targets. However, only 35 of the 60 Market Zones with positive nitrogen reduction target are able to reduce 100 percent of their reduction targets using some of the five BMPs. Similarly, only 30 of the 56 Market Zones with positive phosphorus reduction target are able to reduce 100 percent of their reduction targets.

On average, corn is the most frequently selected land use type for nitrogen reduction. The cost per acre of a BMP implementation is same across all land use. Therefore, selection of a land use is based on the discharge of nutrient loads and available acres under each land use. The land

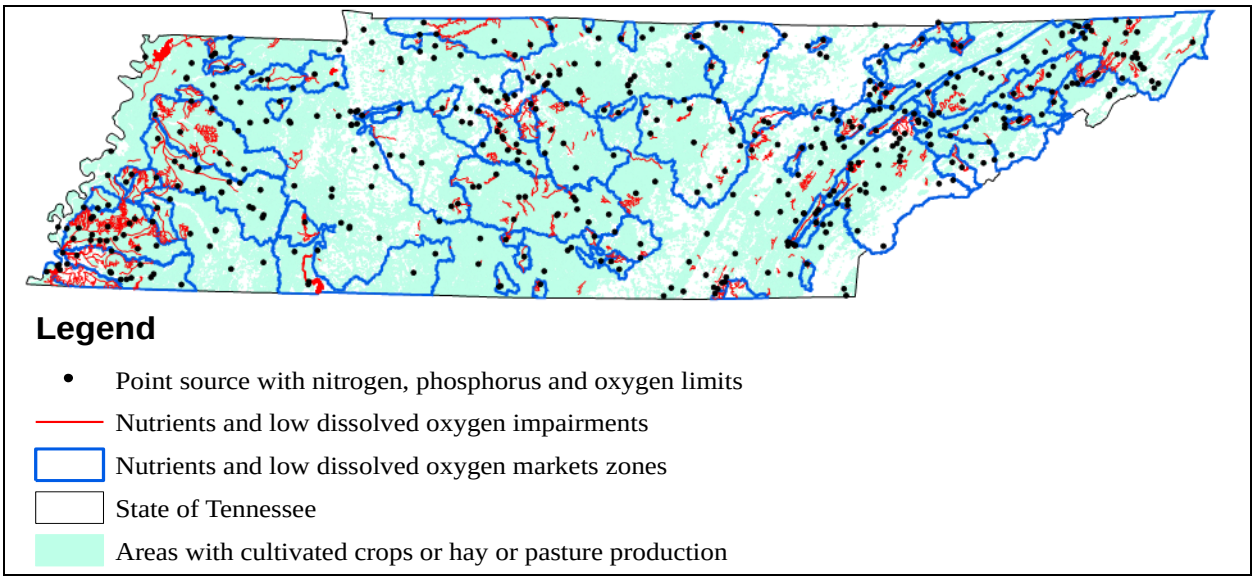

Figure 4.13 Nutrient Impairments, PS with Nutrient Limits, Agricultural NPS and Nutrient Market Zones within Tennessee

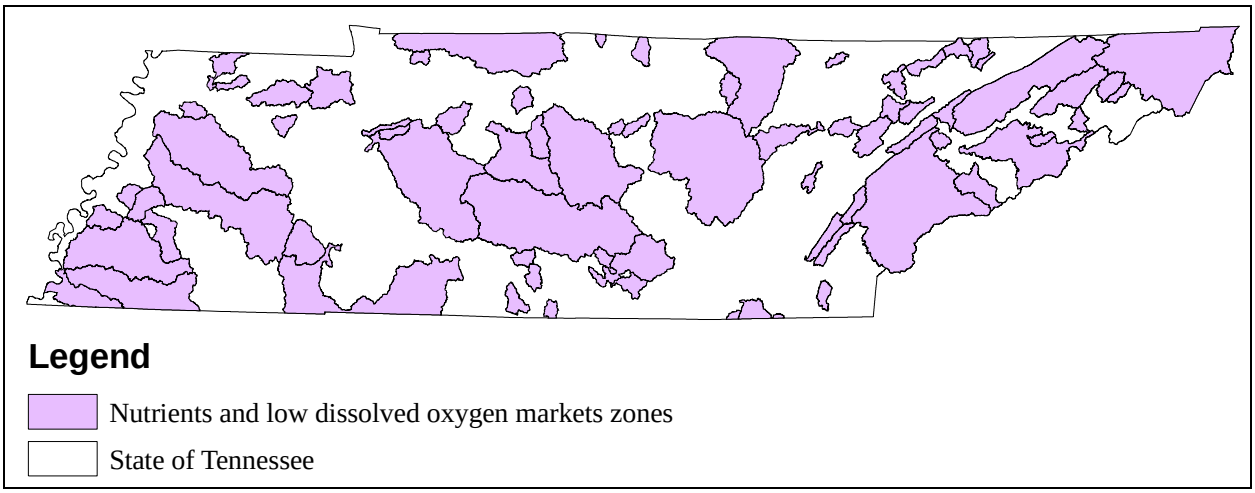

Figure 4.14 Nutrients and Low Dissolved Oxygen Market Zones

use that has the highest nutrient discharge is selected until all available acres under that land use is exhausted. Similarly, continuous no tillage is frequently chosen as the most cost-effective BMP followed by cover crops and filter strips when 100 percent nitrogen reduction is set as the first priority. Figure 4.15 shows the proportion of selected BMP acreage by Market Zones when 100 percent nitrogen reduction is set as reduction target. The selection of BMPs is based on cost per acre of BMPs, efficiency of BMPs in reducing nutrients, nutrient reduction targets and already existing BMP acres in the Market Zones. At low reduction targets, a low cost and less efficient BMP (that is able to fulfill the required reductions) is selected which is replaced by more efficient and expensive BMPs as the reduction targets increases. Figure 4.16 provides an example of BMP selection and associated total cost under various nitrogen reduction targets in Market Zone '051302060708'. The increase in total cost is either due to increase in acres for BMP implementation or increase in proportion of high cost BMPs. Cover crop has lower phosphorus reduction efficiency compared to continuous no tillage and filter strips. Therefore, a decrease in phosphorus reduction is seen as the proportion of cover crop increases and vice versa.

Marginal cost of nitrogen reduction ranges from $3.53 to $1643.42 per pound of nitrogen. The marginal costs are plotted against their corresponding nitrogen reductions to generate nitrogen credit supply curves for each Market Zone which are shown in Figure. 4.17. The dots on curve for each Market Zone indicate nitrogen reduction targets (0-200 percent at 5 percent increments) for those Market Zones. These curves do not consider any target constraint for phosphorus reduction.

Available acres for cotton is exhausted first in case of phosphorus reduction because it has the highest phosphorus load discharge per acre. Nine of the 30 Market Zones only selected

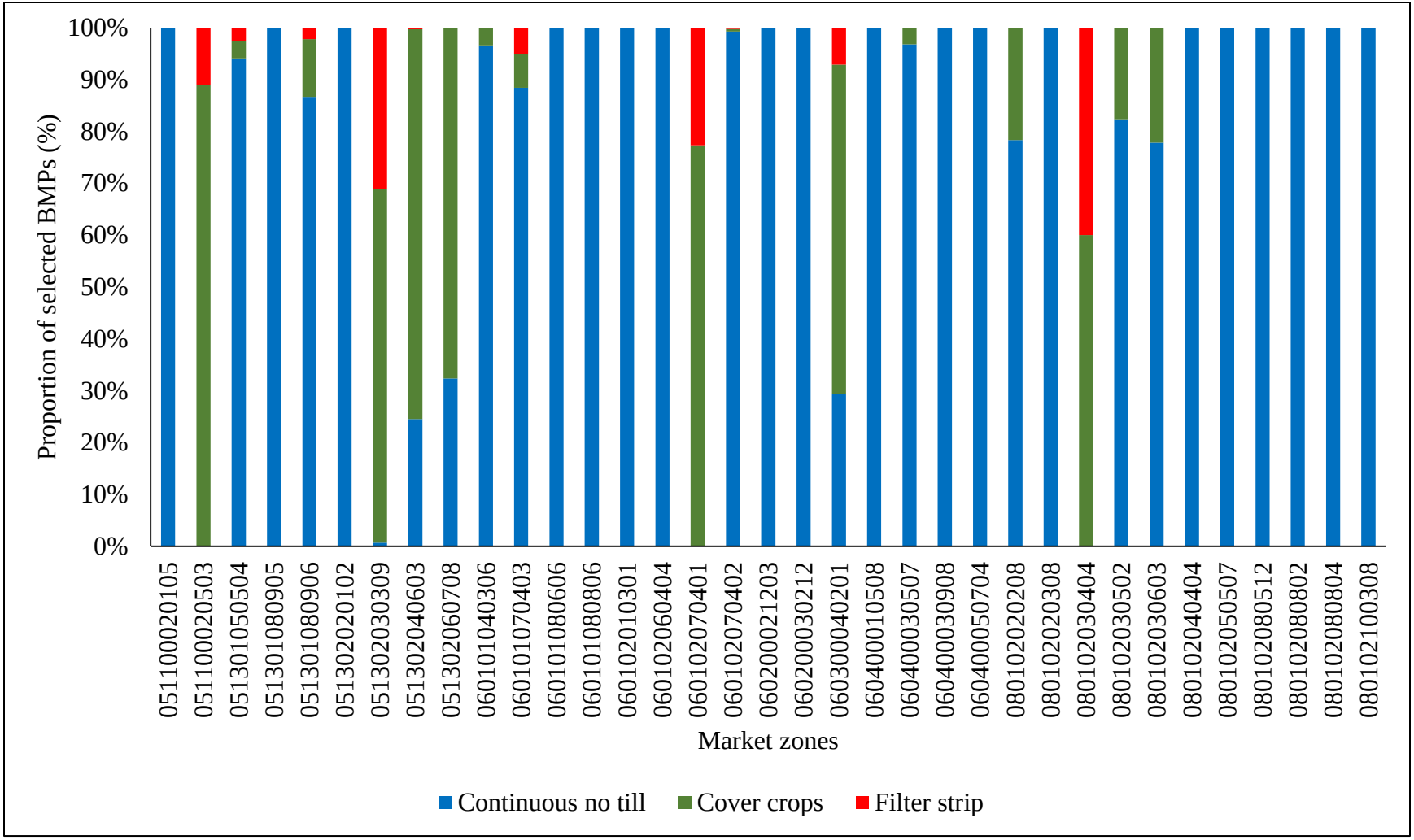

Figure 4.15 Proportion of Selected BMP Acreage by Market Zones when 100 Percent Nitrogen Reduction is Set as Reduction Target

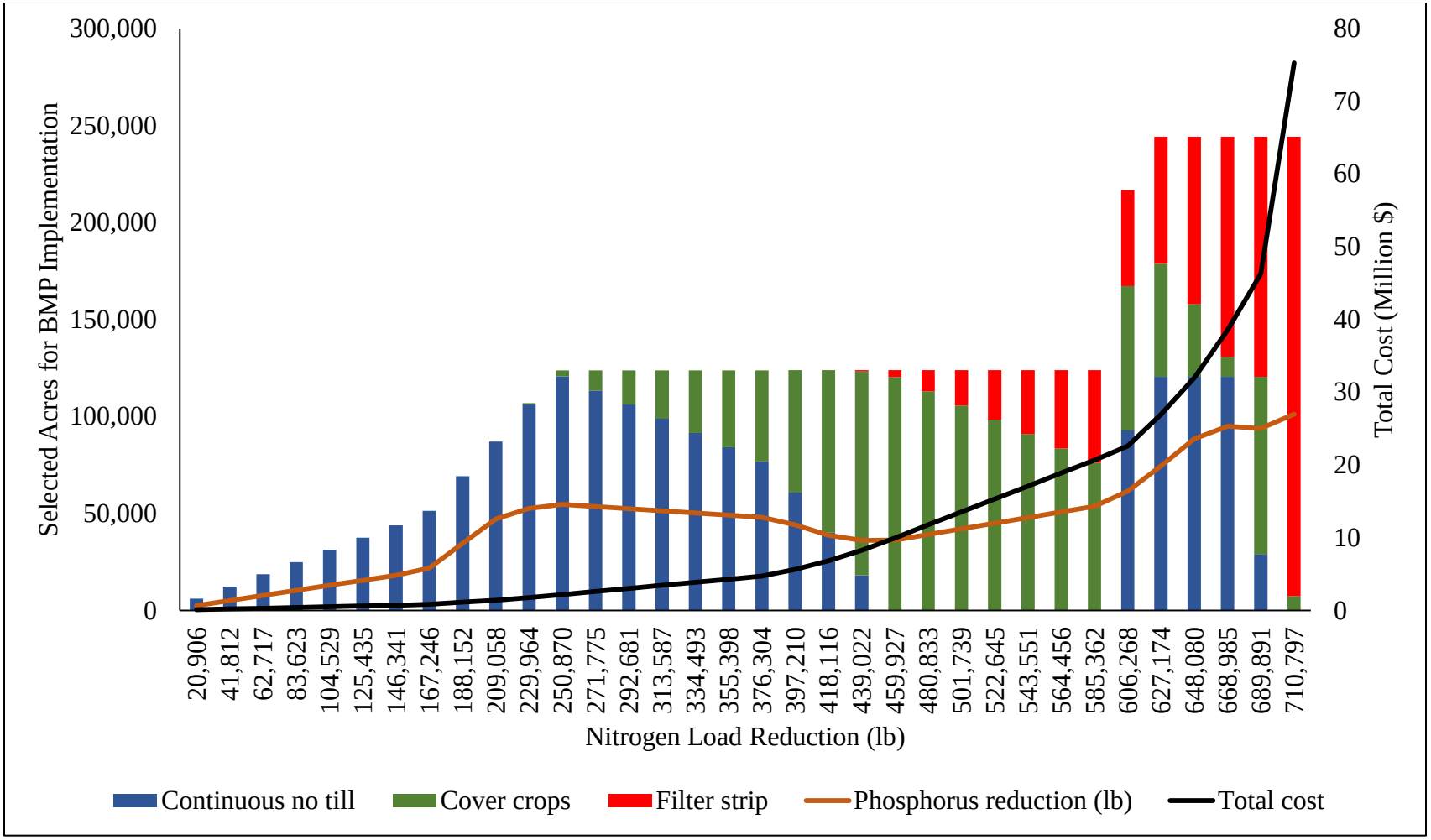

Figure 4.16 Acres of Best Management Practices and Corresponding Total Cost Associated with Achieving Various Nitrogen Load Reduction Targets in Market Zone '051302060708'

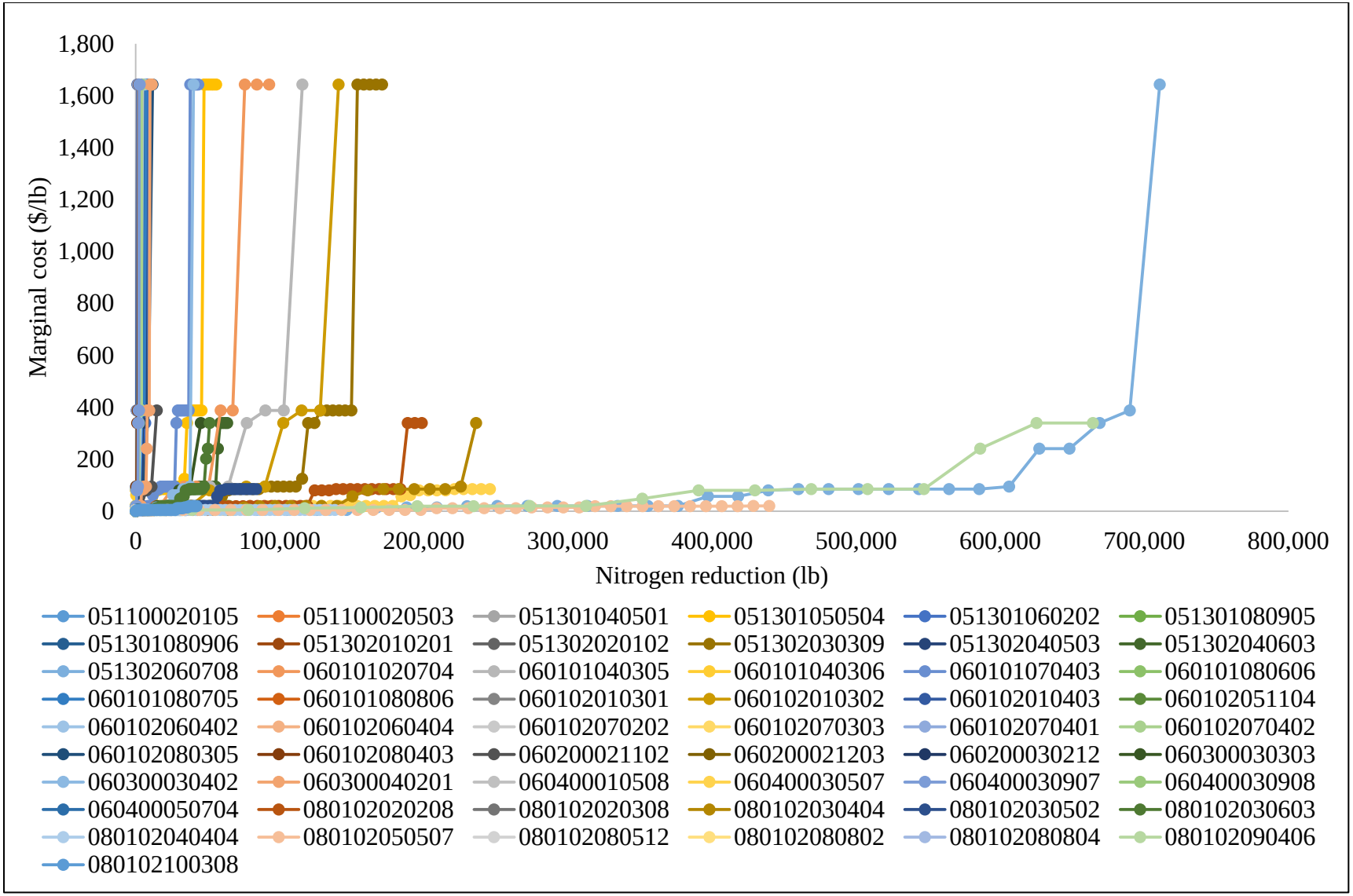

Figure 4.17 Optimal Nitrogen Reduction and Their Corresponding Marginal Costs by Market Zones when 0 to 200 Percent of Point Source Nitrogen Loads are Set as Reduction Targets

cotton for reducing 100 percent phosphorus loads. The selection of land use in other Market Zones is affected by the availability of acres under each land use.

Only continuous no tillage and filter strips are chosen by the model when 100 percent phosphorus reduction is set as the first priority. The model did not select prescribed grazing and alternative watering in either case because of their lower reduction efficiency and higher cost of implementation compared to other BMPs. Figure 4.18 shows the proportion of selected BMP acreage by Market Zones when 100 percent phosphorus reduction is set as reduction target. The marginal cost of phosphorus reduction ranges from $10.07 to $6,694.68 per pound of phosphorus. The marginal costs are plotted against their corresponding phosphorus reductions to generate phosphorus credit supply curves (unconstrained for nitrogen reduction targets) for each Market Zone which are shown in Figure 4.19.

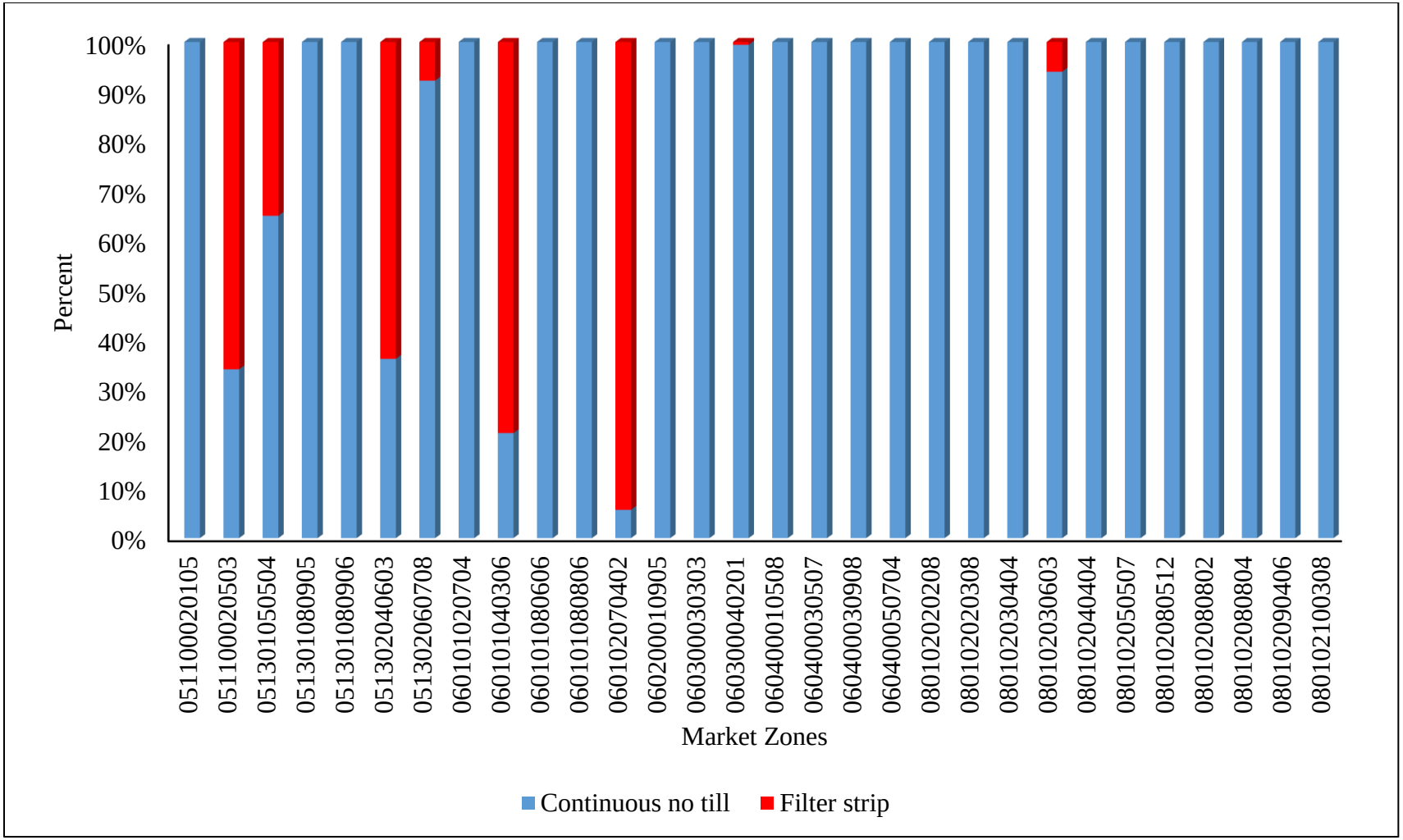

Figure 4.18 Proportion of Selected BMP Acreage by Market Zones when 100 Percent Phosphorus Reduction is Set as Reduction Target

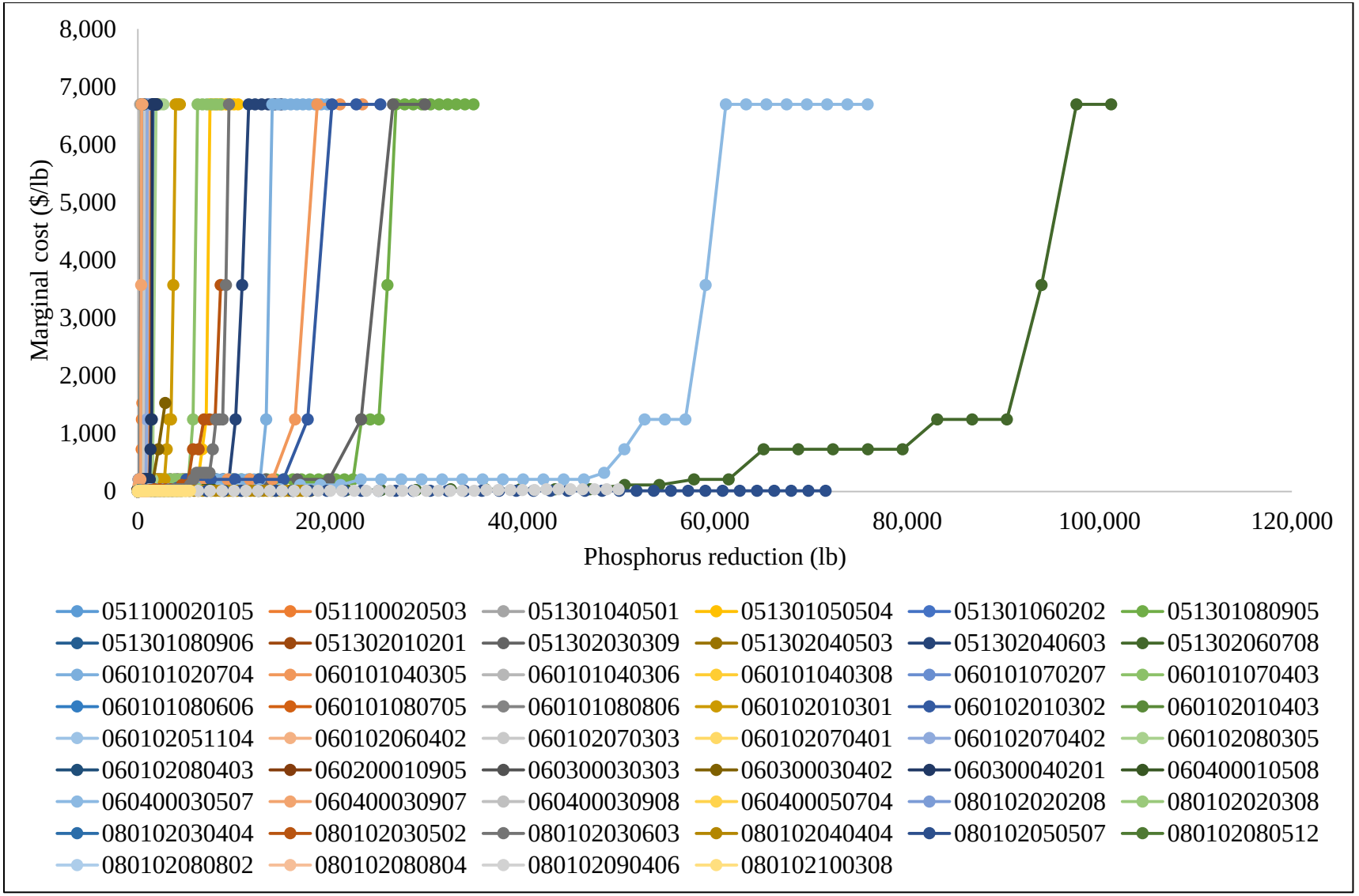

Figure 4.19 Optimal Phosphorus Reduction and Their Corresponding Marginal Costs by Market Zones when 0 to 200 percent of Point Source Phosphorus Loads are Set as Reduction Targets

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

WQT is spatially feasible in some parts of Tennessee. The presence of impairments in headwaters where there is lack of PS with nutrient limits eliminates the possibility of WQT in many areas. More than one upstream HUC 8s are flow-linked to a downstream impairment, therefore limiting trade within HUC 8 boundary can lower the chance of trading as it eliminates some potential contributors to the impairment. A single contributing PS as a potential buyer of nutrient credits in many Market Zones suggests bilateral trading may be the most appropriate form of WQT in Tennessee.

This study not only identifies spatially feasible areas with potential for nutrient credit trading, but also presents the cost associated with NPS nutrient credit supply for each Market Zone. For each spatially feasible Market Zone, NPS nutrient reduction cost can be compared to PS nutrient reduction cost. These cost differences can be helpful in prioritizing areas for WQT implementation in Tennessee.

However, the study has some limitations. It is based on a simple approach which relies on literature for NPS nutrient discharges and effectiveness of BMPs in water quality improvement. The study does not consider variation in nutrient discharges based on soil type and distance between polluting source and waterbody. It also do not consider seasonality of nutrient delivery to the water bodies. A more detailed water quality model which provides better nutrient discharge and effectiveness data and also the transport of pollutants could potentially improve this study. Nutrient reduction targets for PS are not based on strong regulatory drivers such as a TMDL. However, setting reduction targets from 0-200 percent of PS loads is expected to include all possible targets for a 2:1 trading ratio.

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APPENDIXES

Appendix 1. NPDES Permitted Point Sources with Either Nitrogen, Phosphorus or Oxygen Limits Included in the Study

NPDES ID	Permittee	Flow Rate (MGD)	SIC	ZIP Code	Nitrogen limit	Phosphorus limit	Oxygen limit	Market Zone
TN0020877	Lafayette STP	1.500	4952	37083	Yes	Yes	Yes	051100020105
TN0055026	Westmoreland STP	0.300	4952	37186	Yes		Yes	051100020503
TN0064424	Oneida STP	0.980	4952	37841	Yes		Yes	051301040501
TN0004332	USDI - FWS Dale Hollow National Fish Hatchery	20.000	921	38551	Yes		Yes	051301050504
TN0021377	Obey River Recreation Area "A", Recreation Area "B" and Recreation Area "C"	0.002	4952	38551	Yes		Yes	051301050504
TN0021393	USA COE Dale Hollow Lake - Lillydale Recreation Area	0.002	4952	38541	Yes		Yes	051301050504
TN0026085	Star Point Resort	0.015	4952	38549	Yes		Yes	051301050504
TN0058033	Cedar Hill Resort STP	0.010	4952	38551	Yes		Yes	051301050504
TN0062626	Byrdstown STP	0.600	4952	38549	Yes	Yes	Yes	051301050504
TN0062634	Jamestown STP	1.000	4952	38556	Yes		Yes	051301050504
TN0064688	Monterey WWTP	1.000	4952	38574	Yes		Yes	051301050504
TN0021873	Livingston STP	1.620	4952	38570	Yes	Yes	Yes	051301060202
TN0021121	Baxter STP	0.500	4952	38544	Yes	Yes	Yes	051301080905
TN0024198	City of Cookeville WWTP	14.000	4952	38501	Yes	Yes	Yes	051301080905
TN0027618	Pleasant Hill Housing Project	0.004	4952	38578	Yes		Yes	051301080905
TN0055409	Appalachian Center For Crafts	0.021	4952	37166			Yes	051301080905
TN0055531	Uplands Village	0.040	4952	38578	Yes		Yes	051301080905
TN0055981	Holiday Out R.V. Park-Lake Tansi	0.023	4952	38572	Yes		Yes	051301080905
TN0056626	Bledsoe County Correctional Complex (BCCX)	0.315	4952	37367	Yes	Yes	Yes	051301080905
TN0057908	Fall Creek Falls State Park	0.150	0	37367	Yes		Yes	051301080905

NPDES ID	Permittee	Flow Rate (MGD)	SIC	ZIP Code	Nitrogen limit	Phosphorus limit	Oxygen limit	Market Zone
TN0059480	Tennessee Department of Environment and Conservation - Edgar Evins State Park	0.002	4952	38552			Yes	051301080905
TN0060054	City of Cookeville	0.009	4952	38501	Yes		Yes	051301080905
TN0061166	Sparta STP	1.600	4952	38583	Yes		Yes	051301080905
TN0065358	Smithville STP	2.160	4952	37166	Yes		Yes	051301080905
TN0077691	Spencer STP - Caney Fork	0.250	4952	38585	Yes		Yes	051301080905
TN0021539	Town of Alexandria	0.300	4952	37012	Yes	Yes	Yes	051301080906
TN0025488	Watertown STP	0.270	4952	37184	Yes	Yes	Yes	051302010201
TN0064041	Metro Nashville Airport Authority	0.288	4581	37214	Yes		Yes	051302020102
TN0028550	Metro Water Services-J.P.Priest Lake Hamilton Creek Rec Area	0.008	4952	37217	Yes		Yes	051302030309
TN0057797	Buchanan Elementary School	0.017	4952	37127	Yes		Yes	051302030309
TN0057975	Bill Rice Ranch, Inc.	0.100	7032	37128	Yes		Yes	051302030309
TN0024970	Nashville Whites Creek STP	37.500	4952	37208	Yes		Yes	051302020303
TN0020541	Smyrna STP	5.850	4952	37167	Yes	Yes	Yes	051302030309
TN0022586	Murfreesboro-Sinking Creek STP	20.000	4952	37129	Yes	Yes	Yes	051302030309
TN0067237	Texas Eastern Transmission, LP - Gladeville	0.003	4922	37090	Yes			051302030309
TN0066958	Water Authority of Dickson County - Jones Creek	4.000	4952	37055	Yes	Yes	Yes	051302040503
TN0027278	Cartwright Creek, LLC - Grassland STP	0.250	4952	37069	Yes	Yes	Yes	051302040603
TN0028827	The City of Franklin	16.000	4952	37064	Yes	Yes	Yes	051302040603
TN0029718	Berry's Chapel Utility STP	0.400	4952	37067	Yes	Yes	Yes	051302040603

NPDES ID	Permittee	Flow Rate (MGD)	SIC	ZIP Code	Nitrogen limit	Phosphorus limit	Oxygen limit	Market Zone
TN0067164	Williamson County Schools - College Grove Elementary School	0.012	4952	37046	Yes		Yes	051302040603
TN0057835	Williamson County Schools - Page Schools	0.020	4952	37064	Yes		Yes	051302040603
TN0060216	RNM, LLC	0.030	4952	37064	Yes		Yes	051302040603
TN0064297	Williamson County Schools - Trinity Elementary School	0.013	4952	37064	Yes		Yes	051302040603
TN0064475	Williamson County Schools - Bethesda Elementary School	0.017	8211	37064	Yes		Yes	051302040603
TN0067873	Williamson County Schools - Oakview Elementary School	0.010	8211	37064	Yes	Yes	Yes	051302040603
TN0074586	Town of Pegram	0.050	4952	37143	Yes		Yes	051302040603
TN0020621	Greenbrier STP	0.740	4952	37073	Yes	Yes	Yes	051302060708
TN0002640	Tennessee Operations, Eastman Chemical Company	486.70	2869	37662	Yes		Yes	060101020704
TN0025089	Woodbury STP	0.600	4952	37190	Yes		Yes	051302030309
TN0020656	Clarksville STP	25.000	4952	37040			Yes	051302060708
TN0020095	Kingsport STP	12.400	4952	37660			Yes	060101020704
TN0023515	Elizabethton STP	3.500	4952	37643	Yes		Yes	060101020704
TN0023531	Bristol STP #2	15.000	4952	37618			Yes	060101020704
TN0023680	Cloudland School	0.012	4952	37687			Yes	060101020704
TN0023698	Hampton Elementary School	0.014	4952	37658	Yes		Yes	060101020704
TN0023701	Hampton High School	0.016	4952	37658			Yes	060101020704
TN0023736	Keenburg Elementary School	0.016	4952	37643	Yes		Yes	060101020704
TN0021296	CH2M HILL Services (Fort Campbell)	4.000	9711	42223	Yes	Yes	Yes	051302060708
TN0024961	Springfield STP	3.400	4952	37172	Yes	Yes	Yes	051302060708
TN0059404	White House STP	1.400	4952	37188	Yes	Yes	Yes	051302060708

NPDES ID	Permittee	Flow Rate (MGD)	SIC	ZIP Code	Nitrogen limit	Phosphorus limit	Oxygen limit	Market Zone
TN0001643	Domtar Paper Company, LLC	8.100	2621	37660			Yes	060101020704
TN0024236	Johnson City-Knob Creek STP	4.000	4952	37601	Yes		Yes	060101020704
TN0024244	Johnson City Brush Creek WWTP	16.000	4952	37601	Yes		Yes	060101020704
TN0024945	Mountain City STP	1.200	4952	37683	Yes		Yes	060101020704
TN0025135	Sullivan County Board of Education d/b/a East High School	0.018	4952	37618	Yes		Yes	060101020704
TN0025151	Sullivan County-West Middle & Elementary Schools	0.035	4952	37660	Yes		Yes	060101020704
TN0025178	Akard Elementary School	0.006	4952	0			Yes	060101020704
TN0028789	Johnson City Regional WWTP	6.000	4952	37615	Yes		Yes	060101020704
TN0054941	Bays Mountain Park	0.005	4952	37660	Yes		Yes	060101020704
TN0054950	City of Johnson City	0.045	4952	37692			Yes	060101020704
TN0056405	Valley Forge Elementary School	0.020	4952	37643			Yes	060101020704
TN0059641	Central Heights Elementary School	0.012	4952	37617	Yes		Yes	060101020704
TN0061531	Carter County Work Camp	0.055	4952	37683	Yes		Yes	060101020704
TN0074357	State of Tennessee d/b/a Roan Mountain State Park	0.036	4952	37687			Yes	060101020704
TN0075094	Greeneville Sewage, LLC, d/b/a Hampton Carter Commercial Center WWTP	0.012	4952	37658	Yes		Yes	060101020704
TN0001694	World Color Hawkins County	0.029	2732	37642			Yes	060101040305
TN0002330	CWCTEN, LLC (formerly Holliston, LLC)	0.316	2295	37642	Yes		Yes	060101040305

NPDES ID	Permittee	Flow Rate (MGD)	SIC	ZIP Code	Nitrogen limit	Phosphorus limit	Oxygen limit	Market Zone
TN0003671	BAE Systems Ordnance Systems Inc. (Holston) (HSAAP)	2.193	2892	37660	Yes		Yes	060101040305
TN0020672	Rogersville STP	1.300	4952	37857			Yes	060101040305
TN0021105	Rutledge STP	0.200	4952	37861	Yes		Yes	060101040305
TN0021199	Jefferson City STP	1.000	4952	37760			Yes	060101040305
TN0021253	Church Hill STP	2.500	4952	37642	Yes		Yes	060101040305
TN0023507	Morristown STP	7.500	4952	37814			Yes	060101040305
TN0054623	Cherokee Comprehensive High School	0.045	4952	37857	Yes		Yes	060101040305
TN0055590	Keplar Elementary School	0.006	4952	37857	Yes		Yes	060101040305
TN0055603	Mooresburg Elementary School	0.006	4952	37811	Yes		Yes	060101040305
TN0059846	Grainger County Industrial Park STP	0.035	4952	37861	Yes		Yes	060101040305
TN0061026	Kingswood School, Inc.	0.010	4952	37708	Yes		Yes	060101040305
TN0061476	Rush Strong School	0.020	4952	37871	Yes		Yes	060101040305
TN0062057	Mount Carmel STP	0.472	4952	37645			Yes	060101040305
TN0062162	TWRA - Buffalo Springs Fish Hatchery	3.600	921	37861	Yes		Yes	060101040305
TN0074497	Joppa Elementary School	0.008	4952	37861	Yes		Yes	060101040305
TN0064149	Luttrell STP	0.200	4952	37779	Yes	Yes	Yes	060101040306
TN0003352	CEMEX Construction Materials Atlantic, LLC	0.174	3241	37924	Yes		Yes	060101040308
TN0021822	KUB - Loves Creek STP	10.300	4952	37914	Yes		Yes	060101040308
TN0064351	Pilot Travel Centers, LLC #219	0.000	5541	37909			Yes	060101040308
TN0054861	Parrottsville Elementary School	0.023	4952	37821	Yes		Yes	060101051404

NPDES ID	Permittee	Flow Rate (MGD)	SIC	ZIP Code	Nitrogen limit	Phosphorus limit	Oxygen limit	Market Zone
TN0067318	Parrottsville STP	0.013	4952	37843	Yes		Yes	060101051404
TN0020117	Gatlinburg STP	3.000	4952	37738	Yes	Yes	Yes	060101070207
TN0021237	Pigeon Forge STP	6.000	4952	37863	Yes	Yes	Yes	060101070207
TN0003735	Sonoco Products Newport	0.149	2631	37821			Yes	060101070403
TN0020702	Newport STP	4.350	4952	37821	Yes		Yes	060101070403
TN0021245	Dandridge STP	0.900	4952	37725			Yes	060101070403
TN0054879	Cosby School	0.027	4952	37821	Yes		Yes	060101070403
TN0063959	Sevierville (McCroskey Island) STP	4.000	4952	37876	Yes		Yes	060101070403
TN0064971	White Pine STP	0.389	4952	37890			Yes	060101070403
TN0065072	TN DOT I-40 Cocke-Hartford Welcome Center	0.012	4952	37753	Yes		Yes	060101070403
TN0078131	Harbor Crest Homeowner's Association d/b/a Harbor Crest Condominium Association	0.021	4952	37725			Yes	060101070403
TN0056332	ElderReed Health & Rehab	0.005	4952	37681	Yes		Yes	060101080502
TN0024406	Davy Crockett High School	0.039	4952	37659	Yes		Yes	060101080606
TN0057983	Aerojet Ordnance Tennessee	0.004	3369	37659	Yes		Yes	060101080606
TN0021229	Denzil Bowman Wastewater Treatment Plant (Greeneville STP)	7.000	4952	37744			Yes	060101080705
TN0058254	McDonald Elementary School	0.015	4952	37743	Yes		Yes	060101080806
TN0058343	Ottway Elementary School	0.009	4952	37743	Yes		Yes	060101080806
TN0059366	Lick Creek Valley (Mosheim) Wastewater Treatment Plant	0.975	4952	37809	Yes	Yes	Yes	060101080806
TN0063932	Baileyton STP	0.200	4952	37745	Yes	Yes	Yes	060101080806
TN0081566	US Nitrogen LLC	0.573	2819	37809	Yes			060101080806
TN0020052	Sweetwater STP	1.500	4952	37874	Yes	Yes	Yes	060102010301

NPDES ID	Permittee	Flow Rate (MGD)	SIC	ZIP Code	Nitrogen limit	Phosphorus limit	Oxygen limit	Market Zone
TN0060143	SCHOTT Gemtron Corporation	0.105	3231	37874			Yes	060102010301
TN0005045	Tellico Trout Hatchery	13.200	921	37355			Yes	060102010302
TN0020079	Maryville STP	10.000	4952	37777	Yes		Yes	060102010302
TN0020494	Lenoir City STP	3.000	4952	37771			Yes	060102010302
TN0022349	USDI-NPS-Elkmont Camp Ground Great Smoky Mountains National Park	0.035	4952	37738			Yes	060102010302
TN0022594	USDI-NPS-Tremont Institute Great Smoky Mountains National Park	0.009	4952	37738			Yes	060102010302
TN0023353	First Utility District of Knox County - Turkey Creek STP	15.000	4952	0			Yes	060102010302
TN0023574	KUB - Fourth Creek STP	10.800	4952	37919			Yes	060102010302
TN0023582	KUB - Kuwahee STP	44.000	4952	37916	Yes		Yes	060102010302
TN0023906	Peninsula, a Division of Parkwest Medical Center	0.025	4952	37777			Yes	060102010302
TN0024953	Tellico Plains STP	0.410	4952	37385			Yes	060102010302
TN0025020	Madisonville STP	0.800	4952	37354	Yes		Yes	060102010302
TN0026271	Friendsville Elementary School	0.014	4952	38034	Yes		Yes	060102010302
TN0028177	Ritta School WWTP	0.010	4952	37917	Yes		Yes	060102010302
TN0054909	Hiwassee College STP	0.060	4952	37354	Yes		Yes	060102010302
TN0055514	Lost Sea Inc.	0.027	4952	37871			Yes	060102010302
TN0058181	Loudon Utilities Board (LUB)	14.000	4952	37774			Yes	060102010302
TN0058238	Tellico Area Services System - Niles Ferry WWTF	2.000	4952	37885	Yes		Yes	060102010302

NPDES ID	Permittee	Flow Rate (MGD)	SIC	ZIP Code	Nitrogen limit	Phosphorus limit	Oxygen limit	Market Zone
TN0059897	Tellico Reservoir Development Agency (TRDA)	0.750	4952	37885			Yes	060102010302
TN0060780	Duncan's Landing Homeowners Association	0.012	4952	37919			Yes	060102010302
TN0062316	Foothills Pointe Owners Association, Inc.	0.013	4952	37742	Yes		Yes	060102010302
TN0062391	Lanier Elementary School	0.017	4952	37803			Yes	060102010302
TN0064556	Pilot Travel Centers, LLC #270	0.013	5541	37939			Yes	060102010302
TN0064653	Kimberly-Clark Corporation - Loudon Mill	4.060	2621	37774			Yes	060102010302
TN0065081	Arconic Inc./Alcoa Business Park LLC (formerly Alcoa, Inc. - South Plant)	0.000	3334	37701	Yes			060102010302
TN0067199	Alcoa, Inc. - North Plant	0.644	3353	37701	Yes		Yes	060102010302
TN0026158	Rockwood Water Sewer and Gas (RWSG)	1.650	4952	37854	Yes	Yes	Yes	060102010403
TN0055662	Springdale Elementary School	0.015	4952	37879	Yes		Yes	060102050902
TN0080021	LaFollette Wastewater Treatment Facility	1.875	0	37766	Yes	Yes	Yes	060102051104
TN0024791	Claiborne Utilities District STP	0.650	4952	37824	Yes	Yes	Yes	060102060402
TN0060747	Cumberland Gap STP	0.100	4952	37724	Yes		Yes	060102060404
TN0059978	Powell Valley Elementary School	0.030	4952	37870	Yes		Yes	060102060407
TN0060020	West Knox UD - Karns Beaver Creek STP	4.000	4952	37950	Yes	Yes	Yes	060102070202
TN0078905	Hallsdale Powell Utility District STP	9.700	4952	37918	Yes	Yes	Yes	060102070202

NPDES ID	Permittee	Flow Rate (MGD)	SIC	ZIP Code	Nitrogen limit	Phosphorus limit	Oxygen limit	Market Zone
TN0002941	USDOE - ORNL	1.795	9711	37830	Yes		Yes	060102070303
TN0002968	USDOE - Oak Ridge Y-12 National Security Complex	4.450	3499	37830	Yes			060102070303
TN0020885	Oliver Springs STP	0.740	4952	37840	Yes	Yes	Yes	060102070303
TN0024155	Oak Ridge STP	30.000	4952	37831	Yes		Yes	060102070303
TN0057878	Dutch Valley Elementary School	0.009	4952	37716	Yes		Yes	060102070303
TN0025127	City of Rocky Top STP	0.950	4952	37769	Yes	Yes	Yes	060102070401
TN0026263	Caryville-Jacksboro Utilities Commission STP	0.860	4952	37714	Yes		Yes	060102070401
TN0057860	Briceville Elementary School	0.009	4952	37716			Yes	060102070401
TN0020630	Norris STP	0.200	4952	38828	Yes	Yes	Yes	060102070402
TN0074071	Anderson County Water Authority	0.010	4952	37716	Yes		Yes	060102070402
TN0024996	City of Crossville	3.500	4952	38555	Yes	Yes	Yes	060102080305
TN0055719	Cumberland Property and Investment Group, LLC d/b/a Deer Run Property Management, Inc.	0.049	4952	38571	Yes		Yes	060102080305
TN0078727	Flip Fest Properties, LLC	0.010	7032	38555	Yes	Yes	Yes	060102080305
TN0028622	Wartburg STP	0.750	4952	37887	Yes		Yes	060102080403
TN0058564	Petros - Joyner School STP	0.020	4952	37840			Yes	060102080403
TN0059765	Morgan County Economic Development Board on behalf of Brushy Mountain Group	0.150	2085	37845	Yes		Yes	060102080403
TN0002780	Chattem Chemicals, Inc.	0.576	2833	37409	Yes		Yes	060200011003
TN0024201	AUB-Oostanaula Creek STP	6.000	4952	37303	Yes	Yes	Yes	060200021102
TN0067539	Athens Utilities Board (AUB)	1.200	4952	37303	Yes	Yes	Yes	060200021102
TN0067334	Benton STP	0.400	4952	37307	Yes	Yes	Yes	060200030212

NPDES ID	Permittee	Flow Rate (MGD)	SIC	ZIP Code	Nitrogen limit	Phosphorus limit	Oxygen limit	Market Zone
TN0058939	Highland Rim School	0.015	4952	37334	Yes		Yes	060300020302
TN0020508	Decherd Water Works STP	1.000	4952	37324	Yes	Yes	Yes	060300030303
TN0021644	City of Cowan	0.400	4952	37318	Yes		Yes	060300030303
TN0025470	City of Niota	0.400	4952	37826	Yes	Yes	Yes	060200021203
TN0028886	Park Avenue Hotel Group Tennessee LLC	0.023	4952	37303	Yes		Yes	060200021203
TN0021857	Winchester STP	3.200	4952	37398	Yes		Yes	060300030303
TN0023469	Tullahoma STP	5.000	4952	37388	Yes	Yes	Yes	060300030402
TN0078697	Pelham Industrial Park RSF	0.000	0	37366	Yes		Yes	060300030407
TN0065498	Unity School	0.007	4952	37144	Yes		Yes	060300030902
TN0074331	TDOT I-65 Welcome Center - Giles County	0.018	4952	38449	Yes		Yes	060300030905
TN0076007	Elkton STP	0.008	8211	38455	Yes		Yes	060300030905
TN0061841	Cornersville STP	0.100	4952	37047	Yes		Yes	060300040201
TN0055018	Sardis Community Center	0.009	4952	38371	Yes		Yes	060400010403
TN0002232	Packaging Corporation of America, Counce Mill	27.800	2631	38326			Yes	060400010508
TN0022551	Lawrenceburg STP	4.500	4952	38464	Yes	Yes	Yes	060400010508
TN0064785	Adamsville STP	0.299	4952	38310			Yes	060400010508
TN0065501	City of Loretto	0.225	4952	38469	Yes		Yes	060400010508
TN0074870	TDEC - Pickwick Landing State Park WWTP	0.050	4952	38365			Yes	060400010508
TN0002135	Tyson Farms, Inc.	1.085	2015	37160	Yes		Yes	060400030507
TN0002143	Coey Tanning Co., Inc.	0.085	3111	37183	Yes		Yes	060400030507
TN0002275	GrafTech Advanced Graphite Materials LLC (GrafTech International Holdings Inc.)	0.665	3624	38401	Yes		Yes	060400030507
TN0002470	Tennessee Dickel Distilling Company	0.138	2085	37388	Yes			060400030507

NPDES ID	Permittee	Flow Rate (MGD)	SIC	ZIP Code	Nitrogen limit	Phosphorus limit	Oxygen limit	Market Zone
TN0003751	Arnold Engineering Development Complex	47.000	9711	0	Yes		Yes	060400030507
TN0020443	Wartrace STP	0.130	4952	37183			Yes	060400030507
TN0020591	Bell Buckle STP	0.150	4952	37020	Yes		Yes	060400030507
TN0022888	Lewisburg STP	3.024	4952	37091	Yes	Yes	Yes	060400030507
TN0024180	Shelbyville Power, Water & Sewerage System STP	6.500	4952	0	Yes		Yes	060400030507
TN0025038	Manchester STP	4.300	4952	37355	Yes	Yes	Yes	060400030507
TN0056103	Columbia STP	10.000	4952	38401	Yes	Yes	Yes	060400030507
TN0062073	Chapel Woods Homeowner's Association	0.050	4952	37034			Yes	060400030507
TN0064670	Chapel Hill STP	0.170	4952	37034			Yes	060400030507
TN0075868	Spring Hill STP	5.000	4952	37174	Yes	Yes	Yes	060400030507
TN0021741	McEwen STP	0.450	4952	37101	Yes	Yes	Yes	060400030907
TN0020800	Mount Pleasant STP	0.710	4952	38474	Yes	Yes	Yes	060400030908
TN0024937	Centerville STP	0.750	4952	37033			Yes	060400030908
TN0058190	TN DOC-Turney Center	0.200	4952	37140			Yes	060400030908
TN0067130	East Hickman Middle School	0.031	4952	37033	Yes		Yes	060400030908
TN0067415	CYTEC Industries, Inc.	0.086	2869	38474		Yes	Yes	060400030908
TN0078808	Waverly Lagoon	2.000	4952	37185			Yes	060400050403
TN0022616	Big Sandy Lagoon	0.100	4952	38221			Yes	060400050704
TN0061271	Paris STP	2.500	4952	38242	Yes		Yes	060400050704
TN0000132	ConAgra Foods Inc.	1.802	2079	38104		Yes		080101000703
TN0001066	Center Point Terminal Company, LLC	0.000	5171	38106			Yes	080101000703
TN0020711	City of Memphis - Maynard C. Stiles STP North Plant	135.000	4952	38127			Yes	080101000703
TN0058831	Drexel Chemical Co.	0.033	2879	38109	Yes			080101000703
TN0073385	Cummings Environmental	0.014	5093	38113			Yes	080101000703

NPDES ID	Permittee	Flow Rate (MGD)	SIC	ZIP Code	Nitrogen limit	Phosphorus limit	Oxygen limit	Market Zone
TN0000931	Darling Ingredients Inc.	0.290	2077	38261	Yes		Yes	080102020208
TN0021580	Union City STP (A.L. Strub WWTP)	5.000	4952	38261	Yes		Yes	080102020208
TN0064912	South Fulton STP	0.490	4952	38257			Yes	080102020208
TN0073563	Tyson Farms, Inc.	0.970	2015	38261	Yes		Yes	080102020208
TN0062111	Newbern STP	2.200	4952	38059	Yes		Yes	080102020308
TN0021717	Dresden- Printing Factory Lagoon	0.166	4952	38225	Yes	Yes	Yes	080102030404
TN0062294	Gleason STP	0.200	4952	38229			Yes	080102030404
TN0074985	Replogle Enterprises	0.010	2421	38231			Yes	080102030404
TN0062545	City of Martin Wastewater Treatment Plant	2.500	4952	38237	Yes	Yes	Yes	080102030502
TN0020613	McKenzie STP	2.000	4952	38201	Yes	Yes	Yes	080102030603
TN0000060	Milan Army Ammunition Plant (MLAAP)	0.500	9711	38358	Yes		Yes	080102040404
TN0021563	Dyer STP	0.675	4952	38330	Yes		Yes	080102040404
TN0023477	Dyersburg STP	9.450	4952	38025	Yes	Yes	Yes	080102040404
TN0024988	Alamo STP	0.400	4952	38001	Yes		Yes	080102040404
TN0056481	Jackson-Madison County School System	0.004	4952	38305	Yes		Yes	080102040404
TN0058955	Friendship STP	0.090	4952	38034	Yes		Yes	080102040404
TN0062588	Humboldt Board of Public Utilities STP	2.600	4952	38343	Yes		Yes	080102040404
TN0075876	Jackson Energy Authority - Middle Fork STP	6.000	4952	38302	Yes		Yes	080102040404
TN0078271	Trenton Light and Water	1.600	0	38382	Yes		Yes	080102040404
TN0023230	Balgirdhar Hospitality LLC, Ole South Inn	0.020	4952	38391	Yes		Yes	080102050507

NPDES ID	Permittee	Flow Rate (MGD)	SIC	ZIP Code	Nitrogen limit	Phosphorus limit	Oxygen limit	Market Zone
TN0023272	Jackson-Madison County School System - Beech Bluff Elementary School	0.005	4952	38313	Yes		Yes	080102050507
TN0023311	Jackson Energy Authority	0.013	4952	38391	Yes		Yes	080102050507
TN0024813	Jackson Energy Authority-Miller Avenue STP	17.400	4952	38305	Yes	Yes	Yes	080102050507
TN0026026	City of Henderson - East Lagoon	0.200	4952	38340			Yes	080102050507
TN0026247	Bells Lagoon	2.750	4952	38006	Yes	Yes	Yes	080102050507
TN0022519	TravelCenters of America d/b/a Denmark TravelCenter	0.009	5541	38391	Yes		Yes	080102050507
TN0041939	Teknor Apex Tennessee Company	1.370	3087	38012			Yes	080102050507
TN0055786	The Pictsweet Company	0.823	2037	38006	Yes			080102050507
TN0056472	Denmark School	0.016	4952	38391	Yes		Yes	080102050507
TN0057291	Town of Halls	1.000	4952	38040		Yes	Yes	080102050507
TN0060151	Harsh Raj Travelmart	0.011	5541	38006	Yes		Yes	080102050507
TN0064220	City of Henderson - North Lagoon	0.470	4952	38340		Yes	Yes	080102050507
TN0064238	City of Henderson - South Lagoon	0.600	4952	38340			Yes	080102050507
TN0065218	Maury City Wastewater Lagoon	0.150	4952	38050		Yes	Yes	080102050507
TN0067083	JEA - Pinson Lagoon	0.040	4952	38366			Yes	080102050507
TN0068390	Pinnacle Foods Group LLC	0.046	2038	38301	Yes			080102050507
TN0075078	Brownsville Energy Authority Lagoon	2.280	4952	38012	Yes	Yes	Yes	080102050507
TN0062154	Stanton Lagoon	0.288	4952	38069		Yes	Yes	080102080512
TN0074799	Pilot Travel Centers, LLC - Store 149	0.015	4952	38379	Yes		Yes	080102080512

NPDES ID	Permittee	Flow Rate (MGD)	SIC	ZIP Code	Nitrogen limit	Phosphorus limit	Oxygen limit	Market Zone
TN0078671	Pilot Travel Centers LLC #149	0.000	5541	38069	Yes		Yes	080102080512
TN0058084	Brighton Elementary School	0.024	4952	38011	Yes		Yes	080102080602
TN0080918	TVA - Lagoon Creek Combined Cycle Facility	1.400	4911	38012	Yes	Yes	Yes	080102080802
TN0020982	Covington STP	3.620	4952	38019			Yes	080102080804
TN0025011	Henning-Lagoon	0.280	4952	38041	Yes	Yes	Yes	080102080804
TN0001091	The Chemours Company FC, LLC	8.500	2819	38127	Yes	Yes	Yes	080102090406
TN0021067	Millington STP #2	5.800	4952	38053	Yes	Yes	Yes	080102090406
TN0021652	Somerville Lagoon	0.895	4952	38068	Yes		Yes	080102090406
TN0023795	Northwest School	0.007	4952	38049	Yes		Yes	080102090406
TN0026361	Memphis-Chapel Hill S.D. STP	0.045	4952	38127	Yes		Yes	080102090406
TN0026620	Mason STP	0.110	4952	38049	Yes		Yes	080102090406
TN0056863	Your Home, LLC	0.014	4952	38023	Yes		Yes	080102090406
TN0062138	Gallaway STP	0.165	4952	38036			Yes	080102090406
TN0062499	Munford Sewer Department Lagoon	2.000	4952	38058			Yes	080102090406
TN0065277	Viola L. Lenzi	0.003	4952	38004	Yes		Yes	080102090406
TN0066800	Bartlett STP No. 1	2.200	4952	38135	Yes	Yes	Yes	080102090406
TN0068543	City of Bartlett	0.500	4952	38002	Yes	Yes	Yes	080102090406
TN0067482	Pleasant Ridge Trailer Park	0.050	4952	38053	Yes		Yes	080102090406
TN0077836	Oakland - Mechanical WWTP	3.000	4952	38060	Yes		Yes	080102090406
TN0078255	Lakeland STP(City of Lakeland Scotts Creek Wastewater Treatment Plant)	36529.000	4952	38002	Yes		Yes	080102090406
TN0078603	Arlington STP (11150 Highway 70)	2.500	0	38002	Yes		Yes	080102090406

NPDES ID	Permittee	Flow Rate (MGD)	SIC	ZIP Code	Nitrogen limit	Phosphorus limit	Oxygen limit	Market Zone
TN0000078	Penn A Kem, LLC	1.270	2869	38108			Yes	080102100308
TN0000442	AOC L.L.C. - TN Plant	3.456	2821	38017	Yes		Yes	080102100308
TN0021164	Moscow Lagoon	0.180	4952	38057			Yes	080102100308
TN0022560	Grand Junction Oxidation Pond	0.120	4952	38039			Yes	080102100308
TN0023787	Southwest School	0.020	4952	38068	Yes		Yes	080102100308
TN0055069	Dogwood Village-Arlington	0.014	4952	38028	Yes		Yes	080102100308
TN0057461	Collierville STP-Shelton Rd	3.500	4952	37017			Yes	080102100308
TN0064092	City of Rossville STP	2.200	4952	38066			Yes	080102100308
TN0065293	Northwest TN Headstart Center	0.015	4952	38057	Yes		Yes	080102100308
TN0078841	Collierville Northwest STP	6.000	0	38017	Yes		Yes	080102100308
TN0080764	City of Piperton WWTP	3.000	4952	38017	Yes	Yes	Yes	080102100308

Source: Tennessee Department of Environmental Conservation, 2016

Appendix 2. Design Flow Rate, and Annual Pollutant (Nitrogen and Phosphorus) Load for All Point Sources within 73 Market Zones Identified by Spatial Analysis

NPDESID	FlowRate (MGD)	Pollutant Load Nitrogen (lb/yr)	Pollutant Load Phosphorus (lb/yr)
TN0020877	1.5	2309.21	473.84
TN0055026	0.3	2601.58	555.72
TN0064424	0.98	27237.31	1590.13
TN0004332	20	0	0
TN0021377	0.002	0	0
TN0021393	0.002	0	0
TN0026085	0.015	0	0
TN0058033	0.01	0	0
TN0062626	0.6	4722.49	629.99
TN0062634	1	2383.61	249.36
TN0064688	1	26739.73	7461.69
TN0021873	1.62	11021.49	4718.13
TN0021121	0.5	1016.62	212.30
TN0024198	14	19498.92	13760.20
TN0027618	0.004	0	0
TN0055409	0.020	0	0
TN0055531	0.04	0	0
TN0055981	0.022	0	0
TN0056626	0.315	2596.16	2212.23
TN0057908	0.15	581.62	0
TN0059480	0.001	0	0
TN0060054	0.009	0	0
TN0061166	1.6	682.88	0
TN0065358	2.16	7932.18	1713.21
TN0077691	0.25	63.82	0
TN0021539	0.3	3985.93	864.21
TN0025488	0.27	16306.78	1356.37

NPDESID	FlowRate (MGD)	Pollutant Load Nitrogen (lb/yr)	Pollutant Load Phosphorus (lb/yr)
TN0064041	0.288	58.33	0
TN0024970	37.5	30959101.23	13977747.69
TN0020541	5.85	29223.76	3443.81
TN0022586	20	56069.33	62875.17
TN0025089	0.6	239.29	0
TN0028550	0.008	0	0
TN0057797	0.017	0	0
TN0057975	0.1	0	0
TN0067237	0.003	0	0
TN0066958	4	9672.86	2956.15
TN0027278	0.25	4593.68	551.11
TN0028827	16	26755.53	12501.36
TN0029718	0.4	363.48	494.41
TN0057827	0.03	0	0
TN0057835	0.02	0	0
TN0060216	0.03	0	0
TN0064297	0.013	0	0
TN0064475	0.017	0	0
TN0067164	0.012	0	0
TN0067873	0.01	0	.
TN0074586	0.05	0	0
TN0020621	0.74	4001.12	2010.92
TN0020656	25	260531.4	32420.59
TN0021296	4	70059.91	2173.82
TN0024961	3.4	51547.41	16846.89
TN0059404	1.4	31975.94	18836.58
TN0001643	8.1	0	0
TN0002640	486.7	26881.46	0
TN0020095	12.4	0	0
TN0023515	3.5	7680.65	1024.13

NPDESID	FlowRate (MGD)	Pollutant Load Nitrogen (lb/yr)	Pollutant Load Phosphorus (lb/yr)
TN0023531	15	0	0
TN0023680	0.012	0	0
TN0023698	0.014	0	0
TN0023701	0.016	0	0
TN0023736	0.016	0	0
TN0024236	4	22406.61	2247.81
TN0024244	16	85699.86	3839.13
TN0024945	1.2	8136.59	1042.83
TN0025135	0.018	0	0
TN0025151	0.035	0	0
TN0025178	0.006	0	0
TN0028789	6	17527.99	4554.22
TN0054941	0.005	0	0
TN0054950	0.045	0	0
TN0056405	0.02	0	0
TN0059641	0.012	0	0
TN0061531	0.055	0	0
TN0074357	0.036	0	0
TN0075094	0.012	0	0
TN0001694	0.029	0	0
TN0002330	0.316	0	0
TN0003671	2.193	29820.70	0
TN0020672	1.3	148.48	25.40
TN0021105	0.2	0	0
TN0021199	1	32221.05	14162.85
TN0021253	2.5	18126.19	2394.09
TN0023507	7.5	176623.6	30077.81
TN0054623	0.045	0	0
TN0055590	0.006	0	0
TN0055603	0.006	0	0

NPDESID	FlowRate (MGD)	Pollutant Load Nitrogen (lb/yr)	Pollutant Load Phosphorus (lb/yr)
TN0059846	0.035	46.63	0
TN0061026	0.01	0	0
TN0061476	0.02	0	0
TN0062057	0.472	0	0
TN0062162	3.6	1.26	0
TN0074497	0.008	0	0
TN0064149	0.2	180.10	1794.56
TN0003352	0.174	0.71	0
TN0021822	10.3	55301.46	4080.29
TN0064351	0	0	0
TN0054861	0.023	0	0
TN0067318	0.013	0	0
TN0020117	3	26924.36	3368.42
TN0021237	6	30808.68	2725.53
TN0003735	0.149	0	0
TN0020702	4.35	15485.03	9324.48
TN0021245	0.9	206.97	139.77
TN0054879	0.027	0	0
TN0063959	4	5980.56	98.99
TN0064971	0.389	0	0
TN0065072	0.012	0	0
TN0078131	0.021	0	0
TN0056332	0.005	0	0
TN0024406	0.039	0	0
TN0057983	0.0043	265.90	2.45
TN0021229	7	29459.21	4097.79
TN0058254	0.015	0	0
TN0058343	0.009	0	0
TN0059366	0.975	5891.19	828.85
TN0063932	0.2	1218.41	299.94

NPDESID	FlowRate (MGD)	Pollutant Load Nitrogen (lb/yr)	Pollutant Load Phosphorus (lb/yr)
TN0081566	0.573	34.13	0
TN0020052	1.5	3377.41	4604.22
TN0060143	0.105	0	0
TN0005045	13.2	0	0
TN0020079	10	17433.34	3335.44
TN0020494	3	5572.11	3256.18
TN0022349	0.035	0	0
TN0022594	0.009	0	0
TN0023353	15	30318.18	3024.67
TN0023574	10.8	0	0
TN0023582	44	36653.68	0
TN0023906	0.025	0	0
TN0024953	0.41	0	0
TN0025020	0.8	8208.75	8425.73
TN0026271	0.014	0	0
TN0028177	0.01	0	0
TN0054909	0.06	0	0
TN0055514	0.027	0	0
TN0058181	14	142708.40	32404.41
TN0058238	2	0	.
TN0059897	0.75	0	0
TN0060780	0.012	0	0
TN0062316	0.0125	0	0
TN0062391	0.017	0	0
TN0064556	0.0131	0	0
TN0064653	4.06	0	0
TN0065081	0	6961.22	0
TN0067199	0.644	8164.24	0
TN0026158	1.65	12397.55	3428.27
TN0055662	0.015	0	0

NPDESID	FlowRate (MGD)	Pollutant Load Nitrogen (lb/yr)	Pollutant Load Phosphorus (lb/yr)
TN0080021	1.875	10880.73	3834.03
TN0024791	0.65	24630.65	3543.07
TN0060747	0.1	17.15	0
TN0059978	0.03	0	0
TN0060020	4	19213.29	8928.76
TN0078905	9.7	26124.39	38321.59
TN0002941	1.795	297.87	0
TN0002968	4.45	215.96	0
TN0020885	0.74	10366.10	133.05
TN0024155	30	36715.70	3631.38
TN0057878	0.009	0	0
TN0025127	0.95	104.92	2435.18
TN0026263	0.86	1569.73	0
TN0057860	0.009	0	0
TN0020630	0.2	2102.81	1395.81
TN0074071	0.01	0	0
TN0024996	3.5	57928.09	6998.02
TN0055719	0.049	0	0
TN0078727	0.01	3.37	577.83
TN0028622	0.75	6779.52	3966.42
TN0058564	0.02	0	0
TN0059765	0.15	1.68	.
TN0002780	0.576	803.17	0
TN0024201	6	72169.98	86946.58
TN0067539	1.2	963.73	.
TN0025470	0.4	28.48	0
TN0028886	0.023	0	0
TN0067334	0.4	19.09	.
TN0058939	0.015	0	0
TN0020508	1	146082.51	136.69

NPDESID	FlowRate (MGD)	Pollutant Load Nitrogen (lb/yr)	Pollutant Load Phosphorus (lb/yr)
TN0021644	0.4	3298.27	284.75
TN0021857	3.2	1297.71	.
TN0023469	5	47138.37	14168.12
TN0078697	0	0	0
TN0065498	0.0072	0	0
TN0074331	0.018	0	0
TN0076007	0.008	0	0
TN0061841	0.1	8966.28	1305.60
TN0055018	0.0087	0	0
TN0002232	27.8	0	0
TN0022551	4.5	3565.49	4150.86
TN0064785	0.299	0	0
TN0065501	0.225	1791.19	0
TN0074870	0.05	0	0
TN0002135	1.085	35286.66	16755.11
TN0002143	0.085	196.67	0
TN0002275	0.665	0	0
TN0002470	0.138	82.54	0
TN0003751	47	1184.56	0
TN0020443	0.13	0	0
TN0020591	0.15	123.83	0
TN0022888	3.024	0	2971.98
TN0024180	6.5	17204.63	4516.23
TN0025038	4.3	42741.32	12275.39
TN0056103	10	21344.60	4468.43
TN0062073	0.05	0	0
TN0064670	0.17	0	0
TN0075868	5	4787.02	1175.75
TN0021741	0.45	3528.16	1320.08
TN0020800	0.71	7469.25	794.15

NPDESID	FlowRate (MGD)	Pollutant Load Nitrogen (lb/yr)	Pollutant Load Phosphorus (lb/yr)
TN0024937	0.75	2566.97	520.58
TN0058190	0.2	0	0
TN0067130	0.031	0	0
TN0067415	0.086	435.63	160.08
TN0078808	2	0	0
TN0022616	0.1	0	0
TN0061271	2.5	5461.06	119.98
TN0000132	1.802	0	639.56
TN0001066	0	0	0
TN0020711	135	9826050	1381750
TN0058831	0.033	12.63	0.62
TN0073385	0.014	0	0
TN0000931	0.29	1832.22	0
TN0021580	5	15468.34	2376.69
TN0064912	0.49	0	0
TN0073563	0.97	82022.18	0
TN0062111	2.2	17308.01	3123.46
TN0021717	0.166	255.25	25.11
TN0062294	0.2	214542.7	1535.41
TN0074985	0.01	0	0
TN0062545	2.5	41812.80	11451.02
TN0020613	2	25668.63	6772.57
TN0000060	0.5	796.68	0
TN0021563	0.675	494.52	0
TN0023477	9.45	48076.17	6285.04
TN0024988	0.4	1634.73	1504.43
TN0056481	0.004	0	0
TN0058955	0.09	141.05	0
TN0062588	2.6	4591.58	1188.55
TN0075876	6	2217.19	.

NPDESID	FlowRate (MGD)	Pollutant Load Nitrogen (lb/yr)	Pollutant Load Phosphorus (lb/yr)
TN0078271	1.6	11095.10	0
TN0022519	0.009	4.50	0
TN0023230	0.02	0	0
TN0023272	0.005	0	0
TN0023311	0.0125	0	0
TN0024813	17.4	163787.02	21761.52
TN0026026	0.2	0	0
TN0026247	2.75	42979.64	9200.12
TN0041939	1.37	0	1656.66
TN0055786	0.823	548.16	0
TN0056472	0.016	0	0
TN0057291	1	2845.06	288.45
TN0060151	0.012	158.60	0
TN0064220	0.47	0	0
TN0064238	0.6	0	0
TN0065218	0.15	0	1498.79
TN0067083	0.04	0	7.32
TN0068390	0.046	0	0
TN0075078	2.28	9577.40	1348.15
TN0062154	0.288	0	56.48
TN0074799	0.015	0	0
TN0078671	0.000259	4.19	0
TN0058084	0.024	0	0
TN0080918	1.4	318.74	548.16
TN0020982	3.62	3979.21	512.82
TN0025011	0.28	665.86	52.54
TN0001091	8.5	470.36	0
TN0021067	5.8	155392.99	6347.39
TN0021652	0.895	565656.55	0
TN0023795	0.0067	0	0

NPDESID	FlowRate (MGD)	Pollutant Load Nitrogen (lb/yr)	Pollutant Load Phosphorus (lb/yr)
TN0026361	0.045	0	0
TN0026620	0.11	4066.91	2202.94
TN0056863	0.014	0	0
TN0062138	0.165	0	0
TN0062499	2	15483.64	2466.88
TN0065277	0.0025	0	0
TN0066800	2.2	6293.02	8449.54
TN0067482	0.05	0	0
TN0068543	0.5	10007.12	1227.49
TN0077836	3	3324.04	0
TN0078255	36529	974.40	3393.66
TN0078603	2.5	19773.48	903.87
TN0000078	1.27	578.76	0
TN0000442	3.456	56.79	0
TN0021164	0.18	0	0
TN0022560	0.12	314.49	42.26
TN0023787	0.02	0	0
TN0055069	0.014	0	0
TN0057461	3.5	2909.50	1949.66
TN0064092	2.2	6267.54	0
TN0065293	0.015	0	0
TN0078841	6	10992.74	712.03
TN0080764	3	0	.

Source: USEPA's Discharge Monitoring Report (DMR) Pollutant Loading Tool, 2016
Note: MGD= Million Gallons per Day

Appendix 3. Area (in acres) Under Different Land Use within 73 Aggregated Water Quality Trading Market Zones Selected by Spatial Analysis

Market Zones	Corn	Cotton	Sorghum	Soybean	Sweet corn	Winter wheat	Oat	Alfaalfa	Other hay (not alfaalfa)	Grass pasture	Other crops
051100020105	676.1	5.1	4.0	902.9	0.0	2.2	0.0	1.6	3037.7	7427.5	756.4
051100020503	234.8	1.1	0.2	290.4	0.0	0.0	0.0	0.0	509.1	1771.8	106.7
051301040501	44.3	0.0	0.0	16.9	0.0	1.6	0.0	0.2	55.6	2289.6	5.3
051301050504	1879.9	0.0	3.8	2373.2	0.0	43.4	0.0	8.5	18317.1	51898.1	169.5
051301060202	329.8	0.4	2.0	308.5	0.0	4.2	0.0	0.0	3711.3	9933.0	122.8
051301080905	9934.4	3.8	66.5	14754.1	0.0	359.4	0.2	34.9	29359.5	167189.8	1268.8
051301080906	93.9	0.0	0.0	118.1	0.0	0.7	0.0	0.0	1240.3	12029.1	83.8
051302010201	72.3	0.7	0.0	51.2	0.0	0.2	0.0	0.4	495.3	8348.9	30.5
051302020102	29.1	0.0	0.2	294.5	0.0	0.2	0.4	0.0	507.3	8696.5	13.8
051302020303	1.6	0.0	0.0	124.3	0.0	0.0	0.0	0.0	474.6	3008.3	5.8
051302030309	6751.7	1004.1	142.8	10139.9	8.2	202.2	0.2	265.5	8733.9	153917.5	2277.1
051302040503	99.6	0.0	1.1	484.4	0.0	2.0	0.0	0.2	2708.3	12461.7	50.3
051302040603	2959.0	0.0	16.0	8607.6	0.0	17.8	6.0	19.3	10983.9	72805.6	914.9
051302050307	757.7	0.0	0.0	593.3	0.0	1.3	0.0	0.0	1549.0	2370.1	367.0
051302060708	48756.3	1.1	41.1	31755.1	0.0	398.1	4.9	117.6	42138.7	77965.0	43081.4
060101020704	2599.8	0.0	0.0	434.6	0.0	46.9	0.4	90.1	13579.4	134119.9	344.9
060101040305	4021.3	0.0	1.6	4264.0	6.4	159.7	2.9	64.9	8788.6	157554.5	765.3
060101040306	28.0	0.0	0.0	75.4	0.9	0.0	0.0	4.0	958.3	14658.0	3.8
060101040308	26.2	0.0	0.0	56.0	0.2	0.0	0.4	0.0	221.3	3564.3	0.4
060101051404	426.3	0.0	0.0	707.7	0.0	4.0	0.0	0.0	248.2	9456.2	14.0
060101070207	35.1	0.0	0.0	63.4	0.0	0.2	0.0	0.2	101.6	4704.3	1.8
060101070403	1220.7	0.0	0.4	1818.1	0.0	63.2	1.3	3.8	2956.5	56229.4	293.6
060101080502	1842.1	0.0	0.0	427.0	0.0	18.0	0.0	5.1	4766.8	29415.9	20.7
060101080606	443.9	0.0	0.0	70.1	0.0	0.9	0.0	9.8	1114.0	11777.4	2.7
060101080705	149.2	0.0	0.4	79.4	0.0	2.2	0.0	0.2	963.4	15012.3	2.0

Market Zones	Corn	Cotton	Sorghum	Soybean	Sweet corn	Winter wheat	Oat	Alfaalfa	Other hay (not alfaalfa)	Grass pasture	Other crops
060101080806	3716.9	0.0	1.3	937.8	0.0	34.2	0.9	1.1	8232.8	77446.6	207.7
060102010301	2087.4	0.0	62.0	1971.3	0.0	60.0	0.0	3.3	4312.5	13648.8	511.3
060102010302	4818.9	0.0	24.0	11853.9	117.0	209.1	2.9	25.1	20298.6	128862.9	1695.8
060102010403	2.7	0.0	0.0	6.9	0.0	0.0	0.0	0.2	286.2	2411.0	8.2
060102050902	6.9	0.0	0.0	5.3	0.0	0.0	0.0	0.4	110.3	4224.8	1.3
060102051104	3.3	0.0	0.0	2.9	0.0	0.2	0.0	0.0	172.8	5285.4	0.2
060102060402	38.9	0.0	0.0	137.0	0.4	0.2	0.2	0.7	308.7	12612.2	1.6
060102060404	236.4	0.0	0.0	63.8	0.2	0.7	0.7	14.5	365.4	11200.7	101.2
060102060407	269.3	0.0	0.0	234.4	0.2	2.4	0.0	28.2	815.3	14103.6	5.1
060102070202	28.2	0.0	0.0	59.6	1.6	1.8	0.0	0.0	675.6	11587.2	4.4
060102070303	24.5	0.0	2.0	26.9	0.4	1.1	0.2	1.6	336.7	7540.7	12.5
060102070401	3.3	0.0	0.0	12.9	1.1	0.0	0.0	0.7	327.1	4148.3	2.0
060102070402	20.0	0.0	0.0	52.5	0.7	0.0	0.0	0.0	1031.5	10409.2	6.2
060102080305	301.3	0.4	0.7	182.8	0.0	22.2	0.0	7.8	485.7	19471.6	67.4
060102080403	12.7	0.0	0.0	20.5	0.0	0.0	0.0	0.0	85.4	4815.1	3.3
060200010905	51.8	0.0	12.5	123.4	0.0	0.2	0.0	0.4	643.8	2405.9	10.5
060200011003	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	13.6	40.5	0.0
060200021102	734.1	0.0	0.2	1316.6	0.0	81.4	0.0	17.6	2614.5	9926.8	285.8
060200021203	532.9	0.0	1.1	703.4	0.0	1.8	0.0	0.7	2919.4	12023.3	296.9
060200030212	607.1	0.0	0.0	715.9	0.0	0.7	0.0	0.9	439.2	5031.0	245.1
060300020302	1093.1	578.4	1.8	2682.5	0.0	1.3	0.0	5.8	669.6	6399.4	1981.5
060300030303	3110.6	1490.9	2.7	3812.1	0.0	0.0	0.0	2.2	1233.4	8648.0	962.7
060300030402	1793.4	3.8	1.1	994.3	0.0	9.8	0.0	7.6	412.8	4921.8	1873.7
060300030407	15874.3	488.8	2.9	17547.6	0.2	85.4	10.2	6.4	5400.2	29488.2	5669.5
060300030902	466.6	5.1	5.3	444.3	0.0	18.2	1.6	0.4	2421.0	8070.9	95.0
060300030905	2216.8	5.3	2.0	1031.7	0.0	7.6	0.0	8.7	3601.7	9659.9	728.3
060300040201	504.8	0.0	0.0	189.9	0.0	13.3	0.7	2.7	4319.6	7333.5	190.1
060400010403	3570.3	359.4	4.0	15269.6	0.0	2.9	0.0	0.0	107.0	10446.3	57.6

Market Zones	Corn	Cotton	Sorghum	Soybean	Sweet corn	Winter wheat	Oat	Alfaalfa	Other hay (not alfaalfa)	Grass pasture	Other crops
060400010508	23039.4	2928.3	623.6	41619.4	147.4	169.9	0.2	0.4	12649.8	88381.5	6655.2
060400030507	20975.2	34.0	127.9	38265.9	0.7	568.0	97.4	327.8	59726.4	288746.1	10638.3
060400030907	43.4	0.0	0.4	479.3	0.0	0.0	0.0	0.0	712.1	2212.6	4.0
060400030908	9131.8	0.7	74.3	11272.3	0.0	23.4	3.3	10.9	20217.0	95163.2	2177.0
060400050403	73.2	0.0	0.0	178.8	0.0	0.0	0.0	0.0	646.5	3093.7	10.7
060400050704	6009.6	20.9	0.9	9931.9	0.0	32.7	0.0	3.8	934.5	13500.9	2225.1
080101000703	440.1	10.2	7.3	5795.4	0.0	28.9	0.0	0.0	2533.3	3138.9	243.3
080102020208	16132.1	6.9	17.8	21728.4	0.0	1.1	0.0	18.0	421.2	2392.7	2201.0
080102020308	8209.9	651.4	0.0	14234.2	0.0	2.4	0.0	2.4	343.6	696.8	4991.2
080102030404	20347.6	79.6	5.6	16610.0	0.0	44.7	0.0	33.6	1966.4	7793.6	6004.4
080102030502	7746.5	2.4	21.6	6646.3	0.0	13.1	0.0	1.8	431.9	1849.2	1867.9
080102030603	3819.4	1858.6	4.4	3083.5	0.0	8.7	0.0	0.4	743.5	3115.8	1089.5
080102040404	77294.4	41520	8.7	139168	0.0	674.5	0.0	33.1	7570.5	41955.9	61429.7
080102050507	56205.2	46244	15.6	135156	0.0	592.9	0.0	26.2	8872.0	49803.1	31377.2
080102080512	7138.0	7050.1	99.9	24040.7	0.0	38.0	0.0	0.4	6076.0	2484.4	3352.8
080102080602	6231.1	329.8	29.4	16948.7	0.0	5.8	0.0	0.0	1286.8	3167.1	947.4
080102080802	13295.0	9206.0	0.4	28120.9	0.0	36.3	0.0	0.0	1411.3	915.4	5244.5
080102080804	7014.6	1488.0	0.0	11354.4	0.0	8.5	0.0	0.0	1037.9	1282.6	1217.2
080102090406	32887.5	21725	8.0	101275	0.0	122.8	0.0	0.2	29534.5	28102.7	11591.9
080102100308	7766.92	4087.2	84.29	27674.2	0	201.045	0	0	26532.82	21798.25	1743.35

Source: National Agricultural Statistics Service (NASS) cropland data layer 2016

VITA

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