Analyzing Cost Implications of Water Quality Trading Provisions: Lessons from the Virginia Nutrient Credit Exchange Act

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(ABSTRACT)

The purpose of this study was to analyze the cost implications of various provisions of the Virginia Nutrient Credit Exchange Act. The first objective was to estimate the cost implications of point source trading provisions of the Act. An integer programming cost minimization model was constructed to estimate the cost of achieving four point source trading policy scenarios. The model estimated the annual cost of meeting two different nutrient cap levels, each with and without a limits-of-technology concentration standard requirement for new and expanding point sources. The limits-of-technology concentration standard requirement was found to significantly affect cost while providing little apparent benefit to water quality. The second objective was to develop a screening procedure for municipalities to estimate the cost of generating waste load allocation from nonpoint source offsets under their jurisdictional control. A spreadsheet based cost screening procedure was developed for municipalities to estimate the cost of implementing of nitrogen offsets from stormwater practices, septic retirement, and land conversion. One of the important findings from developing the screening procedure is that the cost of generating WLA from non-point sources under the control of local governments was much higher than the cost of removing nitrogen at wastewater treatment plants.

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Chapter 1: The Virginia Nutrient Trading Program and Study Objectives

Economics has an important role to play in informing public policy. The role of the economist is two-fold: to help society understand the tradeoffs between policy alternatives and to guide society in finding and implementing social and institutional arrangements that better provide for society's economic wants. The goal of this research was to fulfill these duties with regard to Virginia's nutrient trading program. More specifically, the goals were to determine the cost implications of different point source nutrient cap levels and trading provisions of the point source nutrient control program and to estimate the cost of implementing urban non-point source offsets under the control of local government. In order to do a more detailed analysis of the program, this research focused on nitrogen loads in the Shenandoah-Potomac watershed. The Shenandoah-Potomac is generally reflective of other watersheds in the Chesapeake Bay basin in that the majority of nutrient loads come from non-point sources[1].

1.1. The Chesapeake 2000 Agreement

On June 28, 2000, Virginia, Maryland, Pennsylvania, the District of Columbia and the United States Environmental Protection Agency signed the Chesapeake 2000 agreement. This agreement recognizes that the water quality in the Chesapeake Bay has become significantly degraded over the last fifty years. Excessive nutrient (nitrogen and phosphorus) discharges into the Bay have been identified as the primary cause of summer

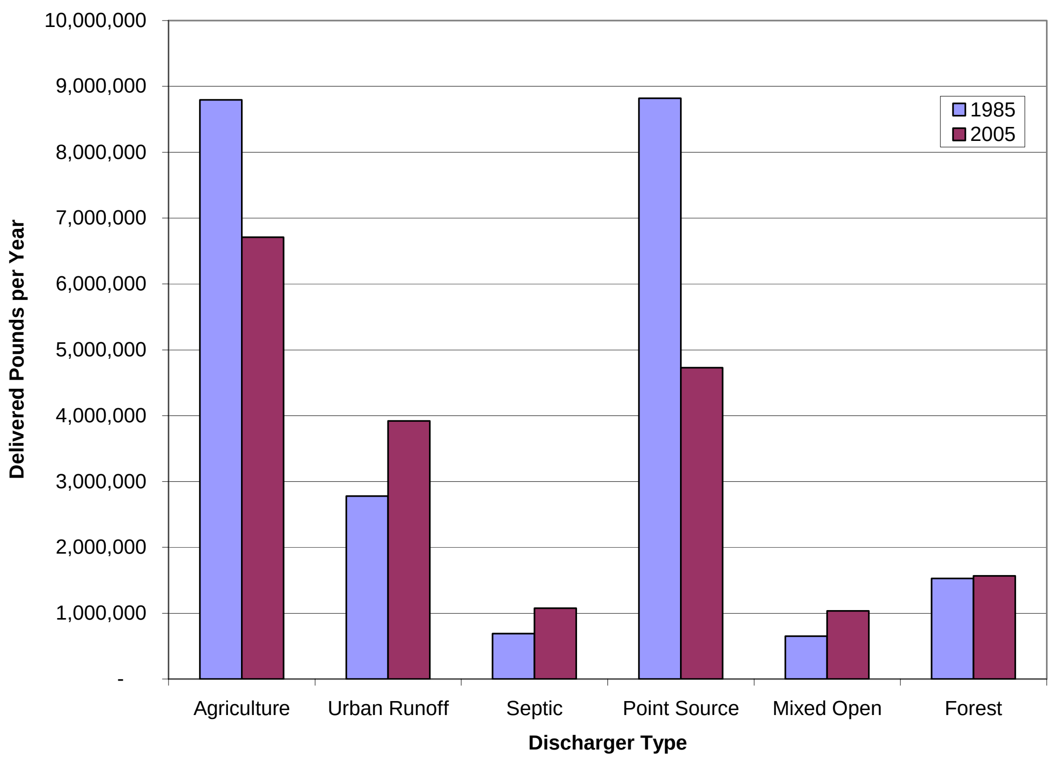
[1] In conducting this research it was helpful to utilize several figures that were created by others. Specifically, Figure 3-1, 3-2, 3-3 and 3-4 are reproductions from documents issued by, or for, government agencies. It is the researcher's belief that their use here is allowable under the fair-use clause of copyright law.

hypoxic zones, which have caused declines in aquatic vegetation and many fin and shellfish populations (Chesapeake 2000). In an effort to restore the Bay's health, the Chesapeake 2000 agreement set a 40% nutrient reduction goal from 1985 levels by the year 2010 (Chesapeake Bay Program, 2000).

Since nutrients are not explicitly classified as a pollutant under the Clean Water Act, the Bay states historically have relied on state programs to achieve Bay program goals. These programs can be generally classified as educational campaigns targeted at specific groups, voluntary cost-share programs for non-point source best management practices, and capital cost-share programs for biological nutrient removal (BNR) controls at wastewater treatment plants.

Since the early 1980s, these voluntary nutrient control programs produced modest gains toward achieving the overall nutrient reduction goals. For example, by 2004 the total nitrogen loads entering the Bay watershed from the Virginia portion of the Shenandoah-Potomac watershed had fallen by an estimated 20 % from 1985 levels .

The total nutrient load discharged to the Bay varies across sources. In the Virginia portion of the Shenandoah-Potomac Basin, for example, the majority (about 60%) of the land-based nitrogen loads come from non-point sources such as agriculture, urban runoff, and septic tanks. Figure 1 shows the change in nitrogen discharges between 1985 and 2005 for different types of sources (Chesapeake Bay Program, 2007). Point sources, primarily wastewater treatment plants, contribute about a fourth of all the nitrogen entering the Bay from the Shenandoah-Potomac Basin in 2005. The Shenandoah-Potomac is generally reflective of other watersheds in the Chesapeake Bay watershed in that the majority of nutrient loads are contributed by non-point sources. In the Shenandoah-Potomac basin, the point sources are the only category of sources to have achieved a 40% reduction in overall nitrogen loads from 1985 baseline.



Source: (Chesapeake Bay Program, 2007)

Figure 1-1. Nitrogen Loads in the Shenandoah-Potomac by Discharger Type

In an effort to fulfill its nutrient reduction responsibilities in a cost-effective manner, the Virginia General Assembly passed *The Chesapeake Bay Watershed Nutrient Credit Exchange Program Act* in 2005 (Virginia code §62.1-44.19:12-19). The legislation establishes mandatory nutrient control obligations for Virginia point sources discharging in the Chesapeake Bay watershed. The Virginia Nutrient Credit Exchange Program is significant in that it is one of the first efforts to impose statutory requirements limiting nutrients and one of the first large-scale water quality programs to use nutrient trading to achieve those requirements.

1.2. Provisions of the Virginia Nutrient Credit Exchange Act

The program begins by granting existing point sources (over a minimum size) an individual nitrogen and phosphorus wasteload allocation (WLA). The allocation is expressed in an annual mass load of nitrogen and phosphorus that can be released by the source. The legislation directs Virginia's Department of Environmental Quality (DEQ) to administer the program and set individual WLAs. DEQ sets individual WLAs based on agency-identified concentration standards multiplied by the point source's permitted design flow. For tributaries that discharge into the upper Bay, such as the Shenandoah-Potomac basin, DEQ used total nitrogen concentrations in the 3 to 5 mg/L range, while WLA established in tributaries that discharge into the lower Bay (James, Rappahannock and York) are based on effluent concentrations in the 5 to 12 mg/L range (9-VAC-25-720-60-c, 2007). DEQ's rationale for using higher concentration to establish the WLAs in the southern tributaries is that these tributaries have a much smaller impact on Bay hypoxic areas than do tributaries that empty into the upper Bay. The sum of individual point source WLAs represents the point source nutrient cap in the specific Bay tributary. While the concentration standards vary between tributaries, all are a dramatic reduction from the current discharge level. For the point sources within the Shenandoah-Potomac River Basin, the cap represents a 57% reduction from the 1985 baseline.

Point sources have some flexibility in how to comply with these new requirements. Existing point sources follow a sequencing procedure in achieving compliance with the statute. First, each point source is required to develop a compliance plan stating how they will keep its discharges below its WLA. Second, if a point source discharges more nutrients than its WLA, that point source can become compliant by purchasing nutrient credits, of equal quantity to their exceedance, from existing point sources. A point source credit is defined as the difference between a point source's WLA and total annual discharge. Unused credits expire at the end of the year. A point source association was authorized by the legislation to facilitate the transfer of point source credits among participating point source dischargers. While exchange of credits is allowed, existing point sources are not allowed to exchange the WLA itself. Third, if there are insufficient point source credits to cover all noncompliant sources, the noncompliant point source must pay a fee into a state directed fund (Virginia Water Quality Improvement Fund) to purchase non-point source credits. Non-point source credits can only be used when point source credits have been exhausted (§62.1-44.19.18A). A non-point source credit is a credit given to a point source for funding best management practices (BMPs) that reduce non-point source nutrient loadings. Possible examples include implementing agricultural or stormwater BMPs, connecting homes using septic systems to the city sewer and converting land to less intensive nutrient uses. An example of a conversion to a less intensive use is the conversion of cropland to forest.

A similar set of conditions exist for new and expanding point sources (§62.1-44.19.15). New and expanding sources are defined as dischargers that expand their facilities to increase their discharges by more than 100,000 gallons per day (MGD) into tidal waters or more than 500,000 per day into non-tidal waters (§ 62.1-44.19:15.A.1). New and expanding sources are not granted any new WLA by the state of Virginia, but must acquire WLA to cover new nutrient loads by purchasing WLA from an existing point source, sponsoring long-term nutrient reductions from a non-point, source or a combination of the two (§ 62.1-44.19:15.B.1). Long-term non-point source reductions, called "offsets," are then recorded in the discharger's individual Virginia Pollutant Discharge Elimination System (VPDES) permit and the point source becomes legally responsible for the continuation of the BMP (ibid). To be counted as an point source offset, nonpoint source reductions must be beyond any reductions required by or funded by law or existing policy (§ 62.1-44.19:15.C). The regulations authorized by the legislation also stipulate that non-point source offsets must be purchased at a 2:1 trading ratio (2 pounds of nutrient reduction achieved for every 1 pound of WLA granted) (9 VAC 25-820-70 Part 2.B.1.b).

The legislation also specifies that new and expanding sources must install state-of-the-art nutrient removal technology at the time of expansion (§ 62.1-44.19:15.A.1). State-of-the-art is defined as a technology that can achieve an average annual concentration standard of 3 mg/L for nitrogen and 0.3 mg/L for phosphorous. This requirement must be met by all new and expanding sources, and applies concurrently to the WLA obligation.

1.3. Potential Cost Implications of Point Source Trading Provisions

There are several provisions of the Virginia Program that have substantial implications on the cost of achieving the point source nutrient cap. The first provision is the level at which the point source cap is set. Each category of dischargers (point sources, agricultural firms, urban runoff) faces some degree of diminishing marginal returns in reducing their nutrient dischargers. If one set of sources was required to reduce their discharges far in excess of the others, the marginal-cost of nutrient removal between sources could differ substantially, violating the conditions necessary for static-cost minimization. The law assigns the point sources a disproportionate responsibility for achieving nutrient load reductions in the Shenandoah-Potomac tributary (57% reduction compared to overall 40% reduction goal). The incremental cost of achieving these near limits of control caps could be relatively high compared to the cost of other sources.

The second provision is the requirement for new and expanding sources to meet a limits-of-control technology concentration standard. The concentration standard provision reduces the discretion that new and expanding sources have to maintain compliance and limits cost-saving trades. For example, the new source concentration standard prevents a new or expanding point source from securing point source WLA or non-point offsets for loads above the concentration standard even if a purchase of WLA or non-point offset is more cost-effective than installing the limit-of-control technology. . Empirically estimating the costs of policy scenarios with various cap levels and concentration standard requirements is the first objective of this research.

1.4. Addressing New Point Source Growth with NPS Offsets

Obtaining WLA will likely be a challenge for most new and expanding sources. Population and economic growth rates in Virginia's golden triangle (District of Columbia to Richmond to Hampton Roads) are well above the national average. For instance, from 1990 to 2000 the population of the Northern Virginia Metropolitan Statistical Area grew 25.2%, nearly twice the national average of 13.2% for the same period (George Mason University Center for Regional Analysis). This growth will require a sustained expansion in municipal wastewater treatment facilities in the coming years to accommodate increased flows. Growth expectations, coupled with the stringent way in which WLAs were granted to existing sources will limit the willingness and ability for existing point source to sell WLA to a new or expanding source New and expanding point sources will likely need to turn to non-point sources to generate WLA.

Obtaining non-point source offsets presents another set of challenges. One is that the statute states that non-point source BMPs that reduce nutrient loads must be included “as conditions of the facility’s individual Virginia Pollutant Discharge Elimination System permit” (§62.1-44.19:15.B.1.b). A concern among point sources is that there is no transfer of responsibility when a point source funds a non-point offset. If a non-point source offset provider fails to produce the agreed upon offset, the point source would be in violation of its VPDES permit and subject to civil and criminal penalties pursuant to the Clean Water Act. A violation of the permit for any reason leads to civil and criminal penalties not to exceed $25,000 per day. In addition, reopening and amending an individual point source’s VPDES permit is not a trivial matter and requires a great deal of time, energy and legal fees. Additionally, there is evidence that firms with permit violations can face substantially longer permit renewal times than those without violations .

Leery of tying permit compliance to the performance of distinct and separate legal entities, point sources are interested in implementing NPS offsets under their jurisdictional control. It is important to point out that many of the point sources that need NPS offsets are municipal wastewater treatment facilities, facilities owned and operated by local government. Local governments often have a collection of non-point sources under their jurisdictional control that have the potential to generate nutrient reductions to offset increased wastewater treatment loads. Examples of possible controls include stormwater management practices, septic tank regulations, zoning laws to direct land use around sensitive urban riparian lands, land conversion to less nutrient intensive uses, and BMP implementation directly on government owned land. The second objective of this thesis is to estimate the cost of nutrient offset opportunities from a variety of non-point sources under the control of local government.

1.5. Objectives

The overarching objective of this research was to inform policy makers regarding the cost implications of different design elements of Virginia's nutrient credit exchange program. The specific objectives of this research were the following:

1. To estimate the cost of achieving a point source cap in the Virginia portion of the Shenandoah-Potomac basin under different point source nitrogen cap levels, with and without the state-of-the-art concentration standard requirement. The cost of four policy scenarios will be estimated:
    a. Achieving a 57% reduction from the 1985 baseline and achieving a 3 mg/L nitrogen concentration standard for new and expanding facilities.
    b. Achieving a 40% reduction from the 1985 baseline and achieving a 3 mg/L nitrogen concentration standard for new and expanding facilities.
    c. Achieving a 57% reduction from the 1985 baseline with no concentration standard requirement.
    d. Achieving a 40% reduction from the 1985 baseline with no concentration standard requirement.

2. To develop a cost screening procedure to allow local governments to estimate the cost of nutrient removal from non-point source offsets under their control.

1.6. Procedure

For the first objective, an integer programming cost minimization model was constructed. The goal of the model was to determine the least-cost set of point source upgrades to meet a nitrogen cap in 2010 in the Shenandoah-Potomac river basin. The model simulated distribution of nutrient discharge among point sources assuming all cost effective point source nutrient credit trades would occur. By varying the nitrogen cap in the model and performance standard constraint on new and expanding sources, the model produces estimates of the total annual cost to meet the point source cap in 2010 under different policy scenarios. The discussion of the cost estimation model and results are presented in Chapter 2.

The non-point source screening model is presented in Chapter 3. A literature synthesis regarding the cost of implementing non-point source offsets under the control of local government was conducted. Both published research and expert opinion was used to identify the implementation costs and nutrient removal effectiveness of different nutrient offset options. These values were then used to construct a spreadsheet-based cost screening procedure to allow a user to quickly estimate the per pound cost of nutrient removal of the various practices.

Chapter 2: Cost Analysis of Virginia's Point Source Cap and Trade Program Design

The role of the economist is to help policy makers understand the ramification of potential policies and, when goals or values are in conflict, to elucidate the tradeoffs between them. As such, the goal of this chapter is to investigate the cost ramifications of several provisions of Virginia's nutrient trading program. The two elements of the program with important cost implications are the size of the point source cap for the Shenandoah-Potomac River Basin and the requirement for new and expanding point sources to meet a 3 mg/L total nitrogen concentration standard.

The annual cost of meeting four policy scenarios in 2010 was calculated: the cost of achieving two different cap levels (the existing point source cap in the Shenandoah-Potomac and a cap based on a 40 percent reduction) with and without the new source performance standard. The difference in the costs between policy scenarios was interpreted as the cost of different cap and concentration standard provisions in the program.

This chapter begins by identifying the key design elements of cap and trade programs. Next, the origin and rationale for different cap levels are described and the four policy scenarios identified. Third, the empirical model used to calculate the total cost of each four policy scenario is presented. Fourth, the results are given and implications discussed.

2.1. Key Design Elements of a Cap-and-Trade program

Cap-and-trade programs begin with the definition of a limited number of discharge rights. Discharge rights (called WLA in the Virginia program) are usually defined as the authorization to release a specific physical quantity of effluent (such as pounds or tons) within a specific time period. Discharge sources are then required to hold enough rights to cover their discharges in order to legally discharge. For example, a discharger wishing to discharge 100 lbs of a pollutant must hold at least 100 lbs worth of discharge rights. The sum of these rights defines a mass load cap that establishes the total amount of effluent that can be legally discharged to a water body. The government is ultimately responsible for creating and initially distributing these rights. Thus, it is the responsibility of government to choose a cap level consistent with society's desired water quality goal.

When establishing a cap and trade program, policy makers must first determine the quantity of discharges (mass load) that can enter the receiving water body and still achieve the water quality goal. Next, program designers select which sources are subject to the cap. Conceptually, if every discharger is required to hold rights in order to discharge, a full cap is established. In this case, the cap equals the mass load identified in the first step. In most cases, however, not all discharging sources are required to hold rights as a condition to discharge. The decision to leave some sources outside a cap could be due to a number of reasons including high monitoring costs or a political unwillingness to regulate a particular group of sources. A situation in which some, but not all, sources are required to hold discharge rights is referred to as a partial cap.

Policy makers must decide the stringency of the partial cap. Regulators may establish the level of partial caps based on a number of different methods. One method begins with a water quality goal and then identifies the total effluent load that can be discharged and still achieve the goal. Next, classes of dischargers are then assigned a proportional share of the load. For example, the 40% reduction goal from the 1985 baseline for the Chesapeake Bay could be translated into a cap based on a 40% reduction for all sources subject to the cap. Another method is to set the partial cap stringently enough to achieve the water quality goal without participation of sources outside the cap. A third approach is for policy makers to identify technology-based effluent limits on all individual sources subject to the cap and then sum individual effluent loads to establish the partial cap.

Examples of water quality trading programs with point source caps include Tar-Pamlico Basin in North Carolina and the Virginia nutrient trading program. The Tar-Pamlico Sound in North Carolina was suffering from hypoxia due to an excess of nitrogen, primarily from agricultural sources. Regulators estimated that a 30% reduction in all anthropogenic nutrient loads (point and non-point) was needed to achieve water quality objectives in the Tar-Pamlico Sound. State regulators set the point source nutrient cap based on a 30% reduction in mass nutrient loads from baseline levels (Woodward and Kaiser, 2002). In contrast, the Virginia program established an aggregate point source cap based on a technology-based concentration standard multiplied by each discharger's permitted design flow.

After policy makers have chosen the cap level they must decide how to distribute the rights to dischargers subject to the cap. Economists often recommend auctions to distribute initial rights (Stavins, 2001). Dischargers often object to paying for these rights because historically they have been granted for free. The result has been that almost all trading programs assign rights administratively without charge. A common basis for the administrative distribution is historical discharges. For example, if a discharger accounted for 5% of historical discharges, they would be assigned 5% of the discharge rights under the cap. Using this approach is problematic because it rewards dischargers that have not invested in technologies to lower their discharges by giving them more WLA than dischargers that have invested in such technologies. An alternative approach is to base initial WLA allocation on regulator identified performance standards, which is the case for the Virginia Program.

After the cap is set, policy makers must establish rules that govern how dischargers may use and trade discharge rights. Ideally, the system should be performance-based, and allow all dischargers discretion to determine how to control discharges and how much to discharge (Shabman and Stephenson). Discretion to decide how to control discharges means the ability to choose whatever method or technology to control dischargers that the discharger deems best. Discretion to decide how much to discharge refers to the flexibility to maintain compliance by reducing discharges, purchasing additional discharge rights or a combination of the two.

While discretion is a critical element in cap and trade programs, it is not unlimited. A challenge with all environmental trading programs is the potential for hot spots, localities with high levels of pollution, to develop. This could occur, for instance, if a set of dischargers in a small area chooses to maintain compliance solely by purchasing discharge rights, resulting in a detrimental level of localized pollution. To prevent this from happening, certain restrictions on discretion are necessary. For instance, Virginia's nutrient trading program only allows point sources to trade within tributaries (§ 62.1-44.19:18.1.A). A point source on the Potomac River can purchase credits from another point source discharger in the tributary, but not from other tributaries like the James River. Also, point sources in impaired river segments are still subject to total maximum daily load and other forms of regulation to prevent increases in load to the impaired segment of the watershed (Virginia statute § 62.1-44.19:14.B).

An important element of the discretion to trade involves designing a system of trading rules with low costs of transferring discharge rights. A trade involves a number of steps. First, dischargers must incur search costs to find trading opportunities. Second, dischargers incur negotiation and contracting costs. Third, regulators must approve and document the trade. Lastly, an enforcement system needs to be established, including monitoring and penalties for non-compliance (Dahlman). High transaction costs effectively reduce the ability and incentive for participating dischargers to engage in trade.

Critical to granting dischargers discretion to choose pollution control strategies and technologies is devising a method for monitoring and measuring effluent discharges. Cap and trade programs focus attention on measuring outcomes – the total discharge of effluent. With an effective effluent monitoring system regulators can allow dischargers the discretion to use the particular technologies, inputs, or pollution control strategies best suited for their site and industry while still ensuring environmental quality. This change in emphasis from the method of pollution control, best typified in technology-based performance standards, to outcomes is an advantage of cap-and-trade regulation.

2.1.1. The mechanics and benefits of trade. Cost-savings associated with cap and trade programs often motivate their use. The benefits of a well-designed and implemented cap and trade program are two fold: first, cap and trade programs assure that the environmental goal is achieved and maintained in the face of economic and population growth and, second, they provide incentives to market participants to create and discover new, lower cost ways of achieving the cap. In economics, the least-cost way of achieving a goal is said to be an efficient outcome. Economists also make the distinction between outcomes that are statically and dynamically efficient.

An outcome is said to be statically efficient if there is no less expensive way of achieving the same result given known or existing pollution control options. In a cap-and-trade program this means there is no other way to allocate the fixed number of discharge rights among dischargers that lowers costs. In terms of a cap and trade program, costs are minimized if all the marginal control costs across all dischargers are equal (Tietenberg). In practice, this is brought about because dischargers have an incentive to trade discharge rights until all potential gains have been captured. A hypothetical example is given below in Figures 2-1 and 2-2.

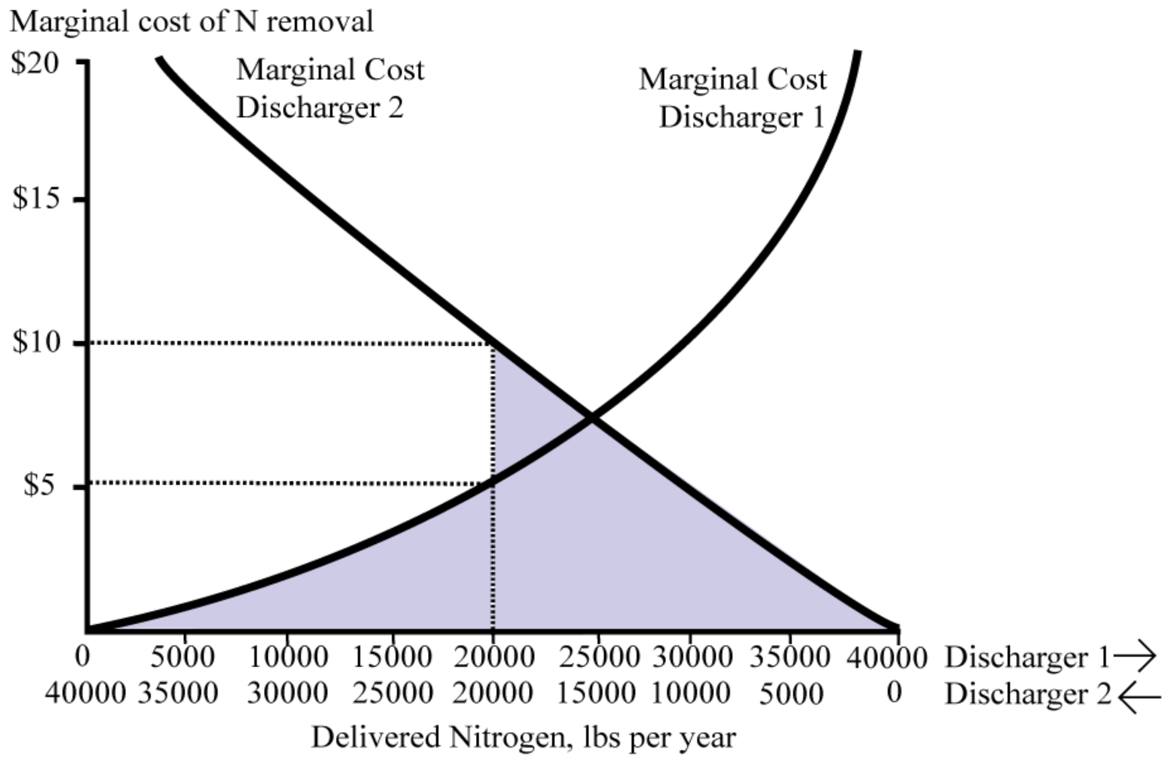


Figure 2-1. Hypothetical Marginal Costs with a Uniform Standard

Suppose there are two dischargers with combined nitrogen discharges of 80,000 lbs. Assume each discharger is releasing 40,000 lbs. Next, suppose that an aggregate cap of 40,000 lbs is established in order to meet water quality objectives. One way to achieve the necessary reduction would be through a uniform load standard. Under a uniform load standard, each discharger would be required to halve their discharges (20,000 lbs each). The marginal control costs of achieving the load standard are shown in Figure 2-1. Each discharger faces increasing costs for additional units of nitrogen reductions. Discharger two faces higher control costs and is incurring a cost of $10 to remove the last pound of nitrogen while discharger one is spending only $5. The total cost of achieving the nutrient goal for both dischargers is equal to the shaded area under marginal cost curves.

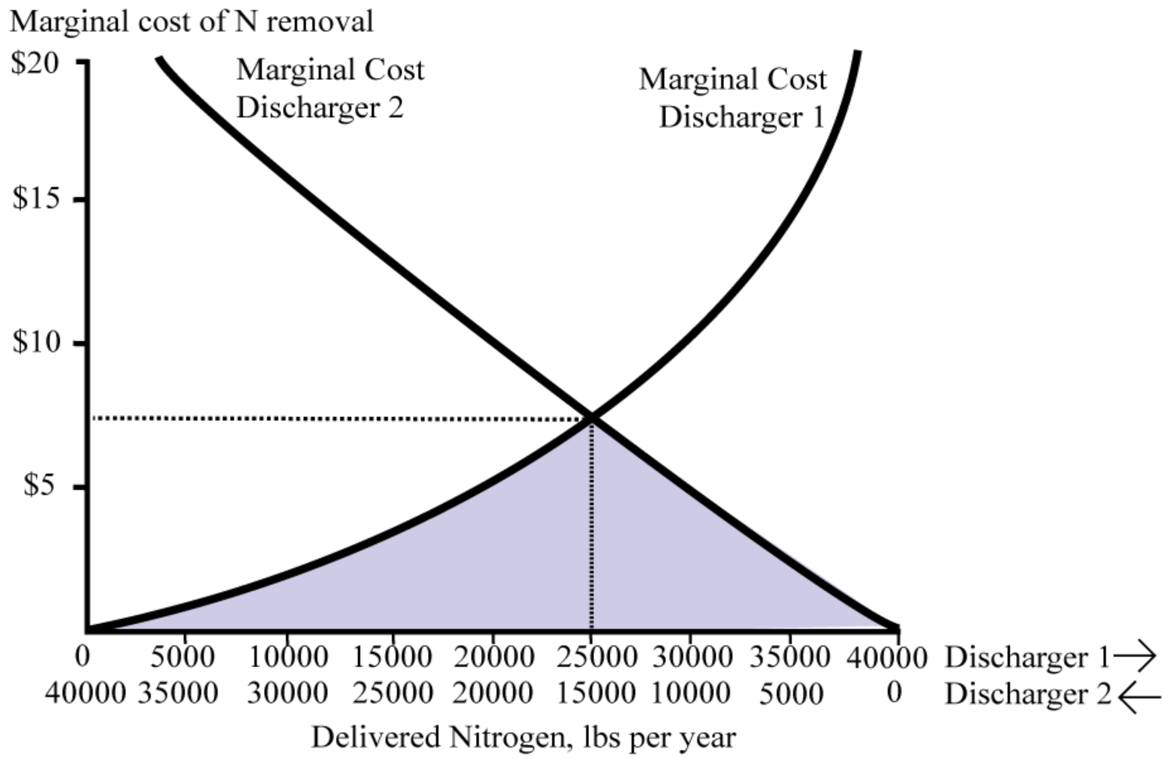


Figure 2-2. Hypothetical Marginal Costs with a Cap-and-Trade Program

If a cap and trade program were implemented instead of a uniform standard, discharger two would find it advantageous to purchase discharge rights from discharger one. Discharger two would be better off purchasing discharge rights for anything less than $10 a pound and discharger one would benefit by selling discharge rights for anything more than $5 per pound. Assuming zero transaction costs, the dischargers continue to trade until their marginal costs are equal and all gains have been captured. This is shown in Figure 2.2. The static efficiency gains (reduction in total costs) are equal to the reduction in the shaded region between Figure 2.1 and 2.2.

While static efficiency is an important motivation for implementing a cap and trade program, economists also suggest that cap and trade programs encourage dynamic efficiency. In static analysis, costs are assumed to be known and fixed and the problem is one of selecting the optimal discharge level for each discharger. In dynamic analysis, pollution reduction costs are malleable and can be decreased if dischargers search for, discover, or invest in new ways to control pollution. Cap and trade programs provide incentives, through the price for discharge rights, for dischargers to achieve dynamically efficient outcomes by decreasing their pollution reduction costs. Thus, dynamic efficiencies come from innovation and discovery of previously unrealized strategies and opportunities to improve effluent control performance. These innovations are usually not new patentable control technologies, but improvements in process of controlling pollution (Burtraw, 1996). Under price incentives created by cap and trade programs, regulated parties are granted the discretion to experiment and search for additional effluent reductions and at lower costs. Because of this, a cap and trade program could allow for a great deal of cost savings over traditional command-and-control policies even if few or no trades occur between dischargers. Studies of cap and trade programs often report substantial reductions in costs from discharger pollution prevention innovations rather than trades between dischargers (Carlson et al.; Shabman, Stephenson, and Shobe; Stavins 1998).

2.2. From Concept to Practice: Point Source Trading in Virginia

How policy makers set the cap and establish trading rules has important implications for the cost of achieving the water quality objectives. Dischargers typically face increasing marginal costs when reducing nutrient discharges. If the government places a stringent cap on one set of sources and chooses not to regulate another, the cost of achieving the environmental program could be significantly higher than if the burden were distributed differently. Likewise, if the government establishes trading rules with insufficient flexibility or certainty in the discharge rights, the cost of achieving the environmental objective could increase further still. It is important to note that cost-effectiveness is not the only concern of government, and the equitableness of how the burden of regulation is distributed can be an important concern.

2.2.1 Virginia's nutrient trading program for the Shenandoah-Potomac River Basins. Virginia's nutrient trading program establishes a partial cap on point sources only. In designing their nutrient trading program Virginia DEQ established cap levels and allocated discharge rights based on a regulator-identified limits-of-technology approach. Each existing point source (over a minimum design flow) is granted an individual nitrogen and phosphorus waste-load allocation (WLA). The allocation is expressed in a total annual mass load (in pounds) of nitrogen and phosphorus that can be released by the source. Virginia's Department of Environmental Quality set individual WLA based on stringent technology-based nutrient concentrations multiplied by the point source's permitted design flow. The sum of individual point source WLA in a particular river basin represents the point source nutrient watershed cap. Individual WLAs are established in a general watershed permit and are recorded only as a mass load. For plants in the Shenandoah-Potomac River Basin, typical concentration standards used by DEQ in the WLA calculation were 3-5 mg/L for nitrogen (Virginia Office of the Governor, 2005). Individual point sources may not need to achieve their reference level concentration standard initially because their flows are below their maximum design flow. Three mg/L for nitrogen is considered the limits of technology for nitrogen removal.

Another way to establish the WLA cap for the Shenandoah-Potomac River Basin is with a proportional reduction. In 1985, the end-of-pipe and delivered nitrogen loadings from all significant dischargers in the Virginia portion of the Shenandoah-Potomac River Basin were approximately 10.87 and 9.4 million pounds of nitrogen, respectively (Personal Communication John Kennedy, VA DEQ). This is roughly equal to the delivered non-point source loadings of 10.343 million lbs for the Shenandoah-Potomac River Basin (Virginia Office of the Governor, 1996). Delivered nitrogen is defined as the portion of discharges that reach the Chesapeake Bay and not assimilated during transport in the river ecosystem. A cap based on a proportional reduction based on the Chesapeake Bay Program 40% reduction goal would establish an end-of-pipe cap of 6.52 million pounds and a 5.64 million pounds delivered load cap.

In 2005, the end-of-pipe and delivered load was approximately 6.29 and 4.89 million lbs, respectively. Thus by 2005, point sources overall had achieved a 48% reduction in delivered nitrogen loads. This was in excess of the 40% reduction goal set for the Bay as a whole. The technology-based cap established for the Shenandoah-Potomac under the Virginia Trading program is 5.15 and 4.0 millions pounds, representing a 57% reduction from 1985 loads. Thus, the Virginia technology-based cap is considerably more stringent than a proportional reduction and thus places a disproportionate responsibility on achieving nutrient reduction goals on the point sources.

The Virginia Program also contains provisions that limit the flexibility of market participants. One such provision requires all new and expanding dischargers to achieve a 3 mg/L nitrogen concentration standard in addition to generating non-point source nutrient reductions to offset growth in loads (9-VAC-25-720-60-c). This concentration standard is in addition to the requirement to limit mass loads to the total amount of WLA owned. While there are economic arguments for requiring dischargers to maintain the cap in the face of growth, there appears to be no obvious water quality benefit to dictating how dischargers remain compliant.

Each of the two cap levels could be implemented with or without the new/expanding source performance standard. The four possible policy scenarios that arise from these combinations of caps and performance standards are shown in Table 2-1. The cost model used to estimate the annual cost of achieving each policy scenario by the year 2010 is described in the next section.

Table 2-1. Point Source Policy Scenarios

Scenario	Cap level	Concentration Standard
Scenario 1	Virginia Program Cap	Yes
Scenario 2	Virginia Program Cap	No
Scenario 3	40% Proportional Cap	Yes
Scenario 4	40% Proportional Cap	No

2.3. Method

A cost minimization model for the Shenandoah-Potomac River Basin was used to estimate the annual cost of each scenario in the year 2010, the target year set in the Chesapeake 2000 agreement. The model identified the least-cost combination of plant upgrades needed to achieve the total nitrogen cap, expressed in pounds of total delivered[2] nitrogen loads into the Chesapeake Bay, in 2010. The cost minimization model mimics the static efficiency element of trading programs by assuming all mutually beneficial

[2] Depending on the location of a discharger in the watershed, a portion of the nitrogen discharged at the end of pipe is assimilated during transport to the Bay. The fraction of each pound of discharged nitrogen passing over the Potomac fall line is the delivery ratio.

gains from trade occur. Such models are a commonly used method to estimate costs in trading programs (Carlson et al.; Bennett, Thorpe and Guse; Faeth; Horan et al.; Ribaudo, Hemlich and Peters). Nitrogen was the focus of this study because it is widely considered the nutrient that is the most expensive and technically challenging for point sources to remove.

The formal model is given in equations 2.1-2.3. Due to the large and lumpy capital costs required to achieve different effluent concentration standards, integer programming minimization techniques were used. Equation 2.1 gives the objective function, to minimize the cost of achieving nitrogen cap. X_{ij} is a matrix denoting the decision of the i^{th} point source to implement the j^{th} upgrade. In the model, each plant faces four possible decisions to control nitrogen discharges. To do nothing, or pursue up to three sequential effluent control upgrades to achieve total nitrogen concentration levels of 8 mg/L, 5 mg/L or 3 mg/L. C_{ij} is a vector of coefficient containing cost estimates of the i^{th} point source implementing the j^{th} upgrade.

Equation 2.2 defined the cap levels. This condition was expressed as the nitrogen reductions from the upgrades must be at least be equal to B_1, the quantity of reductions sufficient to achieve nitrogen cap. R_{ij} is a vector denoting the reduction in the 2010 nitrogen load (expressed in pounds of delivered nitrogen) associated with implementing an j^{th} upgrade. The term B_1 was defined as the difference between the 2010 cap level (either the existing DEQ cap or the 40% proportional reduction cap depending on the scenario) and the estimated 2010 nitrogen discharge levels assuming no new capital upgrades. The nutrient discharges in the year 2010 for each plant in the model were estimated assuming by that no new plant upgrades were undertaken, total nitrogen discharge concentration levels did not change, and wastewater flows continued to grow at a historical rate. Equation 2.3 represents the technology-based performance standard requirement for new and expanding plants. B_2 is a vector denoting the number of sequential upgrades that the new and expanding plants need to implement to achieve a 3 mg/L concentration standard for nitrogen in the year 2010.

$$\text{(2.1)} \quad \text{Minimize} \quad \sum_{i}\sum_{j} CijX'ij$$

s.t.

$$\text{(2.2)} \quad \sum_{i}\sum_{j} RijX'ij \geq B_1$$

$$\text{(2.3)} \quad \sum_{i}\sum_{j} X'ij = B_2$$

Several important assumptions were made in the model. The first and most important was that point sources trade credits when doing so decreases total compliance costs, in other words, all beneficial trades take place. The second assumption was that all nitrogen control costs and nitrogen control technologies are known and constant throughout the model. The third assumption was that the decision-making flexibility and discharger incentives associated with the program would not stimulate unanticipated innovation in pollution prevention. While there is evidence that costs are indeed a function of trading program design, these changes are an unpredictable part of the market process and trying to incorporate such a process into the model was not possible (Shabman, Stephenson and Shobe; Speir, Stephenson and Shabman). This is a limitation of the study and may mean that the model estimates do not represent the final cost of meeting the mass load cap. Lastly, the model estimated the annualized cost of achieving the nutrient reduction goal in the year 2010 and does not account for additional upgrades that may be necessary if flows continue to increase.

2.4. Model Data

Of the 43 point sources in the Shenandoah-Potomac River Basin, the cost model included the subset for which cost data was available, 29 in total. The sources in the model were all publicly owned wastewater treatment plants (WWTP) with design flows greater that 500,000 gallons per day and located in Virginia. This subset was selected because large WWTP account for the vast majority of the nutrient loading for the river basin and are the type of plant for which cost data exist. The 29 plants accounted for 82% of the 2005 point source delivered load in the Virginia portion of the Shenandoah-Potomac River with the majority of the remaining nutrient load coming from a single plant, the Blue Plains facility in the District of Columbia.[3]

The list of plants is given in Table 2-2 along with each plant's current design flow, historical nitrogen loads, and each plant's discharge limits under different cap scenarios. The Virginia Program cap was taken directly from the Virginia nutrient trading program regulation 9-VAC-720-50. The WLA cap established under Virginia's program is 3.178 million pounds for these 29 plants (Table 2-2). An alternative cap, based on a 40% reduction from 1985 loads, was also identified. This cap was calculated by reducing individual WWTP's 1985 nitrogen loads by 40 percent. WWTP constructed after 1985 received no initial WLA. The sum across all 29 plants results in a cap of 4.70 million pounds. Delivery ratios for each plant were calculated by the Chesapeake Bay Program

[3] Blue Plains is an extremely large (370 MGD) WWTP located in the District of Columbia. It treats wastewater from Northern Virginia, Maryland and the District. Because Blue Plains is located in the district and subject to a unique set of regulations, it was thus excluded from the model.

and reported by VADEQ (9-VAC-720-50 regulation published in the Virginia Registrar of Regulations Volume 21 issue 23). These two cap levels were used to in the calculation of B_1 in equation 2.2.

Table 2-2. Virginia WWTPs Included in the Cost Minimization Model

Plant	2005 Design Flow (MGD)	1985 Delivered N (lbs/yr)	2005 Delivered N (lbs/yr)	40% Cap Delivered N (lbs/yr)	Virginia Program Cap Delivered N (lbs/yr)
Norman-Cole	67	2,225,840	494,880	1,335,504	612,158
UOS A	54	346,567	966,622	207,940	763,096
Alexandria SA	54	1,994,010	750,430	1,196,406	493,381
Arlington	40	1,641,280	695,070	984,768	365,467
HL Mooney	24	609,160	210,910	365,496	219,280
North River	16	154,207	84,974	92,524	106,424
Leesburg	10	59,536	51,568	35,722	101,112
Opequon	8.4	167,654	85,759	100,593	75,729
Middle River	6.8	68,380	36,775	41,028	34,792
Aquia	6.5	64,890	110,130	38,934	73,093
Waynesboro	4	80,191	121,649	48,114	20,466
Front Royal	4	72,891	82,043	43,735	31,674
DSC #8	4	38,360	43,010	23,016	42,029
DSC #1	4	91,320	30,890	54,792	42,029
Stuarts Draft	2.4	11,953	6,447	7,172	20,466
Quantico	2.2	82,540	33,570	49,524	20,101
Parkins Mill	2	0	63,906	0	45,074
Massanutten	2	0	11,382	0	7,675
Fisherville	2	18,648	17,728	11,189	20,466
Luray	1.6	1,420	13,906	852	8,187
Purecellville	1	12,757	8,167	7,654	15,167
Dahlgren SD	1	5,690	9,290	3,414	9,137
Strasburg	0.98	27,378	35,633	16,427	7,760
NSWC-Dahlgren	0.72	0	3,150	0	6,578
Stoney Creek	0.6	9,549	6,494	5,729	4,751
Colonial Beach	0.5	22,770	11,640	13,662	18,273
Weyers Cave	0.5	12,062	17,174	7,237	2,558
Round Hill	0.5	2,839	10,309	1,703	7,584
New Market	0.5	9,841	7,456	5,905	3,959
	Total	**7,831,733**	**4,020,962**	**4,699,040**	**3,178,466**

Sources: Virginia Office of the Governor (1996);
Chesapeake Bay Program Point Source Database (2007)

The cost data for the model (C_{ij} in equation 2.1) was obtained from a Chesapeake Bay Program publication (Chesapeake Bay Program 2002). The publication included estimates of the capital and operating and maintenance costs for wastewater treatment to achieve 8, 5, and 3 mg/L nitrogen concentrations. For the purposes of the model, the capital and operations and maintenance costs of meeting 8, 5, and 3 mg/L for nitrogen were converted into annualized costs as if they were loan payments, over 20 years at an interest rate of 7%. Given the large expense of the capital upgrades, localities may need to borrow money to fund plant upgrades. By annualizing the costs over 20 years at 7% nominal interest costs are included in the model and the individual cost estimates for each plant are in a form that is useful to local WWTP managers.

The Chesapeake Bay Program's point source database was used to gather information on nutrient discharge levels, plant wastewater flows, and plant design flows which were used to estimate each plant's 2010 wastewater flows (Chesapeake Bay Program 2006a). The model required estimation of the 2010 nitrogen loads without a cap (equation 2.2). Future wastewater flows for each plant in the model were projected by estimating a simple linear regression trend line through 10 years of flow data (1995-2004) (Appendix A). Using the equations generated for each plant, the 2010 flows were extrapolated and shown in Table 2-3. The estimated 2010 nutrient loadings also assumed WWTPs made no additional reductions in nitrogen concentration levels between 2004 and 2010 (see Table 2-3). Conceptually, the 2010 baseline load is the load that would result if growth were to continue at its present pace but that no upgrades were implemented. The 2010 baseline load is projected to be 4.83 million pounds and in excess of two cap levels identified in Table 2-2. Subtracting this 2010 baseline load from the respective cap level produced the values of B_1 in equation 2.2. Simply holding the line on nutrient dischargers at the 2005 level would require significant expenditures by point sources.

Table 2-3. Estimated plant loads in 2010 assuming no upgrades

Facility	2010 Projected Flows	2010 baseline TN concentration	2010 Baseline TN delivered load
Fisherville	1.53	12.06	23,670
Luray	1.36	4.69	8,139
Massanutten	0.77	13.98	13,697
Middle River	4.45	5.61	31,920
North River	12.26	6.78	106,373
Stuarts Draft	1.46	5.03	9,358
Waynesboro	3.27	9.69	40,531
Weyers Cave	0.51	34.63	22,627
Front Royal	4.06	6.91	55,598
New Market	1.00	14.00	27,688
Stoney Creek	1.10	18.70	40,850
Strasburg	1.19	9.69	22,800
Opequon	7.27	5.55	90,973
Parkins Mill	2.43	11.07	60,672
Purecellville	0.60	8.59	13,011
Leesburg	4.57	5.73	66,181
Round Hill	0.15	18.70	7,092
DSC #1	3.32	3.46	34,945
DSC #8	3.53	4.30	46,223
HL Mooney	13.67	7.35	306,204
UOSA	33.81	15.18	906,570
Alexandria SA	39.83	8.00	970,712
Arlington	29.25	8.42	750,148
Normal-Cole	42.58	7.77	1,007,324
Quantico	0.76	11.30	26,169
Aquia	4.67	7.18	102,209
Colonial Beach	0.98	8.50	25,477
Dahlgren SD	0.16	7.86	3,885
NSWC-Dahlgren	0.33	5.17	5,210
Total:			4,826,256

Equation 2.3 required the identification of plants subject to the new source concentration standard requirement. In regulation 9-VAC-720-50, the Virginia Department of Environmental Quality identified 5 out of the 29 plants in the model as having pre-existing upgrade plans: North River, Purcellville, DSC #1, DSC #8, and Parkins Mill. For purposes of this model, these plants were considered subject to the technology-based performance standard requirement. The average design flow for these plants was 5.4 MGD. This is relatively small compared to the 11.1 MGD average design flow for the sample as a whole. It should be noted that while these expanding plants have to achieve a nitrogen concentration standard of 3 mg/L, they do not have to acquire WLA for their expansions. Instead, DEQ chose to give these plants initial WLAs on their post-expansion design flows.

2.5. Results

A detailed summary of the upgrades that each plant would implement under the different scenarios is given in tables 2-4 through 2-7. The tables give the optimization results for each plant in the model under the different policy scenarios. The costs given are the annualized cost for a plant implement the upgrade. The information in these tables does not represent how the costs would be distributed as municipalities that upgrade may have excess credits to sell to municipalities not upgrading. The distribution of costs among the plants in the model would depend critically on the price of credits. These are the annualized costs that would be spent each year for 20 years to pay for the capital upgrades and increased operation and maintenance expenses. These cost estimates are only for the year 2010 and do not account for any upgrades that might be necessary in future years.

Table 2-4. Least-Cost Combination of Plant Upgrades for Scenario 1 (Existing Cap and New Source Concentration Standard)

Plant	Discharge Concentration	Annualized Cost of Upgrades	Delivered Load
Fisherville	Upgrade to 8 mg/L	$96,115	15,699
Luray	No upgrades	--	8,139
Massanutten	No upgrades	--	13,697
Middle River	No upgrades	--	31,920
North River	Upgrade to 3 mg/L	$2,747,651	47,062
Stuarts Draft	No upgrades	--	9,358
Waynesboro	No upgrades	--	40,531
Weyers Cave	Upgrade to 8 mg/L	$293,085	5,227
Front Royal	No upgrades	--	55,598
New Market	No upgrades	--	27,688
Stoney Creek	Upgrade to 3 mg/L	$493,771	6,554
Strasburg	No upgrades	--	22,800
Opequon	No upgrades	--	90,973
Parkins Mill	Upgrade to 3 mg/L	$573,150	16,441
Purecellville	Upgrade to 3 mg/L	$391,428	4,544
Leesburg	No upgrades	--	66,181
Round Hill	No upgrades	--	7,092
DSC #1	Upgrade to 3 mg/L	$714,462	30,339
DSC #8	Upgrade to 3 mg/L	$903,941	32,271
HL Mooney	No upgrades	--	306,203
UOSA	Upgrade to 8 mg/L	$2,730,594	477,834
Alexandria SA	Upgrade to 5 mg/L	$2,678,247	606,695
Arlington	Upgrade to 5 mg/L	$2,190,419	445,456
Normal-Cole	Upgrade to 5 mg/L	$3,713,654	648,448
Quantico	No upgrades	--	26,169
Aquia	No upgrades	--	102,209
Colonial Beach	Upgrade to 8 mg/L	$9,974	23,974
Dahlgren SD	No upgrades	--	3,885
NSWC-Dahlgren	No upgrades	--	5,210
TOTAL		**$17,536,491**	**3,178,195**

Table 2-5. Least-Cost Combination of Plant Upgrades for Scenario 2 (Existing Cap without New Source Concentration Standard)

Plant	Discharge Concentration	Annualized Cost of Upgrades	Delivered Load
Fisherville	No upgrades	--	23,670
Luray	No upgrades	--	8,139
Massanutten	No upgrades	--	13,697
Middle River	No upgrades	--	31,920
North River	No upgrades	--	106,373
Stuarts Draft	No upgrades	--	9,358
Waynesboro	No upgrades	--	40,531
Weyers Cave	No upgrades	--	22,627
Front Royal	No upgrades	--	55,598
New Market	No upgrades	--	27,688
Stoney Creek	No upgrades	--	40,850
Strasburg	No upgrades	--	22,800
Opequon	No upgrades	--	90,973
Parkins Mill	Upgrade to 8 mg/L	$10,884	43,842
Purecellville	No upgrades	--	13,011
Leesburg	No upgrades	--	66,181
Round Hill	No upgrades	--	7,092
DSC #1	No upgrades	--	34,945
DSC #8	No upgrades	--	46,223
HL Mooney	Upgrade to 3 mg/L	$1,564,419	124,901
UOSA	Upgrade to 8 mg/L	$2,730,594	477,834
Alexandria SA	Upgrade to 5 mg/L	$2,678,247	606,695
Arlington	Upgrade to 3 mg/L	$2,190,419	445,456
Normal-Cole	Upgrade to 5 mg/L	$3,713,654	648,448
Quantico	No upgrades	--	26,169
Aquia	No upgrades	--	102,209
Colonial Beach	No upgrades	--	25,477
Dahlgren SD	No upgrades	--	3,885
NSWC-Dahlgren	No upgrades	--	5,210
TOTAL		**$12,888,217**	**3,171,802**

Table 2-6. Least-Cost Combination of Plant Upgrades for Scenario 3 (Proportional 40% Cap and New Source Performance Standard)

Plant	Discharge Concentration	Annualized Cost of Upgrades	Delivered Load
Fisherville	No upgrades	--	23,670
Luray	No upgrades	--	8,139
Massanutten	No upgrades	--	13,697
Middle River	No upgrades	--	31,920
North River	Upgrade to 3 mg/L	$2,747,651	47,062
Stuarts Draft	No upgrades	--	9,358
Waynesboro	No upgrades	--	40,531
Weyers Cave	No upgrades	--	22,627
Front Royal	No upgrades	--	55,598
New Market	No upgrades	--	27,688
Stoney Creek	No upgrades	--	40,850
Strasburg	No upgrades	--	22,800
Opequon	No upgrades	--	90,973
Parkins Mill	Upgrade to 3 mg/L	$573,150	16,441
Purecellville	Upgrade to 3 mg/L	$391,428	4,544
Leesburg	No upgrades	--	66,181
Round Hill	No upgrades	--	7,092
DSC #1	Upgrade to 3 mg/L	$714,462	30,339
DSC #8	Upgrade to 3 mg/L	$903,941	32,271
HL Mooney	No upgrades	--	306,204
UOSA	No upgrades	--	906,570
Alexandria SA	No upgrades	--	970,712
Arlington	No upgrades	--	750,148
Normal-Cole	No upgrades	--	1,007,324
Quantico	No upgrades	--	26,169
Aquia	No upgrades	--	102,209
Colonial Beach	No upgrades	--	25,477
Dahlgren SD	No upgrades	--	3,885
NSWC-Dahlgren	No upgrades	--	5,210
TOTAL		**$5,330,632**	**4,695,689**

Table 2-7. Least-Cost Combination of Plant Upgrades for Scenario 4 (Proportional 40% Cap without New Source Performance Standard)

Plant	Discharge Concentration	Annualized Cost of Upgrades	Delivered Load
Fisherville	No upgrades	--	23,670
Luray	No upgrades	--	8,139
Massanutten	No upgrades	--	13,697
Middle River	No upgrades	--	31,920
North River	No upgrades	--	106,373
Stuarts Draft	No upgrades	--	9,358
Waynesboro	No upgrades	--	40,531
Weyers Cave	No upgrades	--	22,627
Front Royal	No upgrades	--	55,598
New Market	No upgrades	--	27,688
Stoney Creek	No upgrades	--	40,850
Strasburg	No upgrades	--	22,800
Opequon	No upgrades	--	90,973
Parkins Mill	Upgrade to 5 mg/L	$227,202	27,401
Purecellville	No upgrades	--	13,011
Leesburg	No upgrades	--	66,181
Round Hill	No upgrades	--	7,092
DSC #1	No upgrades	--	34,945
DSC #8	No upgrades	--	46,223
HL Mooney	Upgrade to 5 mg/L	$1,105,586	208,169
UOSA	No upgrades	--	906,570
Alexandria SA	No upgrades	--	970,712
Arlington	No upgrades	--	750,148
Normal-Cole	No upgrades	--	1,007,324
Quantico	No upgrades	--	26,169
Aquia	No upgrades	--	102,209
Colonial Beach	No upgrades	--	25,477
Dahlgren SD	No upgrades	--	3,885
NSWC-Dahlgren	No upgrades	--	5,210
TOTAL		**$1,332,788**	**4,694,950**

The cost implications of the new and expanding source concentration standard are considered first. The concentration standard requirement on expanding sources increases costs $3.99 and $4.64 million per year with the 40 % proportional and Virginia Program cap, respectively. For instance, under the existing Virginia point source cap, the cost of achieving existing Virginia point source cap increases from $12.8 to $17.5 million per year, a 36% increase in costs (Tables 2.4 and 2.5). The same requirement imposed on the proportional cap nearly quadruples total compliance costs. The total cost of achieving scenario one was calculated by summing the cost of each plant upgrade in Table 2-4. Likewise, the cost of scenario 2 was calculated by summing the costs from Table 2-5. In the absence of the technology-based performance standard requirement for new and expanding sources, two of the five plants (Parkins Mill and H.L Mooney) would achieve 5 mg/L for N and the rest would implement no upgrades.

The cost of achieving two different point source caps – a 3.18 million pound nitrogen cap established in the Virginia Program and a 4.69 million pound cap that approximates a proportional 40% reduction in point source loads -- was also estimated. The cost of going from scenario 3 $5.33 million, the sum of costs in Table 2-6, to scenario 1 $17.5 million was $12.17 million. Similarly, the cost of going from scenario 4 $1.33 million, sum of Table 2-7, to scenario 2 $12.8 million, sum of Table 2-5, is e cost of increasing the stringency of the point source cap from 4.69 to 3.18 million pounds is $11.4 million. Thus the estimated cost of increasing the stringency of the cap from 4.69 million pounds to 3.18 million pounds was between $11 and 12 million dollars per year (independent of what was assumed about the new source performance standard).

The total cost of achieving various other cap levels was also computed. Total cost estimates were derived by running the model, with and without the technology based performance standard requirement, with multiple cap levels. Total cost curves were estimated by regressing total costs against a 6^{th} order polynomial of cap levels using ordinary least squares. The equation for the polynomial is given below and the results of the regression are reported in Table 2-8. The total cost curves, with vertical lines denoting the two cap levels, are shown in Figure 2.4.

$$(2.4)\ Y = ß_0+ß_1*Cap+ß_2*cap^2+ß_3*Cap^3+ß_4*cap^4+ß_5*cap^5+ß_6*cap^6$$

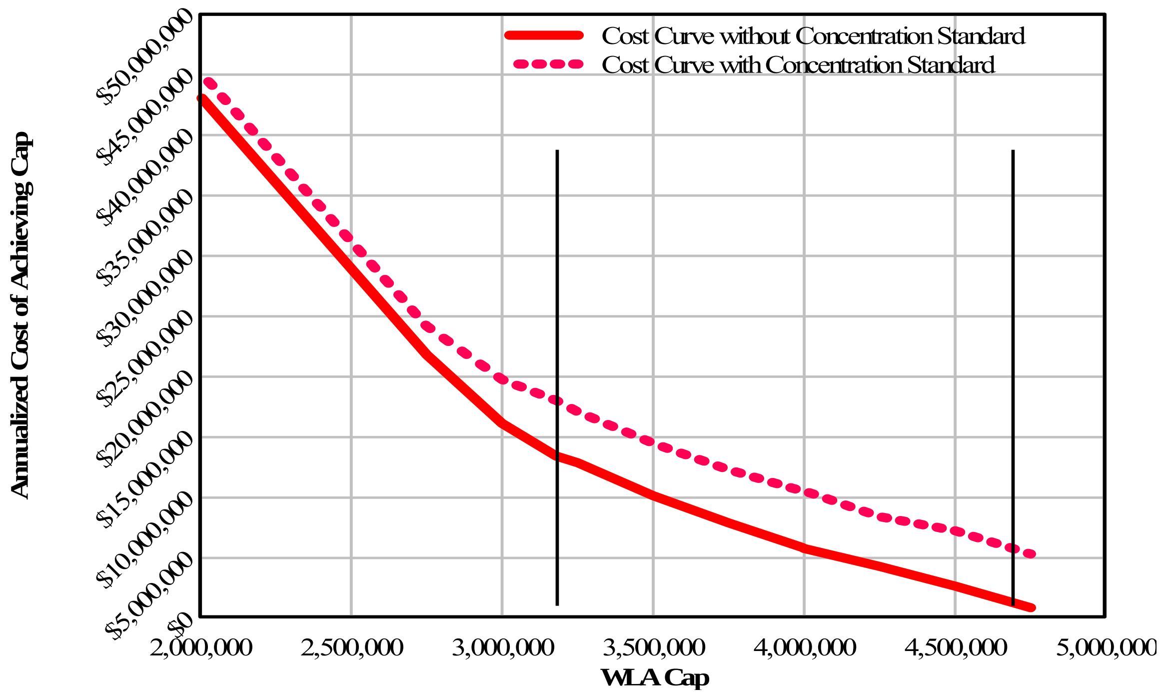


Figure 2-3. Annual Total Cost Curves to Achieve Nitrogen Point Source Cap in Virginia portion of Shenandoah Potomac River in 2010

Table 2-8. Ordinary Least Squares Regression of Load on Total Nitrogen Reduction Costs

Variable	Estimate	t-statistic
ß0	$-8.537*10^{8}$	-1.78
$ß_1$	1742.77	1.88
$ß_2$	-0.0013	-1.79
$ß_3$	$5.0367*10^{-10}$	1.64
$ß_4$	$-1.044*10^{-16}$	-1.47
$ß_5$	$1.1237*10^{-23}$	1.31
$ß_6$	$-4.9305*10^{-31}$	-1.15
R^2	0.9997	

As implied by these estimates, the marginal costs increase substantially as the stringency of the point source cap is increased. Conceptually, the first derivative of the total cost model represents the marginal cost of removing the last pound of nitrogen at the various cap levels. The marginal cost curve without the new source concentration standard is shown on Figure 2-5. The marginal cost curve, however, without the restriction was qualitatively similar. The marginal cost estimate for point sources of achieving a 40% reduction goal was $4.94 per pound of delivered nitrogen. Marginal costs nearly triple to $13.19 under Virginia's technology-oriented cap.

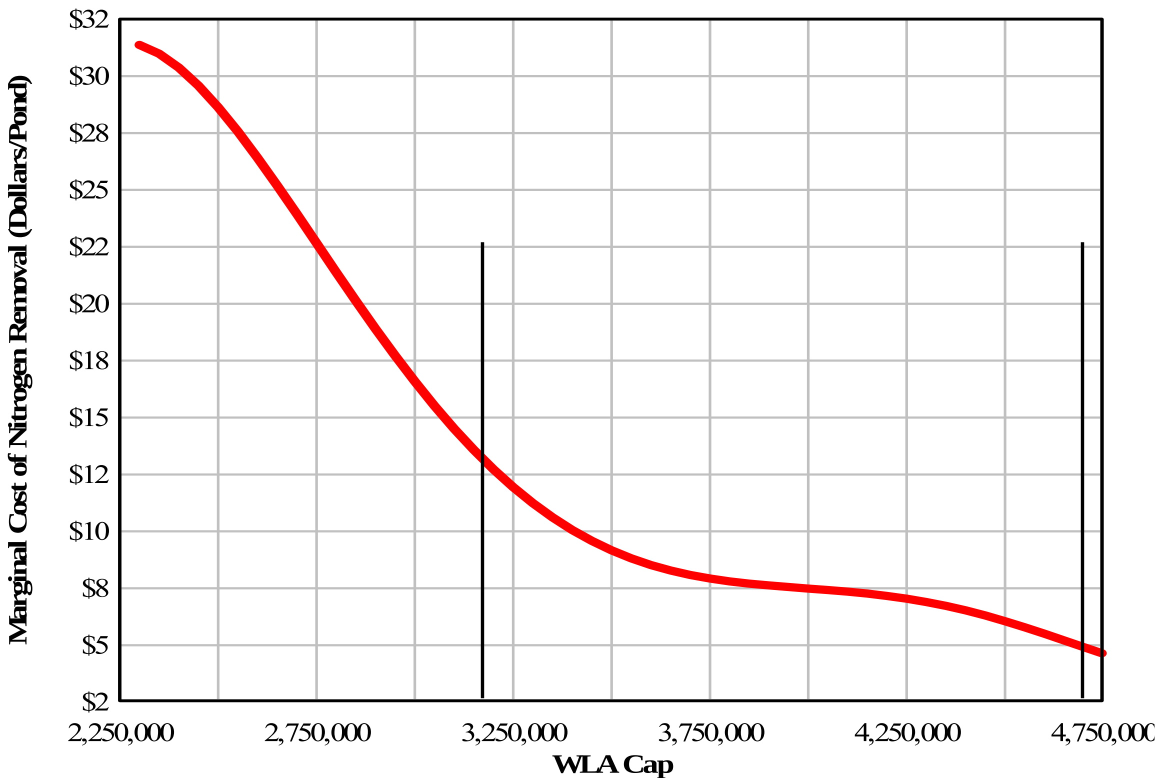


Figure 2-4. Marginal Cost of Nutrient Reduction

These marginal cost estimates are significantly higher than the cost of reducing nitrogen loadings from a suite of non-point source practices reported in a highly publicized Chesapeake Bay Commission report (Chesapeake Bay Commission 2004). For example, reported non-point source removal costs from agricultural sources range from $1.66 to $4.41 pound of nitrogen removed (Chesapeake Bay Commission 2004). Given the stringent baseline requirements that Virginia is considering for counting reductions from agricultural BMPs, discussed in Chapter 3, the actual cost may be larger than this. Still, the possibility exists that more cost effective reductions may be achieved by shifting responsibility of achieving the overall 40% reduction goal for the Bay from point to non-point sources.

2.6. Discussion

This chapter investigated the cost ramifications of several provisions of Virginia's nutrient trading program. Using an integer programming cost-minimization model, the cost of achieving four policy scenarios involving the size of the point source cap and the technology-based concentration standard requirement for new and expanding sources was estimated. The technology-based concentration standard requirement was found to increase costs by 34% with no obvious corresponding benefit to water quality. The Virginia program cap was found to be 70 -130% more expensive than the 40% cap depending on whether technology-based standards are required for new/expanding sources. This is strong evidence that increase cap levels are accompanied by increasing marginal nitrogen control costs.

Consider the tradeoffs between the existing point source cap and point source cap based on a 40% reduction goal. Moving toward the more stringent cap would reduce annual delivered nitrogen loadings by approximately 1.5 million pounds per year with an incremental cost of $12 million per year. The average cost of the incremental nitrogen removal is $8.33 per pound with the marginal cost of removing the last pound being $13.19. To put a 1.5 million pound load reduction into context, the effect of the recent increase in corn prices is estimated to increase nitrogen runoff into the Bay by 15 million pounds (Blankenship 2007). The 1.5 million pound reduction was small compared to this increase in non-point source loading. Given the lower marginal costs of reducing nitrogen from non-point source loads, $4.41 versus $13.19, there is evidence that cost savings could be achieved by increasing the point source cap and funding non-point source nutrient reductions instead.

Next, consider the incremental costs and benefits associated with the technology-based performance standard for new and expanding sources. Including the requirement was found to increase the cost of meeting the nutrient objective by approximately 34% regardless of the cap level. DEQ's rationale for including concentration standards is that concentration standards result in nutrient reductions sooner than would occur with simply assigning WLAs (Virginia Department of Planning and Budget). This rationale, however, was stated in an earlier draft of the regulation in which both existing and new and expanding point sources had to meet a concentration standard in addition to meeting their WLA. In 2004, the Virginia Department of Planning and Budget's economic impact analysis of regulations 9 VAC 25-40 and 9 VAC 25-720 was very critical of the concurrent concentration and WLA standards because they limited flexibility and trading opportunities. The impact analysis outlined other methods by which WLA could be phased-in to have an equivalent affect on nutrient dischargers without limiting trading flexibility. These suggestions were acted upon, but only in part. In the final regulation only new and expanding plants need to comply with a concurrent concentration standard. The requirement in the final regulation, however, has no impact on the aggregate level of nutrients discharged annually because the expanding sources can sell the nutrient credits they generate from achieving 3 mg/L for nitrogen. Thus, the requirement significantly increases cost with no corresponding improvement in water quality.

An important caveat is that during the implementation phase (2006-2010) the five new and expanding sources did not have to acquire new WLA or non-point source offsets. DEQ granted the plants with planned upgrades WLA based on their expected, not current, design flow. New and expanding plants after 2010 must obtain WLA from other point sources or through non-point source offsets.

2.7. Future Research

The cost model developed for this research did not include possible stochastic influences on plant nitrogen removal performance. The model was based on predicted average wastewater flow conditions in the year 2010. Yet, year to year rainfall variations can have significant implications for nutrient removal effectiveness at WWTPs. Because rainfall often infiltrates into pipes and because several municipalities have combined stormwater and sanitary sewer systems, years with a great deal of rainfall can decrease nitrogen removal efficiencies because incoming stormwater displaces water in treatment facilities resulting in decreased hydraulic retention times—that is to say that each gallon of water is treated for fewer hours at the plant than would otherwise occur. Conversely dry years often result in increased nitrogen removal efficiency. A cost model that included a method for analyzing the effects of rainfall variation on cost and trading is a possible extension of this research and might yield new insights.

A model that included year-to-year variation in rainfall would also be well suited to analyzing the affect of a nutrient credit banking provision. Stochastic rainfall patterns may create a year to year variation in the nitrogen credits generated by the regulated point sources. In dry years, plants may produce substantial surplus credits. In especially wet years, plants may exceed their aggregate WLA. The ability to bank credits (temporal trade) would allow point sources the opportunity to use credits generated in one year to be used for compliance purposes in a subsequent year. The addition of a banking provision would allow plants operational flexibility to address year to year climatic conditions and possibly lower compliance costs. Banking may also provide additional incentives for point sources to engage in more aggressive nitrogen reduction efforts in the current period in order to lower future compliance costs. Banking provisions have been found to have substantial potential to lower costs and induce pollution prevention activities in other programs (Stavins, 1998).

Chapter 3: The Cost of Generating Wasteload Allocation From Non-Point Sources Under Municipal Control

The Virginia Nutrient Trading Program requires new and expanding wastewater treatment plants (WWTPs) to obtain waste load allocation (WLA) to cover increases in their nutrient load. As stated in Chapter 1, the availability of WLA from existing point sources will likely be limited due to the stringency of the point source cap and expectations of continued growth in wastewater flow throughout the Commonwealth. Consequently, new and expanding point sources will likely have to acquire WLA through non-point source offsets in the future.

A non-point source offset is defined as a reduction in nutrients due to the use of a best management practice (BMP) above and beyond those “required by or funded under federal or state law, or the Virginia Tributary Strategies” (§62.1-44.19:15.B.1.b). In the Virginia trading program, non-point source BMPs used to generate WLA must also be included “as conditions of the facility’s individual Virginia Pollutant Discharge Elimination System permit” (§62.1-44.19:15.B.1.b). Virginia regulations also state that a 2:1 trading ratio applies to generating WLA from non-point source offsets, meaning point sources must secure two pounds of non-point source nutrient reductions for every one pound of additional WLA (9 VAC 25-820-70 Part 2.B.1.b).

New and expanding WWTPs are concerned about acquiring non-point source offsets from third party providers. A concern among point sources is that there is no transfer of responsibility when a point source funds a non-point offset. In other words, responsibility for assuring that nutrient reductions from offset activities occur is the legal responsibility of the permitted point source. If a third party non-point offset provider fails to produce the agreed upon reductions, the point source would be in violation of its Virginia Pollutant Discharge Elimination System (VPDES) permit and subject to civil and criminal penalties pursuant to the Clean Water Act. A violation of the permit for any reason leads to civil penalties not to exceed $25,000 per day.

Many of the new and expanding point sources are municipal WWTPs. The local governments that own these plants are interested in investigating non-point offset opportunities they can implement themselves to better manage their risk of non-compliance. The objective of this chapter is to develop a cost screening procedure that will allow local governments to estimate the cost of nutrient removal from non-point source offsets potentially under their jurisdictional control.

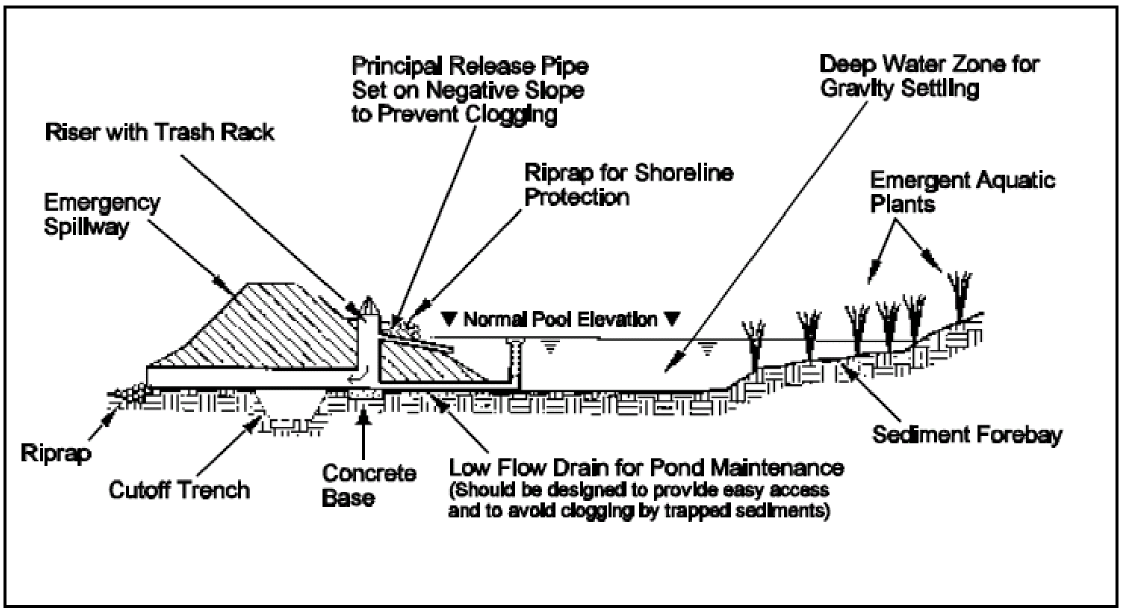
The first section of this chapter provides a description of potential non-point source offsets that could be implemented by local governments to generate WLA. Next, the cost of implementing these offset projects is reviewed. The third section describes a general screening level procedure for municipalities to estimate the per pound cost of implementing various offsets given their particular circumstances. The fourth section illustrates how the tool might be used and provides an initial assessment of the range of per unit costs that might be expected for different offset options. Finally, the chapter concludes with a discussion of unresolved issues in Virginia offset policy that may affect the costs of different offset options.

3.1. Potential Non-Point Source Offsets

Three general types of non-point source offsets that can be implemented by local governments to reduce nutrient loadings were examined: urban stormwater BMPs, septic retirement, and land conversion. Municipalities have the ability to implement urban stormwater BMPs both on land owned by the government and by promulgating regulations requiring developers to meet a specific stormwater standard. Municipalities also have the option of connecting existing developments using septic systems to their wastewater treatment plants or paying for those systems to be retrofitted with more effective nutrient reduction technologies. Lastly, municipalities have the ability to purchase land that is being used in a nutrient intensive manner and convert it into a less intensive use. Each of these general approaches is also acknowledged as acceptable offset option by draft DEQ offset guidelines (Virginia Department of Environmental Quality).

3.1.1. Urban stormwater BMPs. The *Virginia Stormwater Handbook* recognizes several general classes of stormwater control practices, including retention ponds, extended detention basins, stormwater wetlands, bio-retention basins and sand filters. Urban stormwater BMPs can be classified as those practices that are primarily focused on managing stormwater *quantity* and those focused on improving the water *quality* of stormwater runoff. The former, such as detention ponds, was not included in this analysis. Instead the focus will be on practices that are designed to improve stormwater quality, including wet ponds/wetlands, bio-retention areas, and sand filters.

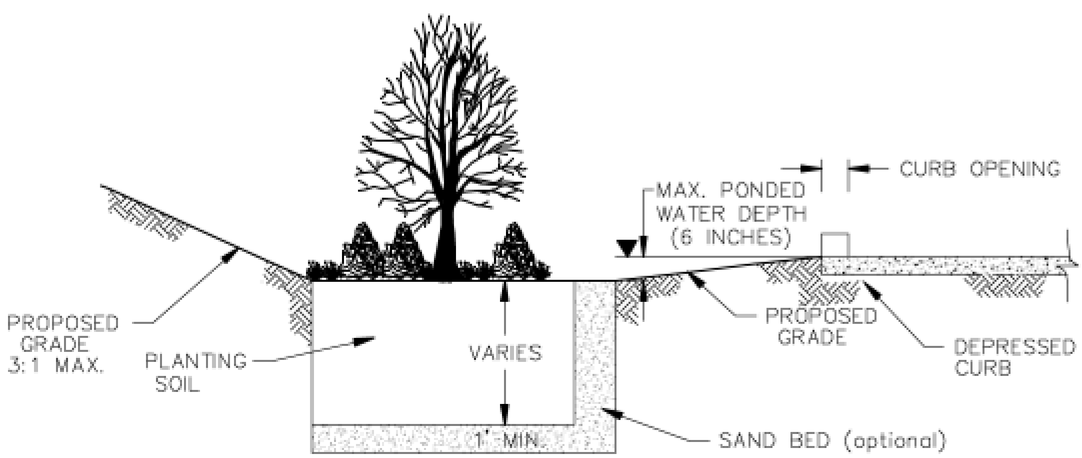
One class of stormwater BMPs available to city managers includes wet ponds and wetlands. These BMPs remove nitrogen by first directing water into a basin with a permanent pool of water (Figure 3-1). Next, the water above the permanent pool level is slowly drawn down as it infiltrates through the ground (US EPA). These BMPs improve water quality via several mechanisms, including sedimentation, infiltration, pollutant degradation, and biological uptake. There are a large number of variations within this class of BMPs. Specific examples of this class of BMPs include pocket wetlands, flood plain wetlands, and retention (wet) ponds. The key difference between a wet pond and a constructed wetland is primarily that wetlands discharge a large quantity of the incoming water after treatment while retention ponds infiltrate all the water entering the pond (Virginia Department of Conservation and Recreation). The Chesapeake Bay Program estimates that these practices remove approximately 30% of incoming nitrogen, 50% of incoming phosphorus, and 80% of incoming sediment (Chesapeake Bay Program 2006b).



Source: (US EPA)

Figure 3-1. Diagram of a Wet pond

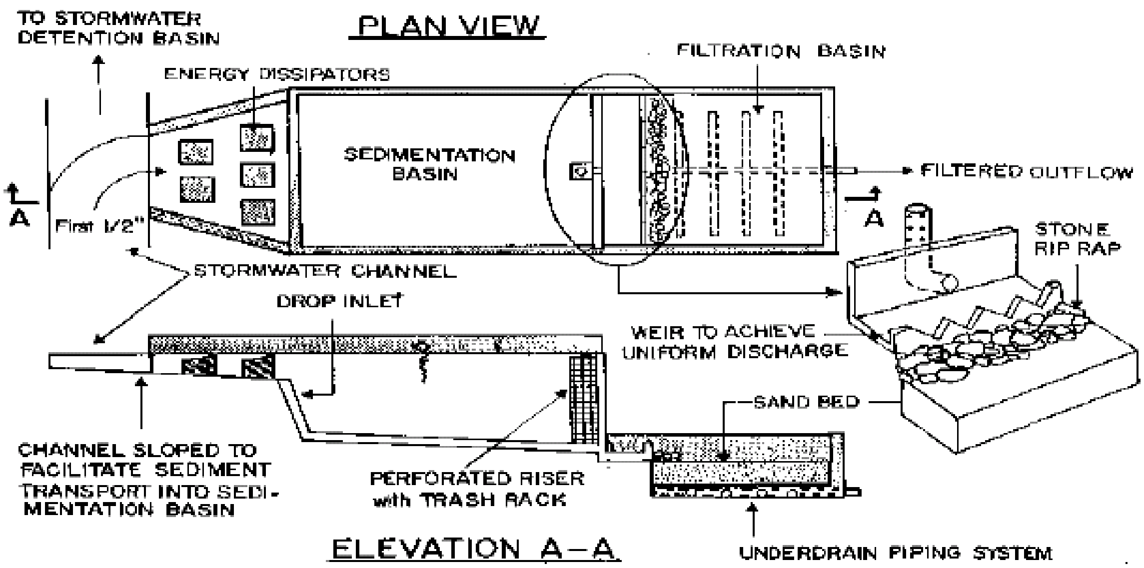
A similar class of stormwater BMP is the bio-retention area. Bio-retention areas, also referred to as rain gardens, are similar to wetlands in that they improve water quality through biological uptake, but are different in that they are not designed to have any standing water between rain events. Bio-retention areas are depressions in the ground “filled with a soil media mixture that supports various types of water-tolerant vegetation” (North Carolina Department of Environment and Natural Resources). It is recommended that some pretreatment, either a grass buffer strip or forebay, be used to limit the quantity of suspended solids entering the BMP. Figure 3-2 shows a diagram of a bio-retention area. Bio-retention areas are advantageous in that they can be located in highly developed urban and residential areas because many small bio-retention areas can be used to treat a single development making them easy to incorporate into site plans. Also, they can be an aesthetically pleasing structural stormwater BMP. Bio-retention areas are also easily constructed along road medians on divided highways. The Chesapeake Bay Program estimates that such infiltration practices remove 50% of incoming nitrogen, 70% of incoming phosphorus and 90% of incoming sediment (Chesapeake Bay Program 2006b).



Source: (Virginia Department of Conservation and Recreation)

Figure 3-2. Diagram of a Bio-retention Area

Sand filters direct water flow into treatment basins and then use media, such as sand and gravel, to filter and remove particulate matter from stormwater. Filtration systems often have a pre-settling chamber to remove a portion of the solids and improve filter longevity (Figure 3-3). Often filters are designed to treat only the first half-inch of runoff, diverting excess stormwater through overflow outlets. The initial stormwater flows are targeted because of the likelihood that first flush flows contain the majority of particulate matter of a rain event (US EPA). A benefit to using filtration systems is that they are relatively small and easy to place in urban environments. The majority of nitrogen entering sand filters in the form of ammonia and organic nitrogen is converted into nitrate. While the vast majority of the sand filter environment is aerobic, there also exist anaerobic microenvironments. Anaerobic bacteria within these anaerobic microenvironments are believed to be the principal source of nitrogen removal in sand filters by converting the nitrate into N_2 gas (Virginia Department of Conservation and Recreation). The Chesapeake Bay Program estimates that these practices remove approximately 40% of incoming nitrogen, 60% of incoming phosphorus, and 85% of incoming sediment (Chesapeake Bay Program 2006b). There are a number of different varieties of sand filters including the Austin, Alexandria and Delaware (US EPA).



Source: US EPA

Figure 3-3. Diagram of an Austin Sand Filter

A summary of the nutrient removal efficiencies are presented in Table 3-1. In addition to the removal efficiencies published by the Chesapeake Bay Program, nutrient removal efficiencies from studies by Brown and Schuler (1997) and Wossink and Hunt (2003) are also included for comparison.

Table 3-1. Summary of Urban Stormwater BMP Removal Efficiencies

	Removal Efficiency	
	Nitrogen	Phosphorus
Wetlands/ Wet Ponds		
Chesapeake Bay Program (2006)	30%	50%
Brown & Schuler (1997)	30%	47%
Wossink & Hunt (2003)	28%	46%
Bio-retention Areas		
Chesapeake Bay Program (2006)	45%	71%
Brown & Schuler (1997)	50%	50%
Wossink & Hunt (2003)	45%	71%
Sand Filters		
Chesapeake Bay Program (2006)	40%	60%
Wossink & Hunt (2003)	41%	59%

3.1.2. Sewer connection. Connecting homes currently using septic systems to the municipal sewer system is another option to reduce non-point source nutrient loadings. Septic systems are used to dispose of sewer waste for houses not connected to city sewer systems. These systems work by creating an anaerobic environment in the tank in which solid and liquid waste are broken down by bacteria. The liquid waste is then discharged into a drainage field. Often a portion of the nutrients reach surface water features before they can be absorbed by plants in the drainage field. The Chesapeake Bay Program estimates that septic systems in the Shenandoah-Potomac River basin were responsible for 1,000,000 pounds of delivered nitrogen into the Chesapeake Bay in 2005 (Chesapeake Bay Program 2007). It is unclear from the Chesapeake Bay Program database how much of this load came from failing septic systems versus normally operating systems.

Municipal wastewater treatment plants with advanced biological nutrient removal may have a greater ability to remove nutrients from wastewater than do septic systems because of their longer retention times and more consistent operation conditions designed to maximize the effectiveness of nitrogen removing bacteria (CH2MHill). If existing septic systems are retired or taken offline by diverting waste to a municipal wastewater treatment plant, non-point source nutrient load is eliminated and the load that would have been discharged by the septic systems can then be credited to the wastewater treatment facility as a non-point offset.

The nutrient load discharged by septic systems that ultimately reach surface waters is variable and subject to uncertainty. Yet, EPA has provided quantitative estimates of septic nutrient loads in approved nutrient trades with regulated point sources since at least 1980 (Woodward). In such cases, regulatory officials have calculated a standard offset for specific permits. For example, in a trade involving Lake Dillon, Colorado, regulators gave the wastewater treatment plant a 1 pound of phosphorus offset per year per home connected (Woodward). In Taos, New Mexico, regulators gave the wastewater treatment plant credit for 23.5 pounds of nitrogen per year per home connected (Wilson).

In addition to these two permitting cases, reducing nutrient loadings by connecting homes currently using septic systems to the city sewer has been studied in detail in Maryland (CH2MHill). The Maryland study focused primarily on identifying homes to connect to sewer and quantifying the nutrient reductions that would result. Several factors that impact the nutrient load from septic systems include the age of system, how well it has been maintained, soil conditions, and its proximity to surface water features (CH2MHill). Depending on the assumptions about these variables, connecting a septic system to the sewer will reduce nitrogen loadings to streams by 5.7 to 27.9 pounds with the median estimate of 17.85 pounds per year (CH2MHill). Most of the variability in these estimates stems from uncertainty regarding the relationship between the proximity of the septic field to the nearest surface water feature and the fraction of nutrients from the septic system that reach surface waters. While the study was conducted in Anne Arundel County, these results are likely applicable to other localities that have similar soil conditions.

3.1.3. Land conversion. The nutrient loads may also be reduced by taking land currently used for activities that produce high nutrient loads and converting the land to less intensive nutrient uses. For example, land currently used for nitrogen intensive crop production, such as growing corn, could be bought and then converted to hay or forest. The quantity of nutrient reduced would depend on the intensity of the pre-conversion nitrogen use, the converted land use, and the lands proximity to surface water.

The Virginia Department of Environmental Quality and Virginia the Department of Conservation and Recreation have produced preliminary draft estimates of nutrient reductions for different types of land conversion for use as offsets (Table 3-2). The land types listed are consistent with land use types used in the Chesapeake Bay model. Baseline nutrient loads for each land type were calculated assuming that nutrient management, cover crops, riparian buffers, and reduced tillage practices were implemented on the land (personal communication Russ Perkinson 5/29/07). The reduction in nutrient loads from land use types were calculated based on estimates derived from the Chesapeake Bay model (version 4.3). These estimates are edge of the field loads and do not incorporate any type of delivery ratios.

Table 3-2. Draft Nutrient Reductions Estimates from Land Conversion for the Shenandoah-Potomac River Basin

	Total Nitrogen (lbs/yr)		Total Phosphorus (lbs/yr)	
Conversion Type	Above Fall Line	Below Fall Line	Above Fall Line	Below Fall Line
Cropland to Forest	16.05	11.58	1.05	0.74
Cropland to Hay	8.49	6.4	0.75	0.26
Cropland to Mixed Open	12.24	8.55	0.43	0.08
Hay to Forest	6.66	4.64	0.79	0.68
Hay to Mixed Open	2.85	1.61	0.17	0.02
Impervious Urban to Forest	5.18	4.98	0.48	0.43
Pervious Urban to Forest	7.57	6.89	0.87	1.08
Pasture to Forest	1.43	2.85	0.41	0.85
Mixed Open to Forest	3.81	3.03	0.62	0.65

Source: Personal Communication Russ Perkins, 5/29/2007

3.2. Implementation Costs

Next, a review and synthesis of the cost of implementing the three potential non-point source offset opportunities described above was conducted. The cost studies described in this section were then used as the basis for the developing cost screening tool described in Section 3.3.

Conceptually, the offset costs include all the value of foregone opportunities and resources associated with the offset. This includes physical resource costs associated with construction and maintenance as well as the opportunity cost of land in its next best use. Economic theory states that, in a competitive equilibrium, that the prices for commodities such as construction materials are equal to their opportunity cost (Samuelson). Total opportunity costs also include time spent on design and time devoted to regulatory compliance costs. The costs of projects could also include losses in producer surplus from changing the amenities of neighborhoods. For example, installing a wetland (swamp) to treat stormwater may decrease home values and decrease the producer surplus from selling homes. Since the objective of this research was to construct a cost screening tool, the analysis focused on land costs and physical resource costs.

3.2.1. Stormwater BMP cost studies. A number studies focusing on the cost of stormwater BMP were reviewed including Wiegand et al. (1986), Southeastern Wisconsin Region Planning Commission (1991), Young et al. (1996), Brown and Schueler (1997), EPA (1999), Wossink and Hunt (2003), Caltrans (2004), Santa Monica Urban BMP Database as reported by DeWoody (2007) and Lambe et al. (2005). Most studies focused solely on construction costs (often including design costs) and only a few studies also attempted to estimate maintenance costs. With the exception of the Caltrans (2004) study and the data provided by Montgomery County, Maryland (published in Lambe et al. 2005), the results of these studies apply to the cost of installing *new* BMPs rather than retrofitting existing BMPs or installing BMPs on pre-existing sub-divisions.

Three general approaches are typically used to estimate the cost of implementing various stormwater BMPs. The first approach gathers data on the BMP implementation costs and characteristics of the BMPS and then statistically estimates a mathematical relationship between an independent variable such BMP size and the dependent variable of implementation cost (Wossink & Hunt, Brown & Schueler, Wiegand et al,Young et al.). The majority of these studies use ordinary least squares (OLS) to fit equations in the form of $Y = \alpha * X^{\beta}$ where Y is the implementation cost, X is a measure of size and α and β are parameters to be estimated by the OLS procedure. Another method of cost estimation is to use empirical cost data on individual activities and materials of BMP construction and sum the components to produce an overall cost for the BMP (Southeastern Wisconsin Regional Planning Commission). In this type of study the investigators list assumptions about basic materials and labor costs and the relationship regarding BMP size and labor and material requirements, and then derive cost estimates from these assumptions. The last approach simply reports the historical cost of implementing BMPs using descriptive statistics. Several government agencies that have extensive experience with implementing stormwater BMPs, including Montgomery County Maryland, Washington State's Department of Transportation and the City of Santa Monica California, have reported descriptive statistics such as the mean, median and a statistic similar to the inter-quartile range (Lambe et al., DeWoody). Instead of presenting the inter-quartile range, these studies give the interval within which some percentage of the observations lie.

A summary of cost studies for wet ponds, constructed wetlands, bioretention areas, and sand filters are given in Tables 3-3 through 3-6. The studies are grouped by BMP type. The cost equations are the original ones presented in the studies and are reported in nominal dollars. The table also notes the any excluded costs. A discussion of the studies follows the tables.

Table 3-3. Cost Estimates for Wet Ponds

Study	Year	Costs	Variable/Unit	Cost Estimate
Construction Costs				
Brown & Schueler	1997	Exclusive of Land Costs	X = total BMP size (cubic feet)	Cost = $106.07*X^{0.615}$
Wossink & Hunt	2003	Exclusive of Land Costs	X = BMP drainage area (acres)	Cost = $13,909X^{0.672}$
South Eastern Wisconsin Regional Planning Commission[a]	1991	Exclusive of Land Costs	X =BMP Size (acres)	Cost = $84,884*X^{0.979}$
Montgomery County, MD	2005	No Data	Cost Per Treated Acre (retrofits)	With Existing Infrastructure $1,000-3,000 Without $3,000-5,000
Washington State Dept of Transportation	2005	Exclusive of Land, includes sales taxes	Mean Cost Per Impervious Acre Treated	$15,000
Maintenance Costs				
Wossink & Hunt	2003	Annual costs discounted at 10%	X = Drainage Area (acres)	Cost= $9,209*X^{0.269}$
Lambe et al.	2005	Annual Costs of Retention Ponds	Mean	Preventative, $590 Corrective, $4,750 Total 5,340

Note: [a] Cost equation was estimated by the author from cost relationships described in SEWPRC

Table 3-4. Cost Estimates for Wetlands

Study	Year	Costs	Variable/Unit	Cost Estimate
Construction Costs				
Wossink & Hunt	2003	Exclusive of Land Costs	X = Drainage Area (acres)	Cost = 3,852*X^0.484
Maintenance Costs				
Wossink & Hunt	2003	Annual costs discounted at 10%	X = Drainage Area (acres)	Cost= $4{,}502*X^{0.153}$

Table 3-5. Cost Estimates for Bio-Retention Areas

Study	Year	Costs Included	Variable/Unit	Cost Estimate
Construction Costs				
Brown & Schueler	1997	Exclusive of Land Costs	X = Water Quality Volume (cubic feet)	$Cost=6.88*X^{0.991}$
Wossink & Hunt	2003	Exclusive of Land Costs	X = Drainage Area (acres)	(In clay soils) Cost = $10{,}162*X^{1.088}$
Wossink & Hunt	2003	Exclusive of Land Costs	X= Drainage Area (acres)	(In sandy soils) Cost = $2{,}861*X^{0.438}$
DeWoody	Data from 1996-2006	Exclusive of land costs, includes sales tax.	Mean and Median	Cost per gallon of capacity: Mean = $8.61 Median = $2.18
Maintenance Costs				
Wossink & Hunt	2003	Net Present Value of Maintenance costs discounted at 10%	X= Drainage Area (acres)	(In clay or sandy soils) Cost = $3{,}437*X^{0.152}$
Lambe et al. 2005	2005	Average Annualized Maintenance Costs (Retention Ponds)	Mean	Preventative 530 Corrective $480 Total $1,010

Table 3-6. Cost Estimates for Sand Filters

Study	Year	Costs Included	Variable/Unit	Cost Estimate
Construction Costs				
Brown & Schueler	1997	Exclusive of Land Costs	X = Water Quality Volume (cubic feet)	$Cost=156.67*X^{0.571}$
Wossink & Hunt	2003	Exclusive of Land Costs	X= Drainage Area (acres)	$Cost = 47{,}888*X^{0.882}$
Caltrans	2004	Exclusive of Land Costs	Impervious Acres Treated	Mean Cost $10,000 per acre
Maintenance Costs				
Wossink & Hunt	2003	Net Present Value of Maintenance costs discounted at 10%	X= Drainage Area (acres)	$Cost = 10{,}556*X^{0.534}$

The 1997 Brown and Schueler study used data from "70 stormwater BMPs in the Mid-Atlantic area for which bond estimates, engineering estimates and actual construction contracts were available." (p. 1) From these data, the authors developed regression equations relating construction costs to BMP size measured in cubic feet. The cost of excavation, control structure, appurtenances, design and engineering costs, sediment control and landscaping costs were all included in the definition of construction costs. Maintenance and land cost data were not collected. Due to the limited number of observations, strong statistical relationships could only be developed for some of the BMP types such as sand filters. The Brown and Schuler (1997) draw upon modified versions of the same data set used by Wieglund et al. (1986), Young et al. (1996), and EPA (1999) (Lambe et al.).

Wossink and Hunt (2003) performed a similar analysis using data from 40 BMPs in North Carolina. Unlike most of the cost estimation literature, statistical cost functions were estimated for both construction costs and maintenance costs. In addition, a procedure for estimating the opportunity cost of land occupied by the stormwater BMPs was reported. The data for the study were gathered from designers and property owners in North Carolina. The construction cost data were either the bid figure submitted by the contractor or the total amount of money spent on the project by a government agency. Maintenance costs were calculated by obtaining data on the amount of money that had been spent or on the amount of labor that each type of BMP required on an annual basis plus any intermittent costs such as dredging. More maintenance cost information was available for wet ponds and sand filters than for wetlands and bio-retention areas. The two explanatory variables used to predict costs were the size of the drainage area in acres and the curve number, a measure of a soil's ability to absorb water, of the drainage area.

The Southeastern Wisconsin Regional Planning Commission (SEWRPC) estimated the cost of the labor and material inputs needed to construct different BMPs based on an extensive review of the empirical literature. The study used engineering techniques to estimate the change in magnitude of these costs as the size of the BMP increases. The study includes low, moderate and high per unit cost estimates. For instance, a typical cost calculation included estimates of per unit clearing, excavation and landscaping costs as well as how the requisite amount of these activities increased with BMP size. No cost equations, however, were reported for overall classes of BMPs. Instead the study provided the information (formulas) necessary to estimate the cost of an arbitrarily sized BMP.

A generalized cost function, however, was derived based on the information provided in the SEWRPC study. First, a range of different size wet ponds (referred to as infiltration basins in SEWPRC) were identified. A total of 97 different wet pond sizes were used, ranging from 0.25 acres to 10 acres in increments of 0.1 acre. Next, The SEWRPC cost estimating procedure was used to estimate the cost of constructing the different wet pond sizes using the moderate unit costs. Finally, an exponential line, $Y = \beta_0 * X^{\beta}{}_1$, was fitted to the data and the results of the regression reported in the Table 3-7.

Table 3-7. Least Squares Regression of BMP size on Construction Costs

Parameter	Estimate	t-statistic
β_0	84884	439.99
β_1	0.979	859.09
R^2	0.998	

The California Department of Transportation study (2004) focused solely on retrofitting transportation sites in California with stormwater BMPs. Only the cost equation for sand filters was used because the analysis did not contain adequate data on wet ponds, constructed wetlands and bio retention areas. The few examples that were included had significant problems relating to unique aspects of California's geology and flora.[4]

Montgomery County, Maryland examined retrofit costs of stormwater features, especially retention ponds. A stormwater retrofit is an ambiguous term in that it can mean improving and/or expanding an existing BMP or installing stormwater BMPs on a land after it is has been developed. Both kinds of retrofits were addressed in the study. Using historical data, the agency responsible for stormwater retrofits developed an 80% confidence interval for cost-per-treated acre when retrofitting sites with retention ponds.

[4] The single retention pond in the study ended up failing because of problems measuring the height of the water table. Also, the swales monitored in the study were never fully vegetated despite . The vegetation that did develop (salt grass) leached a great deal of phosphorous back into the water during its winter dormancy.

The agency found that 80% confidence interval was $1,000-3,000 per treated acre for sites with existing stormwater infrastructure and $3,000-5,000 for sites without previous infrastructure (Lambe et al.).[5] In a similar type of study, the Washington State Department of Transportation estimated that the average cost of building retention ponds was $15,000 per impervious acre treated (Lambe et al.). The costs included in the study were traffic control during construction, project initiation costs, sales tax & engineering & design costs (Lambe et al.).[6] Lastly, mean and median cost data from the Santa Monica Urban Runoff Database, as published in DeWoody (2007), was reviewed. The City of Santa Monica implemented stringent stormwater BMP requirements in the mid-1990s. At the same time the city developed a database recording the type and cost of BMPs installed. The mean and median calculations reported in Table 3-4 come from data reported between 1996 and 2006 (DeWoody). The database also contained information on many different BMP types not relevant to this study. The relevant information from the database included here only relate to sand filters.

Lambe et al. (2005) provide one of the most comprehensive studies of stormwater BMP maintenance costs. Maintenance cost data were collected from 33 city and state agencies responsible for BMP oversight and maintenance for the report. Maintenance costs were for several types of BMPs including retention ponds, extended detention ponds, swales & bio-retention, and infiltration trenches. The reported cost data was then used to calculate an average annualized maintenance expense for different types of

[5] Unfortunately there is no mention regarding exactly what costs the agency included in these figures.
[6] From the economist's point of view, money spent on sales tax is not a cost, but a transfer payment. From the perspective of a municipality however, money spent on sales tax is a very salient expense. The effective sales tax rate in Washington State (state + local) is 8-9% for most localities in the state.

BMPs. The authors do not relate costs to BMP size and provides little detail about how the calculations were preformed.

3.2.2. Septic field retirement costs. Conceptually, the major costs of connecting existing homes using septic systems to city sewer include the excavation required to run interceptor and connector lines, materials costs of the pipe, manholes and structural fill, and the cost of backfilling and compacting. Some county health departments also require that old septic tanks be pumped out and filled in. In addition to the initial connection costs, the newly connected homes may necessitate increased pumping capacity as well as long-term maintenance costs. The magnitude of these costs depends on the proximity of the target development to the nearest trunk line, and the sub-division's housing density.

Two studies provided useful information to the development of the sewer connection cost screening tool (Speir and Stephenson; Environmental Partners Group). In both studies, the costs were estimated costs based on engineering estimates of the materials and labor needed to construct and provide sewer services. Unit costs for each element of the construction process was taken from published construction cost data. The Environmental Partners Group report also came with a spreadsheet showing the estimation process. The same basic approach taken in this spreadsheet was used in the cost screening tool. The unit cost estimates were updated using the 2007 RS Means Building Construction Cost Data (Waier).

3.2.3. Land conversion costs. Land conversion cost consist primarily of two parts, land price and land conversion costs. A long-term reduction in nutrient runoff from land conversion can be secured through simple fee purchase of the land or protected by a long-term easement. An easement would not require full land ownership, but would restrict the existing owner to certain types of land uses. The types of activities allowed under Virginia's land conversion offset policy have not been specified. Under an easement, however, the owner could still exclude others from the land and might continue to use the land for non-consumptive purposes, such as hunting, light recreation, etc. Since a land owner would be transferring fewer rights to the municipality when selling an easement than with a simple fee purchase, easements may be a less costly way for municipalities to generate nutrient reductions from land conversion.

Land conversion costs might include initial costs of establishing and maintaining the new land cover. For example, converting agricultural land to forest would include labor, equipment and material associated with tree planting. Land converted to lower value nutrient uses might also require some long-term maintenance. For example, reforesting existing agricultural land may require costs associated with maintenance and tending of newly established trees. Johnson et al. (1997) produced estimates of converting agricultural land to white pines. The costs incurred to establish the trees, only costs incurred during the first 3 years, was used as the estimate for land conversion costs. The conversion costs included site preparation, planting, replanting, mowing, herbicide application, shearing and insecticide application. Per acre conversion costs, the sum of costs incurred during years 1-3, were estimated to be $698 per acre in 1997 dollars (or $867/acre in 2006 dollars). The Johnson et al. (1997) study assumed that the land would be intensively used for Christmas tree production. Establishment costs could be less expensive for trees planted for conservation purposes than for Christmas tree production.

Though not a social opportunity cost, municipalities might consider forgone tax revenue that results from the government ownership of land as a relevant cost. Local governments often generate a large portion of tax revenue through property taxes. Property converted into lower valued uses could result in reduced tax revenue to the local government where the land conversion takes place. This expense could be modest, however, for crop and pasture land under use-value taxation. Use-value taxation is an option that many counties offer to qualified land holders to base the land holder's property tax obligation on the value of the land in its present use instead of the market price. Given existing use value tax rates for agricultural land, the forgone tax revenue of converting agricultural land under use-value taxation to open space is small compared to the same conversion of land at market prices.

3.3. Cost Screening Procedure for Offsets

A simple cost screening tool was then constructed to estimate the per pound nitrogen removal costs of securing non-point source offsets from stormwater BMPs, sewer connection, and land conversion. The cost screening tool was implemented via a Microsoft Excel spreadsheet. Cost estimates were based on readily available data to be inputted by the municipality. Default values were provided for many input parameters, such as nutrient removal efficiency, but the user was given the option to change the default values if site-specific information were available. The model assumed that two pounds of nitrogen reduction would need to be achieved in order to produce 1 pound of nonpoint offset (point source WLA) because of the 2:1 trading ratio requirement (as required by existing statute and regulation). After inputting basic information about the type and nature of the project, the screening model calculates the cost per pound of generating WLA annualized cost over 20 years. Additionally, a breakdown of the cost per pound into capital, maintenance, and land costs is given as well as an estimate of the total WLA generated by the offset.

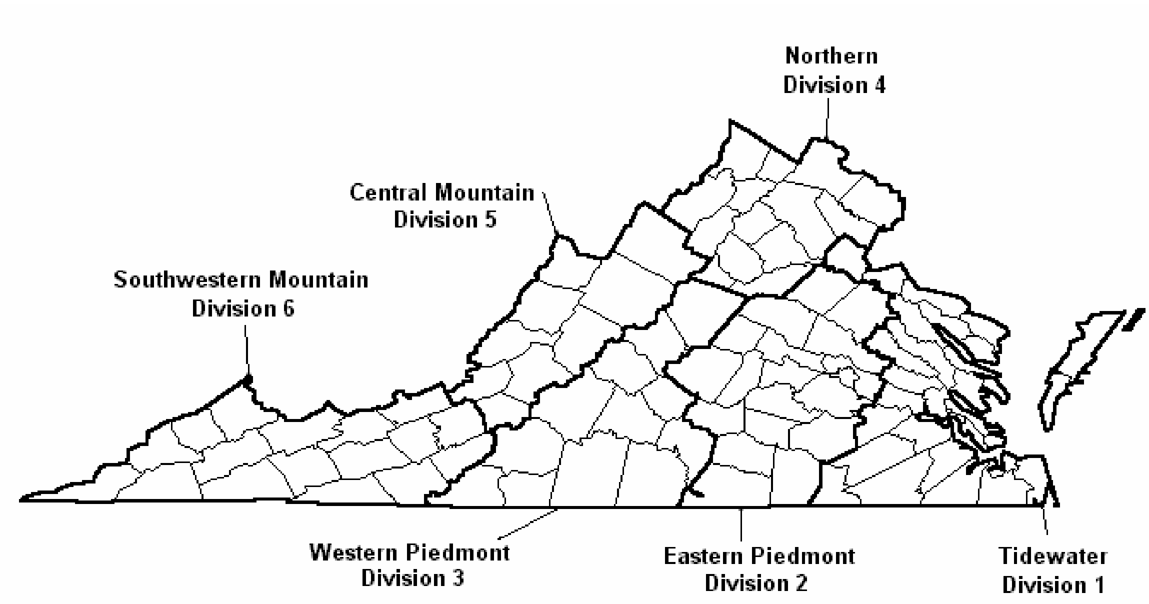
The screening tool made no adjustments for delivery ratios (the portion of nitrogen load delivered from one watershed segment to another segment). In other words, the model assumed that the non-point offset was generated within the same trading region as the point source. Regulations governing the spatial trade of non-point source offsets had not yet been finalized as of the summer of 2007.

The screening model assumed that the only reason for the offset project (urban stormwater BMP, septic retirement, and land conversion) was to provide nitrogen WLA to a new and expanding point source. Yet, any particular project may provide ancillary benefits or have multiple objectives. For example, a regional stormwater pond may also provide an aesthetic amenity to a public park area or additional flood protection for downstream properties. For this screening tool, all project costs were assigned to nitrogen reduction. Apportioning costs to different goals was not a feature that could be included in the screening procedure.

The screening procedure for stormwater BMPs is described first. Next, the screening procedure for sewer connection and land conversion are detailed.

3.3.1. Cost of Urban Stormwater BMPs **.**The screening tool estimates the cost for wet ponds, constructed wetlands, sand filters, and bioretention areas. The steps and data inputs needed to estimate the per pound cost to secure nitrogen offsets is described. The outputs of the model are then given.

The first step in the process is to calculate the runoff volume that results from a particular development. To estimate this, the user must enter information about the size of the drainage area, what region of Virginia the project will be located and the site's curve number. A map of the climatic zones is given in Figure 3-4. Including the different climatic zones was necessary because of the differences in rainfall totals, and thus runoff, between different parts of the Commonwealth.



Source: (Jesiek et al.)

Figure 3-4. Map of National Climatic Data Center Divisions for Virginia

A site's curve number is a measure of its permeability and can be used to predict the quantity of runoff that will occur from rainfall events. Some of the major factors that determine a site's curve number are its hydrological soil group, cover type (bare soil, vegetated, impervious etc) and the site's hydrological conditions (United States

Department of Agriculture Natural Resource Conservation Service). Sites with higher curve numbers are less able to absorb rainfall and generate large quantities of runoff than sites with lower curve numbers. With these inputs, the screening tool used a table provided by Jesiek et al. to look up the estimated the annual runoff volume as a function of the site's curve number and climatic zone.

Next, the user enters the average nutrient concentration in the runoff. The load from the site is calculated by multiplying the volume of runoff by the average runoff nutrient concentration to calculate nutrient loading from the site. The average nitrogen concentration in runoff was perhaps the most difficult of the user inputs to estimate. A default value of 2 mg/L was used. This default value was calculated by taking the weighted average from monitoring data compiled by the International Stormwater Best Management Practices Database (International Stormwater Best Management Practices Database). The database contained information on 71 monitored BMPs. Not all of the BMPs were monitored for incoming total nitrogen and many of the BMP monitored were not considered in the screening model. From this data, incoming total nitrogen flow for 11 BMPs sites from across the Eastern United States sites was collected. The average incoming nitrogen concentration from each of the 11 BMPs was weighted by the number of storm events for which data was collected, 346 in total. The weighted average total nitrogen concentration of runoff entering the BMPs was 1.94 mg/L with a standard deviation of 1.66 mg/L. The lowest average incoming concentration of the 11 BMP sites was 0.763 mg/L, the highest 7.89 mg/L and the median 1.607 mg/L. The highest total nitrogen concentration came from stormwater entering a sand filter in Alexandria, Virginia. Also, while the database provided descriptions of the structural BMPs, little or no information was provided about the physical features of the drainage area. Model users, however, were provided the opportunity to enter more site specific estimates of nitrogen concentrations.

The default nitrogen removal efficiency values for each type of stormwater BMP was provided in the model. Default values were taken from the Chesapeake Bay program (Chesapeake Bay Program 2006b). These default values closely aligned with other values reported in the literature (see Table 3-1). Users, however, were given option to adjust the default removal efficiency values.

After calculating the nutrient load, the user enters additional inputs needed to calculate the cost of the offset including the opportunity cost of land, the expected project life and the discount rate. The default project life and discount rate are 20 years and 7%, though these default values are editable. A complete list of inputs needed is given in Table 3-8.

Table 3-8. Input Variables for the Stormwater Portion of the Cost Screening Tool

Input Variable	Unit
Runoff and Concentration Inputs	
Site imperviousness	Curve Number
Climatic Zone	Categorical variable
Drainage Area	Acres
Average nitrogen concentration in runoff	mg/L
Nitrogen removal efficiency	Percent
Project Cost Inputs	
Opportunity cost of land	Dollars per Acre
Discount rate	Percent
Project life	Years

Using these inputs, the capital and operation and maintenance costs were estimated based on equations from the Wossink and Hunt (2003). These cost equations were chosen based on a several factors. First, the cost equations from the various studies were compared to examine their similarity. Figure 3-4 compares the retention pond construction cost equations after adjusting for inflation (2007 real dollars using the Consumer Price Index). The cost curves were all similar, with Wossink and Hunt (2003) being slightly more expensive than estimates provided in other studies. Second, the data from Wossink and Hunt came exclusively from the Mid-Atlantic Region. The Wossink and Hunt cost estimates also included cost equations for both construction and operation and maintenance costs. Third, Wossink and Hunt provided equations to calculate a BMP's surface area which in turn could be used to calculate the opportunity cost of land. Users were required to provide an estimate of the per acre land price of the land used for construction of the BMP (Table 3-5).

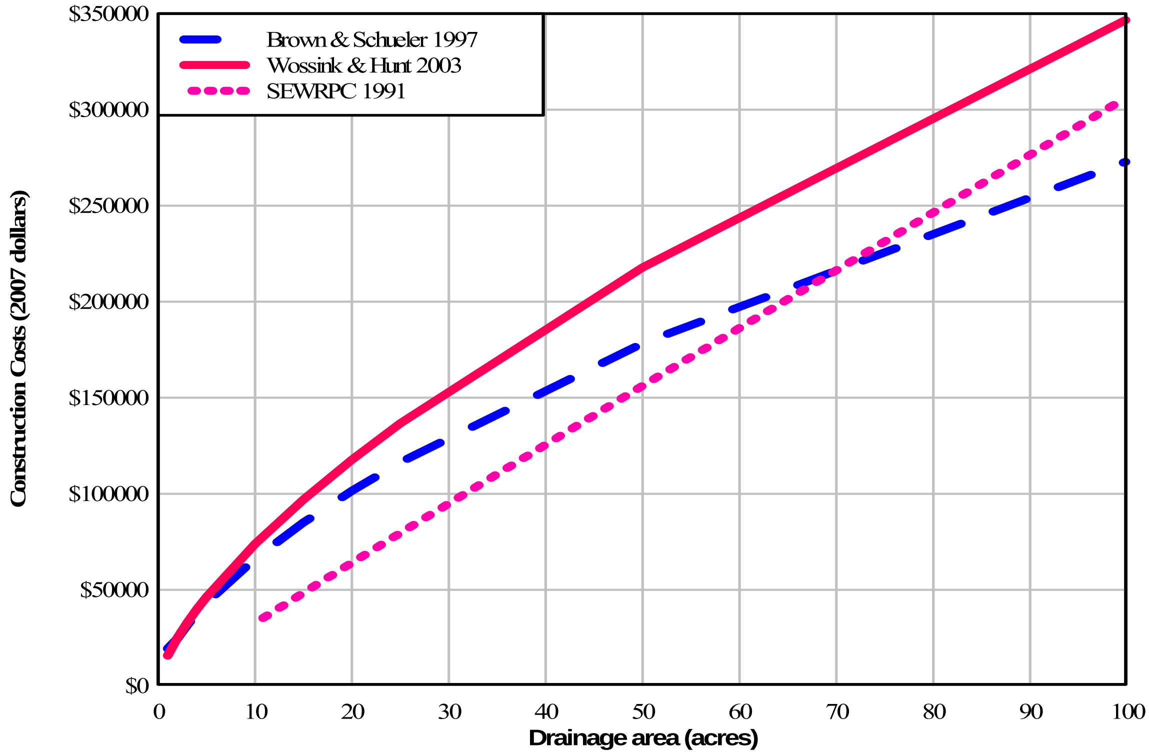


Figure 3-5. Retention Pond Construction Cost Curve Comparison in 2007 Dollars

The output of the screening tool produced a breakdown of the costs of implementing a stormwater BMP including, estimated construction costs, annual maintenance costs, land costs as well as annualized cost of generating a pound of nitrogen WLA. The annualized cost assumes a 20 year payback period at a 7% nominal interest rate though these values were editable. The total amount of WLA generated by the offset was also included.

3.3.2. Cost of Sewer Connection. The sewer connection screening model calculated the cost of a sewer distribution piping network to connect existing homes using septic system to a centralized sewer system. The model required the user to specify the basic dimensions of the distribution system. These inputs included the number of homes to be connected, the average frontage of each home, the length and diameter of the interceptor pipe, and the average distance between manholes. Choices for the diameter of the interceptor pipe are available as a drop-down menu in the screening tool. The necessary inputs and their units are given in Table 3-9.

Table 3-9. Inputs Variables for Sewer Connection Screening Procedure

Input Variable	Unit
Number of Homes to be Connected	Number
Average frontage per home	Linear feet
linear feet of interceptor line required	Linear feet
diameter of interceptor pipe required	Inches
approximate distance between man holes	Linear feet
Average nitrogen load per septic system	Lbs per year
Discount rate	Percent
Project life	Years

The quantity of collector pipe, the pipe that runs along individual streets, was calculated by multiplying the average frontage by the number of homes. The volume of soil to be excavated was calculated assuming the width of the trench is 1.5 feet wider than the diameter of the pipe and the depth of the trench needs to be 3 feet deeper than the diameter of the pipe (Speir). Also, bedding, usually gravel, needed to surround the area immediately around the pipe to prevent damage from compaction. It was assumed that 9 inches of gravel surround the pipe. The per unit cost estimates for the materials, excavation, backfill and compaction costs were taken from the 2007 RS Means Construction Cost Data (Waier).

The screening tool calculates the total nutrient reduction by multiplying the number of homes by the average nutrient reduction. The total nitrogen discharged to surface waters from an individual household septic system was assumed to be 17.85 pounds per home per year. The default value was based on the median estimate CH2MHill study mentioned earlier, but can be changed by the user (Table 3-9). The household nitrogen load from the septic system was assumed to be zero once connected to the centralized sewer system (no latent transport effects).

The output for the sewer connection component of the cost screening tool included an itemized list of costs, an annualized cost of generating nitrogen WLA, and the total amount of WLA generated by the offset. The annualized cost assumes a 20 year payback period with a 7% interest rate, though this can be changed by the user.

There are several caveats to the sewer connection component of the cost screening tool. First, to limit complexity, road demolition, road repair, pumping, wastewater treatment, and design costs were not included in the tool. Items such as road demolition costs can be extremely variable and with little *a prior* information from which to generate a cost estimate. For this reason the cost estimate should be considered a lower bound.

*3.3.3. Cost of land conversion***.** The land conversion component calculated land acquisition costs, land conversion costs, and nitrogen reduction from land conversion. To calculate land acquisition costs, the model required the user to input the cost of the land or easement and the quantity of land being converted (Table 3-10). If known, one-time legal transaction costs can be entered.

Table 3-10. Input Variables for the Land Conversion Portion of the Cost Screening Tool

Variable	Unit
Land or Easement Price	Dollars/Acre
Land Quantity	Acres
Original Land Use	Categorical
Post-Conversion Land Use	Categorical
Land Above the Fall Line	Yes / No
Transaction Costs (legal)	Dollars (Optional)
Discount rate	Percent
Project life	Years
Land conversion costs	Dollars/Acre

In some instances, land conversion may also require expenditure of resources to physically transform the original land use to another state. Sample land conversion costs were given in the screening tool for establishing alfalfa, switch grass and white pines (Virginia Cooperative Extension; Duffy and Nanhou; Johnson et al.). These estimates just provide a frame of reference for the user. The user was not restricted in what land conversion cost values that he or she could enter.

The screening tool used default the nutrient reduction value associated with the type of land conversion to generate load reduction estimates. The nutrient reduction values were taken from draft estimates discussed earlier and shown in Table 3-2 (Virginia Department of Environmental Quality). Land conversion choices came from a drop-down menu in the screening tool and were the same as those shown in Table 3-2. Since DEQ produced draft estimates of nitrogen reduction from land conversion above and below the fall line, the user was required to identify the location of the land conversion relative to the Shenandoah-Potomac fall line (Table 3-10)

The output of the cost screening tool was the annualized cost of generating nitrogen WLA as well as the total amount of WLA generated by the offset. The annualized costs assumed a 20 year payback period and 7% interest rate, though the user could change this if desired. The total WLA generated from land conversion was the estimated nitrogen reduction generated by the land conversion divided by the two (2:1 trading ratio).

3.4. Illustration

This section illustrates the use of the cost screening procedure and presents some cost estimates for the various offset types. The most cost effective offset option for a particular municipality will depend critically on the specific site conditions. The cost estimates presented here are not meant to imply that a particular kind of offset will always be less expensive than another. Instead the cost estimates are provided to establish the general range of costs that municipalities might face for WLA. The cost figures presented account for the 2:1 trading ratio required by law and represent the cost per year (as if paying back a loan) of generating nitrogen WLA. First a stormwater BMP example is given, followed by a sewer connection example and finally a land conversion example.

3.4.1. Stormwater illustration. The stormwater example examined the cost of WLA generated from installing stormwater BMPs on a hypothetical 25 acre residential development. The hypothetical development is located in the northern region of the Commonwealth, the site has a curve number of 75 and the opportunity cost of land is

$25,000 an acre. For this example, 6 mg/L average nitrogen concentration in runoff was assumed, this corresponds to a loading of approximately 66 lbs of nitrogen a year. Similar loading values were used in Brown & Schueler (1997) to compare the cost of different stormwater BMPs. While this is higher than the average noted earlier it is within the observed range of values and is therefore plausible.

Table 3-11. Stormwater Illustration Inputs

Input Variable	Values
Runoff and Concentration Inputs	
Site imperviousness	75
Climatic Zone	Northern
Drainage Area	25 acres
Average nitrogen concentration in runoff	6 mg/L
Nitrogen removal efficiency	Chesapeake Bay Program Values
Project Cost Inputs	
Opportunity cost of land	$25,000/acre
Discount rate	7%
Project life	20 Years

Using the inputs from Table 3-11, the cost screening spreadsheet generated the per-pound cost of generating WLA from a variety of different stormwater BMPs. The results for this example are presented in Figure 3-6.

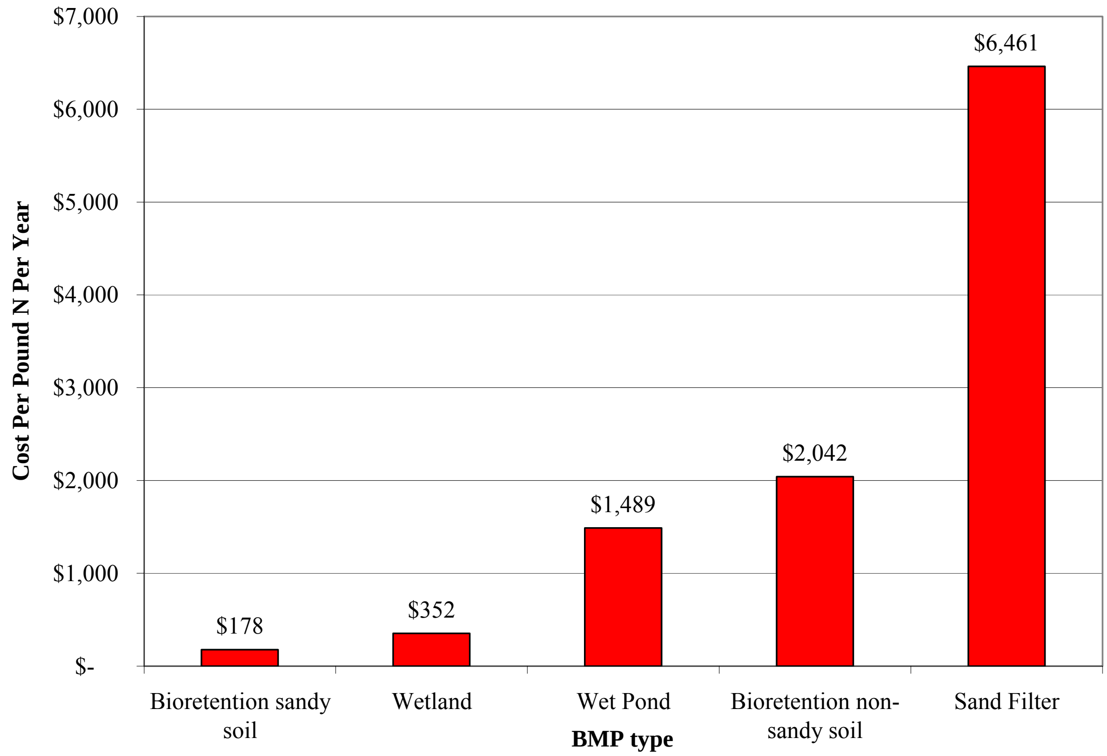


Figure 3-6. Annual Cost of Generating Nitrogen WLA from 25 Acre Hypothetical Residential Development

The least expensive options for generating WLA in this example was a bio-retention area or a wetland. Because Northern Virginia has little in the way of sandy soil, the $178 cost figure will likely not be applicable and the least expensive option is the wetland at $352 per year for 20 years to generate one pound of nitrogen WLA. Recall, these costs included the 2:1 trading ratio.

An important limitation to implementing stormwater BMPs is that they generate a relatively small quantity of WLA. For instance, implementing a stormwater BMP on the 25 acre development described earlier would only generate 9.9-16.5 pounds of nitrogen

WLA depending on the BMP that was constructed. Note that these small values were generated assuming a relatively high nitrogen influent concentration.

To provide a sense for the economies of scale incorporated into the model, Figure 3-7 and presents the costs of generating WLA from a 10 and 75 acre hypothetical residential development. All of the other parameters were identical to the first example.

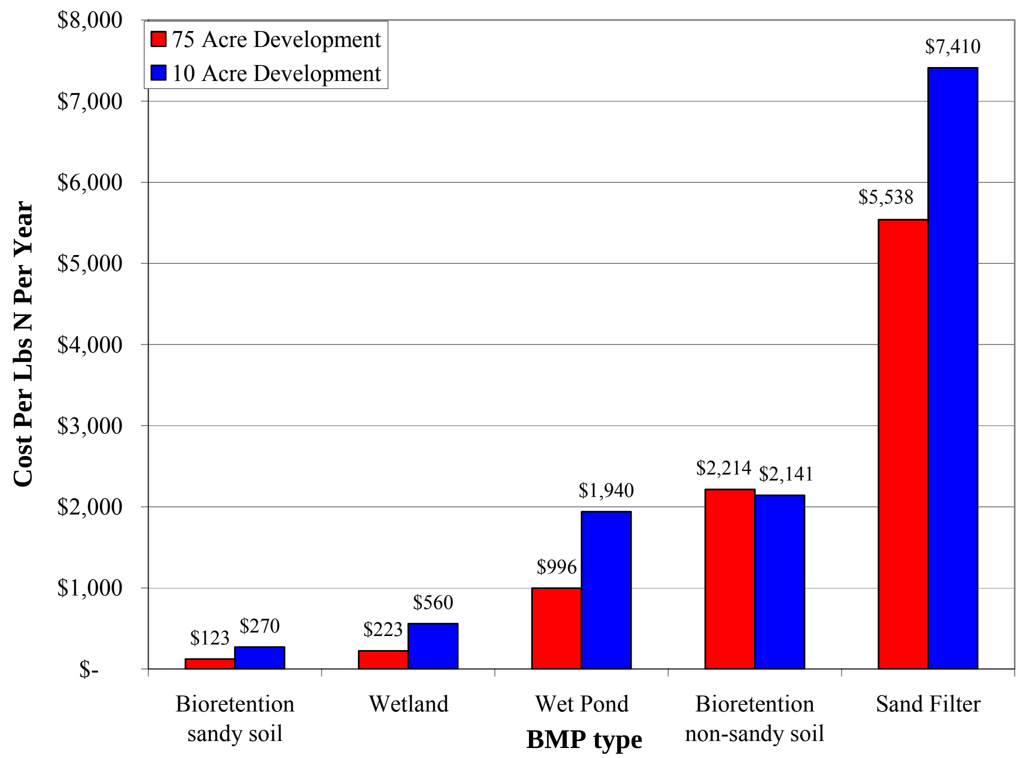


Figure 3-7. Cost of Generating Nitrogen WLA from 10 and 75 Acre Hypothetical Residential Developments

Changing the size of the residential development did not change the rank of the BMPs in terms of cost-effectiveness. tripling the size of the development did, however, decrease the cost of generating nitrogen WLA by 33% for most BMP types. While these economies of scale are significant, the elasticity of scale for this example is an unimpressive -0.165. This implies that a one percent increase in the scale of operation (size of the development being treated) will result in a 0.165% decrease in cost. Decreasing the size of the residential development from 25 acres to 10 acres increased the cost of generating WLA for most BMP types by approximately 60 percent. This implies an elasticity of scale close to 1, or that a 1 % increase in size decreases costs by 1%. This shows that there are significant returns to scale for small residential developments but that these returns dissipate quickly as development size increases.

These cost per pound estimates are a substantially higher than some previous work in the stormwater BMP literature. In an example similar to one presented here, Brown & Schueler (1997) estimated that nitrogen removal costs for a 25 acre residential development treated with a wet pond to be $202 per pound.[7] Using the procedure developed above and neglecting the 2:1 trading ratio, the annual nitrogen removal of wet pond draining a 25 acre site was estimated to be $744/lb/yr (neglecting the 2:1 trading ratio). Brown and Schueler (1997) used the same nutrient removal efficiencies and incoming nitrogen load as reported in Table 3-1). The difference between the two estimates was due to several factors. First, the cost estimate in this chapter included interest expense on the construction costs of the BMP. Interest costs, 7% on a 20 year loan, account for approximately half of the difference between the cost estimates. Second, the cost estimate in this chapter included the opportunity cost of land and maintenance expenses. These expenses account for 25% of the difference between the estimates. Lastly, the useful life of the BMP was different in the two examples, Brown & Schueler used 25 years while 20 was used in this chapter, and the equations used to

[7] The cost estimate from table 8 of Brown and Schueler (1997) is $20 per pound. There is a computational error in the 6th line of the table (quantity of nitrogen removed). Correcting for this error, the total construction cost divided by the quantity of nitrogen removed yields a cost estimate of $202 per pound.

generate the construction cost estimate were different as well. This result shows that the construction costs of a BMP can be a small portion of the total life-cycle costs.

3.4.2 Sewer connection illustration. The sewer connection example examined the cost of connecting a hypothetical 300 home residential development to the city sewer system. The assumed connection would necessitate running a mile of 15-inch diameter interceptor line from the treatment plant to the development. The average frontage for the homes is 119 feet[8] and manholes were assumed to be placed approximately every 500 feet.

With this information, the screening procedure calculated construction costs and presented the information as a series of line item costs as well as the cost of generating WLA. Table 3-12 presents the information for the example described above. The nitrogen load removed per year for each home is 17.85 pounds (approximately 5335 lbs of nitrogen reduction or 2,667 lbs WLA). Using a project life of 20 years at 7%, the estimated cost of generating WLA through septic connection was approximately $61 per pound of WLA. As noted above, this cost should be considered a lower bound estimate.

[8] This corresponds to homes on 1 acre lots arranged in a grid with a length to width ratio of 3:1. A similar configuration was used in Speir and Stephenson, 2002.

Table 3-12. Cost of Sewer Connection for a 300 Home Hypothetical Development

Materials costs	Quantity	unit		unit cost		total cost
8 inch diameter collector pipe[a]	35,700	l.f.	$	13.60	$	485,520
interceptor pipe [b]	5,280	l.f.	$	25.00	$	132,000
Manholes [c]	71	each	$	3,848.00	$	273,208
Bedding						
needed for collector pipes [d]	5746	c.y.	$	16.45	$	94,514
needed for interceptor pipe [d]	1239	c.y.	$	16.45	$	20,380
Excavation costs						
collector pipe excavation [e]	10,504	c.y.	$	5.65	$	59,349
interceptor pipe [f]	2,286	c.y.	$	6.25	$	14,285
Backfill & Compaction [g]	12,790	c.y.	$	51.00	$	652,282
				Total Cost	$	1,731,538
				Annualized Cost		$163,445
				Cost of generating WLA (per pound per year)	$	61.04

Note: RS Means reference codes
[a] 33311315208
[b] 334114 (12-36 inch diameters)
[c] 334913101120
[d] 310516100600
[e] 312316130090
[f] 312316130500
[g] 231500150600

3.4.3. Land conversion illustration. The land conversion example examined the cost of generating WLA by converting a hypothetical 100 acre of cropland into forest. A range of land prices of 5,000, 10,000, and $25,000 were assumed. The higher land price might reflect fee simple purchases of land in areas around urban fringes of areas in the Shenandoah basin. Lower range values might better reflect the option of generating WLA through the purchase of long-term easements. These easements might be able to be purchased at a significantly lower price than the cost of land. A county planning agency might be able to work such an easement into conservation oriented development plans. It is increasingly common for developments to cluster the construction of homes together and then provide green space held in-common by residents on the undisturbed land. It is possible that this kind of development could be encouraged and a conservation easement could be purchased on the green space. The county would acquire WLA and the residents of the development would have a lower tax bill on the land held in common while maintaining all of its amenity value. Because the residents would be giving up little in the way of use rights, it is possible that they would sell the easement rights at a significant discount to purchasing land.

Table 3-13. Land Conversion Illustration Values

Variable	Unit
Land or Easement Price	$5000, $10000, and $25000/Acre
Land Quantity	100 Acres
Original Land Use	Crop Land
Post-Conversion Land Use	Forest
Land Above the Fall Line	Yes
Transaction Costs (legal)	$0
Discount rate	7%
Project life	20 Years
Land conversion costs	$867 Dollars/Acre

Because the land was assumed to be converted into forest, this example also included land conversion costs. The default value of $867 an acre was assumed in converting cropland to white pines (Johnson et al.). No transaction costs were assumed.

Given these inputs (Table 3-13), a 100 acre conversion would generate 800 lbs of WLA. Assuming a 20 year loan and 7 percent discount rate, the cost of generating this

WLA would be $58, $117 and $294 per pound of WLA per year depending on initial land acquisition costs. This shows that land conversion can be less expensive than the cost of generating WLA from stormwater BMPs .

3.4.4. Illustration summary. The cost illustration section shows generally the range of costs that municipalities can expect when generating WLA. Table 3-14 gives a summary of the examples considered above. The cost of generating WLA from stormwater BMPs and land conversion was in excess of $100 per pound. The cost of WLA from septic was significantly lower at $61 per pound, however, this estimate does not include costs relating to the demolition and reconstruction of roads needed when running sewer lines or incremental pumping costs. While there are some economies of scale when installing stormwater BMPs, the savings were found to diminish quickly as site size increased. Perhaps the most interesting information to come from this example is how much WLA could be generated from each type of offset. Connecting 300 homes to the sewer could generate 2667 lbs of WLA. By contrast, converting 100 acres of cropland to forest would generate 800 lbs and installing a stormwater BMP on a 25 acre stormwater example would at best generate only 16.5 lbs of WLA. The orders of magnitude difference between these numbers likely necessitates that stormwater BMPs cannot be used to generate significant quantities of WLA.

Table 3-14. Summary of Costs for Offset Illustrations

BMP Type	Cost of Generating Nitrogen WLA	Quantity of WLA Generated (lbs)
Bio-retention Sandy Soil	\$123 - \$270	7 – 49
Wetland	\$223 - \$560	4 – 30
Wet Pond	\$996 - \$1,940	4 – 30
Bio-retention non-sandy soil	\$2,141 - \$2,214	7 – 49
Sand Filter	\$5,538 - \$7,410	5 – 39
Sewer Connection (lower bound)	\$61	2,667
Land Conversion (100 acre)	\$58 - \$294	800

3.5 Unresolved Baseline Issues

There are a number of unresolved factors that could influence the final cost estimates provided above. There is still significant legal uncertainty surrounding the generation of WLA under the emerging Virginia offset policy. One of the most important legal factors affecting the generation of WLA relates to the clause from the Virginia Nutrient Credit Exchange Act that states that offsets must be generated from practices "beyond those already required by or funded under federal or state law, or Virginia Tributary strategies plans" (Section 62.1-44.19:15 B. 1. b). In effect, the law establishes a baseline for when actions that result in decreased nutrient loadings can be counted towards the generation of WLA. Understanding what portion of the physical nutrient reduction from different non-point source offsets that can be counted as WLA is a necessary step in estimating cost-effectiveness.

The role of the Virginia tributary strategies in setting baseline policy has not yet been firmly established. The tributary strategies are a series of planning documents developed by the Commonwealth to identify the steps necessary to meet nutrient reduction goals for the Bay in each of Virginia's tributaries in the Bay watershed (Virginia Office of the Governor 2005). The tributary strategies by themselves are not legal or regulatory requirements, but rather a series of government planning documents. The tributary strategies contain goals relating to both point and non-point sources. Examples of goals set in the tributary strategies are targets for the installation of agricultural and stormwater BMPs.

Recently, VA DEQ released a draft outlining the baseline requirements for non-point source offsets including the relevant non-point source requirements of the Shenandoah-Potomac Tributary Strategy (Virginia Department of Environmental Quality). The DEQ draft document mentions two different kinds of baseline requirements. The first are prerequisites that a municipality must achieve before claiming certain kinds of non-point source offsets. The second kind of requirement details what portion of the physical nutrient reduction from different types of non-point source offsets can be counted towards the generation of WLA. Each has important implications for the cost of generating offsetting WLA.

First, the draft framework lists four prerequisites that localities must meet before they can generate credits from developed urban land (Virginia Department of Environmental Quality).

1. Jurisdiction's program must be determined by DCR to be consistent with the erosion and sediment control law (ESC)
2. Jurisdiction's program must be determined by DCR to be consistent with applicable stormwater management program (SWM)
3. Jurisdiction must be in compliance with applicable Municipal Separate Storm Sewer (MS4) permit requirements
4. Jurisdictions within the statutorily defined "Tidewater Virginia" must be found consistent with Chesapeake Bay Preservation Act (CBPA) requirements

If a municipality is in compliance with these four provisions it then has a number of options by which to generate offsets including stormwater BMPs and sewer connection.

Thus, defining baselines for urban stormwater BMPs includes existing permitting requirements. Municipalities with separate stormwater sewer system and a population greater than 100,000 people are required by federal law to hold a permit governing the stormwater discharges. These permits, often referred to as MS4 permits, often include language requiring municipalities to implement stormwater practices "to the maximum extent practicable." Because of this, any stormwater BMP enhancements could be interpreted as "practicable" and become requirements of the MS4 permits. If nitrogen reduction stormwater projects are viewed as falling under the coverage of MS4, then it is unclear how any offsets could be claimed through stormwater BMP implementation. Significant regulatory uncertainty exists regarding how the requirements of MS4 permits will be interpreted.

The draft document does not include any specific requirements relating to sewer connection. Instead sewer connection is treated as one of the possible BMPs possible on developed lands. One uncertainty exists, however, regarding sewer connection motivated by health concerns. If a county were compelled to connect homes with failing septic systems for health reasons then the action might be seen as a requirement of state or federal law and thus not eligible for generating WLA.

Second, the draft regulations also propose that a strategy allocation reduction factor (SARF) be applied to physical nutrient reductions generated from developed lands. In the 2005 Shenandoah-Potomac Tributary Strategy a goal for urban and suburban land was to install BMPs on 74% of urban/suburban lands (Virginia Office of the Governor 2005 page v). VA DEQ views this goal as a requirement of the tributary strategy (Virginia Department of Environmental Quality). Because of this, for every pound of physical nutrient reduction secured from BMPs implemented through stormwater BMPs or sewer connection, only 26% of the reduction can be counted towards the generation of WLA. If the SARF is applied, then all per unit costs reported above from stormwater BMPs and septic retirement would need to be revised by multiplying by 3.8 (100/26). Obviously, the application of SARF would have tremendous implications on the cost of generating offsets from stormwater BMPs and septic conversions.

The discussion draft includes another set of requirements related to land conversion and agricultural BMPs. Section one of the June 30, 2006 discussion draft outlines the tributary strategy requirements for agricultural land (Virginia Department of Environmental Quality). The baseline requirement for agricultural offsets is that farm land should have conservation tillage, cover crops, livestock stream exclusion, nutrient management, riparian buffers and permanent vegetative cover on critically eroding areas. The agricultural baseline requirements are important to the land conversion because the change in nutrient loads calculated by DEQ assumes that agricultural land has implemented all baseline BMPs. The list of standard nutrient reduction reported earlier in section 3.1.3, already include these requirements. The list of standard reductions does not, however, account for the two to one trading ratio nor does it account for the problem of delivery ratios.

3.6 Conclusion

In this chapter a cost screening procedure was developed that local governments can use to estimate the cost of nutrient removal from non-point source offsets under their control. The least expensive type of offset for a municipality to implement will depend heavily on-site specific conditions. That being said, the legal uncertainty surrounding stormwater BMPs coupled with their high cost and limited ability to generate WLA raise doubts about their wide spread use. While there may be numerous reasons for constructing stormwater BMPs , the high cost and legal uncertainty will likely limit the use of stormwater BMPs as an nitrogen offset generating activity. Generating land conversion credits through the purchase of easements is potentially the least expensive of the three urban offset options investigated. Enterprising county governments that encourage cluster developments with their zoning ordinances may be able to purchase easements less expensively than the $5,000 an acre estimated in the land conversion illustration. The potential for generating WLA in this way, however, cannot be fully evaluated until the final rules regarding easements are established.

One of the most important results of this chapter is that the estimated cost of generating nitrogen WLA from non-point sources under the control of municipalities was many times more expensive than reducing nitrogen discharges from wastewater treatment plants. Recall that the estimated marginal cost of nutrient removal from WWTPs was $13.19 at the Virginia Program cap. This is an order of magnitude less than the cost of generating WLA from stormwater BMPs installed on a 25 acre residential development, and substantially lower than offsets under either the septic retirement or land conversion options. These large differences in cost may provide an incentive for municipalities to avoid expanding their WWTPs. This avoidance could occur, for example, by increased reliance on decentralized septic systems.

3.6.1. Future research. The high cost of generating WLA from non-point sources under municipal control may lead some municipalities to consider contracting with third parties to implement agricultural BMPs or other practices that might generate WLA at a lower cost. Municipalities have been reluctant to contract with third parties because if the third party does not implement the agreed offsets the municipality is out of compliance with its VPDES permit. One way a municipality could manage its risk of non-compliance when contracting with third parties is to fund more offsets than needed, with the expectation that some of the BMPs may not be implemented. The feasibility of managing risk in this manner is a possible extension of this research. The feasibility would depend heavily on the cost of generating WLA from agricultural BMPs which is also a topic that requires further investigation. Other possibilities include investigating the feasibility of additional end of pipe treatment and gray water reuse or increasing the assimilative capacity of local ecosystems.

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Appendices

Appendix A: Integer Programming Model Data

						Delivered Load if plant implemented upgrades			
Facility	permit #	Design Flow	2010 Projected Flows	2010 baseline TN concentration	2010 Baseline TN delivered load	8 mg/L TN delivered	5 mg/L delivered load	3 mg/L delivered load	Waste Load Allocation
Fisherville	VA0025291	2	1.53	12.06	23,670	15,699	9,812	5,887	48,729
Luray	va0062642	1.6	1.36	4.69	8,139	13,878	8,674	5,204	19,492
Massanutten	va0024732	2	0.77	13.98	13,697	7,838	4,899	2,939	18,273
Middle River	va0064793	6.8	4.45	5.61	31,920	45,539	28,462	17,077	82,839
North River	VA0060640	16	12.26	6.78	106,373	125,497	78,436	47,062	253,391
Stuarts Draft	VA0066877	2.4	1.46	5.03	9,358	14,899	9,312	5,587	48,729
Waynesboro	VA0025151	4	3.27	9.69	40,531	33,448	20,905	12,543	48,729
Weyers Cave	VA0022349	0.5	0.51	34.63	22,627	5,227	3,267	1,960	6,091
Front Royal	VA0062812	4	4.06	6.91	55,598	64,369	40,231	24,138	48,729
New Market	VA0022853	0.5	1.00	14.00	27,688	15,822	9,889	5,933	6,091
Stoney Creek	VA0028380	0.6	1.10	18.70	40,850	17,476	10,923	6,554	7,309
Strasburg	VA0020311	0.98	1.19	9.69	22,800	18,815	11,759	7,055	11,939
Opequon	VA0065552	8.4	7.27	5.55	90,973	131,151	81,970	49,182	102,336
Parkins Mill	VA0075191	2	2.43	11.07	60,672	43,842	27,401	16,441	60,911
Purecellville	VA0022802	1	0.60	8.59	13,011	12,117	7,573	4,544	18,273
Leesburg	MD0066184	10	4.57	5.73	66,181	92,399	57,749	34,650	121,822
Round Hill	VA0026212	0.5	0.15	18.70	7,092	3,034	1,896	1,138	9,137
DSC #1	VA0024724	4	3.32	3.46	34,945	80,903	50,564	30,339	42,029
DSC #8	VA0024678	4	3.53	4.30	46,223	86,057	53,785	32,271	42,029
HL Mooney	VA0025101	24	13.67	7.35	306,204	333,070	208,169	124,901	219,280
UOSA	VA0024988	54	33.81	15.18	906,570	477,834	298,646	179,188	1,315,682
Alexandria SA	VA0025160	54	39.83	8.00	970,712	970,712	606,695	364,017	493,381

Arlington	VA0025143	40	29.25	8.42	750,148	712,729	445,456	267,274	365,467
Normal-Cole	VA0025364	67	42.58	7.77	1,007,324	1,037,516	648,448	389,069	612,158
Quantico	VA0028363	2.2	0.76	11.30	26,169	18,522	11,576	6,946	20,101
Aquia	VA0060968	6.5	4.67	7.18	102,209	113,868	71,167	42,700	73,093
Colonial Beach	VA0026409	2	0.98	8.50	25,477	23,974	14,984	8,990	18,273
Dahlgren SD	VA0026514	1	0.16	7.86	3,885	3,956	2,472	1,483	9,137
NSWC-Dahlgren	VA0021067	0.72	0.33	5.17	5,210	8,063	5,040	3,024	6,578

Appendix A Cont

Facility	permit #	Delivery Ratio	Capital costs (Incremental) 8mg/L	5mg/L	3 mg/L
Fisherville	VA0025291	0.42	$ 790,000	$ 1,636,850	$ 2,360,170
Luray	va0062642	0.42	$ -	$ -	$ 2,013,574
Massanutten	va0024732	0.42	$ 2,548,725	$ 869,735	$ 1,002,125
Middle River	va0064793	0.42	$ -	$ 3,489,698	$ 6,519,322
North River	VA0060640	0.42	$ -	$ 7,040,990	$ 14,491,030
Stuarts Draft	VA0066877	0.42	$ -	$ -	$ 2,706,766
Waynesboro	VA0025151	0.42	$ 2,924,004	$ 2,408,870	$ 4,093,150
Weyers Cave	VA0022349	0.42	$ 2,374,508	$ 627,970	$ 736,700
Front Royal	VA0062812	0.65	$ 50,000	$ 2,408,870	$ 4,093,150
New Market	VA0022853	0.65	$ 2,374,508	$ 627,970	$ 736,680
Stoney Creek	VA0028380	0.65	$ 2,444,284	$ 724,676	$ 842,850
Strasburg	VA0020311	0.65	$ 886,903	$ 1,092,159	$ 1,246,296
Opequon	VA0065552	0.74	$ -	$ 4,107,314	$ 7,905,706
Parkins Mill	VA0075191	0.74	$ 97,000	$ 1,636,850	$ 2,360,170

Purecellville	VA0022802	0.83	$ -	$ 1,250,840	$ 1,493,680
Leesburg	MD0066184	0.83	$ -	$ 2,736,978	$ 4,829,666
Round Hill	VA0026212	0.83	$ 2,374,508	$ 627,970	$ 736,700
DSC #1	VA0024724	1.00	$ -	$ 1,060,000	$ 4,093,150
DSC #8	VA0024678	1.00	$ -	$ 2,408,870	$ 4,093,150
HL Mooney	VA0025101	1.00	$ -	$ 8,011,100	$ -
UOSA	VA0024988	0.58	$ 22,601,459	$ 21,709,370	$ 47,417,650
Alexandria SA	VA0025160	1.00	$ -	$ 20,000,000	$ 55,000,000
Arlington	VA0025143	1.00	$ -	$ 16,305,230	$ 35,286,790
Normal-Cole	VA0025364	1.00	$ -	$ 26,727,500	$ 58,682,020
Quantico	VA0028363	1.00	$ 1,722,985	$ 1,714,052	$ 2,533,468
Aquia	VA0060968	1.00	$ 8,000,000	$ 4,000,000	$ -
Colonial Beach	VA0026409	1.00	$ 90,000	$ 3,360,000	$ 2,360,170
Dahlgren SD	VA0026514	1.00	$ 30,000	$ 520,000	$ 1,493,680
NSWC-Dahlgren	VA0021067	1.00	$ -	$ 531,264	$ 630,530

Appendix A Cont 2.

		O&M costs (total)			Annualized cost (incremental)	
Facility	permit #	8mg/L	5mg/L	3mg/L	8mg/L	5mg/L
Fisherville	VA0025291	$ 14,425	$ 45,787	$ 97,539	$ 88,995	$ 200,294
Luray	va0062642	$ -	$ -	$ 86,910	$ -	$ -
Massanutten	va0024732	$ 50,186	$ 11,663	$ 28,773	$ 290,768	$ 93,760
Middle River	va0064793	$ -	$ 91,418	$ 187,023	$ -	$ 420,821
North River	VA0060640	$ -	$ 169,762	$ 341,889	$ -	$ 834,382
Stuarts Draft	VA0066877	$ -	$ -	$ 108,168	$ -	$ -
Waynesboro	VA0025151	$ 57,932	$ 72,553	$ 150,685	$ 333,937	$ 299,933
Weyers Cave	VA0022349	$ 47,238	$ 13,520	$ 35,082	$ 271,375	$ 72,796

Front Royal	VA0062812	$ -	$ 72,553	$ 150,685	$ 4,720	$ 299,933
New Market	VA0022853	$ 46,327	$ 18,921	$ 49,095	$ 270,464	$ 78,197
Stoney Creek	VA0028380	$ 48,336	$ 8,538	$ 21,635	$ 279,059	$ 76,942
Strasburg	VA0020311	$ 42,119	$ 28,725	$ 68,883	$ 125,836	$ 131,817
Opequon	VA0065552	$ -	$ 131,438	$ 267,606	$ -	$ 519,140
Parkins Mill	VA0075191	$ 922	$ 45,787	$ 97,539	$ 10,078	$ 200,294
Purecellville	VA0022802	$ -	$ 32,404	$ 70,966	$ -	$ 150,474
Leesburg	MD0066184	$ -	$ 51,194	$ 105,691	$ -	$ 309,545
Round Hill	VA0026212	$ 47,177	$ 5,088	$ 13,203	$ 271,314	$ 64,364
DSC #1	VA0024724	$ -	$ 24,433	$ 150,685	$ -	$ 124,490
DSC #8	VA0024678	$ -	$ 72,553	$ 150,685	$ -	$ 299,933
HL Mooney	VA0025101	$ -	$ 267,500	$ 424,845	$ -	$ 1,023,691
UOSA	VA0024988	$ 394,910	$ 466,998	$ 931,433	$ 2,528,328	$ 2,516,209
Alexandria SA	VA0025160	$ -	$ 592,000	$ 800,000	$ -	$ 2,479,859
Arlington	VA0025143	$ -	$ 489,067	$ 976,927	$ -	$ 2,028,165
Normal-Cole	VA0025364	$ -	$ 915,682	$ 1,824,784	$ -	$ 3,438,569
Quantico	VA0028363	$ 47,642	$ 48,464	$ 102,854	$ 210,279	$ 210,258
Aquia	VA0060968	$ 160,000	$ 35,000	$ -	$ 915,143	$ 412,572
Colonial Beach	VA0026409	$ 740	$ 39,766	$ 97,539	$ 9,235	$ 356,926
Dahlgren SD	VA0026514	$ -	$ 13,535	$ 70,966	$ 2,832	$ 62,619
NSWC-Dahlgren	VA0021067	$ -	$ 15,661	$ 41,914	$ -	$ 65,809

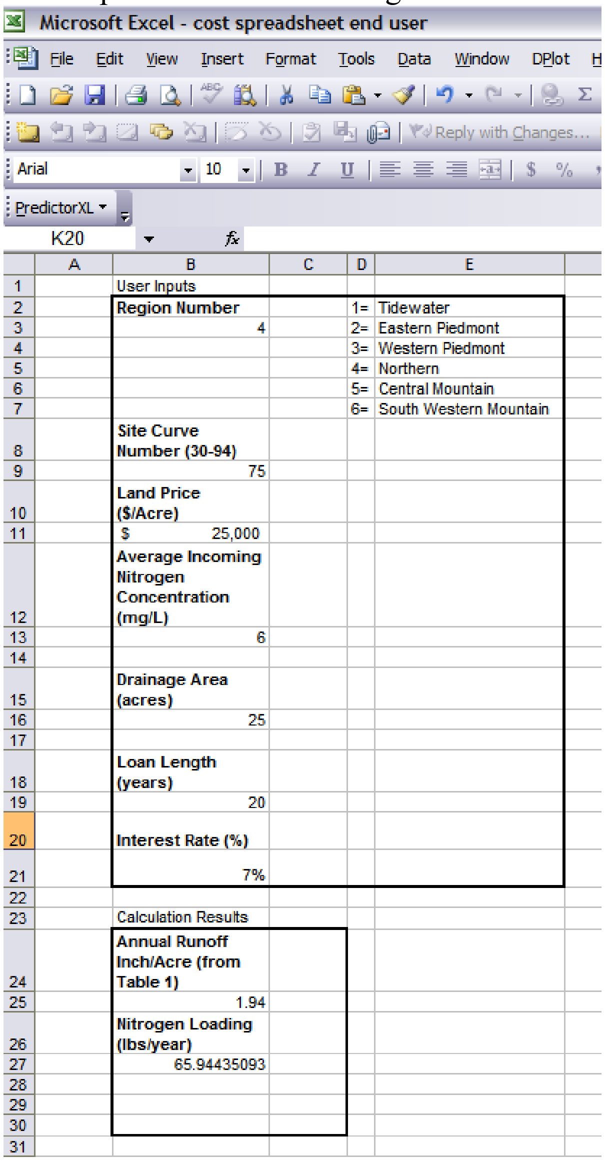
Appendix A Cont 3

Facility	permit #	Annualized cost (incremental) 3 mg/L	Reduction in load from implementing upgrades 8mg/L	5mg/L	3mg/L
Fisherville	VA0025291	$ 320,322	7,971	5,887	3,925
Luray	va0062642	$ 276,977	0	0	2,935
Massanutten	va0024732	$ 123,367	5,859	2,939	1,959
Middle River	va0064793	$ 802,401	0	3,458	11,385

North River	VA0060640	$ 1,709,740	0	27,937	31,374
Stuarts Draft	VA0066877	$ 363,668	0	47	3,725
Waynesboro	VA0025151	$ 537,049	7,083	12,543	8,362
Weyers Cave	VA0022349	$ 104,621	17,399	1,960	1,307
Front Royal	VA0062812	$ 537,049	0	15,367	16,092
New Market	VA0022853	$ 118,632	11,866	5,933	3,955
Stoney Creek	VA0028380	$ 101,194	23,374	6,554	4,369
Strasburg	VA0020311	$ 186,525	3,985	7,055	4,704
Opequon	VA0065552	$ 1,013,849	0	9,004	32,788
Parkins Mill	VA0075191	$ 320,322	16,829	16,441	10,961
Purecellville	VA0022802	$ 211,959	894	4,544	3,029
Leesburg	MD0066184	$ 561,577	0	8,431	23,100
Round Hill	VA0026212	$ 82,742	4,058	1,138	758
DSC #1	VA0024724	$ 537,049	0	0	4,606
DSC #8	VA0024678	$ 537,049	0	0	13,952
HL Mooney	VA0025101	$ 424,845	0	98,035	83,268
UOSA	VA0024988	$ 5,407,324	428,737	179,188	119,458
Alexandria SA	VA0025160	$ 5,991,611	0	364,017	242,678
Arlington	VA0025143	$ 4,307,750	37,418	267,274	178,182
Normal-Cole	VA0025364	$ 7,363,952	0	358,877	259,379
Quantico	VA0028363	$ 341,995	7,646	6,946	4,631
Aquia	VA0060968	$ -	0	31,042	28,467
Colonial Beach	VA0026409	$ 320,322	1,503	8,990	5,993
Dahlgren SD	VA0026514	$ 211,959	0	1,413	989
NSWC-Dahlgren	VA0021067	$ 101,432	0	170	2,016

Appendix B: Screen Shots of Cost Screening Tool

B1. Inputs for Cost Screening Tool



B2. Typical Stormwater Output

	A	B	C	D	E	F	G	H
1	Constructed Wetlands							
2								
3	Size of Drainage area (acres)	25						
4	Price of Land ($/acre)	$ 25,000						
5	Type of development	1						
6	1 Mildly impervious							
7	2 Highly impervious							
8	3 100% impervious (parking lot)							
9	**Nitrogen Removal Efficiency**	30%	Editable					
10								
11	Quantity of Nitogen Entering BMP (Lbs/Year)	65.94						
12	Quantity of Phospherous Entering BMP (Lbs/Year)	0.00						
13	Loan length for land and construction costs (years)	20						
14	Loan interest rate	7%						
15								
16	Construction Costs	Annual Maintenance costs	Necessary land size (acres)	Land Costs	Annualized cost of ownership	Cost Per Lbs of Nitrogen Reduction	Cost Per Lbs of Generating Nitrogen WLA	Total WLA Generated (lbs/yr)
17	$18,293	$865	0.375	$9,375.00	$3,477.00	$ 175.75	$351.51	9.89
18								
19	**List of Potential Removal Efficiencies**							
20	Study	Nitrogen	Phospherous					
21	Wossink & Hunt	28%	46%					
22	Brown & Schueler	30%	47%					
23	Chesapeake Bay Program	30%	50%					

B3. Sewer Connection Screen

Inputs				
Number of Homes to be Connected	300			
Average frontage per home (linear ft)	119			
Avg nitrogen reduciton per home per year (lbs)	23.5			
linear feet of interceptor line required	5280			
diameter of interceptor pipe required (inches)	15			
approximate distance between man holes (ft)	500			
loan period (years)	20			
load rate	7%			
Materials costs	Quantity	unit	unit cost	total cost
8 inch diameter collector pipe	35,700	l.f.	$ 13.60	$ 485,520
interceptor pipe	5,280	l.f.	$ 25.00	$ 132,000
Manholes	71	each	$ 3,848.00	$ 273,208
Bedding				
needed for collector pipes	5746	c.y.	$ 16.45	$ 94,514
needed for interceptor pipes	1239	c.y.	$ 16.45	$ 20,380
Excavation costs				
collector pipe excavation	10,504	c.y.	$ 5.65	$ 59,349
interceptor pipe	2,286	c.y.	$ 6.25	$ 14,285
Backfill & Compaction	12,790	c.y.	$ 51.00	$ 652,282
			Total Cost	$ 1,731,538
			Annualized Cost	$163,445
			Cost of generating WLA (per pound per year)	$ 46.37
			Total WLA Generated (lbs/yr)	3,525

B4. Land Conversion Inputs

	A	B	C	D	E
1	**Land Conversion**				
2					
3	Inputs				
4	Average Price per Acre	$ 10,000.00			
5	Number of Acres	100			
6	Orginal Land use	Cropland			
7	Post-Conversion Land Use	Forest		Suggested Conversion Costs (per/acre)	
8	Is the Land Above the Fall Line?	Yes		Forest	$867
9	Conversion Costs	174		Switch Grass (Hay)	$174
10				Alfalfa	$247
11	Transactions/Legal Costs	0			
12					
13	Length of Loan (years)	20			
14	Interest Rate	7%			
15					

B5. Land Conversion Output

Quantity of Nitrogen Removed per acre	Total Nitrogen Removed	Land Costs	Conversion Costs	Annualized Cost	Cost of physical reduction	Cost of WLA per pound per year	Total WLA Generated (lbs/yr)
16.05	1605	1000000	$ 174.00	$94,409.35	$ 58.82	$ 117.64	803