Maintaining a Nitrogen Cap for Virginia's Potomac River: The Contribution of Alternative Development Patterns

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Maintaining A Nitrogen Cap for Virginia's Potomic River -- Todd Michael Doley

Abstract: The Chesapeake Bay, once one of the worlds most productive estuaries, has been severely impacted by human activity in the water and on the lands around it. Viewed as an ecosystem, the Bay is no longer able to support the variety and abundance of biota that it was historically able to. Several decades of research on the Chesapeake have pointed to human activities as being the principle reason for this decline. Of these detrimental activities, elevated inputs of Nitrogen and Phosphorus to the Bay were singled out as being the greatest cause of water quality deterioration.

The state of Virginia is trying to reduce its annual load of Nitrogen, to the Potomac River, to 60% of what the load was estimated to be in 1985. Virginia would like to accomplish this goal at the lowest cost to its citizens. Therefore the state needs to determine the combination of nitrogen control efforts which will achieve the goal at the lowest cost. The state would also like to be able to maintain nitrogen loads at or below this cap level, indefinitely into the future.

This study was undertaken with three primary objectives. The first was to project the level of annual nitrogen inputs to the Potomac River, from the state of Virginia, over the next 15 years. The second was to estimate the minimum annual costs necessary to achieve and maintain a 40% reduction in total nitrogen inputs, using the Virginia's estimated 1985 inputs as a baseline. The final objective was to assess the potential cost savings that may result from using one of two alternative development patterns within the rapidly urbanizing Northern Virginia portion of the Potomac Watershed. The first alternative is prohibiting low-density development within the Northern Virginia region, and the second is to restrict all new development to be within 5 miles of an existing urban area.

Study results suggest that there has been no significant progress toward meeting the nitrogen reduction goal, due to the increase in population within the watershed, over the past 13 years. To attain the goal in 1998, a minimum of $27 million, above what is currently being spent annually, would be required. Under the current land use trend within Virginia's Potomac Basin, the annual cost for maintaining the goal is estimated to rise to $38 million annually, in 1998 dollars, by the year 2013. This is a 40% increase in cost.

If the first alternative development pattern is adhered to over this 15-year period, then the annual cost will be $33 million, for an annual cost saving of approximately $5 million in 2013. The second alternative could achieve similar results if implemented, costing roughly $5 million less in 2013 than the annual cost per year under the current trend. These findings suggest that the use of alternative development patterns can help slow but not prevent the annual cost, of maintaining the cap, from rising.

The study indicates that the reason for the continuous rise in annual cost, over this fifteen-year period, is due primarily to an increase in nitrogen loading to the Potomac that will result from the wastewater disposal needs of the growing population within the Basin. Furthermore, the state will eventually exhaust its lower cost options for reducing Nitrogen loadings, and at that point the annual cost for maintaining the Nitrogen Cap will begin to rise exponentially. Under current land use trends this rapid rise in cost is unlikely to occur within the next 15 years, and is more apt to occur sometime within the next 20 to 40 years. Once annual expenditures begin to rise exponentially it is unlikely that the state of Virginia would be able to maintain its 40% reduction goal.

This work is dedicated to:
my parents and my children
for all their love and support;
and most of all to my wife
for finding within herself more
patience than I deserved, and
for providing me with more love
and support than I could have
ever wished for.

T.M.D.

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CHAPTER I

INTRODUCTION

1.1. PROBLEMATIC SITUATION

The state of Virginia is trying to reduce its annual load of nitrogen, to the Potomac River, to 60% of what the load was estimated to be in 1985. Virginia would like to accomplish this goal at the lowest cost to its citizens. Therefore the state needs to determine the combination of nitrogen control efforts which will achieve the goal at the lowest cost. The state would also like to be able to maintain nitrogen loads at or below this cap level, indefinitely into the future.

1.2. BACKGROUND TO THE PROBLEM

The Chesapeake Bay, once one of the worlds most productive estuaries, has been severely impacted by human activity in the water and on the lands around it. Viewed as an ecosystem, the Bay is no longer able to support the variety and abundance of biota that it was historically able to. Several decades of research on the Chesapeake have pointed to human activities as being the principle reason for this decline. Of these detrimental activities, the increased release of nutrients Nitrogen (N) and Phosphorus (P) were singled out as being the greatest cause of water quality deterioration.

1.2.1. Cause of the Decline

Nitrogen and Phosphorus are naturally present in waterways, and both of them perform an integral role in the proper functioning of the estuarine and riverine ecosystems. Yet when these nutrients are present in the water, in excessive levels, they act to over fertilize algae. This process is known as nutrient enrichment. As the algae flourishes it blocks out the sun to the detriment of other aquatic vegetation. When the algae begins to die off bacteria start digesting it. This process reduces dissolved oxygen levels in the water to the detriment of aquatic fauna. If the degree of nutrient enrichment is great enough, eventual metabolic activity by bacteria can lead to hypoxic conditions where oxygen levels are very low and few animals can live for long, or even anoxic conditions where there is no oxygen and animals cannot exist. Every year large areas of the Bay become either hypoxic or anoxic, due in large part to the process of nutrient enrichment.

Many activities undertaken by man generate N and P as a byproduct. When these excess nutrients reach the Bay and its tributaries, nutrient enrichment often results. Manmade sources of N and P are numerous and varied. These sources can be classified as either a point source or nonpoint source. The statutory definition of a point source is:

> ...any discernable, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, rolling stock, concentrated animal feeding operation, or vessel or other floating craft from which pollutants are or may be discharged (Water Quality Act, Sec. 502-14, U.S. Congress, 1987).

More typically, point sources are considered to be limited to industrial facilities and publicly owned treatment works, which directly discharge wastewater to an adjacent waterway (Novotny and Olem, 1994). While everything else is commonly referred to as a nonpoint source (Novotny and Olem, 1994). However, neither definition adequately explains the difference between the two.

There are several important defining characteristics for point and nonpoint sources (Novotny and Olem, 1994). Discharge from point sources typically occurs on a regular or controlled basis. Nonpoint source discharge to waterways in a diffuse, intermittent manner. Point source discharge is not usually affected by meteorological events, while nonpoint source loadings are mostly correlated to weather events. Point source discharge can be readily monitored with a high degree of accuracy, but nonpoint discharges are often extremely difficult to monitor. Finally nonpoint source water pollution typically either moves through the air, over the ground, or under the ground before it reaches the waterbody, by contrast, point source pollutants are conveyed directly to the water.

As mentioned, nonpoint source N and P are the result of a wide array of human activities. Most all nonpoint sources of nutrients are the direct result of some land use activity. So these activities are typically separated into three land use categories: agriculture, forestry, and urban (USEPA, 1993). Major agricultural sources are: fertilizers applied to cropland, manure from animal production facilities, eroded sediment resulting from animal traffic or crop production practices. Nonpoint source nutrients from forestry are the result of eroded soil from harvested timberland and logging roads. In urban areas a major nonpoint source of nutrients is from particulate matter, refuse, and other debris that gets transported by stormwater runoff. Another urban source is from the septic systems located in residential areas.

1.2.2. Efforts to Reverse the Decline

In 1987, the states of Virginia, Maryland, and Pennsylvania, along with the Federal government and the District of Columbia, signed a joint agreement that set out objectives for improving the conditions in the Bay. Part of this agreement was a nutrient reduction goal for each state and the District of Columbia. Using the estimated N and P loads to the Bay during the year 1985, each state pledged to reduce its share of the load by 40% before the year 2000 (VDEQ, 1996).

Within Virginia there are four major tributaries to the Bay, the Potomac, Rappahannock, York, and James. Each of these rivers is unique in character, and the state decided that a specific nutrient reduction strategy for each would be the most appropriate approach. The first of these tributaries that Virginia has focused on is the Potomac River. The Potomac, with a drainage area of 14,670 square miles, flows past four states and the District of Columbia. The largest portion of this drainage basin, 5,723 square miles, is within the state of Virginia. To date, the state of Virginia has made good progress towards attaining their P reduction goal for the Potomac. However, much less headway has been made on reaching the N reduction goal (VDEQ, 1996).

A principal reason for this lack of progress toward meeting the N reduction goal is the steady growth in population and urban land within Virginia's portion of the Bay watershed, particularly within the Potomac Basin (VDEQ, 1995). Each additional person is a potential source for increased point and nonpoint N loadings to the Potomac River. The 1987 Chesapeake Bay Agreement also commissioned a panel to estimate future growth in the Bay's watershed up to the year 2020, and to consider what the likely impacts on water quality would be as a result. The panel estimated that between 1990 and 2020, Virginia's population within the Bay watershed will grow by 1.5 million people (Year 2020 Panel, 1988). Along with these new residents will come an estimated 847,916 households. This is a projected 32% increase in population for this area.

Even though they have not made much headway thus far, on reducing the amount of N to the Potomac River, policy makers in Virginia have expressed their commitment to achieving the 40% reduction goal (VDEQ, 1996). At the same time they also expressed their desire to see the goal reached in a manner that is considered to pose the lowest cost to taxpayers and private citizens (VDEQ, 1996). Finally, Virginia pledged, under the 1987 Agreement, to keep N loadings capped at the 40% reduction level into the future. Fulfilling this commitment will require the N control measures, used to meet the goal, be maintained indefinitely.

1.3. NECESSARY FRAMEWORK FOR DETERMINING MINIMUM COST OF ACHIEVING THE NITROGEN REDUCTION GOAL

Determining how to achieve the goal at the lowest cost is made complicated by several factors. The first is the nature of N within the Basin environment. There are a myriad of human activities occurring within the Basin, that contribute to the N load. The physiographic environment, upon which these activities occur, is extremely diverse; as the watershed stretches from the tidal wetlands of the Northern Neck, to the Allegheny Mountains forming the state's western border. To accurately assess the lowest cost for meeting the goal, the necessary steps for achieving the goal must be sufficiently defined. This defining process has three parts: defining the sources; evaluating the source control measures; and assessing the costs associated with the use of these measures.

1.3.1. Determining the Cost of Meeting the Goal

Defining sources requires the evaluation of all human activities with the Potomac Basin that could potentially be sources of N to the Potomac. The same human activity, done under different physiographic conditions, can result in differing loads of N. Therefore where each land use is occurring within the Basin needs to be part of the evaluation, as well. Then the typical annual N loading needs to be estimated for each land use/location combination. The extent to which each land use is occurring in a given area will have to be determined. Finally how the mix of land uses for a given area is likely to change over time needs consideration, as well.

After the principle sources of N to the Potomac are identified, and their relative contribution determined, all the potential control options for each source will require evaluation. To be considered a potential control option, the control should have been proven to be able to reduce the amount of N reaching a water body from the source, and should have at least some limited implementation currently in the Basin. The fullest extent to which a control measure could be effectively used within an area is the control measures feasible implementation level. For example, contour plowing, is a measure used to reduce sediment erosion and nutrient runoff from cropland on hillsides. For farms on coastal plains in the eastern portion of the Basin, such a control measure would have limited feasibility, due to the flatness of the terrain. The feasible implementation level for each control measure would require assessment. Furthermore, once a control is adopted it must continue to be used into the future. This brings up issues concerning long term effectiveness, reliability, and monitoring, for each potential control.

Once possible control measures for each source are evaluated, the cost of implementing the control must be taken into consideration. Typical implementation costs include both the capital costs, for putting the control in place, and the operation and maintenance cost, for continued use of the control. However, an assessment of implementation costs should include any transaction costs incurred by either the state or party adopting the control measure, as well as any opportunity costs likely to be perceived by the party.

The cost of using a control measure can vary significantly under differing circumstances. Therefore, variances in cost as a result of specific site conditions or other circumstances should be incorporated into the evaluation when possible. For instance, an aerated lagoon could reduce N, for a reasonable cost, on large swine operations. Yet they are not typically used for small swine operations, because they are considered to be prohibitively expensive. Since there is no swine industry to speak of in Virginia’s Potomac Basin, implementation of aerated lagoons would not be considered feasible for the small hog farms in the Basin.

Of particular importance to an assessment of the minimum cost for achieving the goal is the notion of cost effectiveness. In terms of N load reduction, the cost effectiveness of a source control would be the dollars per pound of N reduced. Two control measures may have similar costs, yet one may be highly effective and the other very ineffective at reducing. So the cost effectiveness of the two would be quite different.

1.3.2. Determining the Cost of Maintaining the Goal into the Future

Once an assessment of the present minimum cost for meeting the goal has been made, there still needs to be a determination of how much it will cost to perpetually maintain this goal into the future. As mentioned earlier, the steady trend in population growth, over the past 13 years, has thwarted progress toward meeting the N reduction goal (VDEQ, 1996). Increased N, as a result of new population growth, could have the effect of causing the annual cost to rise over time. This is because more control efforts will likely need to be undertaken to compensate for the increased amount of N being generated by the new population.

Coinciding with this urbanization trend has been a decline in both the amounts of farm and forestland within the Basin. As land uses change, so will the resulting N loads. This could cause a need for more or less N control depending on whether total N loadings rise or fall. In turn, this could have a negative or positive impact on the cost of maintaining the cap. Changing land uses will also change the selection of available control technologies. For instance, when cropland declines and urban land increases; then the feasible amount of N control technology, for cropland, is contracting, while the potential amount of urban N control is expanding. This is likely to have an effect on the minimum annual cost, as well. As the current trend in land use changes, is likely to have an affect on the future annual cost of meeting the goal; this raises the possibility that altering the course of land use changes could potentially result in cost savings over the current trend.

Since the 1950s the trend in urban development within the Potomac Basin, has been toward lower density development. Houses tend to be built further apart and on larger parcels of land requiring more miles of roads, utility lines and water mains, per household (Year 2020 Panel, 1988). According to the Year 2020 Panel Report, this trend of low-density development accounted for much of the new development, within the Chesapeake Bay watershed, between 1950 and 1980. In 1950 there was 0.18 acres of developed land for each watershed resident. Over the ensuing three decades, the average amount of new development was 0.65 acres per additional person (Year 2020 Panel, 1988). This low density development has a greater negative impact on water quality than does high density development, as it uses more land area and resources for each new person (Schueler, 1987).

In their report, the Year 2020 Panel laid out a vision of how the people residing within the Chesapeake Basin could live in a more sustainable manner and lessen their impact on the Bay. Among these visions were two that addressed how development could occur in a more sustainable manner. The first was that new development should be concentrated in suitable areas (Year 2020 Panel, 1988). The other was that urban growth be directed towards existing population centers (Year 2020 Panel, 1988). If development in Virginia's Potomac Basin was to occur in a more sustainable manner, as suggested in the Year 2020 Report, total N loadings that result from urban growth might be lower, than they would be under the current development trend. If this was the case, then adoption of alternative settlement patterns within the Potomac Basin could result in lower annual cost than that incurred from continuing the current trend.

1.4. RESEARCHABLE PROBLEM: Determine the minimum annual cost of maintaining the Nitrogen reduction cap for the present and foreseeable future. Evaluate the potential yearly savings, in the cost of maintaining the Nitrogen cap, from the use of alternative development patterns for new urban land within Virginia's Potomac Basin.

1.5. PURPOSE OF STUDY

This study intends to provide policymakers, at both the state and local level within the Basin, with information that will assist them in targeting their efforts toward achieving the 40% N reduction goal, in the most cost-effective manner. This information will also include predictions of the potential cost savings, toward maintaining the N reduction cap, that could be achieved if policymakers were to adopt policies that placed restrictions on the way future development occurs within the Basin. What follows are the three principle objectives of the study, along with more specific sub-objectives. Together they outline the specific information that is expected to result from this study.

I.) To predict the annual nitrogen loadings to the Potomac River, from the state of Virginia, for the years 1998, 2003, 2008, and 2013.

II.) To estimate the minimum costs, above what is currently spent, to meet and perpetually maintain the nitrogen cap, for the years 1998, 2003, 2008, and 2013.

III.) To assess the potential cost savings from changes in land use that result from the adoption of two alternative settlement patterns, for the years 2003, 2008, and 2013. These alternative settlement patterns are:

1) Restricting all post 1998 dwelling units within the NOVA region to medium and high-density settlement patterns.

2) Restricting all post 1998 dwelling units within the NOVA region to settlement patterns that are either within urban areas or are within five miles of an urban center.

1.6. SUMMARY OF PROCEDURES

To derive the anticipated findings, outlined in the study objectives, it will be necessary to construct an optimization model. In order to develop the model, it will be necessary to conduct an extensive literature review. Therefore, the procedures for undertaking this study can be divided into two categories: literature review, and model development. Both of these procedures will be done in a series of iterative steps.

The first step will be the initial literature review, which will have three basic purposes:

1.The enumeration of all sources of nitrogen to the Potomac River, and an evaluation of the relative contribution of each to the total N load, as well as their potential for being controlled.

2. A description of nitrogen control techniques, an assessment of their potential effectiveness at reducing N, and an assessment of the extent of their applicability within the Basin.

3. The estimation of the cost of implementing a control technique, and evaluate their cost-effectiveness.

These three aspects of the literature view will comprise the subject matter for Chapters 2, 3, and 4.

This models structure, equations, and parameters will need to be a mathematical representation of: significant sources of N to the Potomac; methods for controlling the N loads from these sources; the feasible level of implementation of these methods; and the cost effectiveness of using these methods. If the model is able to adequately represent these factors, then current and future scenarios can be developed, which when run by the model will generate the needed data to address the objectives of the study.

The information gathered for Chapters 2,3,and 4 will be to create the structure of the model. Chapter 5 will detail how this information is used to define the scope and breadth of the modelling effort. Chapter 5 will also address the how the model will represent basic features of the researchable problem. Chapter 6 will focus on the specific equations, variables, and parameters used within the model. This will require additional review of the literature to develop sets of parameters which are representative of current and future conditions. Discussion of variables and equations will focus on how they are designed to work together to address specific issues, raised in Chapters 2, 3, and 4.

At this point in the study, the development of a suitable model will be complete. Yet before the model can be used to generate results, a series of scenarios will need to be developed which embody the objectives of the study. In this way the results from the model runs can then be used to address the study objectives. Chapter 7 will describe how the scenarios were developed and how they apply to the study objectives. Chapter 7 will also provide the basic findings, from the results of running the model scenarios. Chapter 8 will conclude the study with: a summary of how the findings address the study objectives; the implications of these findings; and any recommendations for policy makers, based upon these implications. Immediately following Chapter 8 is Appendix A, which contains a glossary of definitions for some of the words and terms found in the text.

CHAPTER II

SOURCES OF NITROGEN

2.1. INTRODUCTION

This chapter consists of five major sections. The first section is a discussion of the various forms of nitrogen, their relevance as a potential pollutant, and the factors that facilitate their transformation. The first source discussed is atmospheric deposition, which is both a direct and indirect source of N. The next section is on the contribution of N from point sources within the basin. From there begins a discussion of the three land use categories, and the potential sources of N loadings to surface water within each. The first land use is agriculture, which is considered to be the greatest source NPS N loadings to the Chesapeake Bay. The second is forestry which has a relatively small impact on the total loadings of N. The last is section is on urban land use sources, which are perhaps the most difficult of all N sources to manage.

2.2. NITROGEN FORMS

An understanding of the element Nitrogen (N) is necessary to fully appreciate its significance as both a pollutant and as a fundamental ingredient for life. Much like the element carbon, N is an integral part of the Earth's biosphere. It exists in many different forms, and goes through many transformations, known as the nitrogen cycle. Most N exists in the gaseous form, comprising over 80% of the atmosphere. Nearly all atmospheric N is a molecule composed of two N atoms (N_2). In this state, it is unavailable to living things, and it is not until bacteria or some form of combustion splits the molecule so that it can form other compounds that it becomes available. This process is referred to as N fixation and it is the first step of the N cycle. Humans now affect the movement of N through this cycle in two important ways (Trefil, 1997). Because of nitrogen's importance as a plant nutrient, humans now fix large quantities of N_2 so that it can be used as a fertilizer. Fixed N is also a byproduct of burning of fossil fuels. Both of these activities serve to increase levels of fixed N in the environment. When high levels of fixed N exist in an environment, there is a greater potential for nutrient enrichment. The process of nutrient enrichment acts to benefit few species, at the expense of most others and ultimately biodiversity (Trefil, 1997).

2.2.1 Nitrogen Cycle

A brief description of the N cycle will be useful for describing some of the forms fixed N can take, the possible transformations it can go through, and also the pathways by which it can enter water bodies. Within the environment N moves through the air, soils, and water in a complex cycle. There are three primary pathways in this cycle through which N reaches waterbodies: air deposition, ground and surface flow, and soil erosion. All the various sources of diffuse N pollution fall into one of these three categories. As N moves through the cycle it is in a constant process of transformation (Novotny and Olem, 1994). Since the main threat to water quality from N is nutrient enrichment, the most problematic forms of N are those which can readily be used by plants as a nutrient. However, immobile forms of N can be converted to soluble forms through microbial reactions so they are considered potential pollutants as well (Novotny and Olem, 1994). Figure 2.1 shows a simplified diagram of the basic Nitrogen cycle.

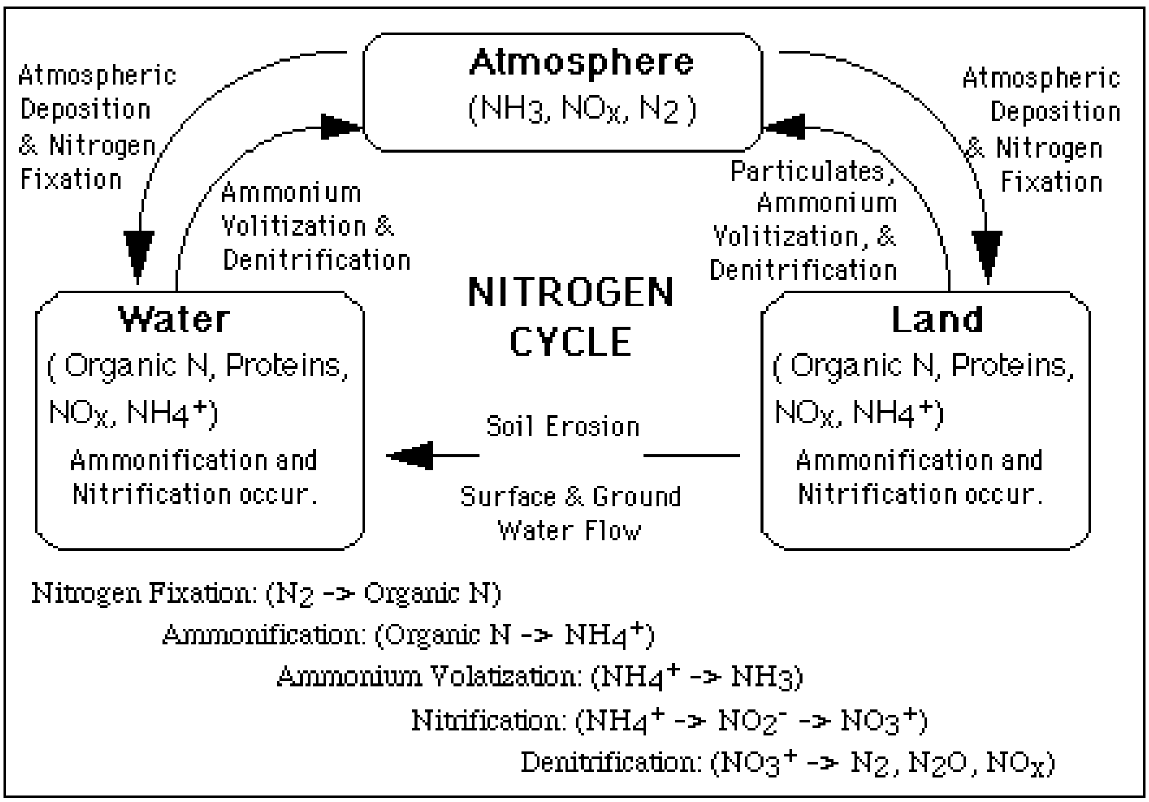

Figure 2.1. Diagram of the Basic Nitrogen Cycle. (Adapted from Novotny and Olem, 1994).

Over 80% of the atmosphere is comprised of N. Nitrogen fixation by microorganisms on the surface is a means by which atmospheric N reaches the land and water. Ammonia and nitrate also exist in gaseous forms, and both act as plant nutrients, when they are deposited upon soils and surface waters (Novotny and Olem, 1994). On the surface, N exists in four basic forms: ammonium, nitrate, organic phytonitrogen, and protein nitrogen. Over 95% of this N is organic phytonitrogen, and protein nitrogen which is not directly available to plants (Novotny and Olem, 1994). These forms of N are typically transported to surface waters by sediment loss due to erosion. Ammonium is mobile and so available to plants, yet it typically becomes adsorbed to soil particulates and reaches water due to sediment loadings as well (USEPA, 1993). Nitrite and nitrate are highly mobile and soluble in water. They can enter waterbodies from surface runoff, interflow through the soil zone, or from leaching into the groundwater that provides the baseflow for waterbodies.

As mentioned in chapter one, another significant source of N to the Potomac River is the direct discharge of N from point sources. The composition and amount of N in treated effluent is a function of both the wastewater characteristics and the treatment process used. Typically most of the N in wastewater is in the form of ammonium, although some organic N and nitrates are present as well (Peterson and Simpson, 1992), (Vesilind and Peirce, 1983). The basic paths by which N enters the Potomac are thus:

- Point Source Discharges
- Surface Runoff and Ground-Water Flow
- Atmospheric Deposition

The amount of N, which is transported to waterbodies through one of these basic pathways, will depend on two factors. The first is the origin or initial source of the N. This could be emissions from a car, erosion from a farm, or sewage from a suburban home. The other factor is the natural and man-made processes that occur along the pathway from the source to the waterbody.

2.2.2. Runoff, Erosion, and Ground-Water Flow

Diffuse water pollution is directly related to watershed hydrology (Novotny and Olem, 1994). As rain falls it can collect pollutants from the air. Once it hits the ground, the impact can disrupt the soil layer causing soil erosion. The rain that collects upon the land will either infiltrate the soil, be removed through evapotranspiration, or become surface runoff. Both the runoff and the water that percolates through the soil can transport N to surrounding waterbodies.

The soluble forms of nitrogen can be transported beneath the surface by interflow and base flow. The layer of soil just beneath the surface typically has a higher permeability than the layers beneath it, causing a portion of the infiltrated water to move horizontally instead of vertically. This shallow flow of water through the first soil layer is interflow. Water that does continue to move vertically eventually reaches the saturation zone where it becomes base flow, more commonly referred to as groundwater.

Surface runoff is the most visible and usually the most common way N reaches surface waters. Runoff carries both soluble N and particulate matter containing N. Soil erosion can be a significant source of the immobile organic form of N to surrounding receiving waters. Although it is the mobile forms of N which readily act to fertilize algae, all N entering the water has the potential to be transformed into a nutrient. Also instream erosion and sediment deposited in waterways can disrupt the habitat of beneficial aquatic plants which would other wise remove some of the N in the water. Figure 2.2 provides a basic diagram of the basic ways in which precipitation interacts with the soil profile.

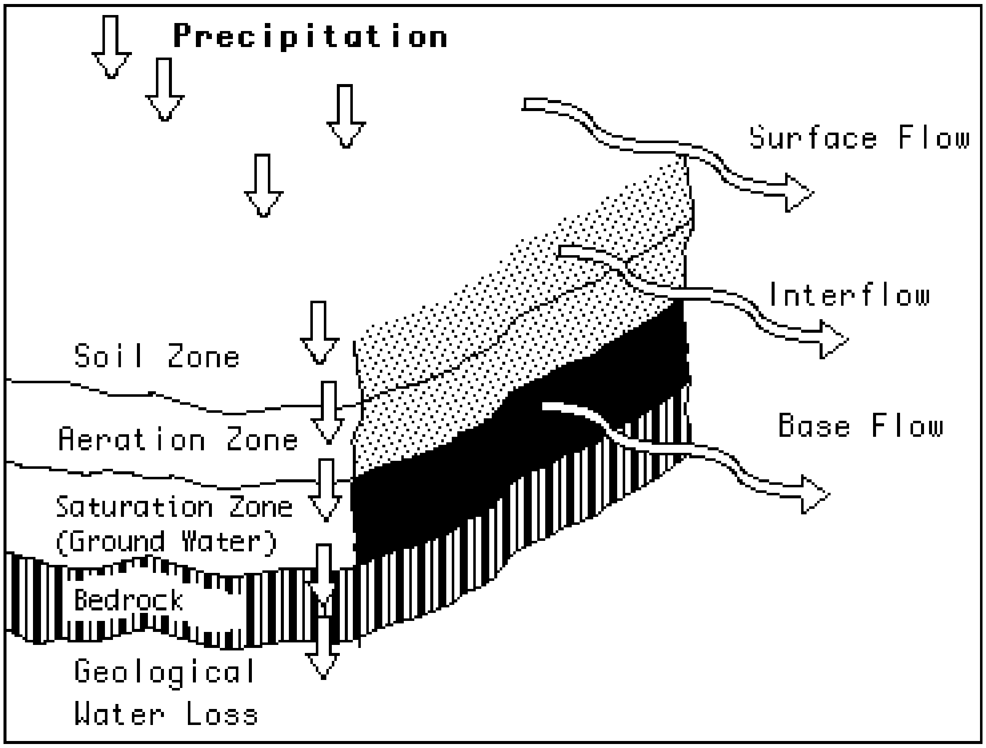

Figure 2.2. Diagram of the Basic Hydrological Cycle. (Adapted from Novotny and Olem, 1994)

Organic N and other materials can be dislodged from the land's surface, by wind, rain, and the movement of humans and animals across the land. The erosion process is the removal of soil from a site, while sediment load or yield is the amount of soil that enters a receiving water body. Sediment transport or delivery is the movement of the detached soil over land or through the air. From a water quality perspective, edge of stream sediment loads are the most important component of this process, yet these loads are a function of both the rate of erosion and the sediment delivery factor (Figure 2.3.) (Novotny and Olem, 1994).

GROSS WATERSHED EROSION • SEDIMENT DELIVERY FACTOR = SEDIMENT YIELD

Figure 2.3. Sediment Delivery Factor

Climate, topography, soil type, and amount of vegetative cover are conditions that affect the rate of erosion and the sediment delivery factor (Novotny and Olem, 1994). Although wind erosion is a significant problem in arid regions, water is the primary cause of erosion in most all cases (Novotny and Olem, 1994). The impact of rain on the ground surface detaches soil particles, and the overland flow of rainwater serves as the transport mechanism. The erosive effect of rainfall does not stop at the water's edge, as flows from large storm events can cause bank and channel erosion. Topography of the land can affect the erosion and sediment delivery in several ways. Precipitation on steep slopes has little chance to collect and percolate, so it becomes surface runoff. The steeper the slope the greater the velocity of the runoff, and so the heavier the particles it can transport. However, terrain with small depressions will cause ponding during rain events, thus encouraging infiltration and reducing the velocity of runoff. Soils with a high content of large particles are less prone to erosion. Clay within soils acts as a cohesive agent, and so is less prone to erosion as well. Vegetative cover reduces the erosion rate by lessening the impact of precipitation, and anchoring the surface soils to the ground. It also lessons the delivery factor by impeding the flow of runoff and thus reducing its velocity.

Erosion and sediment loadings are typically associated with agricultural practices due to the tillage of large areas of soil. Yet they can result from forestry practices such as clear cutting, and from urban construction sites. In built up urban areas there is little erosion, yet the sediment yields can be significant. Dust, litter, and plant debris that accumulate on streets and sidewalks are washed into the storm sewer system by heavy rains.

2.3. ATMOSPHERIC DEPOSITION

Wind, temperature, and the mixing patterns of both air and water have an effect on the rates of atmospheric deposition (Novotny and Olem, 1994). Pollutants in the atmosphere are either gases or particulate matter. Particulate matter that is composed of mostly insoluble material is dust, while particulates with a high content of soluble material are referred to as aerosols. Dry deposition or fallout occurs when particulate matter is brought to the surface by gravity and when gases are absorbed by the earth's surface. Removal of gases and particulate matter during precipitation events is wet deposition.

As mentioned, the earth's atmosphere is comprised largely of N, but exists predominantly as N_2 that is not directly available to plants. Atmospheric N is most problematic when it is in the form of ammonia, ammonium or one of the forms of nitrous oxide. This is when it is a potential plant nutrient. Many human activities are common sources of these forms of nitrogen. In urban areas automobile and industrial emissions are a common source of nitrous oxide. Some agricultural sources are soil loss from wind erosion, volatilization of ammonium fertilizer, and decomposition of farm waste.

Recent assessments suggest that N deposition could account for as much as 30% to 40% of the total N reaching the Chesapeake Bay (STAC of CBP, 1994). The National Oceanic and Atmospheric Administration's Office of Air Resources has used the Regional Acid Deposition Model (RADM) to estimate the potential impact of N deposition on the Bay and to estimate the possible airshed from which the N originates (NOAA, 1995). Their work suggests several important factors concerning the importance of the Bays airshed to the loading rates of atmospheric N:

- The airshed is significantly larger than the watershed, roughly 350,000 square miles, or about 5.5 times the watershed's 64,000 square miles.

- The airshed includes many sources along the middle and upper Ohio River all the way to around Lexington, KY.

- About half of the nitrogen deposition to the Bay itself comes from sources within 200 miles of the Bay.

- Three fourths of the nitrogen deposition to the Bay is from sources within 500 miles of the Bay.

One of the difficulties surrounding atmospheric deposition is how to actually account for all of the N deposition that ends up in the Potomac River. The actual percentage of total N deposition that falls directly onto surface waters of the Potomac Tributary is minor compared to the amount which falls onto the land. Yet this does not mean that atmospheric deposition is a minor source of N. Deposition of N to the ground becomes part of the total N load coming from the land. What this does mean is that most of the N deposition that enters the Potomac will be accounted for in the N estimates from the land's surface. Exactly how much of the N deposition to the land actually makes it to the water is highly dependent upon the characteristics of the land surface. As a result, the total overall effect of N deposition exceedingly difficult to calculate. An implication of this fact is that current efforts to reduce nitric oxide (NO) emissions to the atmosphere have a definite benefit for Potomac River and Chesapeake Bay water quality, yet measuring these benefits will be very hard to assess.

When the goal of reducing the controllable load of N by 40% was agreed to in 1987 and then reaffirmed in 1992, atmospheric deposition was judged to be too poorly understood to be considered controllable. Efforts have been made to incorporate the effects of atmospheric deposition into the Chesapeake Bay Watershed Model, and as more is learned about nitrogen deposition's impact on the bay, the more likely it will be considered in future policy decisions concerning the bay (VDEQ, 1994a).

2.4. POINT SOURCES OF NITROGEN

Point sources account for nearly two thirds of the controllable N entering the Potomac Basin from Virginia. As we defined them in chapter one, point sources are publicly owned treatment works (POTWs) and industrial facilities that discharge effluent containing either N or P. Unlike with diffuse sources, N loads from point sources are not affected by climate or the landscape. Furthermore, their effluent enters the water at specific sites in fairly consistent quantities. As a result, the measurement of annual N loads from these sources a much more reliable process than it is for nonpoint sources.

In the Potomac basin many of the point sources are relatively small treatment plants serving rural communities. Still others are industrial facilities whose residual effluent contains virtually no nutrients. When calculating the controllable N load from point sources within the Potomac basin, the Chesapeake Bay Program reviewed 59 POTWs and numerous industrial sites. To help make the decision as to which ones would be included in the calculation, the sources were categorized as either major or minor (VDEQ, 1994b). For POTWs if their discharge exceeded 0.5 million gallons per day (MGD) they were considered major sources. For industrial sites if their daily discharge of N is as much or more than the discharge level expected from a POTW with a 0.5-MGD capacity, then it was considered major as well. The decision was made to only include major POTWs and industrial sites before the fall line, and to include all point sources after the fall line (VDEQ, 1994a). Of the 59 POTWs considered 20 were major and 39 were minor. Seven of the minor ones were below the fall line so they were considered as well. In addition to these POTWs, six industrial facilities were included. These were the point sources considered in the development of the Potomac Tributary Strategy (VDEQ, 1995). For a summary of the location and technology used for each of these point sources see Appendix B.

2.5. AGRICULTURAL SOURCES OF NITROGEN

Agriculture is the biggest contributor of nonpoint source N to the Potomac River (VDEQ, 1993). Every agricultural activity, whether it be growing corn, operating a dairy, or raising chickens has the potential to be a source of N. Unlike with atmospheric deposition and point sources, agricultural sources of N are measured in terms of both activities and acres. An agricultural N load is the total amount of N estimated to come from an acre of land during the period of a year. This includes both the N that would naturally leave the acre and the additional N that is the result of the agricultural activity.

It will be important to bear in mind during later discussions about the N loads associated with a particular land use that even if the land were left completely unused their would still be a small level of N coming from the land, due to the naturally occurring N cycle. Another important issue when discussing N loads from acres of land is whether or not the load refers to edge of field or edge of stream. Edge of field refers only to the amount of N that emanates from the acre during a year, while edge of stream refers to the portion of the edge of field load that actually makes it to a waterbody. This is analogous to the difference between erosion rates and sediment loads (Figure 2.4) (Novotny and Olem, 1994).

EDGE OF FIELD LOAD * DELIVERY FACTOR = EDGE OF STREAM LOAD

Figure 2.4. Basic Equation for Edge of Stream Loadings

Again the delivery factor is dependent upon the conditions on the land between the acre where the N emanated and the receiving waterbody. The point of this is that an activity, which is a moderate source of N but is carried out on land directly adjacent to a waterbody, is often more damaging than a major source that occurs a long distance away from a water source.

2.5.1. Crop Cultivation

Agricultural sources of N can be divided into those associated with crop production and those associated with livestock management. The process of crop production starts with the removal of the natural vegetative cover from the surface of the land. Then the soil surface must be periodically disrupted so that the crops can be planted. In order to encourage crop growth the farmer must also maintain a minimum level of available N within the soil layer during the growing season. The potential of crop production to be a source of N varies greatly. The choices concerning what land to devote to crops, what types of fertilizers, tillage practices, and crop rotations to use can all affect the amount of sediment loss from these fields. It is estimated that 90% of the N loss resulting from agriculture is due to soil loss (Novotny and Olem, 1994).

The decision of which acres to bring into crop production has typically been made based upon the cost of bringing additional acres into production versus the long-term expected net revenues derived from the additional acres. Little regard is usually given to the potential effects on water quality. However, the choice of which acres to bring into cultivation will have an important impact on the N loads to nearby streams. This is because the potential edge of stream sediment load can vary greatly between different parcels of cropland. Land with steep slopes or loose easily erodible soil is considered “highly erodible land”. When used for growing crops it can generate high sediment loads to nearby waterbodies (VDEQ, 1994a).

Crop production on land immediately adjacent to stream banks can cause extreme bank erosion and stream siltation (Novotny and Olem, 1994). The most direct impact of this is the overall sediment loads are increased. However it is not the only effect. Vegetation within and along streams acts to not only slow the velocity of runoff and trap sediment; it also utilizes some of the available nutrients, thereby removing them from the water. Wetlands have a natural filtering capacity. On the surface wetland plants trap sediment, and take up and store nutrients (Peterson and Simpson, 1992). At the root zone, aerobic and anaerobic microbial activity causes nitrification and denitrification to occur. When wetlands are drained for crop production, the sediment trap is removed, the N stored by plants is released, and the beneficial denitrification process ceases to occur.

The manner and frequency in which the land is tilled has a major impact on the lands erosion rates. Tillage of the soil for crop production disturbs the soil surface making it more susceptible to erosion. Yet tilling the soil also increases the hydrologic surface storage capacity and permeability of the soil potentially reducing the volume of runoff leaving the field (Novotny and Olem, 1994). As a result, the negative effects of the increased erosion rates are partially offset. The manner and frequency of crop rotation can have a direct effect on the edge of field N loads. Cropland, which is left bare during the winter months, is a significant source of N. Crop rotations that include cover crops or crop residues during critical erosion periods can help reduce soil loss.

Nutrient applications are a basic component of crop production. The type of fertilizer used and the way it is applied will affect the amount of N leaving the field. Whenever fertilizers are applied, what is not utilized by the growing crops either accumulates in the soil or is removed by runoff or infiltration to ground water. Some of the different types of fertilizers are synthetic commercial fertilizers, animal manure, treatment plant sludge or effluent, including legumes in a crop rotation, and leaving crop residues on the field. The reason the type of fertilizer is of particular interest is that they differ in the amount of available N they contain and in their solubility. For instance, commercial fertilizers consist primarily of mobile forms of N, which can readily be utilized by the crops, while manure and crop residues are primarily organic sources of N that are slowly converted to plant available forms over the growing season. The N in commercial fertilizer is highly susceptible to being removed from the field by leaching and runoff, and as much as 30 to 50% of it is eventually lost after application (Norris and Shabman, 1988). To compensate for this expected loss farmers will over apply the fertilizer. Many farms include both crop production and livestock operations. As a way of disposing of animal waste, farmers spread manure on their fields. This rate of application often depends more on the amount of waste that needs to be disposed of than it does on the amount of fertilizer needed for crop production. This practice can lead to over application of fertilizers as well.

Timing of fertilizer applications is also very important to the edge of field N load. When commercial fertilizers are applied as needed over the growing season, the overall amount leaving the field is reduced. Animal waste is produced all year round and if it is applied when the ground is frozen much of it can be washed away before it is ever assimilated into the soil. If the manure can be stored for the winter months and then applied at the beginning of the growing season much less of it will be lost to runoff.

2.5.2. Livestock Operations

Livestock are the other major source of N from agriculture. Although livestock production exists within the Northern Virginia region, it occurs on a very small scale. Livestock operations are a much more significant source of diffuse N in the Shenandoah regions (McCarthy, 1996). Within the Shenandoah Sub-basin, the major types of livestock operation are dairy farms, poultry operations, cow/calf grazing farms, and stocker cattle operations (Faulkner and Trott, 1994). Poultry are raised primarily in confinement within poultry houses. With dairy cows and cattle, all the animals will likely spend part of the time in pasture and some time in confinement. Dairy cows are milked two to three times a day and are typically fed feed to ensure the quality of the milk production (Conversation with David Knicely, 1997). Because of this fact, dairy cows spend the majority of their time in confinement. Beef cattle will spend most of their time grazing in pasture, and may be brought into confinement for fattening shortly before they are slaughtered.

Often denuded and almost completely impervious due to compaction from animal traffic, land used for confinement lots typically bears little resemblance to the surrounding terrain. The high degree of compaction, along with the high organic content from manure, cause feedlot soils to become relatively impermeable. The more impermeable the lot becomes, the more sediment loads decline, while the volume of surface runoff increases (Novotny and Olem, 1994). This surface runoff also typically has a high N content since the soil layer loses its ability to assimilate manure, as it becomes impervious.

Animal waste can be a significant source of N from livestock operations. One reason is that the waste is often stored so that it is not protected from precipitation, thus making it susceptible to runoff. Another situation when it can be a problem is if it is applied either when the ground is frozen or right before a large storm. In the Basin poultry litter is typically contained within dry stack facilities for a three to four month period and then applied to the fields. Poultry manure contains a high concentration of N so improper storage and application can lead to runoff with a high concentration of N (Camacho, 1992). On most dairies in the Basin manure is typically stored in pits, in a liquid form. Storage time is a function primarily of the pit size and the number of animals in confinement. These factors will vary considerably between operations, and thus so will the frequency of application.

When pasture are poorly managed or overstocked the result can be increased erosion and surface runoff. When pastures contain more animals than can adequately be supported by the existing vegetation, the foliage is eaten down to the roots leaving the soil surface exposed. This process reduces interception, surface storage, and soil stability during periods of precipitation. Even when the stocking rate is not exceeded, often animals will tend to congregate in one area of the pasture either for shelter or for access to a drinking water source. This behavior can cause those areas of the pasture to become overgrazed as well.

When livestock have uncontrolled access to waterways, the impact can be similar to that of crop production along stream banks. Heavy animal traffic causes loss of vegetation and disruption of soil surface along stream banks. This traffic can eventually lead to bank erosion and instream sediment deposits. While in the stream the animals disrupt streambeds, increasing the amount of suspended sediment in the water. This disruption causes degradation of habitat for aquatic communities (Novotny and Olem, 1994). Also this leads to the animals defecating in or immediately adjacent to the streams. This is a source not only of N but also for many pathogens.

To conclude this section on agricultural sources of N, it may be useful to include a brief synopsis of the various sources.

- Immobile sediment-bound N from cropland erosion due to factors such as tillage practices and crop rotations.

- Dissolved N within runoff from crop fields primarily as a result of fertilizer application.

- Use of highly erodible land, wetlands, or lands adjacent to waterways, for cropland or pasture.

- Runoff from animal waste storage and disposal.

- Confinement lot runoff due to lack of vegetative cover and animal traffic.

- Erosion and runoff from pastures due to overgrazing.

- Stream bank erosion due to cattle traffic to a drinking water source.

2.6. FORESTRY SOURCES

Forest hydrologic activity is very slow in comparison to other landscapes. Trees and vegetation act to intercept precipitation slowing its force while mulch and ground cover act to retain moisture and encourage ponding (Schueler, 1987). As a result, very little sediment and N is lost from forests to surrounding waterbodies. In fact stream side forests help to preserve stream integrity by intercepting runoff from other land uses (Novotny and Olem, 1994).

Logging roads are the main source of erosion from silviculture. Erosion on these roads can often exceed that of highly erodible cropland (USEPA, 1993). The roads are unpaved, and they often run along steep slopes and across small streams. So the logging roads act to disrupt the natural flow of rainwater, as the roads act to concentrate and channel runoff.

The method in which trees are harvested can have an effect on N loads. Clear-cutting removes all the marketable trees while clearing away noncommercial trees to make room for replanting. This method is another source of erosion, but less of a problem than logging roads. A study in conducted in Oregon suggests that the erosion from logging roads is many times greater than from clear-cutting (Figure 2.5)(USEPA, 1993). Clearcutting does promote increased runoff and can increase the level of N in the runoff as well. Vegetation which would normally utilize nutrients is removed, and vegetative debris is left behind which decomposes releasing stored N back into the N cycle.

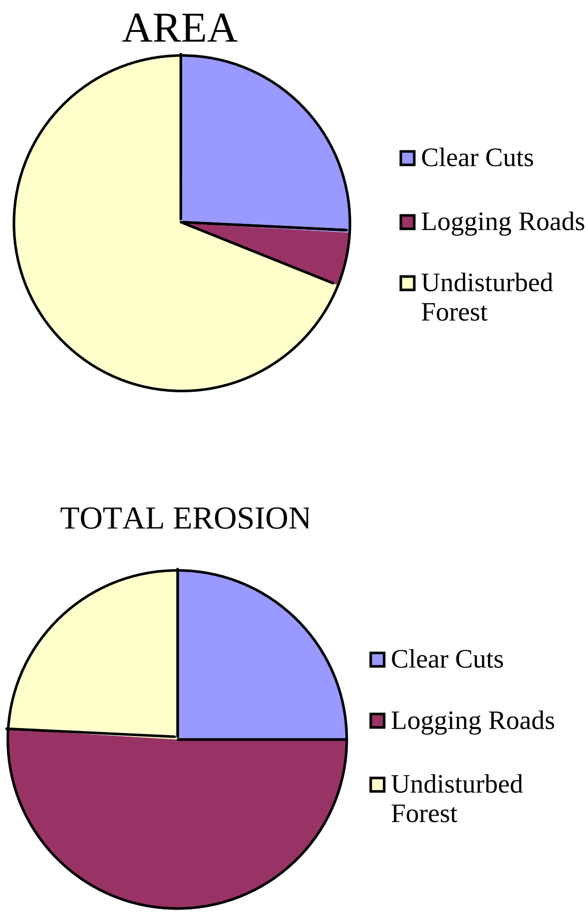

Figure 2.5. Comparison of Forestland Area with Sources of Forestland Erosion

Other harvesting methods such as selective cutting or seed and shelterwood cutting only remove a portion of the commercial trees. These methods leave behind more vegetative cover and less debris at a harvest site. Yet they also increase the number of times the site must be accessed. So there is no guarantee that these other harvesting methods will reduce erosion in all cases (RTI, 1992).

When sites are clear-cut, they can be left to regenerate naturally or the sites can be prepared and then artificially regenerated. Site preparation involves controlled burning and or tillage and disking of the soil. Yet artificial regeneration speeds the reestablishment of vegetative cover. Therefore artificial regeneration increases erosion during the first few years of regeneration, but the net long-term effect on the erosion rate is unclear. In summary increased N loads from silviculture are primarily a result of increased erosion. The three basic sources of N from silviculture are:

- Logging Roads
- Harvesting Methods
- Site Preparation

2.7. URBAN SOURCES

The amount of N coming from an urban source is ultimately determined by the manner in which non-urban land is developed into urban land. Nitrogen from urban areas enters surface waters in three ways. These are effluent from on-site wastewater treatment systems, erosion from construction sites, and urban stormwater runoff. The principal sources of N from urban areas are construction site sediment, atmospheric deposition, street litter, dust, and debris, deicing chemicals, septic system effluent, and fertilizers applied to lawns (USEPA, 1993). Typically decisions on the types of construction practices, eventual wastewater disposal methods, housing density, street width, curbing and guttering are all made before construction has begun. Once development of an area has been completed it is very difficult and costly to then try and control the amount of N coming from it.

Of the three sources, urban stormwater is the most significant long-term contributor of N as well as a most difficult one to identify and control. The characteristics of urban runoff are very different from agricultural runoff. Urban stormwater runoff is varied, diffuse and highly dependent upon the weather much like agricultural NPS pollution. Also in certain urban areas, annual per acre N loads can approach those from agricultural areas. Yet in comparison with livestock or crop production, most activities carried out in urban areas produce little if any N. What separates urban NPS pollution sources from agricultural sources has to do with the nature of the landscape. Urbanization has a much greater and longer lasting impact on the physical, hydrological, and biological characteristics of the land than does clearing it for agriculture (USEPA, 1993). These changes to the land alter the natural hydrological cycle, reducing the ability of the land to incorporate and remediate N causing a higher percentage of it to reach surrounding waterways.

Most of the N from agricultural runoff is sediment bound and is the result of the erosion process. In urban areas, erosion is much less of a problem since the land surface is not routinely disrupted and left exposed as with agriculture. Yet rainfall in urban areas encounters much less pervious surface and vegetative cover. This fact reduces levels of infiltration and evapotranspiration, while increasing the volume and velocity of surface runoff. For urban sources, most of the phosphorus and N in runoff, with the exception of construction sites, is not sediment bound but in soluble form (Schueler, 1987). Conveyance of N from these sources will vary widely between different urban sites, depending on the land surface conditions. To emphasize the importance of these land surface conditions on the ultimate edge of stream loads in urban areas, it is useful to describe the sources of N as they occur through the development process.

2.7.1. The Development Process

Development can affect water quality in several ways. As more people move into an area, municipalities are required to accommodate both a higher demand for clean water and an increase in the volume of wastewater which will need to be treated. Land is cleared for the building of new homes, and for the construction of new roads to connect them to already existing urban centers. Farms and forests are gradually replaced by succession of neighborhoods, shopping centers, and office parks. All of these processes can potentially increase the N loadings to the area's waterways.

Typically before a site is developed it is first cleared of its vegetative cover, graded to a more uniform slope, and then building materials are delivered to the site. At this point, even before building has begun, the potential N load from the site has increased. Undisturbed land has the capacity to assimilate much of the rain that falls during normal storm events. As the vegetative cover is removed the ability of the land to store the rainfall is diminished and a higher percentage of the precipitation becomes surface runoff. As the land is graded much of the humus which helps absorb rainfall is removed, and small depressions which serve to temporarily pond rainwater are filled (Schueler, 1987). This process acts to increase both runoff and sediment loadings which reach nearby streams.

Once construction work actually begins the soil structure changes further. Most of the soil at the site is exposed or is covered with construction debris that leads to increased rates of erosion. Sites that do not employ strict sediment and erosion control measures can be a major source of sediment pollution for nearby waterways (Novotny and Olem, 1994). Other areas will become highly compacted under the weight of heavy machinery. As a consequence, soil infiltration decreases, leading to higher runoff rates.

After the construction phase is finished, erosion rates tend to return to normal once vegetative cover has been reestablished (Novotny and Olem, 1994). However, roads, sidewalks, parking spaces and rooftops are all now part of the landscape. These areas are collectively referred to as impervious surface, and rainfall that hits these surfaces is converted directly into runoff which then must be channeled away from the site through the use of curbs, gutters and storm sewers. The amount of impervious surface found at a site has a direct effect on the nature of the runoff resulting from the site (Schueler, 1994) (Arnold and Gibbons, 1996). As the percentage of impervious surface increases:

- A higher percentage of the rainfall from a storm will leave the site as runoff.

- The velocity of the runoff will increase and so the time it takes to reach adjacent waterways will decrease.

- Peak discharges of storm runoff will increase. As a consequence, the runoff event is less spread out over time, so local streams receive larger pulses of water in a shorter period of time.

- The combination of increased volume, velocity, and peak discharge for the runoff increases the potential for runoff to transport both dissolved and sediment bound forms of N from the site to nearby streams.

The larger volume, velocity, and peak discharge of runoff causes streams to experience more frequent and severe flooding (Schueler, 1994). This flooding can destabilize the streambed and streambanks, causing excessive erosion. Over time this erosion makes the channels wider and deeper as they now must accommodate larger pulses of stormwater.

Another impact of the increased runoff is that less water is infiltrating to groundwater. This process can have the effect of lowering the baseflow of water to streams in between the runoff events (Schueler, 1994). This lowering of baseflow, in combination with the channel erosion, has a negative impact on stream ecosystems. Small pools, riffles, and gently sloping banks are scoured out or covered over by coarse sediment. As a result, the level of aquatic vegetation in and along the streams is reduced, and it also causes the microbiological diversity within the stream to decline. In turn, this has the effect of diminishing the ability of the stream to incorporate and utilize N that enters the water. Also the N that enters the stream through runoff passes through the stream quickly, further reducing the chance that it will be utilized. This negative impact on streams is likely in many situations to increase the transport factor for N. The potential result is that a higher proportion of the N entering streams could eventually make it to the Potomac's fall line and ultimately to the Bay.

Not all stormwater runoff from urban areas goes directly to ephemeral, first and second order streams. In highly urbanized areas, much of it is channeled to stormwater sewer systems that convey the water ultimately to a waterbody. However, this water is often first contained within a stormwater detention basin and then released to a large stream or river.

2.7.2. Impervious and Pervious Surfaces

Virtually none of the activities which occur upon urban impervious surfaces require the need for N. An exception is when fertilizers are used instead of salts for areas such as: deicing, roads, sidewalks, and airports (Dillaha, 1997). What makes impervious surfaces so important is their ability to facilitate the transport of N to waterways (Arnold and Gibbons, 1996). Since roads, sidewalks, and driveways are linear, there tends to be a great deal of border areas between impervious and pervious surfaces (Schueler, 1995). These edges provide a means by which sediment and debris can accumulate on impervious areas. Lawn clippings, tree pollen and leaves, pet droppings, and erosion from land along uncurbed streets, can all be sources of N which can cross over this edge (Schueler, 1995). Most of the dust that collects on street surfaces is the result of airborne eroded sediment from local soils (Novotny and Olem, 1994). Other sources of particulate matter on urban streets are automobile emissions and wet and dry deposition from higher in the atmosphere.

Most all dust in debris on road surfaces will be found within a meter of the curb or roadside (Novotny and Olem, 1994). This fact is due to relatively low amount of air turbulence there as opposed to the middle of the road. In heavily urbanized areas this material will be transported to the stormwater sewer system by the next runoff producing precipitation event. Such events are quite common for impervious surfaces. Since their permeability is essentially zero, once rainfall has exceeded its maximum depression storage level, which is about 1 to 2 mm, runoff begins to occur (Novotny and Olem, 1994).

The amount of impervious surface is not the sole factor affecting the amount of stormwater reaching waterways. The spatial distribution of the pervious and impervious surfaces is also important to consider. This is especially true in the medium and lower density residential areas that comprise a large portion of the urban landscape. Most impervious surfaces are either buildings or part of a transportation network (Schueler, 1994). Pervious areas surround many buildings, particularly in suburban areas. Water leaving an impervious area and entering a pervious area is referred to as runon (Schueler, 1995). By contrast the transportation network crisscrosses the landscape dividing the pervious areas into parcels. Surface water coming off the land onto this transportation network, just like that entering waterways, is referred to as runoff.

If runoff from pervious areas reaches impervious surfaces it will most likely be part of some transportation network. The water moves readily across the network of roads, with many curbsides resembling small streams, until the water is fed into either a storm drain or back onto the land as concentrated flow.

Travelling from impervious to pervious surfaces the water has a chance to be infiltrated and much of the sediment can be filtered out. The rate of infiltration will depend on the soil type, slope and surface conditions, as well as the volume and velocity of the runon. It may be the case that by the time the runon reaches the pervious area, it has enough velocity and volume that it quickly channelizes. If this occurs, very little of the water will actually infiltrate. Even so, runon is much more desirable than having the water flow directly into the stormwater drainage system. The benefits of runon will be discussed in greater detail during the discussion of vegetated filter strips in the next chapter.

As a general rule, areas with less impervious surface produce less surface runoff. Yet this rule does not mean that all pervious surfaces are the same. According to Schueler

(1995), “Urban soils tend to be highly compacted, poor in structure and low in permeability.” This fact is due in large part to the construction process. The stripping of top soil, grading of slopes and depressions, along with the continual movement of heavy machinery over it, all work to reduce soil infiltration. This in turn reduces the soil’s ability to support plant life and soil organisms. In heavily urbanized areas, as much as a third of the soils can have infiltration rates at or near zero (Schueler, 1995). When this is the case, there is little difference between the hydraulic characteristics of this land and concrete.

In many urban areas vegetation is preferable, and the land will actively be managed to produce a thick green vegetated cover. In fact, the application rates of water, fertilizers, and pesticides for some urban land are similar to those used on cropland (Schueler, 1995). These areas are typically referred to as high-input turf, and they may constitute roughly 40% of the permeable surface within an urban area (Schueler, 1995).

From a N load standpoint, high-input turf is a concern because of the high rates of fertilizer applications. As mentioned, it is common for homeowners and lawn care services to apply fertilizers at rates similar to those applied to cropland. This practice is usually far in excess of the nitrogen requirements for a healthy lawn (Schueler, 1995). What is more, the applications are often done without consideration of the likelihood of rainfall events that could potentially carry the nutrients away in runoff. Since commercial fertilizers used on urban turf consist primarily of soluble forms of N they are vulnerable to being washed away. Another potential problem with these heavy loadings of soluble N, is that when the water content of the soil exceeds field capacity due to rainfall or overwatering, the soluble N will percolate down to the groundwater tables usually in the form of nitrates.

2.7.3. On-Site Wastewater Treatment

The most common source of N in groundwater is on-site wastewater treatment systems, more commonly referred to as septic systems (Novotny and Olem, 1994). In Virginia’s Potomac basin approximately 34% of the homes use septic systems to handle their wastewater needs (CBP, 1992). A septic system works by allowing solids to settle out of the wastewater and begin the process of decomposition while being contained within the septic tank. Bacteria, naturally present in all septic systems, begin to digest the solids that have settled to the bottom of the tank, transforming up to 50% of these solids into liquids and gases. When liquids within the tank rise to the level of the outflow pipe, they enter the drainage system. This outflow is then distributed throughout the drainfield through a series of subsurface pipes. Final treatment of the wastewater occurs here as the soil absorbs and filters the liquid, and microbes break down many of the remaining substances in the effluent.

Estimates of the concentration of N in normal household effluent is anywhere between 59 and 72 mg/l (USEPA, 1993). The amount of N removal that occurs in a normally functioning septic system, before the effluent is discharged into the drainfield, is usually pretty low. The reason for this is that most systems are designed only to settle out solids and not to remove N. After being discharged into the drainfield the level of N removal will be highly dependent upon the soil type, the moisture content of the soil, and the depth to the water table. For a properly functioning system, the removal rate is estimated to be about 28% of the N entering it (USEPA, 1993). So the water which leaves the field as interflow or baseflow will likely have a concentration of 47 mg/l. Using a probable daily flow of about 46 gallons per capita per day, this results in an annual load estimate of about 6.64 pounds of N per person (USEPA, 1993).

Improperly functioning systems remove little to none of the N entering the system. Poorly sited systems are the most frequent cause of septic system problems. If the water percolates too slowly, surface ponding can occur. By contrast, if it occurs too quickly, and this means higher loading rates to groundwater. In many areas of the Basin the water table is very close to the surface. This situation can lead to high loading rates to groundwater as well. Neglected systems that are not routinely cleaned and maintained can cause sewage and other household waste to clog the drainfield reducing its capacity to absorb and treat the wastewater. This can reduce soil porosity and eventually result in surface seepage. Rainfall will also have difficulty infiltrating the soil and so it will likely leave the area as runoff.

In conclusion, it is evident that sources of urban N pollution are as varied and complex as those from agriculture. The basic sources of urban N loads are:

- Construction site erosion
- Streambank erosion from increased peak flows, and higher runoff velocity and volume.
- Both wet and dry atmospheric deposition.
- Traffic emissions deposited onto impervious surfaces.
- Litter and vegetative debris deposited onto impervious surfaces.
- Leaching and surface seepages from septic systems.
- Deicing chemicals used at airports.
- Fertilizer applications to lawns and high input turfs.

For many urban N sources, the human activity causing the N loading, does not necessarily generate an excessive amount of N. Instead, it is the diminished capacity of the land to incorporate the N due changes in surface cover and hydrology, resulting from urbanization.

2.8. SUMMARY OF SOURCES

The topics discussed in this chapter were intended to provide a general overview of the sources of N entering the waters of the Potomac. It should be apparent from the discussion above that nearly all of the activities man undertakes can either directly or indirectly affect the amount of N entering waterways. As a result, making a list of all possible sources is an exceedingly difficult if not impossible task. However, the sources mentioned in this chapter encompass most all the major inputs of N to the Potomac that are considered potentially controllable.

Our understanding of the mechanisms by which N is transported from the land

and air into the waters of the Potomac is by no means complete. This will become more evident in the next chapter when control technologies are discussed. A technology that works well to control N from one source may have proven completely ineffective when applied to another similar source. Because of this, many experts consider NPS pollution control to be more of an art than a science, and it is likely to remain so until the complex processes underlying the sources of N are better understood.

CHAPTER III

NITROGEN CONTROL

3.1 INTRODUCTION

For every source of N there are one or more techniques used for controlling the amount that is ultimately delivered to waterbodies. Techniques can be a change in behavior, commonly referred to as a management practice, or they can be structural modification. Structural modification refers to any alteration of the land at or near a source of N. Techniques can reduce the amount of N available, prevent N from leaving the site, or they can intercept and remove N as it is being transported to surrounding waters. Most often management practices will be used to reduce the amount of N leaving the source, while structural controls tend to intercept the delivery of N. As mentioned, techniques used for the control of diffuse sources of pollutants are commonly referred to as best management practices (BMPs), even though many of these are not actual changes in practices but rather structural changes. For convenience, the acronym BMP will be used to refer to control techniques for diffuse sources of N.

Each BMP has several important characteristics which pertain to its overall usefulness for controlling sources of N. These characteristics are typically considered in conjunction with estimated startup and maintenance costs to determine the likely benefits from using the BMP. These characteristics are:

- **Efficiency** pertains to the average percentage of the initial N which is expected to be removed when the BMP is employed. The greater the percentage the more efficient the BMP. This characteristic is used along with expected costs to determine cost effectiveness. However, there are several other factors, besides average expected N reduction, which are important for determining the appropriate BMP for the source.

- **Reliability** typically refers to the failure rate of a BMP. The higher the probability of the BMP not working the less reliable it is. BMP failure can occur due to improper siting, construction, or maintenance of the BMP. It can also occur due to unforeseen circumstances such as floods or blights.

- **Variability** is a characteristic very similar to reliability. When the effectiveness of a BMP varies significantly, with terrain, soil, and climate conditions expected rates of effectiveness are less reliable. BMPs with a high degree of variability require a great deal of site planning to reduce the uncertainty associated with its use.

- **Feasibility** refers to the fact that many BMPs are only effective when specific terrain, soil, and climate conditions are present. When it has been determined that N either originates from or is transported across a given area of land, feasibility refers to the percentage of the land on which the proper conditions exist. Because of this fact, feasibility limitations are most often associated with the use of structural BMPs.

• **Longevity** refers to expected lifespan of the BMP. This concept encompasses more than just the expected length of time the BMP will continue to function. It also pertains to how the rate of effectiveness is expected to change over this time period. Many BMPs experience a steady decline in effectiveness over their lifespan. Yet others will remain relatively unchanged and then decline sharply towards the end of their lifespan. Management practices tend not to have an expected lifespan, but often equipment used for a management practice will wear out and need to be replaced.

Unfortunately information about each of these factors is not available for every BMP.

There are many different methods used for reducing and controlling sources of N. Not all methods are suited to the land uses, climate, or terrain found within the Potomac Basin. Established practices that are used elsewhere in the United States, but are not used in the Potomac Basin are not mentioned here. In addition, many BMPs are simply variations of a basic control process. Therefore, if two or more techniques are very similar in their design, cost and performance, they will be discussed as a group rather than individually.

Nitrogen controls for point sources are additions to the wastewater treatment processes often referred to as retrofits. The agricultural sector has the largest collection of BMPs available for N control. Most of these are either used for controlling erosion and sediment loss from fields, or for reducing the concentration of nutrients in runoff. Forestry BMPs are chiefly employed to control erosion. Urban BMPs are also numerous, yet they are primarily used to intercept and treat stormwater runoff before it reaches a body of water. Another potential method for controlling N from urban areas is modifying the way in which non-urban land is developed and urban land is redeveloped.

Best management practices specifically designed to reduce nitrous oxide emissions into the atmosphere, would ultimately reduce the amount of N entering waterbodies. Air pollution BMPs in the basin will reduce some of the deposition in the basin and elsewhere. Likewise BMPs elsewhere within the airshed will reduce deposition both in and out of the basin. Given how dependent atmospheric deposition is upon meteorological conditions, it is extremely difficult to assign specific reductions of N entering the Potomac to exact instances when a BMP is used. Therefore air pollution BMPs are not included as some of the possible techniques for reducing N to the Potomac River.

3.2 POINT SOURCE RETROFITS

As mentioned in chapter one, N control methods for point sources differ from nonpoint source BMPs in several ways. These differences deserve mention when considering the effectiveness and costs of these retrofits. The significance of these differences will be elaborated upon in the next chapter when the cost effectiveness of control methods is discussed. Municipal and industrial wastewaters contain numerous residual substances besides nutrients, which can have a potential impact on water quality. So wastewater already undergoes treatment for several residuals, such as suspended solids and organic carbon, before being discharged by point sources. There is some nutrient removal that occurs during this basic treatment process. However, the system is not considered retrofitted unless there is a treatment stage added to the process that is specifically designed to remove nutrients.

Point sources typically use either a biological or chemical treatment methods to remove nutrients from the wastewater. Chemical methods can effectively be used removal of phosphorus, yet they are not very cost effective for reducing N (Randall et al., 1987). So biological methods are typically used for removing N. The basic wastewater treatment process has several stages.

• **Primary Treatment** is the separation of solids and particulate matter from the wastewater. This is a physical process that is accomplished in a settling chamber, and is almost always the first stage of treatment. Organic N and ammonia bound to sediments are removed in this process. Anaerobic conditions usually exist in these settling chambers so some denitrification of nitrates occurs as well.

• **Secondary Treatment** is the reduction of organic compounds in the wastewater. This stage is a biological process that occurs when bacteria digest these compounds. The importance of the secondary stage is that it reduces the demand for oxygen in the wastewater. (When wastewater with a high level of biological oxygen demand enters an open waterway, it can cause serious harm to aquatic life by reducing the amount of dissolved oxygen present in the water.) This process typically involves an aeration process that allows microorganisms to break down organic compounds into H_2O, CO_2 , and other more stable compounds. The aeration process also allows for nitrification to occur. Nitrification, as described in the last chapter, is when microorganisms convert organic N and ammonia into nitrates. An incidental level of N is typically removed during this process, this is likely the result of some ammonia volatilization and the presence of some anoxic conditions (VDEQ, 1995).

• **Tertiary Treatment** is any stage where the water is polished through a filtering process, or nutrients are removed through biological or chemical processes. Polishing is the removal of very fine particles from the water. Biological tertiary treatment can entail both nitrification and denitrification or just the latter, depending on how much nitrification occurs in the secondary stage. Denitrification is an anaerobic process where bacteria break down nitrates into N gas that then leaves the water. Some of the chemical processes used to remove N are breakpoint chlorination, ion exchange, and ammonia stripping (Camacho, 1992).

• **Disinfection** is the removal of any possibly harmful pathogens before the effluent is discharged. Typically this is accomplished by first chlorinating the effluent and then removing the chlorine before discharging. Ozone and ultraviolet light are two other common methods of disinfecting wastewater.

• **Land Application** is a further treatment option for low capacity waste treatment plants which often serve rural communities. Effluent is dispersed in a large drainfield, above or just below the soil surface. Vegetation uses some of the available N while aerobic and anaerobic processes within the soil layers provide further treatment for the effluent.

The types of system municipalities choose to construct is based upon expected content and quantity of the wastewater it will process, as well as effluent standards they must meet. Depending on the effluent standards for the point source, treatment of the wastewater may not go past the secondary treatment stage or may only include the polishing of the water. Although some N removal occurs during the primary and secondary treatment stages, the denitrification which occurs in the third stage is needed to significantly treat the wastewater for N (VDEQ, 1995). The typical secondary treatment processes used in the basin are activated sludge, extended aeration, and fixed film systems, with the use of some lagoon systems as well (VDEQ, 1996), (CH2M HILL, 1989). These processes provide a conducive environment for the breakdown of organic compounds by microorganisms.

All of the systems mentioned can be retrofitted with an additional treatment stage to promote further N removal. The biological nitrification and denitrification processes are together typically referred to as a biological nutrient removal (BNR) when used to remove N from wastewater. Retrofitting treatment plants with the third treatment stage so that they can perform BNR is considered a more cost effective way of reducing discharge of N, than other chemical processes (Camacho, 1992). However, the BNR process can experience disruptions due to shock loadings or because of toxins in the untreated wastewater (Randall, 1987). The effectiveness of BNR can also be affected by seasonal temperature fluctuations. The nitrification process slows down considerably during cold weather, and so less N is removed from wastewater in the winter months than in the summer (VDEQ, 1993).

Due to this seasonal fluctuation in effectiveness, some plant operators choose to forego the third treatment stage in the winter months to save on operating costs. So the BNR process can be subdivided into seasonal and annual BNR, or SBNR and ABNR respectively. When a plant is faced with very strict milligram per liter effluent standards, a third possibility for retrofitting referred to as Limit of Technology (LOT) is typically considered. This process is the use of either chemical processes, multiple aerobic and anaerobic chambers for advanced biological treatment, or a combination of biological and chemical processes such as adding methanol to act as a food source for the microbial activity.

In the Potomac Basin since 1985 many outdated plants have been taken off-line and several plants have been upgraded (See Appendix B). However, population growth in the Northern Virginia is causing many treatment facilities to expand their capacities and in the Southern Shenandoah region wastewater flows from industrial facilities are increasing. So even with the improvements that were made, the total point source N loads to the Potomac River actually increased between the years of 1985 and 1994 by 2% (VDEQ, 1996).

3.3. AGRICULTURAL BEST MANAGEMENT PRACTICES

Agricultural BMPs can be divided into those used for crop production and those for raising livestock. They can also be categorized as those that are designed to reduce erosion and sediment loss, where N is just one of several residuals being controlled, and those BMPs that are used just to control nutrients. The Table 3.1 is provided as a general categorization of the different types of BMPs commonly used on farms in the Potomac Basin (McCarthy, 1996).

Table 3.1. Agricultural Best Management Practices

	CROP PRODUCTION	LIVESTOCK PRODUCTION
EROSION & SEDIMENT CONTROL	Conservation Tillage	Confinement Lot Management
	Contour & Stripcropping	Grazing Land Protection
	Cover Crop	Stream Bank Protection
	Vegetated Filter Strips*	
	Erosion and Sediment Control Structures*	
	Reforestation*	
NUTRIENT CONTROL	Split & Site Specific Applications	Animal Waste Control Facility
	Green Manure & Cover Crops	Composter Facilities
	Manure & Compost Fertilizers	Poultry Manure for Cattle Feed

* Can be used for both cropland and for land devoted to livestock operations.

3.3.1. Crop Production BMPs

The BMPs listed as nutrient control measures for cropland are collectively referred to as *nutrient management* (USEPA, 1993). The purpose of nutrient management is to choose the type of fertilizer and its application in such a way as to meet the nutrient requirements for the crop while minimizing loss of nutrients from the field due to runoff or leaching. The nutrient management BMP begins with a nutrient management plan. This plan entails a soil survey, yield expectations, an analysis of the nutrient content of any non-commercial fertilizers, plant tissue testing, and then a selection of the practices that will be used (VDEQ, 1996). The soil survey typically includes the use of field maps, soil tests for current nutrient and pH levels, and an identification of critical areas. Yield expectations are based either on historical yields or data provided by nutrient management specialists. If it is likely that some noncommercial fertilizers will be used, then an analysis of the manure, crop litter or compost is conducted. Also, an assessment of any additional N that may have been derived from a rotation of legume cover crops is often conducted. This information will then be used to select the types of fertilizers and application methods to be used.

Commercial fertilizers use soluble forms of N that are readily available to plants but are readily lost to runoff and leachate. Farmers receive no gain from the N lost so adjusting their practices so that more of the N is utilized is beneficial for them as well. By timing the application of fertilizer so that it is done when the chance of runoff is low and plant uptake is high N loss can be reduced. Splitting the application of fertilizers over the growing season greatly improves the utilization of N as well. Nitrogen in ammonia form is available to plants for uptake, but unlike nitrates it is sediment bound. Using nitrification inhibitors keeps N in the ammonia form longer so more is utilized by plants and less is lost.

Most of the N that is in organic fertilizers is not readily available to plants. Microbial activity within the soil layer slowly converts this organic N to available forms over the growing season. As the usable forms of N become available they are taken up by plants, and so less soluble N is present in the soil at any given time during the growing season, than with chemical fertilizers. Using manure and composted poultry carcasses as fertilizer also provides a beneficial way of disposing of these waste products.

Fertilizer application can be varied per acre so that critical areas can be taken into account. The critical areas are land that is prone to erosion or that is close to a waterbody. Fertilizers can be applied more frequently and in smaller amounts on critical areas.

The use of cover crops within a nutrient management plan provides several benefits. At the end of the growing season N that is left in the soil is prone to being lost when the field is left bare over the winter. A cover crop takes up residual N left in the soil, as well as rainfall through transpiration, thereby reducing runoff and leachate. When Spring arrives, the cover crop can be cut and left on the soil surface or plowed back into the soil. The crop residue then provides a source of nutrients for the growing season. If legumes or green manure plants are used as a cover crop, nitrogen fixation occurs in the soil layer, improving the nutrient content of the soil.

Conservation tillage is any planting practice leaving more than 30% of the previous crops residue on the soil surface (USEPA, 1993). This term incorporates both minimum and no-till practices. Minimum tillage is the tilling of the field, only to the extent that seedbed can be prepared (Novotny and Olem, 1994). No-till is the direct planting of seeds into the soil without tillage. Both practices ensure a layer of ground cover during periods when fields are prone to runoff and erosion. Plant residues absorb the impact of rainfall causing the soil to be less compact, resulting in more infiltration and less runoff. However, the plant residues can also make it more difficult for applied fertilizers to reach the soil layer, possibly causing an increase in the concentration of soluble N in runoff. This problem can be managed by injecting nutrients beneath the soil layer.

No-till is the most effective practice for decreasing erosion, but it can also lead to formation of macropores within the soil which allow more nutrients to reach groundwater (Novotny and Olem, 1994). Minimum till is less effective at reducing erosion, but tends to breakup macropores reducing nutrient leaching.

Contour cropping and *stripcropping* are practices that modify the way in which rows of crops are planted in order to reduce erosion and runoff. Contour cropping is when the planting and cultivating of crops is done to follow the contours of the land. Stripcropping alternates strips of crop rows with strips of sod or close-grown crops. This practice is usually done as a form of contour cropping (VDCR, 1996). Together they are highly effective at reducing erosion. Planting with the contour decreases the ability of rainwater to form gullies, while the strips of unplowed land act as a buffer reducing the flow of runoff and uptaking nutrients.

Cover crops are close-growing grasses, legumes or small grain crops grown on cropland during periods when row crops are not grown (USEPA, 1993). These crops are typically planted in the fall so they can serve as protective cover during the winter months when the ground is frozen. When the spring comes, the cover is cut and either plowed under or left on the surface. The cover not only reduces erosion and runoff, but it also can provide additional nutrients for crops planted in the spring. However, if the cover is harvested then this additional benefit is not provided. The fields also can have limited use as pasture for grazing livestock (VDCR, 1996). This practice allows for more land to be used for rotational grazing, yet it decreases the ability of the cover to protect the soil surface, so the effects of this practice are uncertain.

Vegetated filter strips are strips of permanent cover that are placed on the perimeter of cropland or livestock confinement lot. They are typically placed on the down slope of a field or between the field and a nearby water body. The filter strips are typically comprised of grasses, but can also be shrubs, marsh grasses, or other herbaceous vegetation depending on site conditions (VDCR, 1996), (USEPA, 1993). Trees and large stem vegetation are considered a separate type of buffer system. If a filter strip consists of grass, the strip should then be periodically mowed to promote denser concentrations of plant material at the soil surface.

Filter strips reduce both runoff velocity and volume and help remove nutrients and coarse sediments from the runoff flow. As sediment begins to accumulate in the filter strip, large storm events can overload the filter and wash large amounts of sediment and nutrients into waterways. Over a period of years runoff can begin to concentrate and form gullies through the filter, greatly reducing the effectiveness of the filter. Therefore vegetated filter strips are generally considered to have a short life span, although with proper management and allowing the filter to rest periodically the life of the BMP can be extended.

Because the effectiveness of filter strips is very site specific, there is a general criterion to follow when considering their use. If the slope of the land is greater than 10% then the runoff will likely concentrate before reaching the filter strip. If less than 1% there will not be enough gravitational pull to transport the water across the filter. If the field already contains natural channels filter strips should not be considered. Likewise, if the field experiences high rates of erosion, any filter would have a short life span, as it would soon fill with sediment. For removal of N and other pollutants, the ratio of filter area to field area would be high, ideally 1 to 5 respectively. However, such a large reduction in cultivated land would probably be unacceptable. Therefore a ratio of 1 to 20 is a reasonable ratio and 1 to 50 would be the absolute lowest acceptable ratio of filter to field area (Conversation with Dr. T.A. Dillaha).

When erosion and sediment loss are severe problems, *erosion and sediment control structures* may need to be installed. Depending on what the structure is intended to do, these may be placed up slope or down slope of the field, or within the field itself, as a way of modifying the movement of runoff. Some examples of these types of structures are diversions, terraces, sediment basins, and detention ponds. Diversions are channel and ridge systems built upslope from a field, confinement lot, or waste storage facility (USEPA, 1993). Their purpose is to divert runoff from higher elevations from moving across the field. The channel can just be a slight depression next to the ridge, or it can be an actual ditch. In some cases a subsurface drainage system may be used to send the water to a drainfield, detention pond, or sediment basin.

Terraces are much like diversions in that they use channels and ridges that cut across the slope of hills. The main difference is that while the purpose of diversions is primarily to channel runoff away from fields, terraces are meant to intercept and slow runoff, and increase infiltration rates as well. With terraces one or more embankments are constructed along the slope of the hill thereby separating the total length of the slope into smaller segments. Terraces are typically placed within field but a terrace can also be placed just after a field or confinement lot.

Sediment basins and detention ponds are used to impound surface runoff. As mentioned, these can be used with diversions, so that runoff is intercepted before it reaches a field and channeled to the basin or pond. They can also be placed down slope from a field along with a terrace so that runoff from the field can be channeled to them. Both are designed primarily to remove sediment and sediment bound nutrients from runoff. The primary difference between them is that sediment basins are not meant to retain the water for an extended period, rather they are meant to detain the runoff to slow its velocity, allow settling, and increase infiltration. Detention ponds are built with the intention of preventing the runoff from reaching surface water. Runoff is controlled primarily through infiltration and evapotranspiration, although some ponds are built with an outlet for large storm events.

Another method for managing sediment and nutrient loss is through *reforestation*. This method is a particularly useful alternative for land classified as highly erodible, or on land immediately adjacent to waterways (VDCR, 1996). Reforestation involves more than leaving the land idle. Grasses or other fast growing ground cover must be maintained on the land until the trees can grow large enough to provide a protective canopy. The use of streamside reforestation is referred to as *riparian forest buffers*.

A well functioning riparian buffer will have three zones of vegetation. Runoff initially comes in contact with the third zone that is essentially a vegetated filter strip as described above. This is meant to spread out and slow the speed of runoff as well as remove coarse sediment (CBP, 1995). The second zone is managed forest. Plant uptake and microbial denitrification within the biologically active soil layers help remove nitrates from subsurface flow. Trees have the ability to store large amounts of nutrients as biomass, which can then be removed from the riparian area through selective tree harvesting. When trees are harvested from this zone, its ability to remove N can be diminished while the zone recovers. The first zone, which is permanent streamside forest, provides a stable forest zone during the recovery period for zone two. However, this zone is primarily for the enhancement of stream water quality.

3.3.2. Livestock Production BMPs

A confinement lot is any lot or facility where animals are confined for a total of 45 or more days during a year (USEPA, 1993). *Confinement lot management* like nutrient management is a series of measures that can be used to curb the amount of nutrients in runoff leaving a confinement lot. The measures typically considered are rotational loafing lot systems and improved travel lanes, as well as the vegetated filter strips and the erosion and sediment control measures mentioned earlier.

Within the Potomac basin loafing lots are typically around three acres in size (Faulkner and Trott, 1994). A rotational loafing lot system increases the number of lots to four or more. Cattle are then moved from one lot to another to prevent any one lot from becoming denuded of vegetation. One lot is used as a sacrifice area where cattle are kept during periods of wet weather (VDCR, 1996). The sacrifice areas will experience some erosion so they are usually bordered by filter strips and or sediment and control measures. Travel lanes between barns and loafing lots or milking parlors and loafing lots experience heavy traffic and are prone to erosion. Curbing and walkways made out of concrete or other erosive resistant surfaces may be used along these travel lanes to reduce soil loss and channel runoff.

When cattle and other livestock are grazed on pastureland, excessive grazing and trampling can cause erosion. The number of animals per acre, the amount of time they are grazed on the land each year, as well as soil and terrain conditions will affect the erosion and N loading rates. *Grazing land protection* is a series of practices designed to minimize sediment and nutrient losses form grazing land. Proper stocking rates, rotational grazing, and reseeding practices are all part of grazing land protection

Optimal stocking rates vary with terrain, soil conditions, and management practices. So the rate ultimately should be determined on a per farm basis. Rotational grazing is division of pastureland into several paddocks typically with electrical polywire fencing (Faulkner and Trott, 1994). Each paddock is designed so cattle have access to a water source and an adequate amount of forage. While one paddock is in use the other paddocks are rested to allow vegetation to regenerate after grazing. This practice reduces N loss as less erosion and more infiltration occurs. The improved vegetative cover is able to take up more nutrients. Increased vegetation quality also decreases the amount of fiber in manure allowing it to decompose faster and thereby reduces its pollution potential (USEPA, 1993).

Locating salt licks and shade away from water or erodible land is another beneficial practice. Shade trees may be planted or shelters can be constructed to encourage herds to loaf in more favorable areas. Pasture land seeding is the establishment of grasses and plants that provide good forage and also hold up well to grazing and animal traffic (USEPA, 1993). Depending on the plants selected periodic reseeding may be necessary.

Stream bank protection measures are another set of practices that can be used on pastureland. The main focus of these practices is to reduce or eliminate the effects of animal traffic in and around waterways that run through the pastureland. The most common method for accomplishing this objective is to use fencing so cattle can only access the waterway at specific locations. Using riparian vegetation zones along stream banks can also serve to both limit the access of cattle to streams and to have some remedial effects on runoff. Access ways can then be planted with erosion resistant plants or erosion resistive structures, such as concrete, wood, riprap, or rock gabions, can be installed (Novotny and Olem, 1994). If erosion is a severe problem, animal access to a stream can be eliminated entirely. Water can be piped from stream or well to troughs or artificial ponds that are a safe distance from riparian zones. Often a farm will have pastureland on both sides of a small waterway. Moving cattle and farm equipment across the stream can cause both bank and stream bed erosion. Stream crossings can be installed that allow for cattle and farm equipment to be periodically transported over.

Animal waste facilities are used for the storage and disposal of animal waste products such as manure or poultry carcasses. Waste can be stored in either liquid or dry form. For liquid waste the facilities are typically holding ponds or treatment lagoons, and in some cases a settling basin that separates out some of the liquid before storage may precede the storage facility. For dry waste, composting structures and dry stack facilities are used. In the Shenandoah region, dairy manure is commonly stored in liquid form while poultry litter is stored in dry stack facilities with roofs (Faulkner and Trott, 1994).

If the waste products will be used as a fertilizer for crops, the waste is not likely to be treated to remove nutrients; instead it is usually stored in a holding pond. If the waste is not intended as fertilizer it can be treated in a lagoon system. Lagoon systems are one or more small artificial ponds built into the ground or above ground with earthen dikes. There are four basic types of systems: anaerobic, facultative, and aerated lagoons, and stabilization ponds. They vary according to the amount of dissolved oxygen typically present in the water. The ponds are typically lined with clay or other impervious materials to prevent groundwater contamination. Their purpose is to retain wastewater for an extended period of time. This retention period acts to stabilize the wastewater as heavier particles sink to the bottom and lighter particles rise to the surface of the lagoon. The retention period gives microorganisms time to feed on the nutrients in the water. The use of lagoons to reduce the N content of the liquid waste is currently not used as a means of N control on dairies in the Shenandoah.

Dry storage or composting facilities are used to store solid wastes from feed lots and for poultry carcasses. The purpose of these facilities is primarily to allow decomposition and to make storage and handling of the waste easier, and is not used to remove nutrients. These facilities have a high potential for producing runoff high in N and P, so curbs and gutters are installed to prevent runoff from entering the facility. Often these facilities are built in conjunction with a treatment lagoon that can be used to treat the runoff from the facility.

As mentioned, animal waste can be used as fertilizer for crops. If the amount of manure exceeds the amount needed by the crop, the waste material can be spread over grazing land during periods when runoff is less of a problem. Another method for disposing of poultry and cow manure is to use it as a source of commercial fertilizers for urban and suburban areas. A more controversial method of disposing of poultry litter is to use it as a food supplement for beef cattle.

3.4. FORESTRY BEST MANAGEMENT PRACTICES

Forestry best management practices can be divided into two basic types. The first are those designed to decrease soil erosion during road construction, harvesting, and site preparation. The other type is streamside management through buffers and selective harvesting. A third factor not generally considered as a forestry BMP, but extremely useful at reducing the impact of silviculture, is preharvest planning.

3.4.1. Preharvest Planning

It is important to undergo advance planning in preparation for harvesting a given tract of timberland. Within the tract a road network, a harvesting schedule, harvesting practices, and post harvest site preparation must be planned. During this planning stage many steps can be taken to avoid actions which could lead to increases in nonpoint source pollution.

Logging roads should be built so that steep slopes and hydrologically active areas are avoided when possible. This practice will both help reduce erosion and surface runoff. More importantly logging roads should be built to minimize the number of stream crossings that occur within the tract. Such crossings are a major source of sediment delivery to streams.

Harvesting should be scheduled during the time of year when runoff will be minimized. Sensitive areas prone to erosion should be identified. This information can then be used to determine where harvesting should be minimized or avoided altogether in order to lesson the possibility of landslides (USEPA, 1993).

3.4.2. Erosion and Sediment Control

There are a number of measures that can be taken to minimize erosion during timber harvesting. Implementation of erosion control practices can reduce potential N loads by 80% (USEPA, 1993). The choice of harvesting technique will effect erosion rates. For instance, the harvest technique of selective cutting leaves a higher level of surface vegetation and causes less soil disturbance than clear cutting does. During harvesting slash material can accumulate. Removing slash from areas where it can enter waterways will reduce the amount of debris in waterways. Straw bales or grass seeding should be used to stabilize perimeter of landing areas (USEPA, 1993).

Hauling and timber skid roads that will receive frequent use should be covered with gravel; those that will only be used periodically should seeded with grass. When roads must be built over a stream, culverts and erosion control measures should be put into place. The road should be removed and normal stream flow restored if the road will not be needed after harvesting (USEPA, 1993).

3.4.3. Streamside Management

Streamside management requires that a zone of either undisturbed or minimally disturbed trees be left adjacent to streams. Areas immediately adjacent to streams tend to be hydrologically active making them susceptible to runoff and erosion. The delivery ratio is also extremely high since the areas border streams. Leaving these areas intact reduces the total erosion level for the timber harvest.

The areas also can serve to act as a buffer between the harvesting going on further upslope and the streams. The trees and ground cover within the streamside management zone reduce runoff and trap sediment from upslope activities. In this way they will lower the delivery ratio for the harvesting that does occur. The usefulness of these zones as a buffer depends heavily on the hydrological conditions present. A very important condition is the slope of the land. To serve as a buffer the zone will need to be wider as the slope increases.

If it is decided that harvesting will occur in the zone immediately adjacent to streams, then there are several methods that can be used to minimize the impact. Selectively harvesting only the most valuable trees that have reached maturity in the zone will leave the majority of the trees in the zone intact. The use of skidders and other heavy machinery within the zone can be avoided. Finally, cable assisted directional felling can be used to minimize debris entering the stream.

3.5. URBAN BEST MANAGEMENT PRACTICES

Controlling N loadings from urban areas is more problematic than it is for agricultural areas. This is the case because many of the sources of agricultural N can be reduced through changes in production practices, but in urban areas most all require the installation of a control structure. In addition, when control structures are used in agriculture, the necessary land for it is usually readily available. This is often not the case with urban land, especially in high-density urban areas.

Urban best management practices can be grouped into those that reduce erosion from construction sites; those designed to control urban stormwater; and those that can be used as an alternative to on-site wastewater treatment. Many of these BMPs are similar in design to control practices mentioned earlier for agricultural, forestry, and point source N pollution. Construction BMPs, like many used in agriculture and forestry, are intended to reduce erosion and sediment loss. Treatment processes used as alternatives to conventional on-site wastewater treatment are just smaller versions of those used at POTWs.

3.5.1. Construction BMPs

Since erosion and sediment loss is the principal NPS problem on construction sites, controlling these is the best way to reduce N loads from the area. Careful planning before construction begins is an important first step. Maintaining good surface cover is necessary for minimizing erosion at the site. Use of structures to intercept runoff from the site is main way in which sediment yields can be controlled.

Several steps can be taken during the planning process to reduce potential for erosion at the site. Perhaps the most important is to maintain as much of the existing vegetative cover as possible, by clearing only those areas essential for construction activity (USEPA, 1993). Access roads should be planned so they avoid steep slopes or waterways. This is also true for areas that will be used for storing materials and excavated soils. If construction will occur on a sloped area, berms or diversions can be placed upslope of the site, and stormwater can be channeled to avoid exposed areas.

Once construction has begun access roads for the site should be covered with gravel to reduce soil erosion caused by vehicular traffic. Stockpiles of soil and construction materials should be covered either by tarps, gravel, or mulch mats. As soon as construction work has finished in a given area, mulch mats and seeding should be used to establish vegetative cover.

Sediment loss from the site can be reduced by BMPs that intercept runoff and promote infiltration (USEPA, 1993). Most all runoff at the site begins as sheet flow but will quickly concentrate into channelized flow. Straw bale or filter fabric fences can be used as barriers to reduce water velocity and filter out sediment from areas experiencing sheet flow. Vegetated filter strips much like those used in agriculture can be used to increase infiltration and filter out sediment from sheet flow.

When flow has become channelized detention basins and sediment traps can be employed. Like those used in conjunction with livestock confinement lots, sediment basins at construction sites are designed to temporarily impound the water to allow for infiltration and the settling out of solids. Detention basins are usually located at low areas of the site and drainage ways are put in to channel concentrated flow to it. Sediment traps are smaller impoundments that can be installed along drainage ways. At some sites it will be necessary to direct flow from the site to a storm drain. Barriers made of straw bales or filter fabric can be used to trap sediment at the inlet of the drain before it enters the sewer system.

The state of Virginia established minimum standards for construction practices under the Erosion and Sediment Control Law and Regulations. In 1993 the law was amended to give the Virginia Department of Conservation and Recreation (VDCR) the authority to ensure that these regulations were being implemented by localities throughout the state (VDEQ, 1995). The law requires localities to enforce a series of best management practices set forth in the regulations. These regulations should be integrated into zoning and subdivision ordinances of the various localities. As of 1995, 52% of the localities within the Potomac Basin were in compliance with the law (VDEQ, 1995). The VDCR has the goal of full compliance with the law across the state by the year 2000.

3.5.2. Urban Stormwater BMPs

The predominant method for controlling N loadings from urban stormwater runoff is through the use of structural BMPs. Some management measures such as street sweeping or nutrient management for lawns can be used to reduce the amount of N that will be transported by stormwater. However, the benefits of these measures are considered minor in comparison to the structural techniques (Novotny and Olem, 1994). There are essentially three different categories of urban stormwater control structures: urban vegetated filter strips, ponds, and ultra-urban techniques. Ponds include extended detention dry ponds, extended detention wet ponds, and constructed wetlands. Urban vegetated filter strips include grass filter strips, grass swales, and small forest buffers. Ultra-urban techniques are sand filters of various designs.

Rather than discuss each individual BMP separately it is useful to discuss them within the context of their category. This is the case because each of the BMPs within a category essentially functions the same as the others, and each is a variation on the basic approach. These variations are for good reason, as the use of urban stormwater BMPs is highly site specific. So the more variations and combinations possible the more flexibility engineers have in designing a system that accommodates site characteristics and can also achieve the desired reductions in N loadings.

Ponds are perhaps the most versatile of the stormwater BMP categories. The reason this is the case is because there are several basic designs that can be modified and combined into numerous sizes and configurations. Pond systems work by providing temporary storage for stormwater that has already become channelized. The systems are designed to slowly release the stormwater at a rate that allows for a minimum of 24 hours of detention time. In Northern

Virginia all new ponds must have 48 hours of detention time (NVPDC, 1994b). While the stormwater is impounded, sediment and organic material can settle out of the water. Since much of the N in the stormwater will be in a sediment bound form it will settle out of the water as well. These systems all will need periodic dredging to remove sediment deposits.

When siting ponds a minimum drainage area of ten acres is usually necessary for them to be practical (Schueler et al., 1992). The maximum drainage area they can realistically be designed for is about one square mile. The ponds themselves usually take up 1-3% of the drainage area. As a result, ponds are typically not considered for high-density urban areas, due to size and aesthetic reasons. Wet ponds have the best potential for being incorporated into a dense urban setting because of their potential aesthetic value. However, the pond systems are all well suited for medium and lower density areas.

Extended detention dry ponds are typically dry most of the time, detaining water only during and shortly after a storm event. Because the systems are designed to remain dry between storm events the bottom of the pond will need to be above seasonal water tables. This fact may allow for some infiltration of stormwater to occur while it is impounded. Also dry ponds are typically covered with grass which can utilize the organic N in the sediments once they are mobilized through the ammonification process.

A problem of dry ponds is that sediment deposits often become resuspended each time the pond fills. Eventually the pond can reach a steady state where as much sediment is being resuspended as is being deposited. To help overcome this problem, extended detention dry ponds are commonly used in conjunction with other pond systems (Schueler et al., 1992).

Extended detention wet ponds maintain a permanent pool of water fed by baseflow. As with dry ponds, the primary method of pollutant removal is the settling of solids. However, the standing water eliminates the problem of resuspension. The permanent pool also promotes nutrient uptake by aquatic plants, and to a limited degree the nitrification/denitrification process (NVPDC, 1994b).

The ponds are usually not lined, so to maintain a permanent pool there must be sufficient baseflow. This permanent pool can create siting limitations for wet ponds. Like dry ponds, wet ponds can also reach a steady state where the nutrients entering the pond will be roughly equivalent to those leaving. This steady state can occur after a thick layer of sediment has deposited on the bottom, and the plant mass in the pond is dying off at the same rate as regrowth. Because of this problem, the plant mass and sediment deposits must be removed periodically, which is much more difficult than the maintenance on dry ponds.

Both wet and dry ponds are used by many localities as stormwater management facilities. Used in this way, the detention time in the ponds is inadequate for significant removal of N. However, these facilities can be retrofitted for extended detention by modifying the outflow of water from them to increase detention time.

The third pond system is *constructed wetlands* that typically are a series of connected shallow pools conducive for the growth of wetland vegetation. Constructed wetlands are not meant to be restored wetlands, as they are not intended to replicate all the ecological functions of a natural wetland (USEPA, 1993). Instead they are designed to artificially recreate the nutrient-reducing capacity of natural wetlands.

The benefit of constructed wetlands is that they typically produce a large amount of biomass that requires a proportionate amount of nutrient uptake. The biomass produces a large amount of organic debris that combines with incoming sediment from the stormwater to form a thick layer of substrate (Novotny and Olem, 1994). Due to the saturated conditions most of this layer is anaerobic. Yet the roots of plants transpire oxygen and thus aerate the water and substrate immediately around them (Peterson and Simpson, 1992). These conditions create an environment suitable for microbes to ammonify and then nitrify organic N in the sediments. The plant roots then take up these nitrates. What is not taken up by the plant roots can become denitrified as it becomes diffused in the surrounding anaerobic sediments.

The N uptake of wetlands is high during the growing season but can drop off considerably once the season is over. In fact the die off of aquatic plants during winter months can actually release a pulse of nutrients to down stream waters. Constructed wetland designs can vary from a series of lined cells to a complex pondscape of trees, shrubs and aquatic plants (Schueler et al., 1992). Sites containing established microtopography do not lend themselves to periodic dredging to remove N deposits. However, after the growing season has ended, plant mass can be harvested to reduce the nutrient release back into the system.

Because constructed wetlands do not possess the same ecological integrity of a natural wetland they should not be sited in areas where they may disrupt a healthy wetland (Schueler et al., 1992). However, if sited properly constructed wetlands can act to buffer natural wetlands and other riparian systems from the damaging effects of urban stormwater runoff mentioned in the last chapter (Novotny and Olem, 1994). In urban areas where wetlands once existed or may still exist but in a severely degraded condition, constructed wetlands can be seen as a possible option, as a complete restoration of the wetland is unlikely (NVPDC, 1994b).

Urban vegetated filters strips work in a very similar manner to those used in agriculture, and the descriptions used in the agricultural section above, for grass filter strips and riparian forest buffers, are applicable to their use in urban areas. However, filter strips are not suitable for high velocity flows, nor do they do much good once flows have concentrated. This makes them ill suited for higher density areas, because the high levels of imperviousness encourage higher velocities and concentrated flow. In lower density areas, the land draining to grass filters should not exceed five acres; otherwise sheet flow will become concentrated. The minimum width for the strips should also be 50 feet to ensure a filter to drainage area ratio of more than 1 to 20 (Schueler et al., 1992). An additional 4 feet should be added for every one- percent increase in slope.

The effective width for a riparian buffer zone is about 100 feet wide. Since they are put in directly adjacent to waterways, they will intercept all of the runoff draining into the water at that segment. As a result, the buffer to drainage area ratio is difficult to compute. A general rule of thumb is that riparian buffer zones will be more effective in areas where there is a higher density of streams. Another consideration with riparian buffer zones is that they will be much more effective in areas where the land is flatter. Flatter terrain encourages the sheet flow conditions which improves the performance of the buffers. Because of riparian buffer zones are more suited to the coastal plains region rather than in the mountainous regions to the west.

Grassed swales are conveyance systems with gradual slopes, traditionally used to channel stormwater. They are often used along roads. Typically swales are used to slowdown runoff and promote some infiltration and plant uptake, but because they are a conveyance system stormwater tends to travel too quickly for much nutrient removal to occur. The longer, shallower, and wider a swale the more effective it will be at promoting infiltration, filtering sediment and thus removing N.

Adding check dams or small depressions across the channel can significantly enhance the N removal capacity of an existing swale. These act to reduce runoff velocity and promote ponding. Because many swales are already used for stormwater management, retrofitting them with check dams and small depressions is a simple process (Schueler et al., 1992).

The principal benefit of sand filters is their wide range of applicability, which makes them ideal for high-density urban areas. Sand filters can be located either above ground or below ground depending on the site conditions, and can be used in conjunction with a catch basin or a pretreatment tank (Schueler et al., 1992). The filter is a bed of sand, which acts to reduce the amount of suspended solids and some nutrients that pass through it. Microorganisms attached to the sand particles near the top of filter are able to aerobically nitrify ammonia within the stormwater. Further towards the bottom, where the sand becomes saturated, anaerobic conditions are present and thus denitrification can occur. Underneath the sand bed is a layer of gravel that serves to prevent the sand from being washed out of the system and also acts to further treat the effluent. The bottom of the sand filter is underdrain piping which carries the effluent away to be discharged. Adding a layer of peat, limestone, topsoil, or a combination of these can increase the expected N removal efficiency for sand filters.

There are several different designs for sand filters. Filters placed beneath the ground are referred to as buried filters, while those located above ground are known as open filters (Peterson and Simpson, 1992). *Buried filters* are often used when space or aesthetic considerations are important, as open sand filters can be unsightly and occasionally cause odors. However, buried filters are not easily accessible and they need to be designed to operate effectively with less frequent periodic maintenance. Being sited underground also limits their potential drainage area to approximately 5 impervious acres (NVSWCD, 1994).

Open filters must be readily accessible so they can be routinely raked to break up the crust, and for the removal of sediment, debris, and weeds. After a period of time all the filter sand should be entirely replaced to keep the system running properly. Open sand filter's have been installed to serve areas as large as 50 acres, but the consensus on their design is that they are most appropriate for areas of ten acres or less (Schueler et al., 1992). The ultimate consideration is the expected volume of runoff the system will be designed to handle. Because of this, the level of imperviousness within the drainage area also restricts the possible drainage area. Open filters can be designed to recirculate a portion of the water back to a pretreatment tank so it can pass through the system again. The added benefit of a recirculating filter is that it is able to remove a greater amount of nitrogen from the wastewater than the other types of sand filters. Their primary drawback is that they require a pumping system to recirculate some of the effluent.

3.5.3. Siting Urban Stormwater Best Management Practices

The appropriate choice of urban stormwater BMPs is highly dependent upon the area that they are being considered for. Factors that effect the appropriateness of various BMPs are:

- Existence of any stormwater management structures for the site.
- Physical characteristics of the site.
- Anticipated volume and frequency of runoff.
- Proximity of site to nearest receiving waters.
- Housing density and road network around site.
- Zoning requirements or ordinances which may apply to the site.
- Ownership and management of the BMP.

Each one of these factors has the potential to lower the efficiency, raise the cost, or prevent the consideration of a BMP for a given site. To illustrate some of the difficulties involved in actually retrofitting an area with urban stormwater BMPs it is worth going over each of these factors.

Stormwater management (SWM) facilities are designed to control flooding in urban areas due to the hydrologic effects of urbanization mentioned in the previous chapter. If the site is currently served by a SWM facility, then it is very unlikely that a separate BMP could be installed (NVPDC, 1994b). Instead it is more likely that the SWM would be retrofitted to remove nutrients as well as control flooding. Also the same criteria for siting BMPs is usually used when siting SWM facilities, and so most of the factors listed above have already been taken into consideration. Most SWM facilities are either a wet or dry detention pond, and retrofitting is usually accomplished by increasing detention time of the stormwater.

As with many of the agricultural BMPs, the physical conditions at the site must be accounted for. Slope, soil type, existing surface cover, and site hydrology can all affect the choice of BMP. For instance, a site where the soil has a high clay content may not drain well and might have difficulty maintaining vegetative cover. This situation would preclude the use of vegetated filter strips. If instead the site had a steep grade and shallow bedrock, a detention pond would not be suitable.

Much like the physical characteristics of a site, the expected quantity of water the BMP must treat is also a critical factor. The size of the area that drains to the site will be very important in determining this volume of water. So will the types of land uses found in the area. Expected runoff volume and frequency will play a big factor in not only the type of system, but also the size and configuration of the system as well.

The proximity of the site to nearby receiving waters is also a factor to consider. For example, if the site were adjacent to a stream, this proximity would make a forest buffer more preferable than an extended detention pond. But if it is near a wetland, the use of a constructed wetland before the actual wetland might be a good choice.

As already suggested, the housing density and street network in the area will affect the pervious to impervious ratio, which in turn will affect the volume and velocity of the runoff. Yet they also can affect the amount of available land upon which to locate a BMP. In high-density urban areas, there simply may not be enough space to consider any BMPs other than ultra urban techniques. Street patterns can also play a role as they effectively divide the land into little patches. Such limitations on space may require the consideration of more innovative approaches, such as using series of small detention basins instead of one large one, or perhaps using a sediment basin drainfield combination.

Zoning requirements or ordinances may preclude the use of certain BMPs. These are likely to be more of a concern in areas of higher building density, where issues of safety, land use compatibility, or aesthetics may cause the locality to restrict the types of BMPs which can be considered (NVPDC, 1994b).

Another issue of importance is who will be installing the BMP and who will be required to maintain the BMP. In areas of existing development, retrofitting stormwater BMPs is done by the locality. So the locality will be in charge of both installation and future maintenance of the BMP. If the site is being newly developed, the developer may install the BMP, but the long-term responsibility for the BMP may be unclear. Often times the responsibility of the BMP is deeded over to a homeowners association. This often leads to the BMP never being maintained and eventually ceasing to work.

3.5.4. On-site Versus Regional Coverage

All of the stormwater BMPs mentioned have been described in context of on-site application. In other words, these BMPs intercept and treat stormwater before it enters a stream. The larger the drainage area the more likely the BMP will interfere with the natural flow of a stream or drainage area of a wetland. Flow reaching pond BMPs is often already in the form of an ephemeral channel. This situation raises concerns about stormwater BMPs degrading the integrity of riparian ecosystems. For instance, a potential problem with pond systems is that the impoundment of stormwater can cause temperatures to rise to levels that are dangerous for aquatic organisms further down stream. These concerns effectively limit the considerable drainage area for on-site BMPs to a maximum of approximately 50 acres.

Due to the requirement of a small drainage area, more BMPs will be needed to cover an area. Because of inevitable difficulties in siting BMPs, this requirement can result in a low percentage of an area being served by BMPs. This fact is especially true for higher density areas where there is limited space for siting BMPs. Stormwater BMPs designed to treat runoff from areas greater than 50 acres, referred to as regional stormwater BMPs, would likely require the temporary impoundment of stream flow.

A regional approach to retrofitting existing urban areas is currently being considered by several localities (NVPDC, 1994b). With this approach, the stormwater runoff facilities would be designed to treat runoff from between 100 and 300 acres of land on average. Because only wet ponds, constructed wetlands, and extended detention dry ponds are suitable for covering such large areas; ponds are the only BMP considered for this approach. By covering such large areas, these facilities provide coverage for any non-urban land uses located within the drainage area. This makes the approach particularly well suited for areas that are projected to experience increased urbanization in the future, since any new development will be served by the facility as well.

Despite the benefits of this approach new regional stormwater BMPs are not likely to be built in the near future, due to concerns over the impact on riparian stream ecosystems. However, regional SWM facilities are quite common in older urban/suburban areas (NVPDC, 1994b). Much like the smaller SWM facilities, these facilities could be modified to increase detention time. One concern that does arise is that the flood control functions of the SWM facilities not be compromised. This may require an enlarging of the reservoir or the addition of a peripheral detention basin. The impact of such modifications, if necessary, again raises environmental concerns.

3.5.5. Alternative On-site Wastewater Treatment

The purpose of *alternative wastewater treatment systems* is to provide an additional or substitute stage of treatment that allows a conventional septic system to overcome the limitations of the site. Especially for homes located far from centralized sewers, alternative systems are often the only economically feasible method for dealing with malfunctioning or poorly sited septic systems. Alternative systems can also be considered as a potential BMP for reducing N, as many of the systems remove almost twice as much N from wastewater as do conventional systems (USEPA, 1993). What follows is a brief description of some of the more common alternative systems that have the ability to enhance a conventional system's ability to remove N.

Mound systems are an alternative system already commonly used in Virginia. The system consists of a septic tank, dosing tank, and elevated absorption mound. The mound is constructed over the drainage area and adds additional vertical filtering capacity to the site. Since the substrate typically used in mound systems is sand, mound systems are often classified as a type of sand filter. *Sand filters,* such as those mentioned earlier are often used to augment a conventional septic system. The use of sand filters for municipal wastewater is very similar to their use as a stormwater BMP.

Aerobic treatment units add an oxygen rich treatment stage to the conventional treatment process. These units are often referred to as *small package treatment plants* because they essentially utilize the same process of aerobic digestion that is commonly used by most municipal wastewater treatment plants. Most aerobic treatment units consist of an aeration chamber and one or more clarifying chambers. Typically the first compartment is a clarifying or settling chamber where solids and liquids separate and some anaerobic digestion occurs. From this anaerobic environment, wastewater then passes into the aeration chamber where a pump supplying a constant flow of compressed air and a stirring mechanism is used to oxygenate the water, creating the necessary conditions for nitrification. This process allows more of the organic matter in the water to be digested, reducing the amount of pathogens and other pollutants. The third compartment is another anaerobic chamber that allows for denitrification before the effluent leaves the unit.

The main disadvantages associated with aerobic treatment units are the need for an outside power source and the higher amount of maintenance required to ensure proper system operation. It is more often the case when homeowners try to assume complete responsibility for the maintenance of the aerobic treatment unit and the disinfection process that the system ends up failing. This is the reason why many localities require a maintenance contract with an outside contractor before an aerobic treatment unit is installed.

A small *constructed wetland* system can provide an additional treatment stage, necessary when a conventional system alone is not enough to overcome the limitations of a particular site. These systems are similar to stormwater constructed wetlands. The main differences are that they tend to be much smaller, typically consisting of one or more small trenches referred to as cells. Cell dimension can be adjusted for site conditions, but for an average household the sum of the cell area is about 20 square feet (Peterson and Simpson, 1992). Each cell has a lining that can either be permeable or impermeable depending on the system and contains vegetation anchored in a medium such as gravel. The two basic designs for constructed wetlands are: surface flow systems, where the wastewater passes over the medium; and subsurface flow systems in which the wastewater passes directly through the medium.

Leaching field chambers are an alternative to the conventional network of distribution pipes used in a drainfield. Depending on the drainfield size requirements, one or more chambers can be used, each being connected to form a large underground cavity. The sides and bottom of each chamber have a network of openings to allow for the seepage of wastewater into the soil. These systems allow more of the soil profile to be used since the effluent is distributed not only to the ground below but also to the soil surrounding the chamber. This fact allows leaching chambers to work more effectively than traditional drainfields especially when the drainfield must be located on a steep slope. Leaching chambers do not require any additional maintenance than a conventional distribution system.

Irrigation systems are similar to drainfields in that they use the land's natural assimilative capacity to dispose of wastewater. The principal difference is that irrigation systems are designed to allow the water and nutrients to be used by plants. A vegetative ground cover extracts N from the effluent and also serves to reduce soil erosion and maintain soil permeability. Irrigation systems can be classified into two basic types depending on how the wastewater is delivered to the soil. Spray irrigation systems use sprinklers to distribute the effluent over the surface of the ground. Drip irrigation systems distribute the effluent just below the surface of the ground.

3.5.6. Alternative Development Patterns

At the turn of the century, the American landscape could easily be divided between urban centers and the surrounding rural countryside. Since World War II, the number of Americans living in suburbs has risen rapidly, and the distinction between urban and rural has blurred. New developments continue to spring up all around the fringes of the traditional urban centers, and bedroom communities, suburban office parks, and strip malls are all now integral parts of the American landscape and vocabulary. This phenomenon is due in large part to a change in American society, as the ownership of a single detached family home on a half-acre lot has become for many the realization of the American dream.

Not all urban development is the same. As a result, the potential N loadings of different development patterns are not uniform. Redevelopment of urban areas can occur and alternative patterns that are less detrimental can be used for new developments. The goal of this section is to discuss alternative development patterns (ADPs), which have the potential to reduce the amount of N loadings that result.

3.5.6.1. Suburbanization Process

The advent of the suburban society and use of automobiles have gone hand in hand. Greater access to automobiles earlier in the century provided people with a greater amount of freedom as to where they could locate. No longer did one need to live close to one's place of employment. This mobility opened up large areas of land, which previously would have been impractical to locate homes upon. So the prevailing development pattern became one of bypassing traditional urban areas, where land was scarce, and building in rural fringe areas where land prices were lower and contiguous parcels of land were larger and more abundant. The abundance of affordable land allowed for progressively larger lot sizes, which were then marketed as a symbol of status.

These new developments were typically not located near commercial or employment destinations, so trips in the automobile became more frequent and for longer distances. Greater dependency upon automobiles, in turn required more roads, more lanes on the highways, and more spaces for parking. In Fairfax County, Virginia, between 1975 and 1988, population increased by 31%, while the number of cars increased by 84% (Year 2020 Panel, 1988).

This trend toward suburbanization has led to a patchwork of settlement patterns and population densities. The residential land use category typically comprises more than two thirds of urban land (NVPDC, 1994a). Studies have indicated that impervious cover is closely correlated to the housing density (Arnold and Gibbons, 1996). However the use of such a classification can be misleading, since the housing density will vary depending on the amount of land under consideration. The larger the area being considered the less significant is the density factor. Even at the neighborhood or development tract level dwelling unit density is not enough to determine the likely impervious level. For instance, the amount of impervious surface within neighborhoods of medium density homes has been shown to vary between 25 and 60% (Schueler, 1994).

The pattern in which the houses and streets are laid out will also influence the overall level of imperviousness. Another factor, which is particularly important, is the proximity of the site to an existing urban center. The further away a parcel of land is, the greater the amount of road miles needed to service it. It also increases the cost of providing water and sewer services for the locality. If the development is too remote, these costs may be prohibitive and the new homes will need to be served by wells and septic systems. The use of septic systems is another potential water quality problem especially when there is a large number of homes in a small area (USEPA, 1993).

It is best to view development patterns as a continuum with high density, compact, and being adjacent to urban centers as one end; and low density, dispersed, and isolated development as the other (Ewing, 1997). Most traditional development falls somewhere in the middle. It would be incorrect to characterize one end as being the best type of development and the other to be the worst. What is ultimately the best mix of development attributes for a given area will depend on the areas existing environmental and land use conditions. So broadly speaking, ADPs

can be defined as: the use of a specific mix of development patterns that are intended to minimize possible damage to the surrounding environment, based upon a thorough assessment of that environment.
However, it is useful to separate ADPs into either regional or on-site ADPs. Applying ADPs at the regional level can be considered an aspect of watershed management and planning. While on-site ADPs can be viewed as part of the development site design process. The use of either ADPs can potentially lessen the N load resulting from the urban development process.

3.5.6.2. Watershed Planning: Controlling Where Development Occurs

Until recently, for most localities growth was synonymous with prosperity. However, many fast growing localities have learned that not all growth is the same, and that some developments cost more to accommodate than they provide in additional tax revenues. It is very difficult for a jurisdiction to legally restrict the total amount of growth that occurs within its boundaries. Subsequently, some jurisdictions have instead begun to regulate the way in which development occurs.

Land use designations within most comprehensive plans are used to separate and guide where specific land use activities will occur. For instance, most counties have commercial, industrial, and residential land use designations. These types of designations can be used to define different classes of environmental land as well. As part of the effort to target priority waterbodies, resource inventories can be conducted for each watershed within a locality. Such inventories typically include:

- Assessments of ground and surface water hydrology.
- Evaluation of soil types and ground cover.
- Identification of areas with impaired water quality or at serious risk of impairment.
- Identification of environmentally sensitive areas, such as wetlands, highly erodible land, riparian zones and aquifer recharge zones.

Once the inventory has been completed, the watershed land can be classified into categories, such as critical areas, buffer areas, intensive development areas, and so on.

Such classifications can then be used to locate areas of high imperviousness away from hydrologically active areas. This is accomplished by using the classifications as guidelines for development zoning. For example, critical areas could be excluded from additional development, while buffer areas could be zoned for low-density residential development. Areas of existing development could be zoned for high density and mixed-use development. Furthermore, the classifications can be used to set spending priorities. Funds could be used to purchase land in sensitive areas, or help direct growth to areas slated for intensive development by putting in the necessary infrastructure ahead of time, and providing tax breaks.

Planning for future growth based upon water quality considerations brings up a troublesome issue. Since new development within a watershed will likely have a detrimental impact on some segment of the waterway, the question arises as to which waterbodies within the watershed should development be directed away from, and which should it be directed towards (Schueler, 1994). An element of triage is involved, as decisions will need to be made concerning which waterbodies must be sacrificed in order to prevent others from being impacted or further impaired. Such decisions are also likely to arise when resources are being allocated towards BMPs and restoration efforts.

3.5.6.2.1. Infill and Redevelopment

Two effective methods for limiting the spread of suburbs into rural areas are infilling and redevelopment. Redevelopment is essentially reusing already developed land for new developments. This can be accomplished through building on vacant urban lots, restoring old vacant buildings, or by tearing down old structures and rebuilding. Redevelopment not only is an alternative to developing new land, it also provides an opportunity to reduce impervious levels and to incorporate stormwater BMPs into the design (NVPDC, 1994b). Localities in Virginia, which fall under the Chesapeake Bay Preservation Act, are required to reduce their NPS pollutant loads to the Chesapeake Bay by 10% through the use of redevelopment (CBLAB, 1990).

While redevelopment occurs on land that has already been built upon, infill occurs on parcels of land that have not been developed, but exist between land that has been developed. Although infilling results in higher densities for the area, it generally reduces region-wide imperviousness and can be viewed as clustering on a regional scale (Arnold and Gibbons, 1996).

Another rational for infill is that it helps correct leap frog development. When leapfrog development occurs, it leaves vacant land in between. Thereby, creating a patchwork of developed and undeveloped land. Leapfrog development is often too far from existing infrastructure to economically provide services to it. Infilling land between existing leap frog development makes use of the roads already in place; and the new DUs can create the necessary density needed to make providing infrastructure affordable.

Most development now occurs as a homogenous land use. In other words, a development parcel will eventually contain only one urban land use category, such as low-density housing, high density housing, or an office park. These different land uses are usually separated by small islands of undeveloped land, or by busy roadways, which usually makes walking or biking between them impractical. Encouraging mixed uses for a development, and actively designing it so that it is pedestrian friendly, can lessen the island effect, and reduce the amount of road miles.

3.5.6.2.2. Setbacks, Greenways, and Greenbelts

Setbacks, greenways, and greenbelts are all intended to act as buffers between development and environmentally sensitive areas. Setbacks are zones of vegetation immediately adjacent to waterways, required by a local ordinance. They typically range in width from 50 to 200 feet (USEPA, 1993). Setbacks usually prohibit any development within the zone, but may allow for docks and other small nonenclosed structures. Most setbacks are required to be left in natural vegetation, although exceptions are sometimes made when trees block the views of waterways. The primary purpose of setbacks is usually to provide a minimum buffer zone between runoff from developed sites and adjacent waterways. Yet setbacks can also protect development from the water, as they provide a buffer between buildings and floodwater as well. Another benefit is that they provide habitat for wildlife.

Greenways are very similar to setbacks in that they are usually narrow strips of undeveloped land. However, there are several important differences. First, greenways are typically only used within urban centers, and although they are often found along waterways, they do not have to be. The reason for this is that one of the primary purposes of greenways is to provide contiguous habitat (Sayer, 1997). Buffering waterways from urban runoff is often cited as a benefit, but it is not usually their main purpose. Because greenways are found within extensively urbanized areas, there are usually less strict rules about maintaining native vegetation and the presence of buildings.

Another use for greenways is to provide wildlife corridors for connecting greenbelts. Greenbelts are expansive bands of farm and forestland that surround urban centers (Sayer, 1997). They are meant to provide a boundary against future urban development, and to prevent separated urban areas from merging and thus further fragmenting undeveloped areas. Because greenbelts cover such large expanses of land, some limited low-density development is often allowed within them. One of the primary ways greenbelts are formed is through the purchase of development rights from landowners within the belt.

3.5.6.3. Site Design: Controlling how Development Occurs

At both a regional and a site level attention is paid to minimizing the disturbance of sensitive areas, and both density and pattern are important factors to consider. The main difference is that once a parcel of land has been slated for development, there is nothing that can be done to change where it will be situated within the landscape. So at this point, the proximity to already developed areas and infrastructure is no longer an issue. Although, proximity to existing water and sewer mains will be a key factor in determining whether or not the Houses will have on-site or public water and sewer (USEPA, 1991).

3.5.6.3.1. Clustering and Open Spaces

The two concepts of density and pattern can appear contradictory. On one hand, the higher the density the greater the amount of impervious surface. So it would seem appropriate to limit density within a watershed. However, low-density areas often have much higher per capita levels of impervious surface. The reason for this is that by spreading development out, each house requires greater road surface area to connect it to the regional road network (Arnold and Gibbons, 1996). This paradox persists unless a distinction is made between lot size and dwelling units per acre.

As a rule, densities should be low, especially in environmentally sensitive areas. However, accomplishing this by mandating 5 or 10 acre lots can defeat the purpose, since a greater distance between houses can lead to a greater amount of road surface necessary to connect them. Instead, lot sizes should be smaller and clustered together. In this way the dwelling unit density of an area can remain relatively low, while the housing density of a neighborhood street can be very high. This formula is the fundamental concept behind cluster development and open space requirement (Arendt, 1997). Both an appropriate maximum density and a minimum open space requirement are set for a given area. So for example, a developer wishes to build 20 homes on a 100-acre parcel. The parcel is in an area with a density zoning of one dwelling unit per five acres, but also an open space requirement 85%. This results in an individual lot size of 0.75 acres.

The use of cluster development can reduce N loadings in three ways. First by reducing the distance between houses, cluster development reduces site imperviousness by 10-50%, when compared to traditional development patterns (Arnold and Gibbons, 1996). Secondly, there is less edge area between pervious and impervious surfaces. Finally, the open space requirement and the compactness of the houses can be used to provide a vegetated buffer around the impervious areas of the site.

Many developers voluntarily use clustering since it reduces the cost of installing roads as well as sewer and water lines. However, other developers may feel that the demand for homes in a cluster pattern is less than it is for more traditional patterns. To help encourage clustering, localities can use density bonuses that allow developers to build additional homes in return for greater compactness on their development parcels (Owens and Hirschman, 1991).

3.5.6.3.2. Design and Performance Standards

Localities can also mandate performance standards on development plans and construction practices used in development. These performance standards can be used for more than reducing erosion and sediment loss during the construction phase. They can also be used to minimize long-term N loadings from the site by:

- Minimizing the disturbance of pervious land at the site.
- Designing site so that runoff from impervious to pervious areas is maximized.
- Minimizing the eventual impervious surface area.

The condition of the pervious areas of a site is an important but often overlooked factor. Yet as mentioned in the previous chapter, construction practices of clearing and grading the site, plus the continuous traffic of heavy machinery can be very damaging to soils. The end result can be highly compacted soils. A study in Milwaukee concluded that approximately a third of the disturbed urban soils had an infiltration rate of zero or near zero, exhibiting the same runoff response as concrete or asphalt (Schueler, 1995). There are several steps that can be taken during the construction phase to limit the damage to pervious areas. These steps were listed previously under Construction BMPs section.

As mentioned, earlier not all impervious areas are connected to storm drain network. These disconnected impervious areas can be designed so that the stormwater from them is channeled to pervious areas. According to Schueler, “The hydrologic effect of these disconnected impervious areas can be very significant, particularly in low-density residential watersheds.” In some cases, disconnecting these impervious areas can create enough infiltration to reduce the "effective impervious cover in a watershed by 20 to 50% (Schueler, 1995).”

Roof gutters can be designed to discharge directly into yards, rather than to stormdrains.

Roofs are much less likely to generate runoff than directly connected impervious surfaces, such as those associated with transportation networks (Schueler, 1995). However, roads and other transportation related impervious surface make-up between 63 to 70% of the impervious cover across most urban land uses (City of Olympia, 1994). So, efforts to promote runoff from road surfaces to vegetated areas will have the greatest benefit. This is also true because runoff from roads tends to have a higher concentration of most pollutants than runoff from roofs (Arnold and Gibbons, 1996).

There are several measures used to promote runoff from transportation surfaces to vegetated areas. Small parking lots can be graded so that they drain to adjacent fields or forests. In high-density areas, they can be designed to channel runoff directly onto vegetated islands located within the parking lot. A similar concept can be used for cul-de-sacs.

Curbing is a major impediment to the movement of runoff from impervious to pervious areas. Lowering the height of curbs can reduce the amount of pollutants that accumulate along them, and eventually get washed into storm sewers (Novotny and Olem, 1994). If curbing is not used at all, grassed swales could be put in instead. Yet many town engineers view curbing as essential, as it is considered to provide for both safety and structural integrity of the road, on top of its primary drainage function (Arnold and Gibbons, 1996). However, according to the Connecticut Department of Transportation, the belief that curbs provide these additional benefits is unfounded. Even so developers might be motivated to use them for aesthetic appeal. A compromise could be to curb only one side of the street; perhaps where there is a sidewalk. Then grade the road so that it drains towards the uncurbed side.

Perhaps the most important performance standard would be one that sets a maximum limit on allowable impervious surface. It has been estimated that site design techniques can be used to reduce impervious cover by 10 to 50 percent (Schueler, 1994). Furthermore, the city of Olympia, Washington conducted an impervious surface reduction study, which concluded that a 20% reduction in the expected impervious cover for future development was a feasible goal that would not require exceptional changes to the community (City of Olympia, 1994). There are numerous site design techniques for reducing imperviousness, yet most focus on the transportation network. Two with the greatest potential for reducing imperviousness are reducing road widths, and reducing parking lot sizes.

Going from the typical 32 feet road width to a narrower 20 feet will reduce approximately 1.5 acres of imperviousness per road mile. According to the Olympia study, this translates into an estimated 6% reduction in site imperviousness (City of Olympia, 1994). Using hourglass shaped streets can reduce street widths while accommodating some parking. The use of smaller cul-de-sacs or hammerhead turnarounds can also reduce road space. Providing sidewalks for just one side of the street is another method.

For most developers of commercial/office space, the rule of thumb is 4 parking spaces per 1, 000 square feet. However, studies have indicated that this often provides 60% more parking spaces than are normally needed (Arnold and Gibbons, 1996). Again, according to the Olympia study, developers consistently build 51% more parking spaces than the minimum parking per square foot required by zoning. What is worse, there has been a trend in recent years to supply at least 5 spaces per 1,000 square feet at "big box" shopping malls to accommodate peak demands anticipated during the holidays (Arnold and Gibbons, 1996). Localities could require not only a minimum number of spaces per 1,000 square feet, but also a maximum number as well.

3.6. CONCLUSION

The list of potential BMPs suggested for point sources and the various land use categories, was by no means complete. New methods of control are always being developed, and older less effective control techniques are being modified or replaced. However, the basic set of control options for each the categories presented in this chapter, was meant to be representative of all the BMPs that are widely used, or that are being considered for extensive implementation in the future.

The next chapter will broaden the description of the various BMPs through a discussion of the potential costs associated with each. In this current chapter, some discussion was devoted to the relative effectiveness of the various BMPs. The discussion in the next chapter will expand on this topic by examining the cost-effectiveness of the BMPs. As mentioned in the first chapter, the issue of cost effectiveness is central to the objective of determining the lowest cost for meeting the Potomac's N reduction goal.

CHAPTER IV

THE COST OF CONTROLLING NITROGEN

4.1. INTRODUCTION

As outlined in the first chapter, the task of determining the lowest cost for meeting the N reduction goal requires an examination of: the sources of N, then the control practices for reducing the N loadings, and finally the costs associated with the use of each practice. For each of the many sources of residual N, there are usually several available control practices. In turn, for each practice there are a series of possible costs associated with its use. These costs can be divided into the direct costs of implementing and maintaining the BMP, and the indirect effect they may have on the source activity.

When assessing the costs of using a BMP most consideration is typically given to the likely startup, operation, and maintenance costs. These are the direct costs associated with continuous functioning of the BMP. However other economic considerations such as opportunity costs, and information and enforcement costs will be equally important in the formation of cost assessments for using the BMP. Unfortunately many of these costs are difficult to assess and are usually absent from the literature concerning BMP costs.

4.1.1. Startup Costs

The use of all BMPs requires some initial startup costs. Expenses associated with the purchase of new equipment or the installation of a control structure are the usual startup costs for most BMPs. Startup costs typically take into account materials and labor costs needed for construction. Yet, certain BMPs may require significant land space, site preparations, or operator training before they can be used, and when available, these startup costs should be included as well. Some BMPs, such as with urban lawn care, only require a change in the habits of individual homeowners. Even BMPs such as these must rely upon educational and extension programs to disseminate the needed information.

4.1.2. Operation and Maintenance Costs

The two most common operation costs are those associated with energy inputs, namely fuel or electricity, and labor costs. The planting of winter crop, the dredging of a detention pond, or the lighting at a treatment plant all require energy inputs. With the exception of wastewater treatment plant retrofits, BMPs usually do not require daily labor inputs. However they all require some time to be spent on periodic maintenance of the practice. An additional maintenance cost is the replacement of worn or broken equipment used for operating or maintaining the BMP.

The cost of materials, supplies, and labor required for both the installation and operation of a BMP, may vary slightly from case to case, but overall they are likely to remain uniform over each region. This is the case because a significant difference in costs for similar items would eventually lead to the lower priced supplier or suppliers gaining increasingly larger shares of the market. In turn this process would put pressure on the higher priced suppliers to lower their price, until their price becomes competitive.

4.1.3. Opportunity Costs

Typically opportunity costs are used to describe the economic tradeoffs when choosing between two or more mutually exclusive alternatives (Stiglitz, 1993). Whichever alternative is chosen, its opportunity costs are the foregone benefits that would have been gained from choosing the next best alternative. Then the total cost of using a BMP should reflect not only its startup and maintenance costs, but also any expected changes revenues or expenses as a result of using the BMP.

Before a BMPs opportunity costs can be assessed, it is necessary to first understand why the source activity is occurring. Then one must try to determine how N control will likely affect the way these activities are carried out. Generally activities that are sources of N, are undertaken to generate income or to dispose of a waste product. For example, agriculture is clearly a revenue-generating activity. The introduction of a BMP that affects crop yields or livestock health will most likely have an effect on potential revenues. This effect must be included in any cost assessment of the BMP. In the case of municipal wastewater treatment facilities and onsite septic systems, the activities are primarily concerned with treatment and disposal. So the economic consideration here is minimizing disposal costs. The incorporation of a BMP into the treatment process may increase or decrease the cost of some other stage of the treatment process.

For some activities such as land development, the reasons behind the polluting activity can be more complex. When a site is developed, the resulting amount of impervious surface is likely to be due to both revenue and disposal cost considerations. Yet the final amount will also be the result of such factors as zoning ordinances, aesthetic preferences, and in many cases how aware the developer is of the complex relationship between impervious surface levels and water quality.

4.1.4. Monitoring & Enforcement Costs

For many reasons the adequate maintenance of a BMP may become neglected. For a long-term water quality goal to be met and maintained it is crucial that all the BMPs that are expected to contribute to the goal receive some level of periodic monitoring and inspection. To ensure that chronic neglect of some BMPs does not become a problem it will likely be necessary that procedures for the enforcement of regulations and contracts be instituted. Considering the extensive area covered by the Potomac Basin, the cost of monitoring and enforcement could be the deciding factor as to which policies or practices are ultimately implemented. However, information on these potential costs is absent from typical cost assessments due to the difficulty in deriving them.

4.1.5. Deriving Cost Estimates

There are several factors that can affect the reliability of cost estimates for BMPs. The first is that the BMPs are intended to be very site specific. The reason for this is to ensure that the BMP will function reliably and efficiently over its lifetime. Because of this specificity, BMPs tend to have a wide range of potential costs. In turn, this wide range of costs makes it desirable to get an approximate cost figure by taking the average of several cost figures.

Another consideration is that the average cost of a BMP implemented in the Potomac Basin may vary considerably from the average cost of the same BMP implemented in another state, such as Iowa. This variance can be assumed because of the differences in terrain and climate, and also because of differences in the price of land and the availability of supplies and labor. As a result, it is important that whenever possible the cost estimates used should come from sites actually in the Basin or within close proximity.

A third consideration is to be aware of exactly what factors were included in the cost figure before using it as part of an average cost estimate. Often times such additional costs as access roads or landscaping may be included in an overall cost estimate. The fact that these factors are included in some estimates but not others may lead to unnecessarily large variances in cost. As a general rule, the more information supplied on how a cost figure was derived, the more useful the figure can potentially be.

Even when it is apparent that indirect costs likely to exist for a BMP, it can still be difficult to accurately predict and quantify these costs in monetary terms. Yet these costs are very real to the party that incurs them, and their exclusion from consideration is often the reason why the conclusions of an economic study do not match observed behavior. Therefore it is important to include indirect costs as part of the total cost estimate whenever possible, or to at least mention their likely presence and how they may affect the economic consideration of agents.

4.1.6. Cost-Effectiveness Considerations

Cost estimates in conjunction with estimates of a BMPs effectiveness can be used to derive an estimate of the cost per pound of N reduced. This combination is a more useful than cost estimates alone for determining what the lowest cost combination of BMPs might be. However, determining a BMPs actual effectiveness is no less difficult then deriving accurate costs estimates. With nonpoint sources of N pollution there is no practical way to predict the long-term performance of a BMP under consideration. Nor is the actual benefit of the BMP measurable once it is installed. Long term monitoring of each and every BMP is not feasible, and if it were it would likely be prohibitively expensive. The occurrence of nonpoint source pollution is as much the result of environmental conditions as it is the activities of man. These environmental conditions, chiefly weather patterns, are subject to constant unpredictable change. So even if sophisticated monitoring was used to measure N loads from an area of land covered by a BMP, there is no sure way to compare these N loads to what would have occurred without the BMP.

Cost-effectiveness estimations by themselves do not provide all the necessary information for determining the usefulness of a BMP towards achieving a water quality goal. The BMP’s potential applicability must also be taken into consideration. A BMP may be very cost-effective in comparison to others, but only applicable to a small percentage of the sources of N. If this were the case the BMP’s overall contribution towards meeting the water quality goal, would be minimal. Therefore a complete estimate of the potential benefits of a particular BMP towards meeting a water quality goal must include an estimate of its cost, its efficiency, and its potential for application.

4.2. POINT SOURCE RETROFIT COSTS

One of the principal reasons why pollution from point sources is handled differently than diffuse pollution is the difference in the ability to monitor pollution levels. As a result of the monitoring limitations mentioned earlier, there is a considerable amount of guesswork that goes into NPS pollution control. When land use activities are thought likely to be causing pollution, BMPs are installed to reduce the impact of these pollutants. Effectiveness of the practice is not typically measured, but rather it is extrapolated by comparing the site conditions to those that have been measured by researchers. Then a likely load from the land use activity is estimated, and a probable reduction rate associated with the BMP is used to predict how much pollution was reduced.

By contrast, the volume and chemical make-up of the water entering and leaving a wastewater treatment plant can be measured. Also because effluent, in most all cases, is directly discharged into waterways, the level of N loads from the source can be reliably predicted. This allows for the development of effluent standards that cannot feasibly be set for most sources of diffuse pollution.

Another important difference is that wastewater treatment at a point source is much more of a closed system than are the best management practices for NPS pollution. Precipitation along with other environmental factors such as erosion, infiltration, and delivery rates have no bearing on the N loads being discharged from a point source. Instead, average daily inflow, average retention time, and the system's maximum volume capacity are usually the factors that affect the performance of the system. More importantly since the performance of the system can be measured; modifications to the system can be made to improve overall performance. These modifications can be as simple as changing the average temperature of the water, adjusting the oxygen content of the water, or changing the level of system additives such as methanol or activated sludge. In cases where decreases in performance are due to increases in the wastewater volume entering the system, additional holding tanks can be built to accommodate excess volumes during peak flows.

Due to these differences between point source controls and NPS controls, the cost of retrofitting a plant is highly dependent upon several key factors.

- The current systems design at the treatment plant.

- Current average daily flows and those predicted for future years.

- The current concentration of N in the effluent being discharged, and the effluent standards set to meet specific water quality goals.

- The expected reduction in pollution concentration per liter of wastewater, as a result of the retrofit.

Each of these factors will be different for each point source making it very difficult to compare costs.

Measuring the costs of reducing N from point sources in terms of the average cost per pound reduced may initially appear to be the best approach. Yet this is not a very useful measure for evaluating the cost of retrofitting point sources, nor is it practical for cost comparisons. Although some reduction can be accomplished by adjusting operational procedures, significant changes in N concentrations almost always are the results of expansions to the facility. These expansions require a major investment of capital. As a consequence, it unrealistic to assume a constant marginal cost per pound of N reduced. It is also unlikely that the slope of the cost curve would be smooth. So for example, a POTW might have an average N reduction cost of $20 per pound at a thousand pounds reduced, but the price might jump to $50 per pound at a 1,200 pounds reduced. Due to the need for an additional treatment process necessary to achieve the additional 200 pounds of reduction.

The most common measure used for estimating retrofit cost-effectiveness is to estimate the cost of meeting a performance benchmark (Camacho, 1992). These performance benchmarks would typically be maximum allowable levels of residual concentrations in effluent mandated by water quality standards. Such standards for point sources have precedence within the Northern Virginia region. Over two decades ago, the Potomac embayment standards set limits on the concentration of phosphorus in effluent (VDEQ, 1993). More recently in 1992, Virginia's State Water Control Board adopted standards that place a limit on the level of ammonia in point source effluent. The primary method of reducing ammonia levels is to convert it to less toxic nitrate compounds (VDEQ, 1994). In light of the nutrient reduction goal of the Chesapeake Bay Agreement, an average N reduction goal of less than 7 mg/L was suggested for POTWs in the Northern Virginia area (CH2M HILL, 1989).

However, just using the achievement of a water quality standard for cost comparisons can be somewhat misleading. The reason for this is that differences in initial concentrations or average daily flows between the point sources need to be accounted for. Also it is unlikely that when POTWs install retrofits that they will be able to design them so that they reduce N flows to exactly 7 mg/L. Instead some may just meet the requirement while others may far exceed it. Therefore the point source which meets the goal at the lowest cost may not have the lowest cost per pound of N reduced. For example, two POTW both achieve the 7 mg/L goal, the first achieves 6 mg/L at a cost of 1 million dollars, while the other attains a 5.8 mg/l concentration for 2.5 million dollars. Yet the first POTW had an average daily flow of 4 million gallons with an initial 12 mg/l N concentration, while the other POTW had an average daily flow of 10 million gallons and a beginning concentration of 17 mg/l. So the first POTW appears to meet the benchmark for the lowest cost, but its average cost per pound of reduced N is $13.70, while the second POTW has an average cost of only $7.34. So the approach undertaken by most retrofit studies has been to choose one or more concentration levels for the point source to meet, and then a set of likely retrofits are selected for evaluation. At this point, assessments are made for each facility in the study.

Effluent treatment levels have the greatest influence on the expected cost of retrofits. However, other considerations such as hydraulic constraints as well as space limitations at each plant also affect the overall costs (Engineering-Science, 1993). As a result, generalized cost estimates derived from one or more studies are not very useful for making estimates at a specific plant. Ideally all the cost and load reduction estimates would be based upon an engineering retrofit assessment undertaken at each facility. In this way site specific factors could be incorporated into the assessment.

Such comprehensive data is not currently available for all the point sources within Virginia's Potomac basin. Until studies at each facility can be completed, it is necessary to use generalized estimates for some point sources. These general cost and load estimates are typically derived based upon cost and nutrient reduction information that has been gathered for a few facilities. They are typically either the average cost for a type of treatment system to meet a concentration level, or a cost curve based upon regression analysis (Camacho, 1992). These cost curves are used to approximate the relationship between the cost of achieving a N concentration level and the differing design flows or system types. Extrapolations can then be made about the likely costs and loads for those plants where studies have not been undertaken.

Such extrapolations are subject to a high degree of error since they do not take into account important on-site factors (Camacho, 1992). Consequentially, such estimates are poorly suited for direct comparison between the cost-effectiveness of retrofitting two or more specific plants. Yet it is assumed that they are reasonable estimates for basic comparisons between the cost-effectiveness of point source retrofits and the other N control practices mentioned (Camacho, 1992).

The Virginia Department of Environmental Quality (VDEQ) has developed cost and load estimates made for three different retrofit scenarios, for all the point sources with flows greater than 0.5 MGD in Virginia's Potomac basin (VDEQ, 1994). Those sources below the 0.5 MGD level were not considered, because within the Chesapeake Bay watershed, facilities with flows of less than 0.5 MGD contribute less than 10% of the total point source load (Camacho, 1992). These estimates were based upon a series of retrofit cost studies done in the Potomac region. Not all of the basin's point sources were included in the studies so many of the estimates required extrapolation (VDEQ, 1994). The treatment technologies considered for the scenarios were seasonal BNR, annual BNR, and LOT.

Appendix B contains a series of tables that provide retrofit cost estimates for the Basin's point sources, based upon the VDEQ estimates and subsequent information from Dr. Clifford Randall of Virginia Tech. The appendix also contains a summary of general information upon each of the point sources considered by the VDEQ. Location of the facility, systems design, wastewater characteristics, and flow rates are included in most all of the summaries.

As was mentioned in the previous chapter, biological nutrient removal of N requires both the nitrification and denitrification process to occur. Although a limited amount of nitrification occurs during the second treatment stage, most systems do not actively promote the nitrification process unless they are subject to ammonia standards. If a plant does have nitrification in place then achieving BNR only requires the addition of the denitrification process. Plants currently using nitrification have lower projected costs for achieving BNR (Engineering-Science, 1993).

As previously mentioned, the performance of BNR systems will vary with the season. Since they rely upon microbial digestion to carry out the nitrification/denitrification process, the level of N removal will decline during the winter months as colder temperatures slow the metabolic activity of the microorganisms. So year round use of BNR may not always be cost effective depending on annual operating costs and the fluctuations in N concentration levels.

The costs associated with limit of technology are highly dependent upon site conditions since they require the consideration of advanced biological treatment where the wastewater must go through a long detention period and pass through a series of chambers. Such systems may be infeasible at specific plants due to space constraints. Chemical methods of removing N, such as methanol denitrification tend to be prohibitively expensive, averaging over $200 in capital costs and about $30 in annual maintenance costs per person served (Randall et al., 1987).

4.3. AGRICULTURAL BEST MANAGEMENT PRACTICE COSTS

Agricultural BMPs tend to be the most cost effective at reducing N loads. There are two reasons for this. First, certain agricultural practices have the potential to contribute very high loadings of N per acre. Secondly, many of the agricultural BMPs do not require expensive construction practices typical of urban BMPs. In fact some BMPs actually have the potential of increasing net returns to farmers (Randall et al., 1987), (Faulkner and Trott, 1994). Often the primary obstacle to implementation is obtaining the capital to cover the initial startup costs.

4.3.1. Cost of Crop BMPs

The cost of implementing conservation tillage will vary somewhat depending on the form of tillage practiced. Each of the various methods requires different machinery and varying amounts of labor, fuel, and chemicals. An approximation of the likely annual startup, operation and maintenance costs is $22.89 per acre (USEPA, 1993). However, when conservation tillage is implemented it replaces the use conventional tillage. There is a greater disruption of the soil with conventional tillage, and this can require a greater amount of fuel, labor, and wear on machinery. Conservation tillage may actually reduce fuel, labor, and equipment replacement costs by as much as $24 per acre (Randall et al., 1987).

Conservation tillage can cause yields to increase or decline depending on the soil characteristics of the field (Randall et al., 1987). Fine textured soils with high clay content will likely experience a decline in production. Conventional tillage of these soils helps increase infiltration and lessen compaction making them more productive. However, coarser soils with a high sand or gravel content are likely to experience increases in production.

Nutrient Management, like conservation tillage can often result in increases to net income. The reason is that the primary cost associated with the BMP is the development of the nutrient management plan (USEPA, 1993). An annual average cost estimate for the development of a nutrient management plan is $2.40 (Camacho, 1992). The average annual cost per acre is often subject to economies of scale, where farms with more acres will tend to have a lower cost per acre. For example, the nutrient management plan for a 200-acre farm may not cost any more to develop than if the farm had 250 acres. Yet on a per acre basis the nutrient management plan would be 20% less if the farm had 250 acres.

The adoption of nutrient management tends to benefit farmers in two ways. The plans generally call for the more judicious use of fertilizers that can save on overall fertilizer purchases. Farms with livestock tend to experience the greatest cost savings (USEPA, 1993). The reason is that many nutrient management plans call for the use of slow release organic fertilizers, and the animal waste produced by livestock is a readily available supply. The second benefit of nutrient management is that they can actually result in higher yields per acre (Randall, 1987). Taking into account estimated costs and benefits associated with nutrient management, the estimated net change in income after adopting the BMP is $4.08 per acre (Camacho, 1993), (Faulkner and Trott, 1994), (VDEQ, 1996).

The cost of cover crops is associated with the cost of the seed, fuel, equipment wear, and labor necessary for the seed bed preparation. The approximate annual cost for this BMP is $20 per acre (Camacho, 1992), (Faulkner and Trott, 1994), (VDEQ, 1996). If the cover crop is harvested and then used as livestock feed or sold, the resulting cost savings or revenues from the harvest can offset these costs or provide a profit. If the cover crop is killed then plowed under or left on the field, it will provide a source of organic N for the next growing season. This will in turn, reduce the need for additional fertilizers.

Contour plowing and strip crops can typically cost around $16 to implement per acre to implement (Camacho, 1992), (Faulkner and Trott, 1994). The annual maintenance costs are relatively low, estimated to be only 1% of installation cost. However, there is an additional opportunity cost, not included in the above figure. Strip cropping requires that some of the field be devoted to the filter strips. This reduces the amount of field space devoted to the primary crop ultimately reducing the per acre yield. If the filter strips consist of close growing crops that can be harvested, then this can help offset the loss in net revenues from lower yields of the main crop. If the filter strips consist of grasses then they may be able to provide some benefits as a source of hay or forage.

The costs associated with vegetated filter strips is approximately $36 per acre (Camacho, 1993), (Faulkner and Trott, 1994), (VDEQ, 1996). Like strip cropping, vegetated filter strips placed adjacent to crop fields require that some of the field be taken out of production, thereby reducing the net revenues from those acres. Filter strips placed adjacent to confinement lots will not likely be replacing a revenue generating land use. Most all of the vegetated filter strips in use in Virginia are used with fields of row crops (Dillaha, 1997).

Erosion and sediment control structures such as terraces, diversions, sediment basins, and detention ponds tend to be considerably more expensive per acre, due to the high installation cost associated with them. The cost of implementing them is also very site specific. Data from Virginia's agricultural cost share program indicates that few of these practices are adopted, even when economic incentives are given.

4.3.2. Livestock BMP Costs

The cost of N control for livestock operations can be separated into BMP costs and changes in expected revenue. The cost of livestock BMPs will tend to vary between operations, due to differing circumstances. The important factor affecting costs is the number of animal units present. The size of livestock operations can vary tremendously even within the same county from only a few animals to several thousand. Generally the larger operations will have a higher per animal cost (DPRA Incorporated, 1992).

It is common for linear approximations of cost per animal unit to be used for providing initial cost estimates (DPRA Incorporated, 1992), (Camacho, 1992). However, these linear approximations are usually only accurate when calculated for a small range of animal numbers. Also linear approximations tend to be more suitable for medium size operations, rather than those operations with very few or very many animals. Costs will also vary depending on site conditions and the presence or lack of existing facilities and equipment.

As mentioned, the two most prominent types of livestock operations in the Potomac Basin are dairies and broiler houses. The costs of best management practices for dairies are dependent upon the confinement area and facility characteristics used. The confined area of a dairy can be an enclosed facility with minimal open lot space, or at the other end of the spectrum it can be an open lot facility with minimal sheltered areas (DPRA Incorporated, 1992). Many of the same types of facilities used to control animal waste, such as detention ponds, are also used to control runoff from the loafing lots. However, loafing lots in the Shenandoah Valley typically do not drain into on-site waste storage structures, so the costs for controlling animal waste can be discussed separately from the cost of confinement lot management (Faulkner and Trott, 1994). The cost of these best management practices is related to not only site conditions but also to herd size. As herd size increases, the process of controlling N runoff becomes more complex, and the cost per animal tends to increase (DPRA Incorporated, 1992). Cost estimates mentioned here are those associated with a herd size of roughly 100 to 110 cows, which is typical for the Shenandoah region (Faulkner and Trott, 1994).

On dairies, most control systems for the liquid waste will consist of either an earthen pit or a concrete tank and the necessary equipment for pumping and spreading the liquid waste on to the fields. In terms of N control, the storing and spreading of the waste will fall under animal waste facilities BMP. The nutrient management BMP covers the way in which the waste is applied to the fields. From the standpoint of reducing N runoff the primary concern with storage facilities is not the lack of these facilities, but instead the limited storage capacity of most systems. Most all dairies with more than 20 milking cows will have a storage facility in place, yet the typical dairy manure pit has only a three to four month holding capacity (Faulkner and Trott, 1994). This holding capacity is not sufficiently large enough to contain the dairy's manure supply through the winter months, when the ground is frozen, until after the spring thaw. When manure is applied to frozen ground it is not readily incorporated into the soil profile, making it highly susceptible to being washed away during periods of wet precipitation. If the farmer tries to hold off the spreading of the manure, the storage capacity of the pit may become exceeded, and overflow from the pit may leave the site during large storm events. As a result, the recommended storage capacity for these facilities is at least 6 to 7 months of manure production depending on the herd size.

The cost of animal waste facilities for dairies should thus be separated into the cost of installing new facilities and the cost of upgrading existing facilities. Regardless of whether it will be a new or upgraded system, the operator will need technical assistance to ensure that the future system will meet his pollution control needs. The cost of this planning and assistance is estimated to be roughly 17% of the total construction cost. Routine annual maintenance and equipment replacement will be roughly 10% of the construction costs. These systems are expected to work effectively for roughly 10 years before any major upgrades or repairs will need to be made.

Since most poultry litter is stored in dry form before being disposed, the cost of these facilities will be less expensive per animal unit than the cost for dairy waste systems. Often the litter produced by a poultry operation generates more fertilizer than can be readily incorporated by the crop and pasture acres on the farm, especially if the farmer is also applying manure from a dairy operation (Parsons, 1995). The farmer must either over apply fertilizers to his field or have the manure hauled away to be disposed of elsewhere.

The cost of having the manure hauled away will depend upon what the litter is used for and the distance it must be transported. The poultry litter is most often used as a fertilizer by another farmer. However, it could also be delivered to a processing plant where it is pelletized for later use as a commercial fertilizer, or used as a feed supplement for beef cattle. Farmers will receive payment for the use of their poultry litter, but they must also pay to have it transported. In many areas of the Southern Shenandoah Region the available supply of litter exceeds the demand for its use. So the litter must be transported outside of the region. Yet this may not deter farmers from trying to sell their excess litter for two reasons. First, application of poultry litter on to fields costs approximately 1 dollar per ton, and applying excess fertilizer to the poultry farmer's own fields will not likely increase crop yields (Parsons, 1995). Secondly, the state recently passed the Virginia Agricultural Stewardship Act which requires the state to investigate complaints about any agricultural activities potentially causing water quality problems (VDACS, 1997). This may deter farmers from applying excess animal waste to their fields as it may produce high levels of nutrient runoff that could pollute local waterways.

Another waste consideration for poultry farmers is the disposal of bird carcasses. Roughly between 0.08% and 0.1% of the birds in a poultry house die each day (Faulkner and Trott, 1994). The carcasses can either be taken to a rendering plant where they are frozen until processed as pet food, or they can be composted and used as an additional source of fertilizer. Here the tradeoff is between the cost of composting and the cost of hauling. The cost of constructing a compost facility for a broiler operation is approximately \$0.084 per bird capacity with \$0.072 in annual operation and maintenance costs (DPRA Incorporated, 1992). The mortality rate is slightly lower for layers so the costs are \$0.063 and \$0.02 respectively. Hauling costs are likely to be similar to that of hauling manure.

Runoff from confinement lots can be managed by either diverting runoff through diversions and roof gutters, intercepting the runoff leaving the site with sediment basins, detention ponds, and filter strips, or by reducing the amount of runoff that is generated through use of rotational loafing lots. The cost for using diversions or filter strips for confinement lots is equivalent to their use with crop fields. The costs associated with sediment basins and detention ponds will depend on the size of the lot and the number of animals.

Rotational loafing lots tend to be the least expensive option available for confinement lot management. The cost of expanding the loafing lot and separating it into four paddocks is \$130 per acre (Faulkner and Trott, 1994). This installation cost includes fencing materials, labor, and sod planting. Annual maintenance costs are approximately 8% of installation cost. Since the rotational loafing lot system will likely require that the additional necessary acres will have to come from either pasture or cropland. So there will be some loss in income from the change in land use. However, the use of rotational loafing lots improves the forage growing within each paddock. The practice also has been shown to dramatically reduce the incidence of mastitis and reproductive infections amongst the herd. This practice results in less health care costs for the animals and may also result in increased milk production. A recent study that took into account many of these factors estimated that the total annual cost for this BMP was approximately \$1.85 per animal, based upon a herd size of 110 animals (Faulkner and Trott, 1994).

4.3.3. Cost of Best Management Practices on Pasture Land

The two principal best management practices for pastureland are grazing land protection and the protection of stream banks. Both have relatively low startup costs in comparison to the other BMPs associated with cattle since their main cost tends to be fencing materials (USEPA, 1993). However, if the pasture land or stream banks are in poor condition the start up costs can be considerably more. Both BMPs have been shown to often provide considerable benefits to the farmer beyond just reducing erosion and N loadings.

Rotational grazing is a common practice used to improve the conditions of pasture in the Shenandoah region. It costs approximately $8.18 to install fencing per acre, and $250 per electrical fence charger. Including operations, maintenance, and replacement costs, and using a 9.5% discount rate over a 25-year amortization period, the average annual cost per acre is $4.16 (Faulkner and Trott, 1994). When other more expensive pasture management practices such as alternative water sources and stock walkways are also considered, the average cost goes up to around $10.14 per acre. Also, pasture management practices may not have high installation and maintenance costs but they are more time intensive than regular grazing practices.

The purpose of stream bank protection is to reduce the impact of cattle traffic on the stability of the stream bank. Fencing is the least cost method of accomplishing this, costing an estimated $1.70 per foot of streamside. However it tends to concentrate cattle in other areas of stream that could lead to increased erosion at these spots. Streamside planting of permanent vegetation or structural stabilization methods can overcome this, yet they are considerably more expensive at $15 per foot (VDEQ, 1996). When costs are based upon the projected number of pasture acres benefited, the estimated average annual cost for all methods of stream bank protection, is approximately $75.90 per acre (Faulkner and Trott, 1994).

Many of the practices considered part of grazing land protection could also help to reduce stream bank erosion as well. Cattle commonly prefer alternative water sources and stock walkways to using the actual stream, making it unnecessary to fence them out of the water. Also with rotational grazing, the section of stream which is used by the cattle is periodically switching, giving the stream side vegetation time to recover.

Rotational grazing and alternative water sources may provide additional benefits to farmers who employ them. Rotational grazing can double to triple the rate of growth of pasture forage thereby increasing the feed intake of pastured animals. A recent report suggested that the monetary benefits provided to the farmer from rotational grazing far outweigh the costs of implementing the practice, projecting a net gain of $19 per acre of pasture. The use of watering troughs over ponds or streams can reduce infections and thus improve herd health. The reason is that streams used as watering sources for herds tend to have high bacterial counts from fecal matter getting into the water.

4.4. FORESTRY BMP COSTS

By far preharvest planning is the most cost-effective method for controlling erosion and nutrient loadings from timber harvesting. Careful road planning can reduce overall road construction costs since building roads across streams and along steep grades increase building costs (USEPA, 1993). Careful planning of roads to minimize erosion will also result in longer road life and reduced maintenance. Highly erodible areas in general are more expensive to harvest. Avoiding harvesting timber on these areas will therefore have a lesser impact on profits than not harvesting an average acre.

The cost of erosion and sediment control measures used in silviculture can vary significantly. The reason is that the designs of the roads and landing sites as well as the selection of BMPs are all governed by the terrain conditions. The more difficult the terrain the greater the costs will be for all aspects of harvesting. The most expensive practice associated with timber harvesting is road building (USEPA, 1993). The two erosion control practices that contribute most to the cost of road building are using culverts and covering the surface of the roads. The cost of culverts will depend on the number required which will vary with terrain conditions. Grass surfacing costs approximately $280 per mile of road. For gravel the cost can range from $3208 to $14284 per mile of road, depending on design specifications (USEPA, 1993). However, roads built with erosion control measures are estimated to be 30% less costly to maintain than roads without these measures in place.

Putting in forest buffers generally reduces per acre harvests by about 0-6% for 55 foot wide buffers and 6-17% for 150 foot wide buffers along stream banks (USEPA, 1993). Buffers also tend to increase road costs because they must be built around these areas. But they reduce actual harvest costs, as fewer trees will be cut. Overall costs are reduced by approximately $161 per acre, based upon a harvest area of 640 acres (USEPA, 1993). There is an overall reduction in harvest amount of about 3.76 thousand board feet (mbf) per acre. At a price of $150 per mbf there is a loss of $564 per acre, again using a harvest size of 640 acres. This results in a $403 loss in net income per acre.

4.5. URBAN BEST MANAGEMENT PRACTICE COSTS

Urban BMPs, as a whole, tend to be more expensive per pound of N reduced than the BMPs used for other land uses. One reason for this difference is that there are not many source control measures available, and source control tends to be more cost effective than interception and treatment techniques. Another reason is that while forests and agricultural BMPs are applied to hundreds of acres at a time, many urban BMPs must be applied on a much smaller scale. When BMPs are limited to small sites, such as a one-acre parking lot or a 4-person home, there is no opportunity to benefit from economies of scale. Difficulties in siting urban BMPs, which are a factor with other land uses, also tend to push up costs.

4.5.1. Cost of Construction BMPs

Much of the cost of construction BMPs will depend on how well they are incorporated into overall development plans. This fact is particularly true of the nonstructural BMPs (USEPA, 1993). By retaining topsoil and vegetative cover, many can actually save money, since they reduce the cost of site enhancement after construction is complete. Unfortunately cost and cost saving information concerning individual nonstructural controls is not readily available.

Fortunately, the cost of structural controls has been more extensively documented. The use of surface cover for erosion reduction will typically be the most cost effective per pound of N reduced (USEPA, 1993). Seeding the ground with grass is the least expensive costing $300 per acre annually. Using a combination of both mulch and seeding raises the expected cost to $1,100 per acre annually. Using mulch alone can range from $3,500 to $18,000 per acre depending on the materials used.

Materials are the principal cost of inlet protection and sediment barriers on the perimeter of construction sites. When the material used is filter fabric the cost per acre is typically $850. By contrast the use of straw bales can cost $6,800 per acre annually. The reason is the bales tend to deteriorate quickly, making it necessary to replace them frequently.

Detention basins and sediment traps cost approximately $700 and $1,300 per acre, respectively. The difference in cost is likely due to the fact that sediment traps are designed to serve a much smaller area. Since there are usually significant economies of scale associated with the building of pond systems, smaller systems will tend to have much higher per acre costs.

Maintenance costs tend to be a higher percentage of total costs of construction BMPs than they are for other types, for several reasons. Many construction site BMPs, such as sediment barriers and inlet protection, are typically not meant to be permanent. Therefore the materials they are designed with typically do not last more than a few months and so will need to be periodically replaced. Sediment basins can be either temporary or permanent. When intended to be permanent they will likely need to be dredged after construction work has been completed. The reason is due to the high erosion rates experienced at many sites. If the basin will be temporary then the natural drainage characteristics of the land should be restored as much as possible.

4.5.2. Cost of Urban Stormwater BMPs

Urban stormwater BMPs are relatively new in comparison to many agricultural BMPs that have been used to control soil loss for several decades. Because of this there is less information available on the long term effectiveness and cost of the urban BMPs (Schueler et al., 1992). In addition the highly site specific nature of these BMPs, casts doubt over the reliability of the scant cost information. However, from the little information that is available some general conclusions about the costs of stormwater BMPs can be made.

Stormwater BMPs tend to be more expensive to implement on a per acre served basis than those used for either agriculture or forestry. One reason is that they generally rely on interception and detention of stormwater that requires structural modifications of the landscape. Another reason for the higher costs is that these structures can require the purchase of land to place them on which is rarely necessary for farm or forest BMPs. This purchase can be a significant cost in some urban areas with high land values.

The cost of stormwater BMPs is very site specific. Ideally, when siting a BMP, it would be placed where it could do the most good for the lowest cost. Yet, as a result of many of the site limitations that can arise when implementing an urban BMP, the number of available sites is usually very limited. As a result, the design of the BMP often must be modified to accommodate the unique circumstances of the site. These modifications generally require an increase in cost of implementation. Total design and engineering costs are approximately 32% of base construction costs (Schueler, 1997b).

Using a BMP to serve an existing urban area is generally more expensive than using the same BMP in a new development. For established areas, the BMP must be designed to accommodate the existing characteristics. By contrast, the layout of the new development can be designed to accommodate the need for siting the BMP. When BMPs are being considered for a new development, there tend to be fewer restrictions and greater flexibility in siting. Less modifications to the basic design are necessary.

4.5.2.1. Pond System Costs

The choice of stormwater detention pond system will depend on the projected cost-effectiveness of various designs given the site limitations. The more elaborate the design the greater the likely N removal rate and the higher the total expenses will be. Extended detention dry ponds will tend to have the lowest construction costs, with extended detention wet ponds costing slightly more on average, and constructed wetlands being slightly more still (USEPA, 1993), (Randall et al., 1987). Yet the difference in cost between system designs is far outweighed by the differences due to system size. There are significant economies of scale associated with the size of the drainage area. As a result, regional systems have a considerably lower average cost per acre served than do on-site systems.

One of the advantages of stormwater detention ponds is that they can be used to retrofit existing SWM facilities. The retrofit option can reduce much of the design and construction costs that would be involved in trying to install a new system to serve an existing community. SWM facilities are in widespread use in established urban areas of Northern Virginia, providing many opportunities for retrofitting. The average installation cost for retrofitting an existing SWM is approximately $1,500 per acre for systems serving less than 100 acres, and $500 for those over 100 acres (NVPDC, 1994b).

The extended detention wet ponds typically have the lowest average annual maintenance cost, with extended detention dry ponds being slightly more. The difference is due primarily to the mowing and maintenance of the turf for the dry ponds. The maintenance for wetlands will be slightly more for the first few years until the vegetation has become well established. After that their cost should be comparable to those of other pond systems. These cost will tend to be between 3 and 5 % of construction costs.

There is a caveat concerning the maintenance costs of pond systems. At one time the consensus on the performance and longevity of detention ponds was that sediment had to be removed only once every 2 to 5 years. It was thought that they could go for 10 to 15 years before they would need major restorations (Schueler et al., 1992), (Randall et al., 1987). However, many researchers have begun to question the long-term effectiveness of pond systems (Schueler, 1996). It is now widely accepted that there exists an irreducible level of N concentration in stormwater that the systems cannot remove. Furthermore, these systems will likely achieve a level of steady state where the level of N in the outflow will be approximately that of the inflow (Conversation with Occoquan Watershed Monitoring Lab). The only way to prevent this and maintain peak efficiency is through frequent sediment removal, perhaps as much as twice a year (Dillaha, 1990). Major overhauls of the system may be needed as frequently as every 3 to 5 years. This could dramatically escalate the cost of maintaining these systems.

4.5.2.2. Urban Vegetated Filter Strip Cost

The literature on the costs of vegetated filter strips reports a higher cost for their use in urban areas than on farmland. The sharpest difference is in the cost of maintaining filter strips. Presumably one of the reasons for this could be that the farmer has the necessary implements for maintaining the filter strip on hand, thereby reducing equipment costs. Likewise labor inputs are usually not factored into the cost of maintaining the strips on farms as they are for urban areas. The reason is that the work of maintaining the urban strips is usually contracted out, and so is readily measurable; while a farmer uses his own labor and so incurs an opportunity cost, which is more difficult to measure.

However, another possible reason for this could be that less consideration is given to the long-term maintenance of agricultural filter strips. An assessment of the performance of filter strips on Virginia farms reported that many had become inundated with sediment and thus were no longer functioning properly (Dillaha, 1990). Furthermore, many of these had been put into place under cost share programs where the economic incentive was given for implementation but not long term maintenance. Thus the farmers had little reason to adequately maintain the filter strips.

The cost and performance of vegetated filter strips will vary depending on the level of maintenance given to it. Regular mowing, periodic removal of sediment, regrading, and reseeding should be performed on all filter strips. As a rule, these should be done more often the steeper the slope or the lower the ratio of filter strip to drainage area. The strips also require periodic inspection to see if level spreaders or berms need to be added to overcome channellization problems.

Those filter strips which use existing vegetation and that allow natural succession to occur are relatively inexpensive. They have a negligible installation cost and the maintenance costs are less since they do not require reseeding. The annual maintenance cost of these filters is about $112 per acre of filter (USEPA, 1993).

If the existing vegetation is sparse or in poor condition, or if the filter strip will be in a high profile area, the strip will usually have a higher maintenance cost. The site will need seeding with grass, and it also may require other changes such as: grading, soil mending, or installation of a level spreader at the beginning of the strip to reduce channellization. More frequent mowing, weed control, and reseeding may also likely be additional expenses. These higher maintenance filter strips can cost approximately $936 per acre annually (USEPA, 1993).

Grassed swales cost around $5-$15 per linear foot to install, and their annual maintenance costs are similar to those of grass filter strips. An important consideration with grassed swales is that they are often used as an alternative to installing curbing and gutters. Swales are less expensive to install than curb and gutter systems. They also promote stormwater runon to pervious areas rather than directing it to a stormdrain. This can reduce the costs of street sweeping and storm drain cleaning.

The cost of the three zone buffer system will be different for each zone. The grass zone will require the same maintenance as a normal grass filter strip. The managed forest zone may actually make money through the sale of timber. The unmanaged stream side zone is likely to have negligible maintenance costs.

4.5.2.3. Sand Filter Costs

As with pond systems, there are sizable economies of scale associated with sand filtration systems (Schueler et al., 1992). A study undertaken to assess the cost-effectiveness of various stormwater quality controls derived the cost estimates, given in Table 4.1, based upon empirical data. Giving each potential drainage area equal weight provides an average construction cost of $5,596 per acre. There was also a similar reported decrease in the cost per pound of N reduced as the level of imperviousness within the drainage area increased.

Table 4.1. Sand Filter Costs

WATERSHED ACREAGE	CONSTRUCTION COSTS
1	$13,613
2	$16,880
5	$25,682
10	$38,115
15	$46,283
20	$54,450
30	$70,785
From NVPDC/Urban Retrofit Techniques: Applicability, Costs, and Cost Effectiveness/November, 1994, p.D32.	

One of the principal costs of sand filters is the vault which contains either just a filtration chamber or both a settling chamber and filtration chamber. Initially, when they first were used their cost was very high. After use of these vaults became more widespread, their cost declined by 60% to about $14,000 per vault. As use of sand filters continues in urban areas there is a possibility that prefabricated and modular components could further reduce their cost (NVSWCD, 1994).

As mentioned in the previous chapter, sand filters require a good deal of light manual maintenance during the year. The projected cost range for this maintenance is 5 to 7 percent of capital costs. Sand filters also require the periodic removal and replacement of sand about once every three years, which cost approximately $5,000 to $6,000.

4.5.3. Alternative On-site Treatment System Costs

Most alternative systems are designed to enhance conventional septic systems rather than replace them since the settling which occurs in septic tanks is still a needed component. So when an existing system is retrofitted it is not usually the case that the septic system is replaced. Therefore the cost of using an alternative system should not include the cost of the septic tank or drainfield. When an alternative system is used for a newly built home, the cost of the septic tank and drainfield should not be included either. This is because these components would have to be installed anyway, and so their costs are sunk costs.

Like many BMPs the cost of alternative systems can vary from site to site due to differing circumstances. Another important factor is the availability of components needed for the system. However, the likely cost range for most alternative systems is between $4,000 and $8,000 dollars, for an average size home with four occupants, with the probable average being $6,300 (USEPA, 1993). The one exception is constructed wetlands, which have a much lower projected cost range of $1,000 to $3,000. The lower cost of these systems could be due to the fact that they are built at ground level, and thus avoid much of the cost of excavation. Table 4.2 provides a range of possible values.

The maintenance requirements for all alternatives can be separated into those costs incurred annually and those for maintenance done every three to five years. Annual costs include routine inspections to ensure proper performance, electricity inputs for any pumps or aeration devices, and removal of debris and weeds from any open systems. Costs incurred every three to five years are for the periodic pumping out of accumulated sediments from settling chambers, and the periodic replacement of filter media for filtration systems. The systems with the highest reported annual maintenance costs are aerobic treatment units with an estimated cost of $620 (Peterson and Simpson, 1992). Sand filters, mound systems, low-pressure systems, and constructed wetlands had estimated maintenance costs of $325, $180, $150, and $70 respectively.

Table 4.2. Alternative On-site Wastewater Treatment Installation Costs

System Type	Virginia (Peterson & Simpson, 1992)	Nationwide (USEPA, 1993)
Mound System	$3,800- $15,000	$7,000- $10,000
Low Pressure System	$5,000- $8,000	$4,000- $6,000
Aerobic Treatment Unit	$3,600	No reported value
Sand Filters	$5,000- $13,000	$4,000- $8,000
Constructed Wetlands	No reported value	$1,000- $3,000

4.5.4. Economic Considerations of Alternative Development Patterns

To assess the potential benefits and costs associated with an ADP, it must be compared to the prevailing development pattern within the Potomac Basin, commonly referred to as Sprawl (Year 2020 Panel, 1988). Sprawl can be defined specifically as single family detached housing at a gross density of 2 or less houses per acre (RERC, 1974). More generally speaking, Sprawl is urban development that is either not concentrated or not composed of mixed urban uses (USCOTA, 1995). Certainly, the use of ADPs could effect development costs, the retail value of the property, and ultimately the local tax base. Yet a complete analysis of the costs and benefits incurred from the use of an ADP instead of traditional Sprawl development would require that not only monetary impacts but quality of life impacts be considered as well. Many supporters of ADPs see them as both a means for preserving existing rural and urban communities, while fostering strong community ties in new neighborhoods (Ewing, 1997). While detractors of ADPs view them as an attempt to deprive new homebuyers and businesses the right to purchase the type of development they truly prefer (Gordon and Richardson, 1997).

The arguments for and against the use of ADPs touch on a wide range of issues such as: tax codes which favor Sprawl style development; the short term gains verses the long term costs of Sprawl; and whether or not a centralized or decentralized urban area is more efficient. To provide a complete accounting of the full economic tradeoffs between these two different approaches to development would be exceedingly difficult, and it is beyond the scope of this literature review. Instead an attempt will be made to highlight some of the key issues surrounding the costs and benefits of ADPs.

4.5.4.1. The Potential Costs and Savings from Watershed Planning and Growth Management

Much of the debate between proponents of ADPs and proponents of Sprawl regional scale issues. One argument for Sprawl is that utilizing open space outside of urban centers provides rural landowners with a higher valued use of their land, while at the same time keeping the price of land in cities down (Gordon and Richardson, 1997). This benefits rural landowners, developers, as well as new home buyers and businesses.

An important issue to keep in mind is that ADPs are not intended to limit the number of new homes or businesses, but rather to actively direct where they can occur (Burchell, 1997). Channeling growth away from environmentally sensitive areas, and towards existing development and infrastructure, will lower potential returns on land for some property owners, but also create economic rents for others (Feitelson, 1993). Existing home and nonresidential building owners, as well as landowners zoned for new development, all stand to potentially gain from limits on areas for new developments. These potential benefits would need to be weighed against the potential costs to land owners who fall under the zoning restrictions.

The most direct financial burden of Sprawl is typically born by local governments who are responsible for providing infrastructure and services to new communities. Leapfrog and low-density growth can require localities to spend a great deal of money on providing roads and public utilities to the new residents. It also increases the amount of roadway and utility lines per DU. This infrastructure must continue to be maintained into the future, but with a decreasing amount of tax dollars per segment. Growing rural communities may find it necessary to upgrade the treatment of their municipal water supply, as a result of increased pollutant loads in stormwater runoff. Additional schools, libraries, and fire stations are often needed to serve new developments located too far from existing centralized communities.

Many localities that once saw development as being a source of economic prosperity for their community are now realizing that unplanned growth does not pay for itself. Localities believed that by charging developers impact fees, in return for extending services to the sites, they would receive the benefits of increased tax revenues, while avoiding the infrastructure costs. However, as the amount of infrastructure that the locality must maintain increases, so do the annual expenditures on maintenance and replacements. While development is occurring, the revenues gained from charging developers often covers these rising costs. Yet as available land for development declines, the pace of growth slows and so does the extra revenue (Kinsley and Lovins, 1996). Loudoun County, Virginia, experienced rapid growth during the 1980s, but as growth slowed, local officials found that the average family received $5,800 in services annually while paying only $1,280 in return. Their conclusion was that the economic boom experienced in the 1980s had not paid for itself (Kinsley and Lovins, 1996).

There is not a great deal of information on the cost incurred by a locality, for implementing a watershed management plan. Many of the costs become absorbed into the operating budgets of various county agencies, and so are difficult to assess (USEPA, 1993). However, some examples of potential costs do exist. The first step of designating acceptable land uses requires a resource inventory for the area. The City of Virginia Beach, Virginia, conducted a resource inventory for the entire locality which cost the city $84, 000 (USEPA, 1993). Watershed management plans will need to be updated periodically, and many plans call for the purchase of sensitive lands or just their development rights. Howard County, Maryland, was given $1.14 million by the state to cover these expenses (USEPA, 1993).

Yet, viewing the preservation of sensitive areas as an expense can be somewhat misleading. The city of Boulder, Colorado actually discovered that while it cost them on average $75 per acre per year to maintain land as open space, it was costing them between $2,500 to $3,200 annually to provide services to an acre of developed land (Kinsley and Lovins, 1996). So, under some circumstances, preserving sensitive land as open space can actually save localities money.

4.5.4.2. The Costs and Benefits of Alternative Site Designs

` For individual developments, the use of on-site ADPs will tend to lower construction costs. Most developers are responsible for installing the roads and utility mains on their development parcels. Clustering houses, narrowing roads, and other methods for reducing impervious surfaces, will actually save money for many developers. To encourage clustering many localities will actually allow developers to build more homes. For example, a developer is allowed to build only 20 DUs on a hundred-acre tract. Yet, if he guarantees that at least half the land will remain as open space, he may be allowed to build 25 DUs. Similarly, a locality can just set a limit on the allowable level of imperviousness, such as only one out of ten acres, and then let a developer build as may houses as he affordably can (USEPA, 1993). These approaches are more flexible than traditional zoning methods, so they give developers the chance to meet the requirements in the most cost-effective manner. After development has occurred, the long-term maintenance of the infrastructure becomes the responsibility of the locality. So, localities also benefit financially, when developers reduce imperviousness and cluster houses.

Even though in most cases the developer will actually save money from reducing imperviousness, they may not have sufficient economic incentives for adopting many of the suggested measures. For instance, a developer may feel that minimizing site disturbance would not be worth the effort. In response, localities can establish limits of disturbance standards; and create a program to both promote and enforce the standards. The EPA estimates such a program would cost a typical community $110,000 per year to operate (USEPA, 1993). Most of this money would go to pay for staffing.

Another factor which may prevent developers from utilizing on-site ADPs is the impression that there is a greater demand for lower density single use development and therefore their overall net returns will be higher if they keep the density low. For many developers, clustering and mixed use are financial gambles, and until sufficient evidence suggests that these are viable alternative to low density single use development, reluctant developers are not likely to change.

4.6. CONCLUSION

The purpose of this and the preceding two chapters was to provide an overall description of: what is contributing to the excess levels of N in the Potomac River; what can potentially be done to address the problem; and what the associated costs may be. These costs, discussed in this chapter, were both the direct costs, as well as possible indirect costs. Not every potential cost described at the beginning of this chapter was considered for each BMP. Lack of thorough information on all the potential costs surrounding BMPs, prohibited such a complete discussion.

This chapter completes the initial literature review of the necessary components for any study about the cost of meeting the 40% N reduction goal, defined by the 1987 Chesapeake Bay Agreement. The next chapter will be concerned with the design of the model, and Chapter 6 will involve the equations, variables, and parameters contained within the model.

CHAPTER V

MODEL STRUCTURE

5.1. INTRODUCTION

This chapter explains the basic research method used for evaluating the researchable problem. Since the problematic situation is one of achieving a goal for the lowest cost, an optimization technique would be appropriate. Due to the scope and complexity of the problem, it was determined that a linear programming (LP) model would be the best analytical tool. When modelling large problems with many variables and parameters, LP has several advantages over other modelling techniques. Linear programming models can consistently derive the globally optimal solution, and they allow for the conducting of sensitivity analysis (Hillier and Lieberman, 1995).

5.1.1. Modelling Aims

The model is intended to be a tool for evaluating the potential costs of meeting the N reduction goal under various policy options. It is designed to maximize revenues, while achieving the nitrogen reduction target, subject to a series of land availability constraints. Therefore the aim of the modelling effort is to mathematically represent these three components of the problem. The model can readily be broken down into three goals or aims based upon this design.[1] These are:

• Achieving nitrogen reduction goal

• Maximizing Revenues

• Satisfying land constraints

The nitrogen reduction goal embodies the sources and control practices of the second and third chapters. The maximizing of revenues introduces the economic dimension to the problem described in the last chapter. Finally, satisfying the land constraint is not so much of an aim as it is a necessary condition for satisfying the other two aims. The land constraints ensure that the economic and nitrogen reduction goals are based upon conditions found within the Basin. What follows is an explanation of how the linear programming model mathematically represents these three aims.

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[1] The term aim is used rather than goal, so as not to create any confusion between the goals of the modelling effort and the state's goal of reducing N to the Potomac River by 40%.

5.1.2. Model Structure

All LP models are comprised of four basic parts: decision making variables, constraint equations, parameters, and an objective function (Hillier and Lieberman, 1994). These are used to mathematically represent the important elements of the situation being modelled.

Decision making variables are those factors that can be used in differing amounts to achieve an optimum outcome. There are four basic types of decision-making variables within the model: population variables, land use variables, BMP variables, and land use/BMP combinations referred to as land activity variables.

Constraints are restrictions on the amounts and combinations of decision-making variables. All constraints within this model can be classified as either capacity constraints or accounting constraints. A capacity constraint simply limits the amount of use for a resource represented as a variable. The model contains two types of capacity constraints. The first is a land use constraint, which limits the acreage that can be devoted to a particular land use. The second type is a feasibility constraint, which places restrictions on the level of implementation that can occur for a particular N control technique. An accounting constraint ensures that specific relationships between different variables are accounted for within the model. For instance, any grain fed to cattle must be either grown or purchased. So an accounting constraint ensures that every bushel of grain fed coincides with a bushel grown or purchased.

Parameters are the magnitude with which each decision making variable is considered within the objective function and constraints. The parameter will vary for each constraint based upon the unit of measurement that is relevant to the constraint.

5.1.3. Submodules

From the previous three chapters, it is apparent that both the sources and potential solutions, to the N loading problem, are numerous and varied. Modelling such a large and diverse group of activities can be difficult. By partitioning these activities into smaller groups the task was made more manageable. An easily made division was between rural and urban activities. Rural activities can be broken down further into an agriculture and silviculture. While urban activities can be separated into point sources and urban land activities. The activities were not separated further since many of the activities are very interconnected, and further divisions could make representing these interdependencies more difficult. These four separate sections can be seen as smaller models that are all connected by the three aims mentioned above to form the actual model (Figure 5.1). Therefore, they will be referred to as the agricultural, forestry, point source, and urban submodules.

Activities, occurring within each submodule, all require the use of land. So each land constraint contains decision-making variables from each submodule. This ensures that an increase in land use for one submodule requires a decrease by another. All the land uses and BMPs from each submodule all affect the level of N entering the Potomac River. So decision-making variables from each submodule are included within the N load constraint. Many of the land uses within the agriculture and forestry submodule are undertaken to generate revenues, and all the BMPs within the submodules have an implementation cost. So there are decision-making variables from each submodule within the objective function.

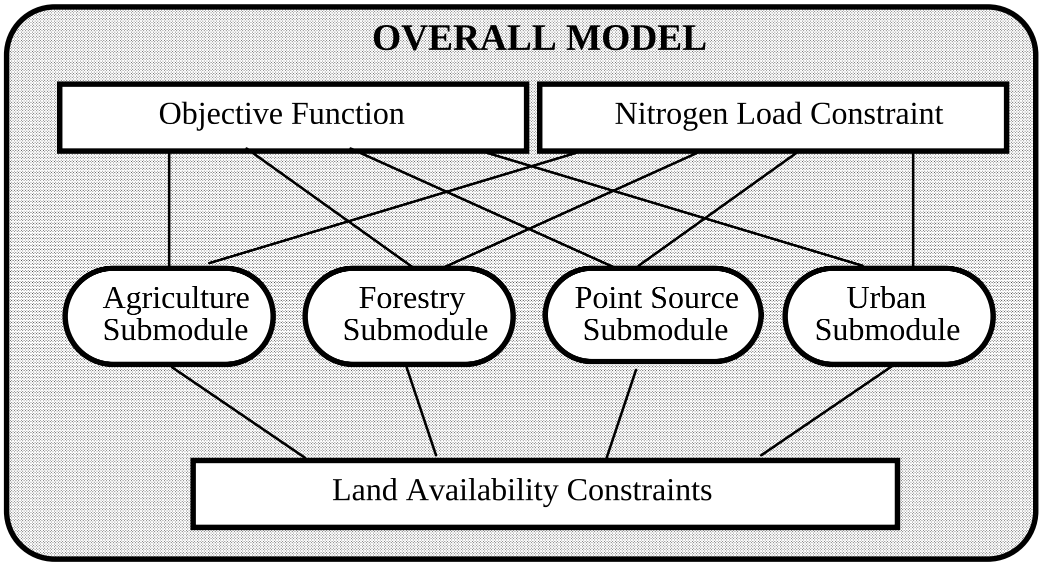


Figure 5.1. Relationship between Model and Submodules

The next three sections of the chapter explain how the three modelling aims were developed within the context of the linear programming model. They also touch upon some of the important issues that arose during the model development process.

5.2. NITROGEN REDUCTION GOAL

The N reduction goal is represented within the model in three ways. First through the inclusion of land use variables, which represent the sources of N. Secondly, through the N control techniques, which represent the best management practices employed. Each land use variable will have one or more N control techniques associated with it. Thirdly, through the N load constraint, which represents the 40% Basin wide reduction set by the state. This constraint is set up in the model so that there is a N load for every acre in the Basin. For each acre this load depends upon the land use activity occurring on it, as well as any N control activity the model chooses to employ on it.

5.2.1. Land Uses

The most difficult aspect of structuring the model was depicting land uses. The task was to model all the land uses that cause N to enter the Potomac River. In practice, these land uses are numerous and varied, and often interconnected with one another. Separating land uses into the four submodules helped make the task of modelling them more manageable. Further division of land uses becomes more difficult, because of the interrelationship between many of them. For instance, within the agricultural submodule, dairy cows are fed either with purchased corn grain or with corn grain and hay grown on Basin farmland. Further separation of land uses would make it difficult to keep track of such relationships.

Deciding what land uses to include within each submodule was accomplished by starting with the most prominent N sources and working downward to less significant sources, based upon VDEQ estimates of each source's relative contribution to the Bay (VDEQ, 1995). The decision of when not to include further sources was a trade-off between accuracy and manageability. This trade-off is well illustrated by the decision of how many crops and BMPs to include in the agricultural module. Because a crop is typically grown in rotations with others, an additional crop requires consideration of the likely rotations that it could be a part of. This cannot be overlooked because different rotations will have different expected returns. In turn, each rotation has a set of BMP combinations that it can be used with. For each additional crop or BMP considered for the agriculture submodule, the number of crop/BMP combinations can increase exponentially. Therefore, land uses and BMPs, which were determined to be infrequently used within the Basin, were not considered.

For every type of land use considered in the model, there is at least one BMP for N control considered as well. Likewise, for every BMP there is at least one land use it can be used for. The model contains a decision making variable for each of these BMP/land use combinations. For convenience these combinations are referred to as a land activity. Land activities also include cases where no BMP is used. So for each acre of land considered by the model, a land activity must occur on it.

5.2.2. Nitrogen Control Best Management Practices

Best management practices for N control are represented within the model in three ways. First, each time a BMP is used as part of a land activity, it will reduce the N load from the land use. Secondly, each time a BMP is used, this must be reflected as an increased cost with the objective function. Finally, in practice, there are limits to the extent to which a BMP can be used. So each BMP will have a performance efficiency, reflected in the N load constraint; a cost, reflected in the objective function; and feasible application level, reflected in a feasibility constraint.

The performance efficiency for each BMP is based upon estimates from published literature. This performance efficiency is incorporated into the model as a percentage reduction to the basecase load for each land use. If the BMP has a 50% reduction efficiency, and the basecase load is 20 lbs. of nitrogen per acre annually, then the resulting load would be 10 lbs. If the model chooses a land activity where a combination of BMPs are used, then their performance efficiencies are considered to be additive (Based on conversation with Dianne McCarthy, 1996).

In the objective function, there is a variable for each BMP and a corresponding cost coefficient. This cost coefficient is the estimated annual cost per acre for installing and maintaining the BMP. Equipment purchases and installation costs are assumed to be paid off over a twenty-year period, based upon a loan with a fixed 5% annual interest rate. Computing the long-term maintenance costs for BMPs varies due to the different nature of the practices involved. Those BMPs that have an indefinite life span and a routine annual maintenance schedule are relatively straightforward to compute. However those that have a limited life span and must be either replaced or receive a major renovation after a period of years are more difficult. For instance, a BMP that has an expected life span of 10 years and then needs to be completely replaced should be given different treatment than a BMP that has the same initial cost but a twenty-year life span. However, reported cost figures are rarely broken down far enough so that such differential treatment could be done. The manner in which the annual cost for each BMP was calculated will be addressed in the next chapter.

The model contains an accounting constraint for each BMP and land use variable. The accounting constraints ensure that for every increase in a land activity variable, which contains a land use and one or more BMPs, the corresponding land use variable and BMP variables also increase. To illustrate this, suppose that a BMP is used as part of ten land activities. Then there would be an accounting constraint that sets the BMP variable equal to these ten land activity variables. This would ensure that every time the model uses the land activity variable, the corresponding BMP variable would increase within the objective function.

In addition to an accounting constraint, each BMP variable has a feasibility constraint. The feasibility constraint is based upon several factors. First, since each BMP is connected to a land activity, the number of acres that the model devotes to that land activity directly limits the number of acres upon which a BMP is employed. Secondly, some BMPs are restricted in where they can be used by specific site conditions. When this is the case, the model is restricted to only adopting the BMP on some percentage of the land. Thirdly, two or more BMPs can often be employed on the same acre, such as with nutrient management and conservation tillage. In other instances, they can be mutually exclusive, as with an on-site septic system and a sewer connection. Finally, the BMP is likely to already be in use on a percentage of the land. These existing BMPs should be included in the feasibility constraint, but not in the objective function. So an estimate of the existing number of BMPs is included as part of both the accounting constraint and the feasibility constraint for each BMP.

5.2.3. Nitrogen Load Constraint

The N load constraint is set up to limit the total annual estimated nitrogen load for the entire Basin. This is done by including within this constraint all the potential land activities. For each land activity there is an estimated N load. As mentioned above, this load reflects the base load for the land use, minus the load reduction that result from the performance efficiency of BMPs used.

It is important to understand that the N load constraint does not restrict the amount of N emanating from any one particular type of activity or locality. As will be shown later, setting up the constraint in this way is necessary for estimating the lowest cost solution. However, there is an important reason why in actual practice state policy makers would like to limit the amount of N coming from certain areas.

By applying the reduction target to the entire Basin, rather than to smaller areas, the model can satisfy the goal by reducing nitrogen in one area, while allowing nitrogen loads to actually increase in another. Yet, in reality this solution would likely be unacceptable to people within a locality where N loads stayed the same or increased, because it could eventually lead to significant degradation of the environment there. This pollution control problem is commonly referred to as localized effects. However, localized effects are not a significant modelling problem because the model could be readily modified to ensure that some N level standard was met for each locale. Such additional constraints are likely to raise the total estimated cost of reaching the primary goal of a 40% reduction of N to the Bay. This is because the model would be constrained to reduce N in an area where the lowest marginal cost for a pound of N reduction was higher than the lowest marginal cost of reducing an additional pound elsewhere.

5.3. AVAILABLE LAND

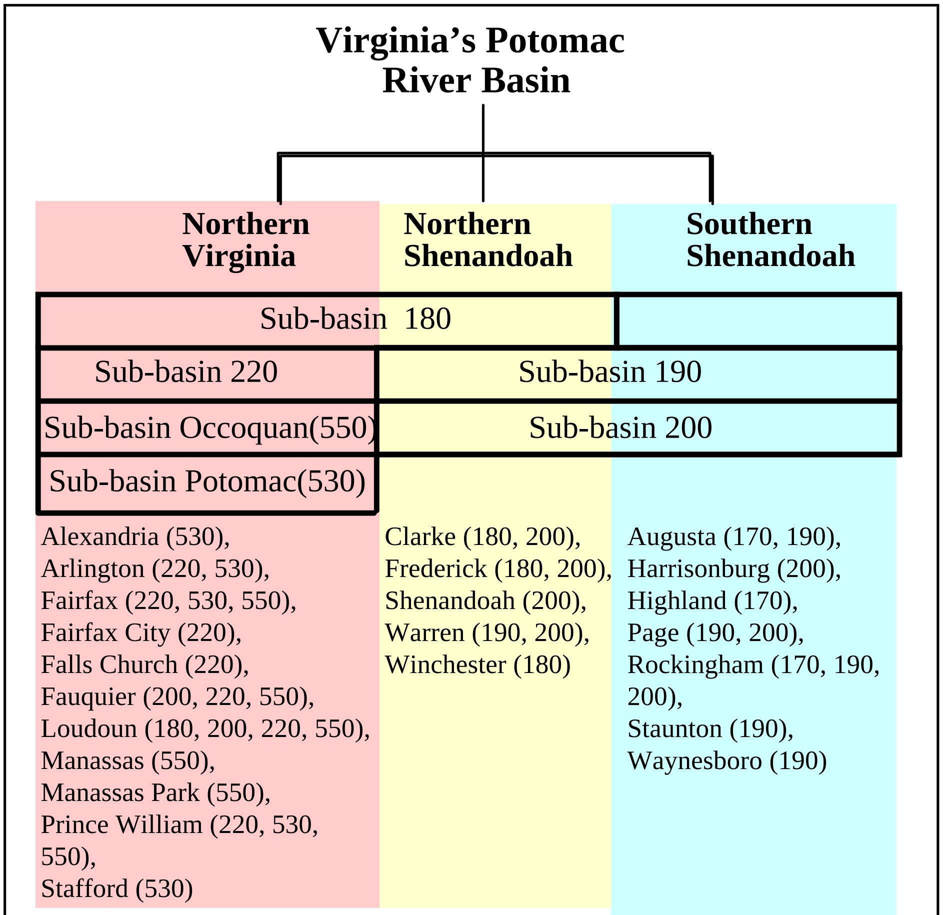
With the exception of point source flow constraints, all the constraints of the model are either directly or indirectly based upon available land area. Each land use variable is directly limited by available land through a series of land constraints. The BMP variables are indirectly limited by the quantity of land, since they must occur in combination with a land use. There were several important factors concerning land availability, which needed to be addressed within the model. The first being how to account for all the different political jurisdictions and physical characteristics found in the Basin. The second was how to accommodate changes in land use and population growth within the context of the model. The third was how to incorporate some of the spatial dynamics associated with the movement of N within the Basin.

5.3.1. Sub-regions

The physical and land use characteristics vary widely across Virginia's portion of the Potomac Basin. So it was necessary to partition the land area into smaller more manageable units. However, there are two ways in which the land can be partitioned. Using political boundaries, the area is comprised of eighteen counties and nine cities. Alternatively using the physical characteristics, Virginia's Potomac Basin contains all or portions of eight major sub-basins, as defined by the USEPA (Camacho, 1993). Dividing by localities would have resulted in twenty-seven subunits, which was considered too many. So to take into account the differences in demographics, the Basin was divided into three regions: the Southern Shenandoah, Northern Shenandoah, and Northern Virginia. To account for differences in terrain and hydrology the Basin was further divided into sub-basins. This resulted in separation of the Basin into 10 parts. Henceforth, "regions" will refer to the three way demographic separation, and "sub-region" will refer to the additional partitioning of each region by sub-basins.

The number of acres within each subregion remains constant regardless of land activity going on within them. Therefore all land activities are constrained by the available amount of land. Even point source discharges are indirectly restricted by available land, since wastewater treatment plants rely upon a network of sewer lines to deliver the influent. If population growth occurs in areas where the infrastructure is not available then a residential pattern with onsite sewage treatment can be used.

It is important to mention here that although the model is broken down into subregions, the series of equations pertaining to each subregion are identical. The only differences from region to region are the parameter values. Therefore model variables and equations can be described without needing to distinguish between particular regions. This fact greatly simplifies the explanations provided in the next two chapters.



In the above diagram, the three columns represent the three regions considered within the Potomac Basin. The rectangles represent the model sub-regions. The three lists underneath the sub-regions represent the localities within each sub-region. All the numbers signify the sub-basin that the sub-region or locality is in.

Figure 5.2. Diagram of the Model Sub-Regions

5.3.2. Loading Rates and Transport Factors

Every land activity has a nitrogen-loading rate. These loading rates are based upon edge of stream and not edge of field rates. So the changes in nitrogen loads as runoff travels from field to stream are therefore included in the actual loading rate. Yet conditions between field and stream can vary considerably depending on distance, slope, terrain, soil types, vegetative cover, time of year, and many other factors. The delivery ratio from field to stream is only based upon average estimates of these conditions within a given sub-region. However, this is necessary since the model has not been designed to account for the spatial variability between sources and waterways. To incorporate such spatial variability into the model it would need to be linked to a continuous watershed hydrologic assessment model with distributive parameters (Novotny & Olem, 1994).

Once the nitrogen runoff enters the waterways, there are in stream-processes that will affect final amount of nitrogen reaching the fall line. In the model's nitrogen load constraint, the total nitrogen load for each sub-region is multiplied by a transport factor. These transport factors are based upon an average estimated transport factor for each sub-basin (Camacho, 1993).

5.3.3. Population Growth and Land Use Changes

For many of the localities within the Potomac Basin, particularly those in the Northern Virginia region, population growth is causing significant changes in the way land is being used. Farm and forestlands are being transformed into residential communities and urban spaces. Determining the effects of this process on nitrogen runoff can be difficult. The nitrogen load from an acre of land can go up or down depending on the specific change in land use. For instance, if an acre of crop land, where no BMPs are currently employed, is converted into low density housing, the nitrogen load from the acre is likely to go down. Yet if an acre of forest is cleared for a parking lot the nitrogen runoff will certainly increase.

The model is designed to allow for transferring land from one submodule to another. The model will transfer land from one module to another for two reasons: to decrease N loadings, or to accommodate population growth in the Basin. However, there are several restrictions built into the model on how land uses can change. First, the model does not allow the number of farmland acres to exceed their currently estimated levels within the Basin. The number of forested acres is allowed to rise or fall within a range of values. While, urban acres are restricted from falling below current levels. So farmland can be converted to forestland or urban land, forestland can only be converted into urban land, and urban land can only increase. This current arrangement of land use restrictions can be readily modified in to ways. The first is by either adjusting parameter values, which changes the minimum or maximum amount of land allowed for a particular land use. The other way is by changing equations from being a "less than or equal to" equation to being a "greater than or equal to equation," or vice versa. This has the effect of changing the allowable conversions of land use. For example, if the urban land constraint was changed to being a less than or equal to equation, this would allow urban land to be converted to either farm or forest land.

The model has been structured to simulate increases in population. As additional population is introduced, the model must accommodate the increased population by increasing the number of urban acres. Unless otherwise constrained the model accommodates population growth by converting the land in such a manner that the N goal is still met and net revenues are still maximized. However, from a practical standpoint many of these changes may be unrealistic. A great deal of political will would be required to accomplish such an ideal development strategy. Therefore the model can be constrained to simulate different urbanization scenarios. In this way policy makers could take into account existing zoning regulations and simulate the effects of changes to these regulations.

5.4. REVENUE MAXIMIZATION

The revenue maximization goal of the LP model is mathematically represented by the objective function equation. The model's objective function is the optimization equation. The output is net revenue. The decision making variables are either a land use variable, which generates revenues and production costs, or a BMP, which has an implementation cost.

Since the goal is to meet the N reduction target for the lowest cost, it might seem more appropriate for the objective function to be a cost minimizing equation. However, the model works to minimize costs as it maximizes net revenues, since a cost is essentially negative revenue. So by formulating the equation to maximize net revenues the model is able to more accurately represent profit maximizing behavior and opportunity costs. For instance, if two activities produce only marginally different loads, but one generates significantly more income, the model will choose the high-income activity. Likewise, if the model transfers acres from an activity that generates high nitrogen loads to an activity generating low loads, it automatically takes into account any loss of revenue.

5.4.1. Revenue Maximization Assumptions

The model is not representing the revenue maximization decision of any one particular individual landowner or locality. Instead the model maximizes revenue across the entire Basin as if it was one entity. Modelling the revenue maximization decision of each landowner in the Basin would be impossible. However, it would be feasible to model the revenue maximization problem for each locality, but that is not likely to produce the lowest cost result for meeting the Basin wide reduction goal. If the model was structured to maximize revenues for each locality it would also need to be structured so that the 40% N reduction goal was met by each locality. The marginal cost for attaining a forty- percent reduction in N loadings is likely to be different for each locality. If this is the case, additional savings could be derived from having some localities reduce N loads by more than 40%, thereby allowing others where the marginal cost is high to reduce by less.

All four submodules include N control activities that generate costs and both the agriculture and forestry submodules contain revenue-generating activities. This is not to say that there is no money being generated in point sources or in urban areas. Certainly a fiber processing plant, which might discharge nitrogen, is producing a revenue-generating product. Likewise, a parking lot, which is contributing to urban runoff, may surround a busy shopping mall. However, an assumption was made that the only way to reduce N in these modules is to introduce a control technology. It is assumed that the volume of wastewater treated by point sources will not be reduced; only the level of N within each liter discharged. Likewise, once land has been urbanized it stays urbanized. It follows that any loss of net revenue will not be due to a land use change, but solely to the addition of N control technology. So the revenues from other potential land uses can effectively be ignored.

The only costs considered for the point source and urban modules are those incurred as a result of implementing a N control technique. Other costs are not considered because they are essentially irrelevant to meeting the N reduction goal. This would seem a completely acceptable proposition, if this were a completely static model. However, as mentioned, the model allows for the increases in population. As new people are introduced the model settles them into differing residential patterns. Each of these residential patterns has differing loads per acre due to factors of impervious surface cover and wastewater treatment methods. So the model can place people into differing residential patterns to reduce nitrogen loads, essentially using this as a pollution control technique. These different residential patterns can vary considerably in their estimated costs, and so the settlement pattern is definitely not a cost free process.

5.4.2. Cost Analysis

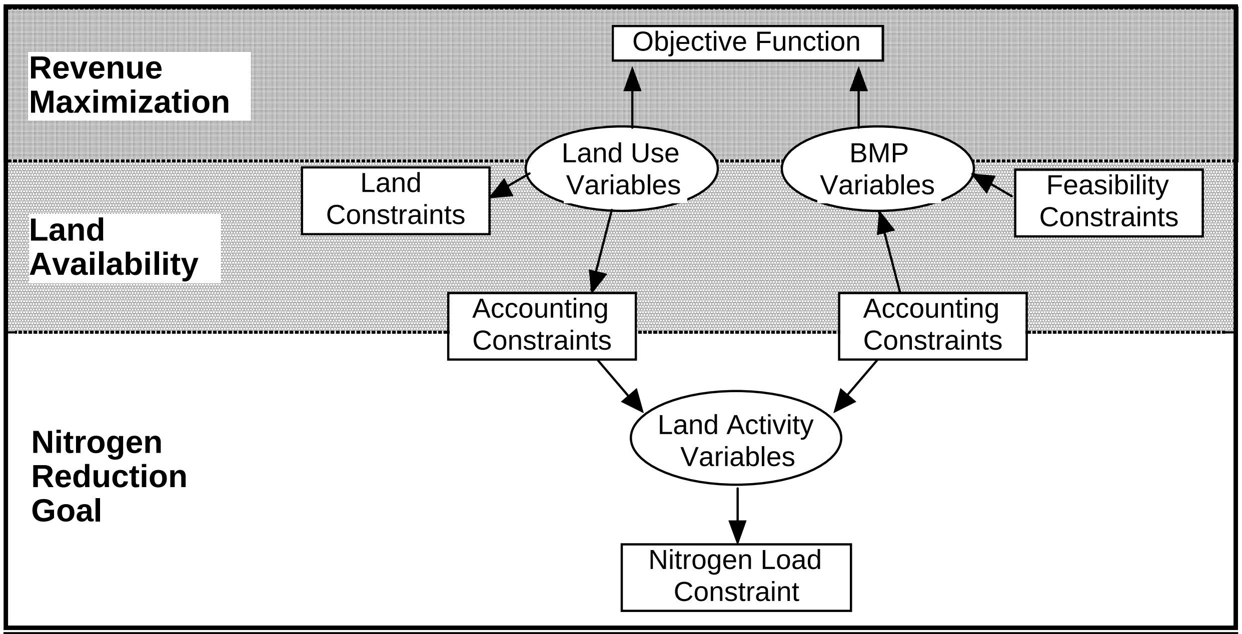
As the model is currently formatted, it will provide a projection of the lowest cost combination of N control BMPs to achieve the N reduction goal within the entire Potomac Basin. Population parameters can be adjusted to simulate future population growth, and the model will increase the number of urban acres in such a way as to minimize the resulting increases in N loadings from the new urban land.

Run in this way the model results provide a “best case scenario” for achieving the N reduction goal. However, the results are not likely to represent viable policy options for state and local officials. By restricting: the model’s ability to select BMPs, transfer land from one land use to another, or accommodate new population growth, alternative policy options can be examined within the context of the model. This can be accomplished through the inclusion of additional constraints. Adding constraints to an LP model can only result in a solution that is equally or less optimal. So these additional constraints will increase the cost of achieving the goal. In this way policy makers can examine the potential costs of various policy options.

5.5. CONCLUSION

This completes the general overview of the model structure. Before proceeding to the next section it may be helpful to briefly summarize the description of the model thus far. First, the model is a linear programming optimization model with an objective function, decision-making variables, parameters, and constraints. Secondly, the purpose of the model can be broken into three aims: maximizing revenues, achieving the N reduction target, and satisfying the available land constraints. The objective function is the mathematical representation of the revenue-maximizing objective. The N load constraint represents the N reduction goal. Capacity constraints are used to ensure that the land activity variables of the model are constrained by what is possible within the Basin.

The Figure 5.3. provides a diagram of how the model's basic structure is designed to meet the three modelling aims, stated in this chapter.



The above diagram illustrates how the decision making variables (ovals) are connected to the model constraints (rectangles). Each submodule contains a set of decison making variables, accounting constraints and feasibility constraints. The point source submodule is set up slightly differently. A detailed diagram of each submodule will be contained within the next chapter.

Figure 5.3. Diagram of Basic Model Structure.

To make the model more manageable the decision making variables, feasibility constraints, and accounting equations were separated into four submodules. The four submodules are agriculture, forestry, point sources, and urban. The four submodules are linked to form the overall model through the objective function, the N load constraint, and available land constraints. How each of the submodules is set-up; what assumptions needed to be made; and how the parameters were derived, are the three main issues of the next chapter.

CHAPTER VI

MODEL EQUATIONS, VARIABLES, & PARAMETERS

6.1. INTRODUCTION

This chapter is intended to describe the way in which each submodule is organized. This requires a discussion of the variables, constraints, and parameters that compose each submodule. The discussion will focus primarily on the basic variables, equations, and parameters, while the details concerning specific variables and equations will be illustrated through diagrams, and specific parameter values will be given in tabular format.

The variables and equations within each submodule are configured to meet the three modelling objectives. All the submodules share the total land constraint, N load constraint, and the objective function. However, some submodules share additional land use variables and constraints. This is to be expected, since the activities represented by each submodule are not completely separate from one another.

Since variables represent land use, and constraints represent limitations on land use and interrelationships between land uses, then ideally their combination should characterize conditions within the Basin. An important purpose of this chapter is to list and describe the methods used to derive the parameters associated with the variables of each submodule. The parameters associated with the variables and constraints provide a more direct link between the submodules and actual circumstances. The reason is that the parameter values are based completely, or in part, on data concerning the Basin.

6.1.1. Comparing Present and Future Conditions

Every submodule has a set of parameter values. Each set of parameter values consists of a basecase and trend equations. The basecase contains the parameter values that reflect conditions that are estimated to currently exist in 1998. However, many of the parameters such as costs, and land use levels will likely change in the future. Therefore, when the model is run to assess meeting the N reduction goal in the future, these parameters will need to be adjusted to reflect the projected changes in their value. This was accomplished through the use of published projections, asking the opinions of experts on the topic, linear trend equations from historical data, or some combination of these.

One of the primary purposes of the model is to provide an indication of how future population growth and land use changes may affect the cost of attaining the N reduction goal. This requires a comparison between present and future conditions. The greater the time span the more apparent the effects will be.   However, the further the future date that the estimation is made for, the greater the chance for inaccuracy. Therefore, the modelling of future conditions should be kept within a limited time span. This topic will be dealt with in greater depth in the next chapter, as part of the discussion on model scenarios.

The way the model reflects different periods in time is through differences in parameter values. So the set of parameters used to describe future conditions will be different than the set for 1998. Many parameter values, such as wastewater flow, can be expected to change over time. Likewise, the range of potential values for a decision making variable may change as a result of expected trends in land use or due to specific policy decisions. Therefore, the parameter values mentioned in this chapter will be those that reflect the current situation, or basecase conditions. Any changes made to the model to represent future conditions will be mentioned in the next chapter on results. It should be pointed out that all the cost figures used for representing the current conditions have been adjusted to reflect the estimated 1998 price. Therefore, these prices will not have to be adjusted for inflation for future years, and any changes in costs will be expressed in real terms.

6.2. AGRICULTURE SUBMODULE

The agricultural submodule is the most complex of the four submodules. This is a result of the numerous possible land use decisions that can occur on a farm. Farm enterprises are broken down into crops, pastured livestock, and confined livestock. These different activities can be characterized by their effect on farm income, their contribution to N loadings, and their use of land. Although, the scale of farm operations can vary widely within the Basin, most farms are involved in the production of several agricultural commodities. In developing the agricultural submodule the primary objective was to include those production activities that are a significant source of N. However, these production activities typically do not occur independent of one another. For instance, crops are fed to livestock and animal manure is used as a fertilizer for the crops. So the second objective was to include some of the interrelationships between these activities.

Feasibility constraints set upper and lower bounds on the activities that occur on the farm. Accounting constraints are used to link together land activities, which are typically done in conjunction on farms. For instance, within the submodule there are a series of constraints that link growing corn to feeding cattle. The first constraint specifies that all corn grain produced must be either sold or used as feed. Then another constraint specifies that all corn grain produced for feed must be consumed by existing farm animals. Finally, a third dictates that all cattle must be fed with crops grown on the farm or by feed that is purchased.

6.2.1. Agricultural Basecase and Trends

The 1992 Virginia Agriculture Census was the primary data source for the current basecase estimate[2]. To use this data for creating a baseline scenario, several assumptions needed to be made. To begin, the census breaks down cropland into several different categories that include: harvested cropland, pastured cropland, summer fallow, and cropland not pastured or harvested, and idle cropland. All of these categories are considered cropland for the baseline; except idle cropland that is considered just idle land that is not in permanent vegetative cover. All of the cropland is considered harvested, except for pastured cropland that is considered to be unharvested hay.

[2] According to the glossary of the 1992 Virginia Agricultural Census, farms are establishments that can potentially make $1,000 per year through the production of crops, livestock, animal specialties, or horticultural specialties.

The Census categorizes woodland on farms as pastured and unpastured woodland. For the basecase, woodland that is pastured is regarded as pastureland, and unpastured woodland is considered idle land in permanent vegetative cover. So pastureland for the basecase includes the census categories of: pastureland and pastured woodland.

Idle land for the basecase includes idle cropland and woodland, as mentioned above, but it also includes the two census categories of: orchard land; and land in house lots, ponds, and roads. These two are included because it is assumed that idle land is the best approximation for the potential N load from these acres. However, the acres in these categories are not included in those considered for permanent vegetative cover.

To estimate future conditions within the Basin, trend estimates had to be derived for each land use. Ordinary least squares was used to derive linear trend lines based upon historical data. However, linear estimations imply a constant rate of change, and this is often not the case as factors such as new regulations or shifts in preferences can alter the rate of change significantly.
Also, many land use trends may experience a leveling off which cannot be captured by the linear approximation. For instance, the historical data may show a steep decline in dairy cattle for a county, and a linear trend line would show all dairies in the county gone eventually. However, the decline could be a result of smaller dairies going out of business, while medium and larger size dairies remain stable or grow slightly. Therefore, a more appropriate trend line would show a leveling off of the decline, and perhaps an eventual upward trend.

For cropland trends, data from the years: 1982,1987,1992, 1993,1994,1995,1996, were used to create future crop level forecasts. If the trend line showed future crop levels either decreasing or increasing by 50%, over the next ten years, then the year 1982 was removed from the trend calculation. If the trend still over 50% then 1987 was removed as well. Since these two dates are both 5 and 10 years before 1992 they were considered to be less significant to current and future trends. It was assumed that the data for the 5 years between 1992 and 1996 was the most significant for 1998 and 2003 estimates.

Linear trends were also developed for future livestock levels. However, some sectors of the livestock industry have experienced considerable growth in the past decade. So livestock experts within the Basin were asked to give their opinions on the likely trend in livestock numbers for the next five years (See Appendix C). The linear trends were then adjusted to reflect the opinions of these experts. Experts were asked to give an estimate of the percentage increase in livestock numbers that is likely to occur over the next five years for a particular locality within the Shenandoah Regions. This percentage was then averaged with the percentage increase in five years, predicted with the historic trend line, to derive the adjusted figure.

6.2.2. Revenue Maximization in Agricultural Submodule

Best management practices and their likely cost, were discussed in chapters three and four respectively. Likewise, in the previous chapter, a basic explanation of how BMPs were incorporated into the model was given. Therefore, this section will primarily emphasize how the model accounts for other economic factors, such as market prices and production costs. The basecase parameter values for farm BMP costs along with other revenue and cost parameters are provided in Tables 6.1., 6.2., & 6.3. .

6.2.2.1 . Crops

The various crops that can be grown on the cropland are: corn grain, corn silage, soybeans, wheat, alfalfa, and other types of hay (Table 6.1). Together these crops accounted for more than

95% of the harvested crops in the Basin, according to the 1992 Virginia Agricultural Census (Census of Agriculture, 1993). The model requires that the crops produced from each acre of cropland be either sold or fed to confined cows as part of their feed ration.

The production of each crop is represented within the objective function in two ways. The first way is through the potential returns from an acre of each crop. Historical yields were combined with current market prices to derive the returns from each acre of cropland. The second way is through the estimated cost of production for each crop acre. It was necessary not to combine costs and returns per acre into a net return figure, because the gross returns from an acre of crops is dependent upon whether it is sold or fed to cows.

Crops can also be purchased for use as feed. However, the model will feed produced crops to confined cattle rather than selling the produced crops and then purchasing feed. The reason is that the retail price paid for the crop will tend to exceed the wholesale price received for the crop. For example, if a positive number of acres of corn grain is grown in a subregion where there is a positive number of dairy cows, then the acres of corn grain will be used to feed cattle, until a specified ration requirement of corn grain for each cow is met, after which it will be sold. However the model is not restricted to maintain a minimum level of cropland to support the feed requirements of confined cows, since there could be no acres of crops grown, and all confined cows could be fed with purchased crops.

The Table 6.1 contains the parameter values for the different crops used in the model. These parameters are associated with three variables within the model: CROPSOLD, CROPPAID, and CROPCOST. CROPSOLD represents the wholesale price received by farmers. CROPPAID is the retail price paid by farmers. CROPCOST represents the farmers' annual cost for producing the crop.

The return from an acre of hay is price received in Virginia for a ton of hay, as of Dec.1997, multiplied by an average of historic yields from 12 counties in the Basin reporting hay production (Census of Agricultural 1992, 1993), (ERS, 1998), (NASS, 1997). The returns from an acre of alfalfa were computed in the same manner. The returns from corn grain and wheat were computed the same way, except the historic yield was an average from 11 counties within the Basin. For soybeans the historic yield was from 10 counties.

For the CROPPAID variable, the parameter values for alfalfa, corn grain, wheat, and soybeans were derived from the average prices paid by farmers in the Appalachian region from 1992-1996 (USDA, 1997), (NASS, 1998a). The price paid for hay was not found in the literature survey, so it was extrapolated from the price paid for alfalfa. It was assumed that, since the wholesale cost of a ton of hay was 71% of the cost of a ton of alfalfa, the retail price paid for a ton of hay would be 71% of the retail alfalfa price.

For the 1998 costs of producing an acre of soybeans, wheat, and corn were determined through regression equations based on historical production costs for these crops within the southeast United States (USDA, 1997), (NASS, 1998b). The costs for producing hay and alfalfa were based upon those used in Robert Parson's dissertation (Parson, 1995).

Table 6.1. Parameter Values for the Revenues and Costs Associated with Crop Production.

	MODEL VARIABLES					
	CROPSOLD		CROPPAID		CROPCOST	
	Unit	Parameter Value	Unit	Parameter Value	Unit	Parameter Value
Hay	ac	$157.40	ton	$197.38	ac	$32.00
Alfalfa	ac	$365.46	ton	$278.00	ac	$110.00
Corn Grain	ac	$250.03	ton	$168.00	ac	$202.36
Wheat	ac	$133.26	ton	$231.86	ac	$110.48
Soybean	ac	$187.76	ton	$283.14	ac	$124.04

CROPSOLD: represents the wholesale price recieved by farmers.
CROPPAID: represents the retail price paid by farmers.
CROPCOST: represents the farmers cost for producing the crop.

6.2.2.2. Livestock Revenues and Costs

The module considers three types of livestock operations: pastured cattle, dairy cows, and poultry. The types of poultry considered are layers, broilers, and turkeys, which are all confined. Poultry are measured in animal units, with one unit equal to a 100 chickens, and 5.5 turkeys (USEPA, 1993). The Table 6.2 provides the provides the net returns from these operations, used in the model. The three variables used in the model for representing these costs are PSTRSOLD, DCOWSOLD, and PLTRNRET (Table 6.2).

The agricultural census divides all the cows within each county into the categories of: beef cattle; heifers and heifer calves; steers, bulls, and steer or bull calves; and dairy cows Census (Census of Agriculture, 1993). It is assumed that 95% of the beef cattle are in pasture while 5% are in confinement lots. [3] Heifers and heifer calves, as well as steers, bulls, and steer or bull calves are all considered to be in pasture. (Conversation with David Knicely) Dairy cows are primarily kept in confinement, but spend at least 85 days out of the year in pasture. (Camacho, 1993)

Since the overwhelming majority of confined cattle, within the Basin, are dairy cows, the attributes of dairy cow operations were used to describe all confined cattle. The parameter value for the variable DCOWSOLD is based upon the net return for dairy products produced by an average cow in Virginia, minus those inputs to the feed ration which could be grown on the Dairy farm (USDA, 1997), (NASS, 1998b). The basic feed requirements specified for each dairy cow were based upon those specified in Parsons, 1995. The components of this feed ration that can either be purchased or produced on dairy farms are:

- 9.42 tons of corn silage
- 5.49 bushels of corn grain
- 1.45 tons of ryelage and wheat

[3] This is based upon estimates of 5% of beef cattle in confinement in both Rockingham and Augusta counties that together account for 39% of the total beef cattle operations in the Basin. The 5% estimate was made by both Bobby Whites Carver and David Knicely.

- 0.96 tons of alfalfa

For poultry, it is assumed that the farmers have entered into contracts with poultry integrators. (Faulkner, 1994) The integrators provide the farmer with the birds and rations while the farmer houses and feeds the birds, and assumes responsibility for managing the manure and dead bird carcasses. So the parameter value for the variable PLTRNRET is the expected net revenue received by the farmer from fulfilling his part of the contract (Table 6.2). This net revenue includes all costs incurred by the farmer except those that result from the adoption of a waste management BMP.

An assumption, which needs mentioning, is that the normal yearly cost of managing waste produced by livestock is included in the net revenue calculation. Any adoption of best management practice simply adds to this cost. This is likely not to be the case however, since the use of the BMP will mean that the waste is being handled differently. An improvement to the agricultural module would be to separate management of waste from net revenue and consider it as a base line cost. Then the cost of adoption of a BMP would cover the entire cost of managing waste. This would provide for a better approximation of the change in cost incurred by the farmer from adopting a BMP.

6.2.2.3. Pasture Value

For the agricultural submodule the number of pasture acres is a function of both the total number of cattle and calves within each subregion and an estimated stocking rate. This is based upon two assumptions. Even though much of the cattle, such as dairy cows, spend the majority of their time in confinement, it is assumed that all cattle within the Basin will spend at least a portion of their time in pasture each year. The second assumption is that an average stocking rate of 1.4 cows per acre can be used for all the pastureland in the Basin. This stocking rate was derived, using census data from each county (Census of Agriculture, 1993). First, estimating the number of days that the cattle and dairy cows within a particular county spend in pasture. This number was then divided by 365 to derive the number of animals in pasture per year. Secondly, the number of pasture acres in each county was estimated by adding together all the pastureland plus a third of the woodland used for pasture. Only a third of the wooded pasture was used because it was assumed that an acre of wooded pasture will only provide about a third of the forage derived from an acre of grass pasture. Then the stocking rate was determined by dividing the total number of a animals by the total number of pasture acres. A weighted average, based upon each county's portion of the Basins cattle, was taken to determine an overall stocking rate for the entire Basin.

The annual net return of pasture acres is determined in a slightly different manner than the total number of acres. The value of pasture is based upon the total number of beef cattle, heifers, steers, and calves, within each subregion. Dairy cows were not included, because the value of the dairy products produced by dairy cows is used to represent the returns from confined cattle. Including them in the revenue from pastureland would result in double counting. So only the pasture acres necessary to provide forage for nondairy cows have a value. So the parameter value of PSTRSOLD, in Table 6.2, is the average net return of a pastured animal, subtracted by the estimated per cow cost for maintaining pasture, then multiplied by the stocking rate (USDA, 1997), (NASS, 1998a), (Parson, 1995). The net return for a pastured animal is the expected return minus the expenses of: veterinary and medicine; hauling; marketing; protein and by-products; custom feed mixing; fuel, lube, and electricity; machinery and building repairs; hired labor; general farm over head; taxes and insurance and interest (USDA, 1997).

Table 6.2. Parameter Values for the Revenues and Costs Associated with Livestock Production.

MODEL VARIABLES						
	PSTRSOLD		**DCOWSOLD**		**PLTRNRET**	
	Unit	Parameter Value	Unit	Parameter Value	Unit	Parameter Value
Cattle	ac	$224.20				
Dairy Cows			au	$1,450.07		
Poultry					au	$4.15

PSTRSOLD: estimated average value per head of cattle, minus per head pasture cost.
DCOWSOLD: net return for milk produced, excluding feed costs, for each cow.
PLTRNRET: represents the farmers net returns from raising poultry.

6.2.2.4. Idle Land Value

The last agricultural land use considered is idle land. In a broad sense idle land encompasses all the land on a farm which is not being used for growing crops or grazing animals. It is assumed that idle land does not make any money. However, this is not always the case since many of the acres counted as idle land are part of either the Conservation Reserve Program or Wetlands Reserve Program. Timber from idlelands can also be harvested for income. Woodland on farms within the Basin account for only 18% of total Basin forest land (Census of Agricultural, 1993) (VDEQ, 1995).

6.2.2.5. Agricultural Best Management Practice Costs

The costs for agricultural BMPs have been already been addressed in Chapter 4. However, the steps, taken to derive the model parameters representing BMP costs, need elaboration. The Table 6.3 provides a listing of the agricultural BMP costs used for the model. All the numbers have been adjusted for inflation, using a 3% inflation rate. However, the method used to arrive at a cost figure was different for each of the BMPs. So what follows is a brief description of how each was estimated.

The three livestock BMPs were all derived from different sources (Table 6.3). For animal waste facilities, the annual cost was based upon a100 milking cow herd, using tractor scrape and a concrete 114,000 ft3 storage tank (Camacho, 1993). The annual cost for confinement lot management was the per animal cost of installing and maintaining rotational loafing lots for a herd of 110 dairy cows (Faulkner and Trott, 1994). To derive the per bird cost of poultry waste facilities, several assumptions were made. It was assumed that the waste facility was a dry stack shed. It was also that the average house stocking rate of 20k birds with 6.5 sets of birds per year. Then using an expected per house cost of $3750, and a 20 year loan period at 5% interest, the per animal unit cost was $0.23.

As mentioned, for the cost of crop BMPs, and average was typically derived from several different sources. For conservation tillage there were three sources (Randall et al., 1987), (Camacho, 1993), (VDEQ, 1994). The BMPs nutrient management, cover crops, and permanent vegetative cover all had the same three sources (Camacho, 1993), (VDEQ, 1994), (Faulkner, 1996). The vegetated filter strip BMP had four sources (Randall et al., 1987), (Camacho, 1993), (VDEQ, 1994), (Faulkner, 1996). Strip crops had two sources (Camacho, 1993), (Faulkner, 1996).

Table 6.3. Parameter Values for the Costs Associated with the Implementation of Agricultural Best Management Practices.

	MODEL VARIABLES							
	LVSTBMPS		**PSTRBMPS**		**CROPBMPS**		**IDLEBMPS**	
	Unit	Parameter Value	Unit	Parameter Value	Unit	Parameter Value	Unit	Parameter Value
Animal Waste Facility	au	$314.40						
Confin. Lot Manage.	au	$2.13						
Poultry Waste Facility	au	$0.23						
Rotational Grazing			ac	$4.78				
Stream Protection			ac	$75.90				
Conservation Tillage					ac	$8.55		
Nutrient Management					ac	$4.08		
Vegetated Filter Strips					ac	$36.03		
Cover Crops					ac	$20.00		
Strip Crops					ac	$15.93		
Perm. Vegetated Cover							ac	$8.28

6.2.3. Agricultural Nitrogen Loadings

Agricultural N loading rates for the model are quite numerous, and so are provided in tabular format. To better explain how they were derived, the discussion begins with the preBMP loading rates, and then moves to an explanation of how BMP efficiency was modelled.

6.2.3.1 Agricultural Baseline Loading Rates

The pre-BMP nitrogen loading rates used for the agricultural submodule were based upon load estimates calculated by the Watershed Model component of the Chesapeake Bay Water Quality Model (CBWQM) (Camacho, 1993). The loading rates are for cropland, hayland, pasture, forestland and livestock, and they are specified for each hydrologic sub-basin within the

Chesapeake Bay watershed. These loading rates are a lumped parameter value, which aggregate the various soil and terrain characteristics within each sub-basin.

Since Virginia's Potomac Basin is composed of seven of these sub-basins, this allowed for some spatial variability between loading rates, within the agricultural submodule, based upon location of the land activity. These sub-basins are quite large, however, typically encompassing parts of several counties. Aggregating soil and terrain characteristics over such broad areas results in the loss of important spatial information. As it is currently configured, there is no way for the model to specify how much farmland currently exists on the various soil and terrain types within a subregion. This level of detail would greatly improve the model's ability to locate the most marginally beneficial acres for reducing N loads.

For the model to operate at this level of detail, two improvements would need to be made. First, geospatial data would need to be used to determine the quantity and proximity of different soil, terrain, and land use characteristics. Secondly, this information could then be used as input for a hydrologic model that could provide an estimate of the potential loading.

6.2.3.2 BMP Loading Rates

The efficiency of many BMPs is likely to change over time due to a host of factors. For instance, a BMP, such as permanent vegetated cover, may take several years to become fully established, while a BMP, like grass filter strips, gradually fills with sediment and so is likely to decline in efficiency. Still other BMPs, such as nutrient management, may improve in effectiveness due to technical improvements in their implementation. Yet, these changes in efficiency are difficult to predict. Therefore, the basecase efficiency values will not change with different runs of the model.

Since, the baseline loading rates for the agricultural submodules are based upon those from the CBWQM, N loads from crops grown within each subregion must be approximated by either the cropland or hayland loading rates. Therefore, the crops considered within the agricultural submodule were divided into crops grown on cropland: corn, wheat, and soybeans; and crops grown on hayland: alfalfa, and hay.

The effectiveness of BMPs at reducing N loadings was obtained from several sources. Table 6.4 provides the estimated N load reductions used for the model. In the agricultural submodule, conservation tillage can be used with all crops grown on cropland, while nutrient management can be employed on both cropland and hayland. The Chesapeake Bay Program Nutrient Reduction Strategy Reevaluation (Camacho, 1993), gives the expected efficiency of both of these practices for each sub-basin. However, it does not provide these values for nutrient management on hayland, so single estimated value was used for hayland (VDEQ, 1995).

The one BMP for idle land is permanent vegetated cover. For the agricultural submodule, this BMP represents the re-establishment of forest cover on idle farmland. Since the baseline loading rate for idle land is the same as pasture loading rate from the CBWQM, the expected effectiveness of permanent vegetated cover was estimated to be the difference between the loading rates for pasture and forest. So the value for permanent vegetative cover was approximated to be the difference between the loading rates for pasture and forestland, for each sub-basin (Camacho, 1993). For BMPs that have effectiveness ratings that vary for each sub-basin, the values reported in the Table 6.4, are averages of these efficiency ratings for each BMP.

The other efficiency ratings were based upon published literature and are uniform across the Basin. The BMP reduction efficiencies for vegetated filter strips, grazing land protection, stream bank protection, and dairy waste facilities were all derived from averaging the reported values from three sources (USEPA, 1993), (VDEQ, 1995), (McCarthy, 1996). The efficiency values for vegetated filter strips were used as an approximation for strip cropping, because published values on strip cropping effectiveness were not located. Winter cover crop effectiveness value comes from two sources (VDEQ, 1995), (McCarthy, 1996). The effectiveness of confinement lot management and poultry waste facilities were taken from (VDEQ, 1995) and (McCarthy, 1996) respectively.

Table 6.4. Estimated Effectiveness at Reducing Nitrogen Loadings for Agricultural Best Management Practices.

Agricultural Land Use	Best Management Practices	Reduction in Nitrogen Load
CROP LAND	Conservation Tillage	22%
	Nutrient Management	27%
	Vegetated Filter Strips	43%
	Winter Cover Crops	39%
	Strip & Contour Cropping	43%
PASTURE	Grazing Land Protection	50%
	Stream Bank Protection	31%
IDLE LAND	Permanent Vegetative Cover	46%
CONFINED DAIRY COWS	Dairy Waste Facility	78%
	Confinement Lot Management	43%
POULTRY	Poultry Waste Facility	90%

The loading rates used as parameter values in the model, for BMP land use combinations, referred to as land activities, are listed in Table 6.5. In the table, the first column represents all the different possible agricultural land activities. The other 10 columns list the annual estimated N load from the land activity, for each of the 10 subregions. Within the model these activities are referred to as set items, and they are represented by the FARMACTV variable. The name of each set item has three parts. The key at the bottom of the table explains what each of these parts stands for. For example, the value listed in row CGCT and column 1X, is the annual N load from an acre of corn grain, with conservation tillage, in subregion 1X. In the model this set item is written as CGCT1X.

Table 6.5. Model Parameters for Agricultural Nitrogen Loadings (lbs./ac/year).

	SOUTHERN SHENANDOAH			NORTHERN SHENANDOAH			NORTHEN VIRGINIA			
FARMACTV	**170**	**190**	**200**	**180**	**190**	**200**	**180**	**220**	**550**	**530**
Set Items	**1X**	**1Y**	**1Z**	**2X**	**2Y**	**2Z**	**3W**	**3X**	**3Y**	**3Z**
CGBL	23.40	33.90	28.30	23.10	33.90	28.30	23.10	17.60	21.40	20.50
CGCT	18.74	28.24	22.27	19.27	28.24	22.27	19.27	13.57	15.86	14.39
CGNM	21.48	21.70	16.78	14.37	21.70	16.78	14.37	12.76	17.42	15.52
CGVFS	13.46	19.49	16.27	13.28	19.49	16.27	13.28	10.12	12.31	11.79
CGWC	14.27	20.68	17.26	14.09	20.68	17.26	14.09	10.74	13.05	12.51
CGSC	13.46	19.49	16.27	13.28	19.49	16.27	13.28	10.12	12.31	11.79
CGCN	17.04	16.97	12.70	11.58	16.97	12.70	11.58	9.54	12.97	11.08
CGCV	10.78	16.24	12.81	11.08	16.24	12.81	11.08	7.80	9.12	8.27
CGCW	11.43	17.23	13.59	11.75	17.23	13.59	11.75	8.28	9.67	8.78
CGCS	10.78	16.24	12.81	11.08	16.24	12.81	11.08	7.80	9.12	8.27
CGNV	12.35	12.48	9.65	8.26	12.48	9.65	8.26	7.34	10.02	8.92
CGNW	13.10	13.23	10.24	8.76	13.23	10.24	8.76	7.78	10.63	9.47
CGNS	12.35	12.48	9.65	8.26	12.48	9.65	8.26	7.34	10.02	8.92
CGVW	8.21	11.89	9.93	8.10	11.89	9.93	8.10	6.17	7.51	7.19
CGVS	7.74	11.21	9.36	7.64	11.21	9.36	7.64	5.82	7.08	6.78
CGWS	8.21	11.89	9.93	8.10	11.89	9.93	8.10	6.17	7.51	7.19
CGCNV	9.80	9.76	7.30	6.66	9.76	7.30	6.66	5.49	7.46	6.37
CGCNW	10.39	10.35	7.74	7.06	10.35	7.74	7.06	5.82	7.91	6.76
CGCNS	9.80	9.76	7.30	6.66	9.76	7.30	6.66	5.49	7.46	6.37
CGCVW	6.57	9.90	7.81	6.76	9.90	7.81	6.76	4.76	5.56	5.05
CGCVS	6.20	9.34	7.36	6.37	9.34	7.36	6.37	4.49	5.24	4.76
CGCWS	6.57	9.90	7.81	6.76	9.90	7.81	6.76	4.76	5.56	5.05
CGNVW	7.53	7.61	5.89	5.04	7.61	5.89	5.04	4.48	6.11	5.44
CGNVS	7.10	7.17	5.55	4.75	7.17	5.55	4.75	4.22	5.76	5.13
CGNWS	7.53	7.61	5.89	5.04	7.61	5.89	5.04	4.48	6.11	5.44
CGVWS	4.72	6.84	5.71	4.66	6.84	5.71	4.66	3.55	4.32	4.13
CGCNVW	5.98	5.95	4.45	4.06	5.95	4.45	4.06	3.35	4.55	3.89
CGCNVS	5.63	5.61	4.20	3.83	5.61	4.20	3.83	3.15	4.29	3.66
CGCNWS	5.98	5.95	4.45	4.06	5.95	4.45	4.06	3.35	4.55	3.89
CGCVWS	3.78	5.70	4.49	3.89	5.70	4.49	3.89	2.74	3.20	2.90
CGNVWS	4.33	4.38	3.38	2.90	4.38	3.38	2.90	2.57	3.51	3.13
CGCNVWS	3.44	3.42	2.56	2.34	3.42	2.56	2.34	1.92	2.62	2.23
CSBL	23.40	33.90	28.30	23.10	33.90	28.30	23.10	17.60	21.40	20.50
CSCT	18.74	28.24	22.27	19.27	28.24	22.27	19.27	13.57	15.86	14.39
CSNM	21.48	21.70	16.78	14.37	21.70	16.78	14.37	12.76	17.42	15.52
CSVFS	13.46	19.49	16.27	13.28	19.49	16.27	13.28	10.12	12.31	11.79

Table 6.5. Continued

	SOUTHERN SHENANDOAH			NORTHERN SHENANDOAH			NORTHEN VIRGINIA			
FARMACTV	**170**	**190**	**200**	**180**	**190**	**200**	**180**	**220**	**550**	**530**
Set Items	**1X**	**1Y**	**1Z**	**2X**	**2Y**	**2Z**	**3W**	**3X**	**3Y**	**3Z**
CSWC	14.27	20.68	17.26	14.09	20.68	17.26	14.09	10.74	13.05	12.51
CSSC	13.46	19.49	16.27	13.28	19.49	16.27	13.28	10.12	12.31	11.79
CSCN	17.04	16.97	12.70	11.58	16.97	12.70	11.58	9.54	12.97	11.08
CSCV	10.78	16.24	12.81	11.08	16.24	12.81	11.08	7.80	9.12	8.27
CSCW	11.43	17.23	13.59	11.75	17.23	13.59	11.75	8.28	9.67	8.78
CSCS	10.78	16.24	12.81	11.08	16.24	12.81	11.08	7.80	9.12	8.27
CSNV	12.35	11.89	9.93	8.10	11.89	9.93	8.10	6.17	7.51	7.19
CSNW	13.10	11.21	9.36	7.64	11.21	9.36	7.64	5.82	7.08	6.78
CSNS	12.35	11.89	9.93	8.10	11.89	9.93	8.10	6.17	7.51	7.19
CSVW	8.21	9.76	7.30	6.66	9.76	7.30	6.66	5.49	7.46	6.37
CSVS	7.74	10.35	7.74	7.06	10.35	7.74	7.06	5.82	7.91	6.76
CSWS	8.21	9.76	7.30	6.66	9.76	7.30	6.66	5.49	7.46	6.37
CSCNV	9.80	9.90	7.81	6.76	9.90	7.81	6.76	4.76	5.56	5.05
CSCNW	10.39	9.34	7.36	6.37	9.34	7.36	6.37	4.49	5.24	4.76
CSCNS	9.80	9.90	7.81	6.76	9.90	7.81	6.76	4.76	5.56	5.05
CSCVW	6.57	7.61	5.89	5.04	7.61	5.89	5.04	4.48	6.11	5.44
CSCVS	6.20	7.17	5.55	4.75	7.17	5.55	4.75	4.22	5.76	5.13
CSCWS	6.57	7.61	5.89	5.04	7.61	5.89	5.04	4.48	6.11	5.44
CSNVW	7.53	6.84	5.71	4.66	6.84	5.71	4.66	3.55	4.32	4.13
CSNVS	7.10	5.95	4.45	4.06	5.95	4.45	4.06	3.35	4.55	3.89
CSNWS	7.53	5.61	4.20	3.83	5.61	4.20	3.83	3.15	4.29	3.66
CSVWS	4.72	5.95	4.45	4.06	5.95	4.45	4.06	3.35	4.55	3.89
CSCNVW	5.98	5.70	4.49	3.89	5.70	4.49	3.89	2.74	3.20	2.90
CSCNVS	5.63	4.38	3.38	2.90	4.38	3.38	2.90	2.57	3.51	3.13
CSCNWS	5.98	3.42	2.56	2.34	3.42	2.56	2.34	1.92	2.62	2.23
CSCVWS	3.78	33.90	28.30	23.10	33.90	28.30	23.10	17.60	21.40	20.50
CSNVWS	4.33	28.24	22.27	19.27	28.24	22.27	19.27	13.57	15.86	14.39
CSCNVWS	3.44	21.70	16.78	14.37	21.70	16.78	14.37	12.76	17.42	15.52
SOYBL	23.40	19.49	16.27	13.28	19.49	16.27	13.28	10.12	12.31	11.79
SOYCT	18.74	20.68	17.26	14.09	20.68	17.26	14.09	10.74	13.05	12.51
SOYNM	21.48	19.49	16.27	13.28	19.49	16.27	13.28	10.12	12.31	11.79
SOYVFS	13.46	16.97	12.70	11.58	16.97	12.70	11.58	9.54	12.97	11.08
SOYWC	14.27	16.24	12.81	11.08	16.24	12.81	11.08	7.80	9.12	8.27
SOYSC	13.46	17.23	13.59	11.75	17.23	13.59	11.75	8.28	9.67	8.78
SOYCN	17.04	16.24	12.81	11.08	16.24	12.81	11.08	7.80	9.12	8.27
SOYCV	10.78	12.48	9.65	8.26	12.48	9.65	8.26	7.34	10.02	8.92
SOYCW	11.43	13.23	10.24	8.76	13.23	10.24	8.76	7.78	10.63	9.47

Table 6.5. Continued

	SOUTHERN SHENANDOAH			NORTHERN SHENANDOAH			NORTHEN VIRGINIA			
FARMACTV	**170**	**190**	**200**	**180**	**190**	**200**	**180**	**220**	**550**	**530**
Set Items	**1X**	**1Y**	**1Z**	**2X**	**2Y**	**2Z**	**3W**	**3X**	**3Y**	**3Z**
SOYCS	10.78	12.48	9.65	8.26	12.48	9.65	8.26	7.34	10.02	8.92
SOYNV	12.35	11.89	9.93	8.10	11.89	9.93	8.10	6.17	7.51	7.19
SOYNW	13.10	11.21	9.36	7.64	11.21	9.36	7.64	5.82	7.08	6.78
SOYNS	12.35	11.89	9.93	8.10	11.89	9.93	8.10	6.17	7.51	7.19
SOYVW	8.21	9.76	7.30	6.66	9.76	7.30	6.66	5.49	7.46	6.37
SOYVS	7.74	10.35	7.74	7.06	10.35	7.74	7.06	5.82	7.91	6.76
SOYWS	8.21	9.76	7.30	6.66	9.76	7.30	6.66	5.49	7.46	6.37
SOYCNV	9.80	9.90	7.81	6.76	9.90	7.81	6.76	4.76	5.56	5.05
SOYCNW	10.39	9.34	7.36	6.37	9.34	7.36	6.37	4.49	5.24	4.76
SOYCNS	9.80	9.90	7.81	6.76	9.90	7.81	6.76	4.76	5.56	5.05
SOYCVW	6.57	7.61	5.89	5.04	7.61	5.89	5.04	4.48	6.11	5.44
SOYCVS	6.20	7.17	5.55	4.75	7.17	5.55	4.75	4.22	5.76	5.13
SOYCWS	6.57	7.61	5.89	5.04	7.61	5.89	5.04	4.48	6.11	5.44
SOYNVW	7.53	6.84	5.71	4.66	6.84	5.71	4.66	3.55	4.32	4.13
SOYNVS	7.10	5.95	4.45	4.06	5.95	4.45	4.06	3.35	4.55	3.89
SOYNWS	7.53	5.61	4.20	3.83	5.61	4.20	3.83	3.15	4.29	3.66
SOYVWS	4.72	5.95	4.45	4.06	5.95	4.45	4.06	3.35	4.55	3.89
SOYCNVW	5.98	5.70	4.49	3.89	5.70	4.49	3.89	2.74	3.20	2.90
SOYCNVS	5.63	4.38	3.38	2.90	4.38	3.38	2.90	2.57	3.51	3.13
SOYCNWS	5.98	3.42	2.56	2.34	3.42	2.56	2.34	1.92	2.62	2.23
SOYCVWS	3.78	33.90	28.30	23.10	33.90	28.30	23.10	17.60	21.40	20.50
SOYNVWS	4.33	28.24	22.27	19.27	28.24	22.27	19.27	13.57	15.86	14.39
SOYCNVWS	3.44	21.70	16.78	14.37	21.70	16.78	14.37	12.76	17.42	15.52
WHTBL	23.40	19.49	16.27	13.28	19.49	16.27	13.28	10.12	12.31	11.79
WHTCT	18.74	20.68	17.26	14.09	20.68	17.26	14.09	10.74	13.05	12.51
WHTNM	21.48	19.49	16.27	13.28	19.49	16.27	13.28	10.12	12.31	11.79
WHTVFS	13.46	16.97	12.70	11.58	16.97	12.70	11.58	9.54	12.97	11.08
WHTWC	14.27	12.48	9.65	8.26	12.48	9.65	8.26	7.34	10.02	8.92
WHTSC	13.46	13.23	10.24	8.76	13.23	10.24	8.76	7.78	10.63	9.47
WHTCN	17.04	12.48	9.65	8.26	12.48	9.65	8.26	7.34	10.02	8.92
WHTCV	10.78	11.89	9.93	8.10	11.89	9.93	8.10	6.17	7.51	7.19
WHTCW	11.43	11.21	9.36	7.64	11.21	9.36	7.64	5.82	7.08	6.78
WHTCS	10.78	11.89	9.93	8.10	11.89	9.93	8.10	6.17	7.51	7.19
WHTNV	12.35	9.76	7.30	6.66	9.76	7.30	6.66	5.49	7.46	6.37
WHTNW	13.10	10.35	7.74	7.06	10.35	7.74	7.06	5.82	7.91	6.76
WHTNS	12.35	9.76	7.30	6.66	9.76	7.30	6.66	5.49	7.46	6.37
WHTVW	8.21	9.90	7.81	6.76	9.90	7.81	6.76	4.76	5.56	5.05

Table 6.5. Continued

	SOUTHERN SHENANDOAH			NORTHERN SHENANDOAH			NORTHEN VIRGINIA			
FARMACTV	**170**	**190**	**200**	**180**	**190**	**200**	**180**	**220**	**550**	**530**
Set Items	**1X**	**1Y**	**1Z**	**2X**	**2Y**	**2Z**	**3W**	**3X**	**3Y**	**3Z**
WHTVS	7.74	9.34	7.36	6.37	9.34	7.36	6.37	4.49	5.24	4.76
WHTWS	8.21	9.90	7.81	6.76	9.90	7.81	6.76	4.76	5.56	5.05
WHTCNV	9.80	7.61	5.89	5.04	7.61	5.89	5.04	4.48	6.11	5.44
WHTCNW	10.39	7.17	5.55	4.75	7.17	5.55	4.75	4.22	5.76	5.13
WHTCNS	9.80	7.61	5.89	5.04	7.61	5.89	5.04	4.48	6.11	5.44
WHTCVW	6.57	6.84	5.71	4.66	6.84	5.71	4.66	3.55	4.32	4.13
WHTCVS	6.20	5.95	4.45	4.06	5.95	4.45	4.06	3.35	4.55	3.89
WHTCWS	6.57	5.61	4.20	3.83	5.61	4.20	3.83	3.15	4.29	3.66
WHTNVW	7.53	5.95	4.45	4.06	5.95	4.45	4.06	3.35	4.55	3.89
WHTNVS	7.10	5.70	4.49	3.89	5.70	4.49	3.89	2.74	3.20	2.90
WHTNWS	7.53	4.38	3.38	2.90	4.38	3.38	2.90	2.57	3.51	3.13
WHTVWS	4.72	3.42	2.56	2.34	3.42	2.56	2.34	1.92	2.62	2.23
WHTCNVW	5.98	8.50	7.30	5.30	8.50	7.30	5.30	5.40	11.10	8.10
WHTCNVS	5.63	6.25	5.37	3.90	6.25	5.37	3.90	3.97	8.16	5.95
WHTCNWS	5.98	8.50	7.30	5.30	8.50	7.30	5.30	5.40	11.10	8.10
WHTCVWS	3.78	6.25	5.37	3.90	6.25	5.37	3.90	3.97	8.16	5.95
WHTNVWS	4.33	6.84	5.82	7.09	6.84	5.82	7.09	7.62	6.21	5.83
WHTCNVWS	3.44	3.42	2.91	3.55	3.42	2.91	3.55	3.81	3.11	2.92
ALFBL	11.10	4.70	4.00	4.87	4.70	4.00	4.87	5.24	4.27	4.01
ALFNM	8.16	2.35	2.00	2.44	2.35	2.00	2.44	2.62	2.13	2.00
HYBL	11.10	6.84	5.82	7.09	6.84	5.82	7.09	7.62	6.21	5.83
HYNM	8.16	3.71	2.74	3.80	3.71	2.74	3.80	3.19	2.54	3.95
PSTRBL	9.90	13.50	11.30	11.86	13.50	11.30	11.86	12.55	12.32	12.32
PSTGLP	4.95	3.04	2.54	2.67	3.04	2.54	2.67	2.82	2.77	2.77
PSTSBP	6.81	7.76	6.50	6.82	7.76	6.50	6.82	7.21	7.08	7.08
PSTRGS	3.40	1.75	1.46	1.53	1.75	1.46	1.53	1.62	1.59	1.59
IDLBL	9.90	13.50	11.30	11.86	13.50	11.30	11.86	12.55	12.32	12.32
IDLPVC	3.95	9.92	8.31	8.72	9.92	8.31	8.72	9.22	9.05	9.05
DCOWBL	12.90	12.32	12.32	12.32	12.32	12.32	12.32	12.32	12.32	12.32
DCOWDWF	2.90	2.77	2.77	2.77	2.77	2.77	2.77	2.77	2.77	2.77
DCOWCLM	7.42	7.08	7.08	7.08	7.08	7.08	7.08	7.08	7.08	7.08
DCOWAC	1.67	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.59
PLTRBL	12.90	12.32	12.32	12.32	12.32	12.32	12.32	12.32	12.32	12.32
PLTRPWF	9.48	9.05	9.05	9.05	9.05	9.05	9.05	9.05	9.05	9.05

Table 6.5. Continued

ITEM PREFIXES **	ITEM MIDDLE TERMS***	ITEM SUFFIXES ****
CG = corn grain	BL = baseline	1X = Southern Shenandoah, Sub-Basin 170
CS = corn silage	CT = conservation tillage	1Y = Southern Shenandoah, Sub-Basin 190
SOY = soybeans	NM = nutrient management	1Z = Southern Shenandoah, Sub-Basin 200
WHT = wheat	VFS = vegetated filter strips	2X = Northern Shenandoah, Sub-Basin 180
ALF = alfalfa	WC = winter cover crop	2Y = Northern Shenandoah, Sub-Basin 190
HAY = hay	SC = strip and contour cropping	2Z = Northern Shenandoah, Sub-Basin 200
PST = pasture	GLP = grazing land protection	3W = Northern Virginia, Sub-Basin 180
IDL = idle	SBP = stream bank protection	3X = Northern Virginia, Sub-Basin 220
DCOW = dairy cows	PVC = permanent vegetated cover	3Y = Northern Virginia, Sub-Basin 550 (Occoquan)
PLTR = poultry	DWF = dairy waste facility	3Z = Northern Virginia, Sub-Basin 530 (Potomac)
	PWF = poultry waste facility	

** Item prefixes for the FARMACTV variable pertain to land uses.

*** Item middle terms for the FARMACTV variable pertain to a BMP. When BMPs are used in combination then only the first letter of each BMP is used.

**** Item suffixes for the FARMACTV variable pertain to the subregion used.

In order to determine these N loads per acre or animal unit, other factors bedsides the efficiency rating for each BMP needed to be considered. What follows is a discussion of these factors.

The use of vegetated filter strips and strip cropping also affect N loads, because both practices require that a portion of cropland be taken out of production. Since contour cropping typically involves alternate strips of row crops and a close growing crop or sod, it was assumed that hay would be planted in between the strips of row crops. Since hay has a lower loading rate than row crops this also serves to reduce overall loading rates. Likewise, vegetated filter strips require that the land around the edge of crop fields not be used. So every time the model chooses to reduce loadings from an acre of crops by using vegetated filter strips, 5% of the cropland must be transferred into idle land. It needs mentioning that these two BMPs are different from the model simply transferring land from one use to another, because these BMPs represent the specific placement of vegetated strips to intercept runoff from cropland. So there is an additional benefit from their use.

The two BMPs considered for pastureland are grazing land protection and stream bank protection. For stream bank protection it is difficult to estimate the total amount of upland area benefited by installment of fencing along a stream. In the Shenandoah region approximately 1.84% of the pastureland is immediately adjacent to waterways (Garst, 1997). The purpose of stream bank protection is to limit the damage done by cattle to the stream, and not necessarily to act as a filter for upland runoff. Therefore, it primarily benefits only those acres adjacent to streams. However, the way the submodule is set up, there is no differentiation between an acre of pasture adjacent to a stream, and another acre 300 yards uphill. The reason is that the loading from an acre of pasture is an average loading for all pasture acres, including those next to streams and those far uphill. So the benefits of stream bank protection apply to all pasture acres considered in the model.

Loading rates from confined livestock are expressed in terms of animal units instead of acres. The reason is that the amount of land taken up by confinement lots and poultry houses is not considered to be significant, in comparison to the other farm land uses. The model instead accounts for the number of livestock in confinement. As this is much more relevant to revenue and N loads.

The BMPs for livestock are dairy and poultry waste facilities and confinement lot management. The effectiveness of these BMPs is typically expressed on a per facility basis, rather than per animal unit. Estimates of reduction per dairy cow were obtained from the CBWQM (McCarthy, 1996). However, for poultry, reduction estimates were based upon information on reductions per facility (VDEQ, 1996). The assumption was made that on average the percentage reduction per poultry unit is the same as the percentage reduction per facility. Yet, this would not likely be the case if there was a wide range of animal densities between different facilities. The reason is that the animal density per acre does have a bearing on the ultimate N load from the facility.

6.2.4. BMP Feasibility

Each BMP has a range of possible future implementation levels. Obviously, for a given agricultural land use, the range of potential BMP coverage is bounded by the two extremes of no implementation and complete implementation. However, there are two factors that can create a subset within this range of potential implementation. The first is that a BMP may not be compatible for all acres or animal units. For instance, dairy operations with less than 20 milking cows are usually considered too small to require a manure pit (DPRA, 1992). So if a percentage of the cows within a subregion are on small dairy operations like this, then that percentage should not be considered for potential BMP coverage. The second factor that restricts the amount of future implementation of a BMP is the extent of existing coverage. If 75% of the crop acres in a subregion are already covered by a BMP, then the range of future coverage could not exceed 25%.

When the number of acres devoted to an agricultural activity are expected to change, there is no readily available method for predicting what percentage of the activity will be covered by current BMPs. As the agricultural submodule is currently set up, the model will always choose to take out of production an uncovered acre, rather than one that is currently covered by a BMP. The reason is that there is no cost incurred for an existing BMP, and since an acre of covered land generates less N per year then an uncovered acre, the model will take the uncovered acre out of production. As a result, the estimated number of acres currently covered by a BMP within a subregion will remain constant even if the land use that it is used for declines substantially. Only when the number of total acres of the land use drops below the number of currently covered acres, does the number of currently covered acres begin to decline.

For this study all crop and pastureland is considered 100% coverable and so future BMP implementation is only bounded from below by current level of coverage. Dairy cows are not 100% coverable, since a portion of the Basin's dairy cows are in small herds of less than twenty. Several sources were used to determine the existing and future levels of BMP adoption. The two principle sources were the appendix to the Shenandoah and Potomac River Basins Tributary Nutrient Reduction Strategy (VDEQ, 1996), and data provided by the Virginia Department of Conservation and Recreation (McCarthy, 1996). However, it was necessary to gather additional information through an informal telephone survey of state cooperative extension agents and Soil & Water Conservation District officers that work within the Basin (Appendix C).

6.2.5. Summary of Agricultural Submodule

To summarize the structure and content of the agricultural submodule it is useful to examine the Figure 6.1. This figure is meant to be a schematic diagram of the interrelationship between the equations and variables of the agricultural submodule, and also how they relate to the three modelling objectives described in the last chapter. In a sense, this diagram can be considered a magnification of the agricultural submodule in Figure 5.1. The large white rectangle with the rounded corners represents the agriculture submodule; the shaded area around it represents the overall model. The small rectangles represent equations and the ovals are variables. The arrows are meant to symbolize the basic cause and effect relationship between the various variables and equations. Therefore, the arrows all begin at the land variable and end at a rectangle with a bold border. These equations with the bold border are feasibility constraints, when inside the submodule; or one of the three modelling objectives described in Chapter 5, when outside the submodule. The columns below the diagram provide definitions for the prefixes and suffixes used to create the equation and variable names.

In the diagram in Figure 6.1, the arrows emanate from the variables: FARMLAND, DCOWPROD, and PLTRPROD. The farmland variable represents all the farm acreage, and it is on these acres where all the farmland uses occur. The other two variables stand for dairy and poultry production. It is from these three basic sources where all farm revenues, costs, and N loadings come.

Tracing the arrows from the farmland variable, the acres are used for either crop production or pasture, or they remain idle. Arrows from cropland and pasture can be traced to the objective function since they are used for generating revenue. Similarly, arrows from dairy and poultry production can be traced to the objective function. The variables representing dairy and poultry operations, idle land, cropland, and pasture are all traceable to the FARMACTV variable, which represents all the activities that generate N loadings. The FARMACTV variable is also connected to the BMPs variables. In turn, these BMP variables are connected to the objective function because they incur a cost.

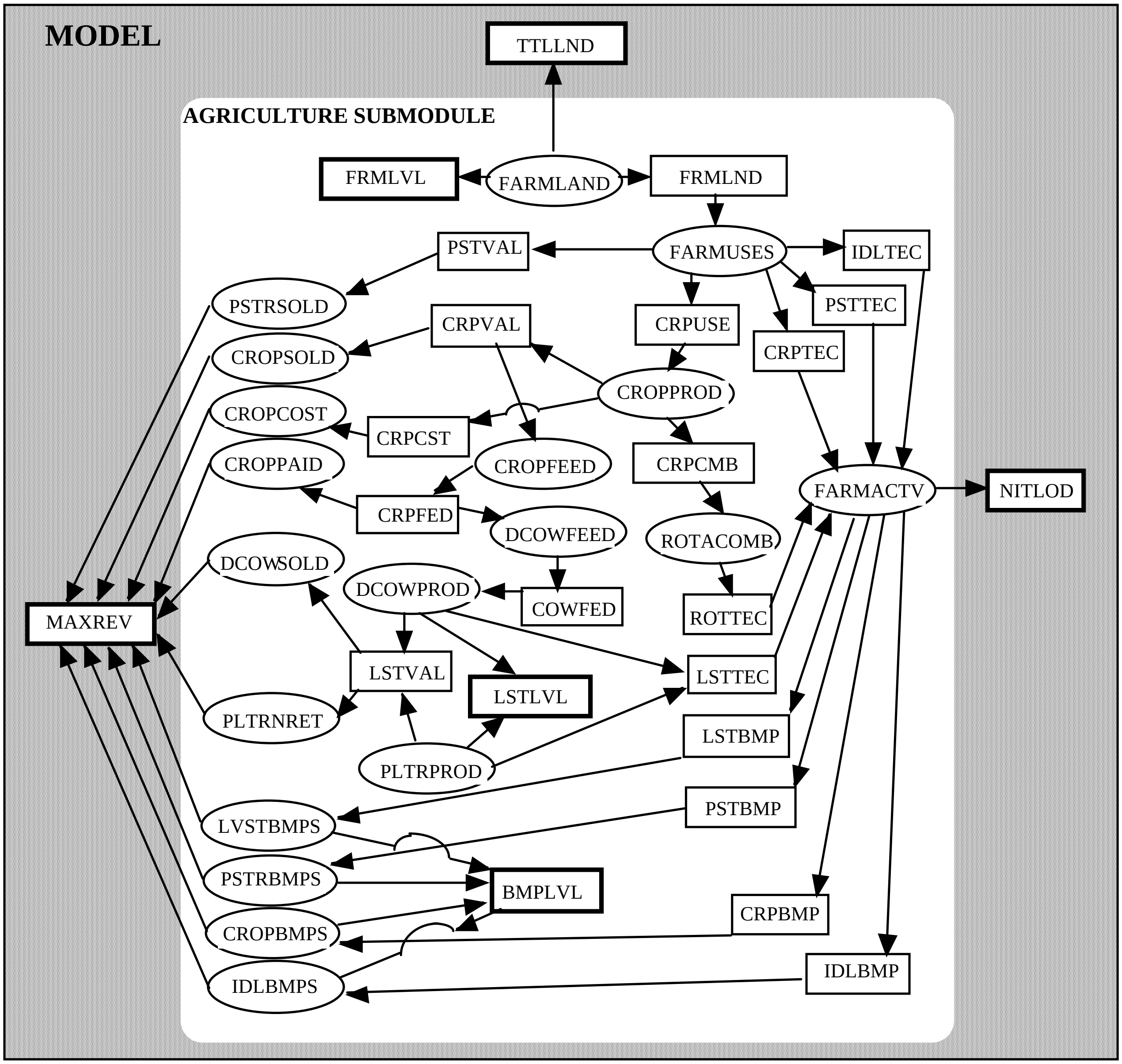


Figure 6.1. Diagram of Relationship between Agriculture Submodule Equations and Variables (The Key to the Figure is on the Next Page)

Variable Prefix	Equation Prefix	Prefix Meaning	Variable Suffix	Equation Suffix	Suffix Meaning
	BMP	Best Management Practices used to control nitrogen.	ACTV		Acitivity, represents landuse or landuse/BMP combination.
CROP	CRP	Various Cops that can be grown.	BMPS	BMP	Best Management Practices used to control nitrogen.
DCOW	COW	Confined cows, primarily dairy cows.	COMB	CMB	Combination of one or more variables.
FARM	FRM	General term for agricultural land and practices.	COST	CST	Cost of production
IDLE	IDL	Idle land.	FEED	FED	Feed for confined cattle.
LVST	LST	Livestock which includes both poultry and cows.	LAND	LND	Land measured in acres.
	MAX	Maximize the level of the variable.		LOD	Edge of stream loading.
	NIT	Nitrogen measured in pounds.		LVL	Sets maximum, minimum, or exact value for variable.
PAST	PST	Pastureland used for grazing livestock.	NRET		Net return.
PLTR		Poultry consisying of layers, broilers, and turkeys.	PRCH		Purchased item.
ROTA	ROT	Crop rotations.	PROD		Produced item
TOTL	TTL	Total amount of variable within a subregion.		REV	Revenue.
			SOLD	SLD	Item sold.
			TECH	TEC	Nitrogen control technology.
			USES	USE	Land use.
			VALU	VAL	Market value.

Figure 6.1. Continued. (Key to Diagram on Previous Page)

6.3. FORESTRY SUBMODULE

The forestry submodule is much less complex than the submodule for agriculture, and there are several reasons for this. To begin, timber harvesting is the only land use activity considered for forestland, as other activities, such as camping or hunting are recreational and are irrelevant. Timber harvesting, in comparison to other nonpoint sources of N within the Basin, is considered to be relatively minor contributor (VDEQ, 1995). Finally, in 1993, Virginia legislators passed the Silviculture Water Quality Bill, giving the Department of Forestry the ability to regulate timber harvesters who are causing water quality problems. This bill, along with voluntary efforts by timber harvesters, have led to a marked increase in the number of forestry BMPs being employed in Virginia; and it is expected that there will be near 100% adoption of forestry BMPs by the year 2000 (VDEQ, 1995).

The forestry submodule divides all forestland, including woodland found on farms, into harvested and unharvested forest (Figure 6.2). It is estimated that approximately 1% of the forestland in Virginia is harvested during a typical year (VDEQ, 1996). So the submodule is constrained to only allow 1% of all forestland within each subregion to be harvested.

All the land within the basin is categorized into three main types: urban, agriculture, and forest. The amount of forestland in each subregion can be calculated in two different ways, depending on how the model is run. The first way is to subtract all the urban and agricultural land from the total land area. The remaining land within each subregion is then considered to be in forest cover. This can be switched so that forestland has either a maximum or fixed value, but when this is done the level of agricultural land must be allowed to fluctuate. Since forest cover is the natural state that the land would eventually revert to if left idle, it is most reasonable to require that forestland fluctuate depending on the level of urban and agriculture. However, the forestry submodule does contain equations specifying a minimum number of forest acres for each subregion. This is to account for publicly owned forestland, since it is unlikely to be converted to agricultural or urban uses.

Revenues and N loading rates from forestland are a direct function of the annual number of acres harvested. State officials estimate that every year approximately 1% of forest land within the Potomac basin is harvested for timber (VDEQ, 1995). This also includes timber harvests from farms. Therefore, the equation WODUSE is used which makes acreage harvested a function of the number of total forest acres as well as the number of farmland acres in permanent vegetative cover (Figure 6.2).

6.3.1 . Forestry Revenues

In the agricultural submodule, revenues and costs were kept separate since crops could be grown for sale or for consumption by livestock. However, since the sole purpose of harvesting wood is assumed to be for the production of wood products, net returns have been used for the forestry submodule. These net returns include the mill revenues and harvesting costs, but do not include additional costs for pollution control (RTI, 1992).

The per acre return will depend upon the composition of tree species and the cost of harvesting the wood. Both of these factors can vary depending upon physiographic conditions. Typically the steeper the slope of the land that the timber comes from, the higher the extraction costs. Since there is considerable variance in the topography of Virginia's Potomac Basin, two net returns were used. These were based upon average returns from forests in the SouthEastern United

States (RTI, 1992). An average net return for wood harvested from mountains and rolling uplands was used to represent the expected returns from the Shenandoah region. For Northern Virginia, an average return from flood and coastal plain forests was used.

6.3.2 . Forestry BMP Costs

The forestry best management practices considered for the forestry submodule have been grouped into soil retention and water control (SRWC) practices and streamside buffers (Figure 6.2). The per acre cost for SRWC practices is $51.12 (VDEQ, 1995). To compute the per acre cost of streamside buffers, it was first necessary to determine what percentage of forest acreage was adjacent to waterways. For the Shenandoah region this value is 1.82% (Garst, 1997). It was assumed that this same percentage could be used for the Northern Virginia region. Since this acreage would have to be maintained as a buffer it was assumed that no harvesting would occur within them. So the per acre cost for using stream buffers is the opportunity cost of not harvesting this timber, which is 1.82% of the per acre net revenue.

6.3.3. Forest Nitrogen Loadings

The annual per acre nitrogen loading rates, from forestland, were based upon those used in the CBWQM (Camacho, 1993). It was assumed that when timber is harvested from an acre, it will generate ten times the normal N load (VDEQ, 1995). In the forestry submodule harvested acres are not separate from forest acres, but are instead a subset of forest and idle farmland acres. Therefore, the coefficients representing the loading rates from harvested acres, have the unharvested loading rate deducted from them, since that portion of the load has already been accounted for in the forest and idle farmland acres.

The SRWC practices are assumed to reduce N loadings from harvested timber land by 50%, and buffers are expected to reduce N by 57.5% (VDEQ, 1995). The BMP adoption rate for forest operations in Virginia, was estimated to be approximately 61% in 1994, and is projected to be 100% by the year 2000 (VDEQ, 1995). Assuming a linear trend for the adoption rate, the model was constrained to have an 85% coverage rate for 1998 and a 100% coverage for 2003.

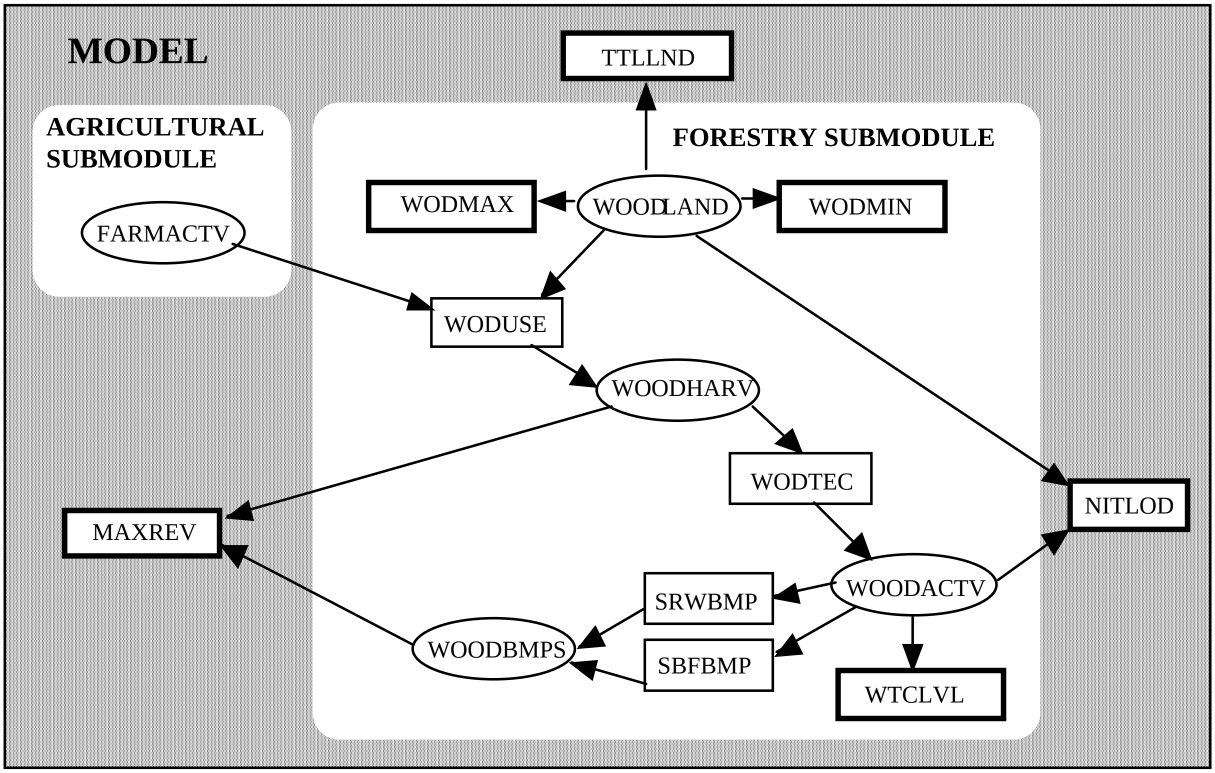


Figure 6.2. Diagram of Relationship between Forestry Submodule Equations and Variables. (The Key to the Diagram on the Next Page)

VARIABLE PREFIX	EQUATION PREFIX	PREFIX MEANING
FARM		General term for agricultural land and farm practices.
WOOD	WOD	General term for forest land and forestry practices.
	MAX	Maximize the level.
	NIT	Nitrogen measured in pounds.
	SBF	Streamside buffers.
	SRW	Soil retention and water control.
	TTL	Total amount of variable within a subregion.
	WTC	Forest best management practice technology.

VARIABLE SUFFIX	EQUATION SUFFIX	SUFFIX MEANING
ACTV		Activity, represents landuse or landuse/BMP combination.
BMPS	BMP	Best management practices used to control nitrogen.
HARV		Harvesting of a product.
LAND	LND	Land measured in acres.
	LOD	Edge of stream loading.
	LVL	Sets maximum, minimum, or unique value for varaibles.
	MAX	Sets maximum value for a variable.
	MIN	Sets minimum value for a variable.
NRET		Net return.
PRES		Preserved woodland which cannot be harvested or converted to other uses.
	REV	Revenue.
	TEC	Nitrogen control technology.
	USE	Land use.
	VAL	Market value.

Figure 6.2. Continued. (Key to Diagram on Previous Page)

6.3.4. Summary of Forest Submodule

The Figure 6.2 is a schematic diagram of the forestry submodule. The diagram uses the same approach as that taken in Figure 6.1, to represent the variables and equations of the submodule. The diagram shows how woodland and farmland in forest cover can be used for harvesting timber, and how BMPs can be used during this activity. It also displays how N loadings result from both unharvested and harvested forestland. Finally it shows the two connections to the objective function through timber net revenues and BMP costs.

6.4. POINT SOURCE SUBMODULE

The design of the point source submodule differs significantly from that of the other submodules in the way in which activities are constrained. Rather than being based upon available land, the capacity constraints were based upon the maximum daily flows that each plant was designed to accommodate. However, spatial context are not irrelevant to the point source submodule, since they have an indirect affect the loading rates and costs. For example, point sources located in the Southern Shenandoah will have a lower loading rate per pound of N discharged than a point source in Northern Virginia, due to the instream transport factor.

Another distinction between the point source submodule and the other three was that unlike individual nonpoint sources, each major point source could be modelled based upon specific information about the site.

The 27 point sources included within the submodule were located within 6 of the 10 subregions used for this study. Each point source has parameter estimates for current flow volume, maximum potential flows, estimated N concentrations, as well as reduction efficiencies and costs associated with each potential plant retrofit.

Current estimates of flow volume and N concentrations for 1998, and previous years were derived from several sources (VDEQ, 1995), (VDEQ, 1996), (VDCNR, 1996), (Randall, 1998). However, the projected flows for POTWs are derived differently than those from industrial facilities. As with the 1998 flows the 2003 flows for industrial facilities are based upon linear trend estimates. For each POTW the future flow is the 1998 flow, plus the additional flows that result from increased connections to the POTW. These connections are the result of population increases within the subregion where the point source is located.

The Table 6.6 provides the flow volumes, N concentrations, and estimated N loadings from all the point sources considered in study. The values used for this table are primarily derived from data used by the state of Virginia (VDEQ, 1995), (VDEQ, 1996), (VDCNR, 1996). The exception are the values in bold font, as these came from the study headed by Dr. Clifford Randall at Virginia Tech (Randall, 1998). The Woodstock facility is a new POTW, which replaced older treatment works, and so data was not complete for it. As a result, the N concentration used, was the default value of 18.7 mg/l used by the CBP when historical data was lacking. The 1998 flow level was estimated by using a linear trend equation from the 1994 volumes to the projected 2000 volumes. The 1998 concentrations used for 1998 are the ones anticipated for the year 2000.

Table 6.6. Point Source Flow Volume, Nitrogen Concentrations, and Nitrogen Loadings for the Years: 1985,1994, and 1998.

Year	**1985**			**1994**			**1998**			**1998 Retrofit Options**						**2000**
	Flow	N	N load	Flow	N	N load	Flow**	N***	N load	Alternative 1		Alternative 2		Alternative 3		Flow
	MGD	mg/l	lbs./yr.	MGD	mg/l	lbs./yr.	MGD	mg/l	lbs./yr.	mg/l	lbs./yr.	mg/l	lbs./yr.	mg/l	lbs./yr.	MGD
Southern Shenandoah (Region 1)																
Dupont Waynesboro	4.34	22.68	299,634	3.54	9.55	102,912	**0.7**	**21.45**	**45,691**	**8**	**17,033**	**8**	**17,033**	**4**	**8,517**	**3.26**
Fisherville	0.78	18.7	44,401	1.09	9.2	30,526	1.297	**11.2**	**44,204**	**8**	**31,560**					**1.09**
HRRSA-N.river	6.45	18.7	367,164	9.07	16	441,760	9.69	**13.86**	**408,686**	**8**	**235,790**					**16**
Luray	0.74	18.7	42,124	1.51	5	22,983	1.51	5	22,975	3.1	14,244	1.9	8,602	0.8	3,683	**2**
Merck	6.44	11.93	233,876	9.07	9.7	267,817	9.07	5.5	151,800							**1.2**
Middle River	2.58	18.7	146,866	3.4	6.29	65,101	5.53	**6.9**	**116,112**	**4**	**67,282**					**3.5**
Rocco Quality Foods	0.08	51.3	12,493	0.21	4.4	2,813	0.25	4.4	3,347	1.7						0.25
Stuarts Draft	0.5	18.7	28,462	0.71	6.87	14,848	**0.98**	**10.4**	**31,014**	**4.5**	**13,414**					**1.4**
Waynesboro	3.2	19.6	190,926	3.68	17.6	197,160	**3.63**	17.6	194,412	8	88,330	4	44,165			**4**
Verona	0.28	18.7	15,939	0.94	18.7	53,509	**0**	18.7	0							**0**
Northern Shenandoah (Region 2)																
Front Royal	1.97	18.7	112,142	2.17	18.7	123,526	3.39	**15**	**154,737**	**8**	**82,490**					**4**
FWSA Opequon	0	0	0	5.64	18.7	321,055	6.05	**20.86**	**384,037**	**12**	**220,825**	**9**	**165,619**	**8**	**147,217**	**6.25**
Rocco Farm Foods	0.57	84.9	147,313	0.95	84.95	245,666	**1.2**	84.95	310,204	12	43,816	7	25,507	3	10,986	**1.2**
Parkins Mill	0	0	0	0	0	0	**1.09**	**9**	**29,852**	**6**	**19,893**	**4**	**13,262**			**2**
Strasburg	0.74	18.7	42,124	0.54	18.7	30,739	0.83	**13.35**	**33,718**	**6**	**15,148**					**0.975**
Woodstock*	0.47	*18.7*	26,800	*0.668*	*18.7*	38,024	**0.8**	*18.7*	45,523	12	29,190	7	16,994	3	7,297	**1**

All table values, except those in bold or italic, are from information published by the USEPA, VDEQ, and VDCNR.

All values in bold are from study conducted by Dr. Clifford Randall, 1998.

* *The italicized values, for the Woodstock POTW, are extrapolations based upon information from the USEPA, VDEQ, and VDCNR.*

** 1998 flows were estimated by using a linear trend from 1994 values to the year 2000 projections.

*** Concentration values used for 1998 are the ones projected for the year 2000.

Table 6.6. Continued

Year	1985			1994			1998			1998 Retrofit Options						2000
	Flow	N	N load	Flow	N	N load	Flow**	N***	N load	Alternative 1		Alternative 2		Alternative 3		Flow
	MGD	mg/l	lbs./yr.	MGD	mg/l	lbs./yr.	MGD	mg/l	lbs./yr.	mg/l	lbs./yr.	mg/l	lbs./yr.	mg/l	lbs./yr.	MGD
Northern Virginia (Region 3)																
Leesburg	1.26	18.7	71,725	2.62	18.7	149,143	4.207	18.7	239,396	**13**	**166,352**	**7**	**89,574**			**4.85**
Purcellville	0.27	18.7	15,370	0.36	18.7	20,493	0.453	18.7	25,778	12	16,574	7	9,691	3	4,166	0.5
Blue Plains	17.3	15.5	816,275	28.59	13.12	1,141,844	36.86	7.5	841,239					3	336,474	41
Alexandria	35.6	18.4	1,994,006	36.83	22.71	2,546,112	41.08	18.17	2,271,372	12	1,500,282	7	875,109	3	375,047	54
Aquia	1.14	18.7	64,894	2.87	4.46	38,965	4.76	7	101,393					3	43,492	6
Arlington	26.56	20.3	1,641,280	29.8	9.78	887,184	32.6	9.78	970,196			7	694,418	3	297,608	40
Dale City #1	2	15	91,323	2.61	12.22	97,089	**3**	**12**	**109,548**	**12**	**109,500**	**8**	**73,000**	**4**	**36,500**	**3**
Dale City #8	0.84	15	38,356	1.75	18.66	99,405	**2.12**	**12**	**77,414**	**12**	**77,380**	**8**	**51,587**	**4**	**25,793**	**3**
Lower Potomac	32.96	19	1,906,336	39.42	15.42	1,850,375	44.47	11.5	1,556,209			7	947,249	3.2	433,852	67
Mooney	7.58	26.4	609,161	10.47	20.85	664,525	13.49	16.68	684,717	12	492,568	7	287,324	3	123,164	24
Quantico	1.45	18.7	82,541	1.47	18.7	83,679	1.556	7	33,144					3	14,193	2.2
UOSA	9.41	20.86	597,534	20.63	19.36	1,215,803	29.14	19.36	1,716,713	12	1,064,100	7	620,703	3	266,003	54

All table values, except those in bold or italic, are from information published by the USEPA, VDEQ, and VDCNR.

All values in bold are from study conducted by Dr. Clifford Randall, 1998.

** The italicized values, for the Woodstock POTW, are extrapolations based upon information from the USEPA, VDEQ, and VDCNR.*

** 1998 flows were estimated by using a linear trend from 1994 values to the year 2000 projections.

*** Concentration values used for 1998 are the ones projected for the year 2000.

6.4.1. Point Sources and Population Growth

As mentioned, the model can be run so that the model chooses how to settle new population, or it can be constrained to require that the new population be settled in a specific settlement pattern. When the model is unconstrained in how it settles future population, it will automatically settle the new people in a housing pattern that minimizes additional N loadings. However, to assess the impact of specific land settlement patterns on meeting the N reduction goal, the model can also be run so that it is constrained to settle the new population is a specific residential settlement pattern. Once either the model or the modeler chooses the new housing pattern,, the model is then constrained to provide some type of wastewater treatment for the new houses. Depending on the different types of housing patterns used, the new dwelling units can be connected to: an individual on-site treatment system, an on-site cluster system serving the neighborhood, or be connected to a sewer main. It was assumed that for each new person an additional 82.5 gallons of wastewater was generated per day. Using a DU density of 2.25 people per house, there is an estimated increase in flow of 67,753 gallons per DU, annually (USEPA, 1993), (Engineering-Science, 1993). The additional flow that results from new connections is automatically routed the POTW, within the same region, that has the lowest concentration of N per liter of effluent. This occurs until the combination of new and existing flows equals the maximum allowable flow for the plant. Then additional flow is routed to the plant with the next lowest N concentration level.

6.4.2. Point Source Retrofits

The submodule is set up so that there are as many as four possible options for each point source, depending upon the current level of technology at the plant. Either the current level of technology is maintained or one of the retrofit options is chosen.

As the point source submodule is designed, each source can either continue to use its existing technology or it can be retrofitted to reduce the N concentration in its effluent. Each point source has between 1 and 3 possible retrofits that the model can choose. The potential retrofits, and associated costs and loadings, were based upon: VDEQ estimates, using the methodology outlined in the Interstate Commission on the Potomac River Basin (ICPRB) report, "Financial Cost Effectiveness of Point and Nonpoint Source Nutrient Reduction Technologies in the Chesapeake Bay Basin" (Camacho,1993); and more recent estimates made by Dr. Clifford Randall of Virginia Tech (Randall, 1998). The VDEQ created estimates for all the point sources considered within the submodule, while Randall's estimates were only for 15 of the 27 point sources. It needs mentioning that there was considerable discrepancy between the initial VDEQ estimates based upon the ICPRB methodology and the later estimates made by Randall. The ICPRB method has significant limitations and is more suitable for developing planning level cost figures (VDEQ, 1996). The estimates created by Randall are based upon an extensive three year study of specific point sources within the Chesapeake Basin, and therefore are likely to be the more accurate (Randall, 1998). However, since the Randall study did not cover all the point sources considered in the submodule, the estimates based upon the ICPRB method are used for those sources not covered by the Randall study.

There is a significant difference between the way N control methods are modelled for point sources and the way they are modelled for nonpoint sources. While nonpoint source BMPs are typically applied on a per acre basis, point source retrofits are applied to the entire plant rather than on a per unit basis. This is to ensure that the model does not choose a solution that is not possible at one of the plants. To ensure that only one retrofit option is chosen, and that it is applied to the entire plant flow, would require the use of integer programming. However, integer programming requires the use of algorithms that limit the potential scope of the output analysis. So, instead of using integer programming, an equation was included for each point source that ensures that the option chosen for each point source must equal one. It does not prevent a possible combination of two or more options being used to equal one. However, that is very unlikely to occur since the model uses linear programming, all marginal costs are constant. So when the model chooses one option, it should use it until it is constrained from using it further, which is when the option equals one. So the only instance where the model will use less than the entire retrofit option, and instead use a combination of two, is when the N load constraint is satisfied before the retrofit option has been exhausted by the model.

The retrofit equation mentioned above only applies to existing flows. Since POTWs will have increased flows as a result of new connections, the new flows must also have the same retrofit as the existing flows. To ensure this, a set of additional, equations is used for each POTWs that requires the same retrofit technology be applied to both new and existing flows. All new flows are accounted for in the N load constraint, and the estimated cost for connecting to the sewer system is included in the objective function, but the increase in flow does not change the cost of retrofitting the plant. This is based upon the assumption that the additional flow will be relatively small compared to existing flow at each POTW, and so the impact of new flows on overall costs would not be significant. Since most cost figures are based upon design flows rather than existing flows, this is a reasonable approximation for capital costs. However, for plants that experience significant new flows this may over or under approximate operation and maintenance costs, depending on whether the retrofit increases or decreases the annual cost a unit of wastewater.

6.4.3. Summary of Point Source Submodule

The Figure 6.3 provides an illustration of how the point source submodule is structured. The arrows originate from both the POPLVL and NULLVL equations, which stand for new population level and new urban land level, respectively. If the model is supposed to automatically settle the population, then the POPLVL equation sets the POPUGROW variable equal to the estimated number of new people, and then the model is constrained to put them into residential housing patterns by the NEWPOP equation. If the model is run so that the residential patterns are prespecified, the POPLVL -> POPUGROW -> NEWPOP sequence is not used, and the NULLVL equation is used to set the residential settlement patterns directly.

The NURBUSES variable represents the various new residential patterns. Each residential pattern is constrained to have all or a portion of the new houses connected to public sewer mains. The portion not connected to sewer mains is placed on septic systems. For those on sewer mains the new flow is routed to an existing POTW.

The variable EXNWPSRC represents all existing and new wastewater flows going to the existing point sources. For all the POTW and industrial point sources, the model is constrained to choose either a retrofit option or to maintain the current technology for the existing flow of wastewater. The model is then constrained to apply this same technology to any new wastewater flows coming to that point source. Retrofit options for existing flows incur a cost, so they are connected to the objective function. Both the new and existing flows add to the N loading from the point source so they are connected to the NITLOD equation.

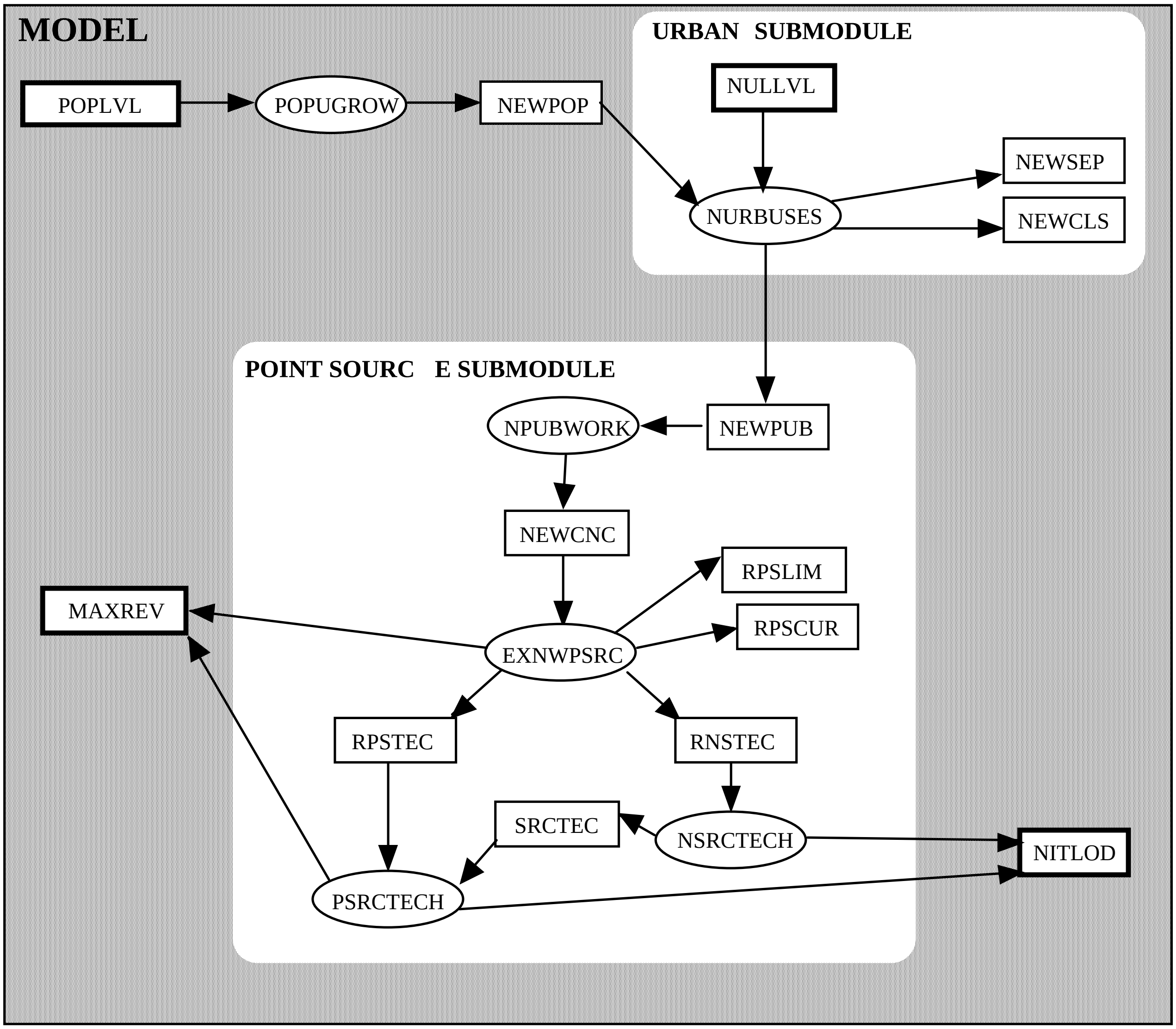


Figure 6.3. Diagram of Relationship between Point Source Submodule Equations and Variables. (Key to the Diagram is on the Next Page)

VARIABLE PREFIX	EQUATION PREFIX	PREFIX MEANING
EXNW		Existing and New.
	MAX	Maximize the level.
	NEW	
NPUB		New public works.
NSRC		New point source flows.
	NIT	Nitrogen measured in pounds.
	NUL	New urban land use.
NURB		New urban land use.
PSRC		Point source.
POPU	POP	Population.
	RNS	Region/New point source flow.
	RPS	Region/Point source.
	SRC	Point source.

VARIABLE SUFFIX	EQUATION SUFFIX	SUFFIX MEANING
	CLS	Cluster system.
	CNC	Connection.
	CUR	Current.
GROW		Increase.
	LIM	Limit.
	LOD	Edge of stream load.
	LVL	Level.
	POP	Population.
PSRC		Point source.
	PUB	Public works.
	RPS	Region/Point source.
	REV	Revenue.
	SEP	Septic system.
TECH	TEC	Control technology.
USES		Uses.
WORK		Treatment works.

Figure 6.3. Continued (Key to the Diagram on Previous Page)

6.5. URBAN SUBMODULE

For the urban submodule, less information was available on the different levels of land use, than was for the agriculture and forestry submodules. Therefore, it was necessary to use data from several different sources to determine the current and likely future levels of these urban land uses. So this section on the urban submodule will begin by explaining the process used to derive these land use levels. Next, the methods used for determining future trends in urban land use will be discussed. Then the discussion will turn towards the modelling of N loads, as well as the costs and feasibility of urban BMPs. Finally, this section will conclude with an explanation of the equations and variables used to represent future urbanization.

6.5.1. Determining Current and Future Population Estimates

Levels of urban land use and impervious surface are closely related to population levels. Therefore having an estimate of current and future population is useful for predicting urban land use levels. The 1998 population estimates for each subregion were accomplished in several steps. County population data from the Virginia Employment Commission (VEC) and the Weldon Cooper Center (WCC) at the University of Virginia were used to derive 1998 population estimates for each county (VEC, 1993) (WCC, 1996). Census tract data from the 1990 Census was then used to estimate how the population was dispersed throughout each county (National Census,1991). This required the assumption that the population distribution within a county has remained relatively unchanged between 1990 and 1998, even if a county has experienced significant growth. The next step was to then determine which census tracts were within each subregion. This was done in order to derive an estimate of each subregion's 1998 population. Using future population projections from the VEC and WCC, the same method was used to derive population the increase in population after 1998.

Annual data on the number of residential building permits granted by each county, was then used to estimate the increase in dwelling units(DU) between 1990 and 1998. To project the DU increase from 1998 to 2003, a people per unit density had to be used in conjunction with the estimated population increase for this period. There were two estimates, of people per unit, available for doing this. The first was from the 1990 census, and these numbers represent the occupant density for all dwelling units existing in 1990 (National Census,1991). The second estimate was derived by dividing each counties population increase from 1990-1996 by the number of residential permits issued during this period. This second estimate may be more representative than the first, since it is an estimate of the occupant density for new DUs, and data from the Weldon Cooper Center shows that a large percentage of people moving to these counties are young families that tend to have more people per household than the existing DU average (WCC, 1996). However, if the occupant density within existing DUs changes over this same period, then the second estimate will be inaccurate. The reason is that the number of new DUs is small relative to the number of existing DUs, and if the overall occupant density increases or decreases slightly, then much of the new population could be moving into existing houses or many of the new houses could be occupied by existing county residents. Therefore, an average of the two estimates was used to determine the necessary number of new dwelling units to house the new population.

6.5.2. Urban Land Use

All land within each subregion that is currently being used for residential, commercial, industrial, and civic functions is considered urban land. Commercial, industrial and civic land uses tend to share several general characteristics. Several large buildings tend to be clustered together. Large numbers of people work in and visit these buildings on a daily basis so large parking areas accompany the buildings. Little outdoor recreation occurs at these buildings so pervious surfaces or green spaces are usually minimal. Finally, they all tend to be located in areas readily accessible by major roadways. Because of these similarities these urban land uses are compiled into one category.

6.5.2.1. Residential Land Use Categories

Residential land use, by contrast, is varied in nature and should be divided into smaller categories. The reason is that different residential patterns produce differing levels of N loads. Based upon detailed housing data from the 1990 Census, six residential categories were defined for the model (National Census,1991). These categories are based upon the residential housing characteristics of density, proximity, and pattern. These characteristics were chosen because residential areas that differ by these attributes will also likely differ in resulting annual N loads.

In the context of the residential categories, the density characteristic is defined as the number of DUs per acre for a defined geographic area. This is the most commonly used characteristic for computing impervious surface estimates for residential land.

Proximity is a measure of how far the residential acre is from an urban center. It is probably best to view this category as center point within a large town or city, and then drawing concentric rings around that point. As the distance between these DUs and commercial, employment, public destinations increases, so does the number of road miles which will be needed to connect them. More roads result in an increase in overall impervious surface.

The third characteristic of pattern has to do with the spatial relationship between lot size and the size of the development. For example two residential developments may both have 50 houses on 100 acres, yet the average lot size of the first may be 1.5 acres/DU with 10% green space, while the average lot size for the other was 0.5 acres/DU with 65% green space. So although the density and proximity of the developments could be identical the development pattern and impervious surface levels will likely be quite different.

For convenience, the residential categories are labeled Residential Types A, B, C, D, E, and F. What follows is a general description of each of the six residential categories.

- Residential Type A - Acres within this category are defined as having a housing density ranging from 0.2 - 2 DU/acre; being further than five miles away from an urban center; and having a dispersed settlement pattern.
- Residential Type B - Acres within this category are defined as having a housing density greater than 2 DU/acre; being further than five miles away from an urban center; and having a conterminous settlement pattern.
- Residential Type C - Acres within this category are defined as having a housing density ranging from 2 - 6 DU/acre; being less than five miles away from an urban center; and having a conterminous settlement pattern.
- Residential Type D - Acres within this category are defined as having a housing density greater than 6 DU/acre; being less than five miles away from an urban center; and having a compact settlement pattern.

- Residential Type E - Acres within this category are defined as having a housing density ranging from 0.2 - 2 DU/acre; being less than five miles away from an urban center; and having a dispersed settlement pattern.
- Residential Type F - Any acres where the housing density is less than 0.2 DU/acre. This is rural housing which tends to be immediately adjacent to or within agricultural or forestland.

These residential categories are based upon several considerations. The first is what information is necessary for deriving N loads. The second is what information is needed for selecting potential BMPs. Thirdly it was important to consider what information may be useful for the analysis of potential policy options. Finally, the makeup of the data used to determine the level of residential acres, dictated what needed to be included and what needed to be left out. These considerations will be explained in more detail in the following sections.

6.5.2.2. Determining Residential Acres

In general, when estimating the extent of various land uses, the degree of accuracy attained is a function of the size of the area being examined, with smaller areas providing more accurate estimates. Ideally each acre in the Basin would be examined on an individual basis to determine if it was farm, forest, or urban land; and if it was urban land then the number and size of the buildings on it could be determined. However, such an in depth analysis would require highly detailed geospatial data that is not readily available for all the land within the Basin. For this project, data provided by the U.S. Census Bureau was the primary source for the estimates of residential land use (National Census,1991) (CIESIN, 1998).

The determination of residential land use levels began with the determining of DU density, since it is the attribute that is typically used to derive impervious surface estimates. However, density estimates are very sensitive to the rudimentary unit of measurement. For an example, consider the county of Fairfax. The counties land area is 253,094 acres, and the number of DUs in 1990 was 307,949, so the DU density is 1.22 DU/acre. Yet this value includes other urban activities, as well as farm and forestland.

Using census tract data attains a greater degree of accuracy. Census tracts are divisions of land defined by the U.S. Census Bureau to aid in the process of gathering and analyzing data. According to the Census Bureau:

Among the criteria that the Census Bureau has established for defining tracts is that they should be compact contiguous areas with populations of about 4000 persons and that the area should, if possible, try to avoid combining non-homogeneous areas. The ideal census tract would be a locally recognized "neighborhood" within a city (CIESIN,1998).

Using census tracts we can separate the land area into much smaller geographic areas. Fairfax is divided into 168 census tracts, which average 1500 acres in size. Rather than one density value now there is the potential for 168. This helps distinguish areas of the county with differing housing densities. However, there is still no way for us to determine if a tract contains a town surrounded by farmland or consists of several large low-density subdivisions.

To achieve the higher degree of accuracy, without the aid of GIS, census block data is needed. The Census Bureau defines census blocks as:

... the smallest geographic entity recognized by the Census Bureau. It is generally the smallest area that can be formed by intersecting visible features. The classic census block is the rectangular city block bounded by 4 streets. With the extending of block assignment to rural areas for the 1990 census, we also now have the 100-square-miles-of-open-desert blocks and the classic single farm or portion of farm block (CIESIN,1998).

Fairfax county has 6,158 census blocks that average approximately 40 acres in size. Using census blocks as the rudimentary unit of measurement there is the potential for thousands of density values instead of one. However, the characteristics of proximity and pattern required spatial as well as numerical context. Geospatial information was needed to augment the numerical information provided by census data.

In order to provide a spatial context for the census data, it was necessary to compile population and housing data files for each Basin county. Using the application MABLE/GeoCorr, provided over the internet by U.S. Census Bureau and the Center for International Earth Science Information Network, data files were compiled for every census block within a given county (CIESIN,1998). The data for each census block was:

- The USGS hydrologic unit that the block is contained within. [4]
- The census tract that the block is contained within.
- The number of acres contained within the block.
- The number of DUs contained within the block.
- The blocks proximity to an urban center.
- Whether the block has been classified as urban or rural by the U.S. Census Bureau. [5]

From these six attributes, each block could be categorized as residential or nonresidential; and if it was residential it could be classified into one of the six residential categories mentioned.

The census blocks were initially sorted by census tracts. As mentioned in the last chapter, USGS hydrologic units were used for determining the subregions used for the model. Knowing the hydrologic unit each block was within, allowed the census tracts to be divided by the subregions used in the model.

The two attributes, of acres and dwelling units, were used to derive a housing density value for each block. All blocks within each subregion were then sorted in descending order by their density value, and then the data was parsed into DU/acre categories of {(• to 6),(6 to 2),(2 to 0.2),(0.2 to 0.001),(0)}. These are the density categories are based upon those used by the Northern Virginia Planning Commission (NVPDC) in their 1994 USEPA Clean Lakes Report.

The GeoCorr application was then used to determine the proximity of each census block to an urban center. The application allowed for the specification of concentric rings around delineated latitude and longitude points, and determined which census blocks were within each ring. The cities of Harrisonburg, Manassas, Manassas Park, Staunton, Waynesboro, and Winchester, as well as the towns of Dale City, Herndon, and Leesburg were used as focal points around which a concentric ring with a five-mile radius was specified. GeoCorr then separated the blocks into those that were within five miles of the urban center, and those that were more than five miles away.

Due to the highly urbanized nature of the Northern Virginia area adjacent to the District of Columbia, a different approach was used to determine proximity to urban area. A circle with a seven mile radius was defined which encompasses the jurisdictions of: Alexandria, Arlington, Falls

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[4] Hydrologic Unit Codes are based on the Hydrologic Unit Maps published by the U.S. Geological Survey Office of Water Data Coordination. The hydrologic units used in this project are the ones used by the Chesapeake Bay Water Quality Model, which based units on the USGS units.

[5] All census blocks are assigned this characteristic by the Census Bureau. A place is urban if it is in a major city, its suburbs, or in a town of 2500 or more. All other blocks are rural.(MABLE/GeoCorr, 1998)

Church, and Fairfax City, as well as the vicinities of Annandale, Burke, Springfield, Tysons Corner, and Vienna. A second circle with a twelve-mile radius was then added, so that any census blocks within five miles of this urban area could be determined. Yet, this approach to proximity has a limitation in that it presupposes a circular pattern for urban areas. Metropolitan areas often develop around main thoroughfares, creating urban corridors. A good example of this is in the eastern portion of Prince William County, along Interstate 95, where clusters of densely populated neighborhoods and businesses have developed.

In an effort to account for the nonspherical shape of some urban areas, the urban/rural classification given to each block by the Census Bureau was also used as an indicator of a census blocks proximity to an urban area. According to the census bureau:

All census blocks are assigned this characteristic by the Census Bureau based on its standard definition of the concept of "urban": All population and territory within the boundaries of Urban Areas (UA's) and the urban portion of places outside of UA's that have a decennial census population of 2,500 or more... Urban Areas are area consisting of a central place(s) and adjacent urban fringe that together have a minimum residential population of at least 50,000 people and generally an overall population density of 1,000 people per square mile of land area. The Census Bureau uses published criteria to determine the qualification and boundaries of UA's. The interesting shortcut used in this definition is the reference to "published criteria". It saves many pages of fine print. If someone asks you what it means the best answer is just to say "A place is urban if it is in a major city, its suburbs or in a town of 2500 or more". That's not exactly true, but its much simpler and its real close (CIESIN,1998).

Using both the urban/rural classification and the concentric circle measurements, a binary index was developed which could be assigned to each block. If the block was within a five-mile radius of an urban center or was designated as an urban area by the census, then it received a one, if it did not meet either of these it was given a zero. All blocks with a one were considered to be within five miles of an urban area. After each block was assigned a proximity value, the blocks within each density category were then sorted by the proximity index.

Unfortunately there was no direct way to calculate the pattern characteristic without using geospatial data. The reason for this is best understood by contrasting the two characteristics of density and pattern. The density characteristic is essentially a numerical count of DUs within a given area; while the pattern characteristic is a measure of the contiguous nonresidential land, (i.e. that is not within a lot), for a given area. From the above definition of a census block, it is apparent that housing patterns did play an important role in the demarcation of the census blocks. This is evident from the fact that census blocks with a high density of DUs per acre tended to be less than 10 acres, while areas with no houses were usually over 100 acres in size. Yet there is no way to distinguish between a census block which consists completely of residential parcels and one which is a mix of residencies and some other land use.

A potential method for distinguishing different residential patterns within a census block would be to use geospatial road data in conjunction with census block data. The U.S. Census Bureau produces geospatial data that contains the road patterns within each county. This data includes neighborhood, connector, and arterial roads, along with major thoroughfares. If this data was overlaid with census block divisions, then a ratio of neighborhood road density to housing density could be tabulated for each block. Those blocks with a higher proportion of road surface to housing units would be in a more dispersed pattern, while those with a lower proportion would be in a more compact pattern. However, such an analysis was not undertaken for this project.

Before these data files could be used to determine the number of different residential acres, it was considered necessary to first compare the results of this method for determining residential land use with another more established method. As mentioned determining density levels is the most frequently used method for classifying residential land, and the most widely accepted method for determining density levels is the use of geospatail analysis. Fortunately, the NVPDC's "USEPA Clean Lakes Report for the Occoquan Watershed," contains estimates of different residential land uses for portions of Prince William, Fairfax, Fauquier, and Loudoun county that lie within the Occoquan watershed. This was accomplished through the use of high altitude photographs and a geographic information system (GIS). As mentioned, the density levels used to parse the 1990 Census Block Data for the present, were based upon those used for the Clean Lakes Report. So this made a comparison between the resulting residential land use levels possible.

However, there were two differences between the information set used by the NVPDC and the files created from census data using GeoCorr. The first was that the watershed boundaries used by the NVPDC vary slightly from those used for the USGS hydrologic units. The NVPDC boundaries do not extend to where the Occoquan river meets the Potomac, but stop after the Occoquan reservoir, since their main focus was the integrity of the reservoir (NVPDC, 1994a). The other difference is that the NVPDC data is from the year 1989, while the census data was gathered a year later in 1990. Because of these differences, a direct comparison, between quantities of acres in each residential category, was not done. Instead the percentage of basin land estimated to be in residential development was compared for each county's portion of the watershed, and then for the entire watershed. Then the percentages of the residential land that fell into each category were compared for each county and the watershed. (See Figures 6.4. - 6.8.)

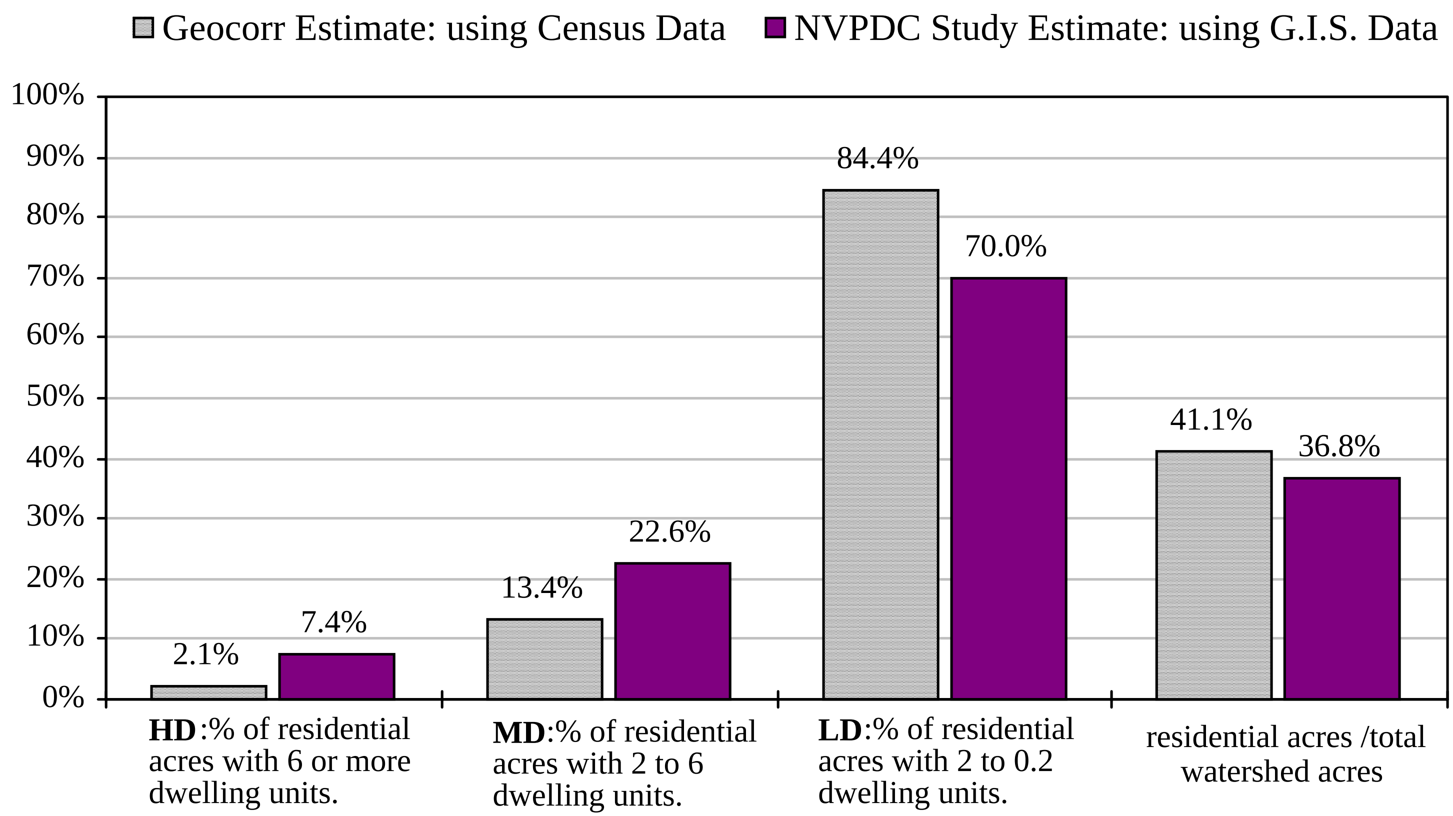

Figure 6.4. Comparison of Two Different Residential Land Use Estimates for the Portion of Fairfax County within the Occoquan Watershed.

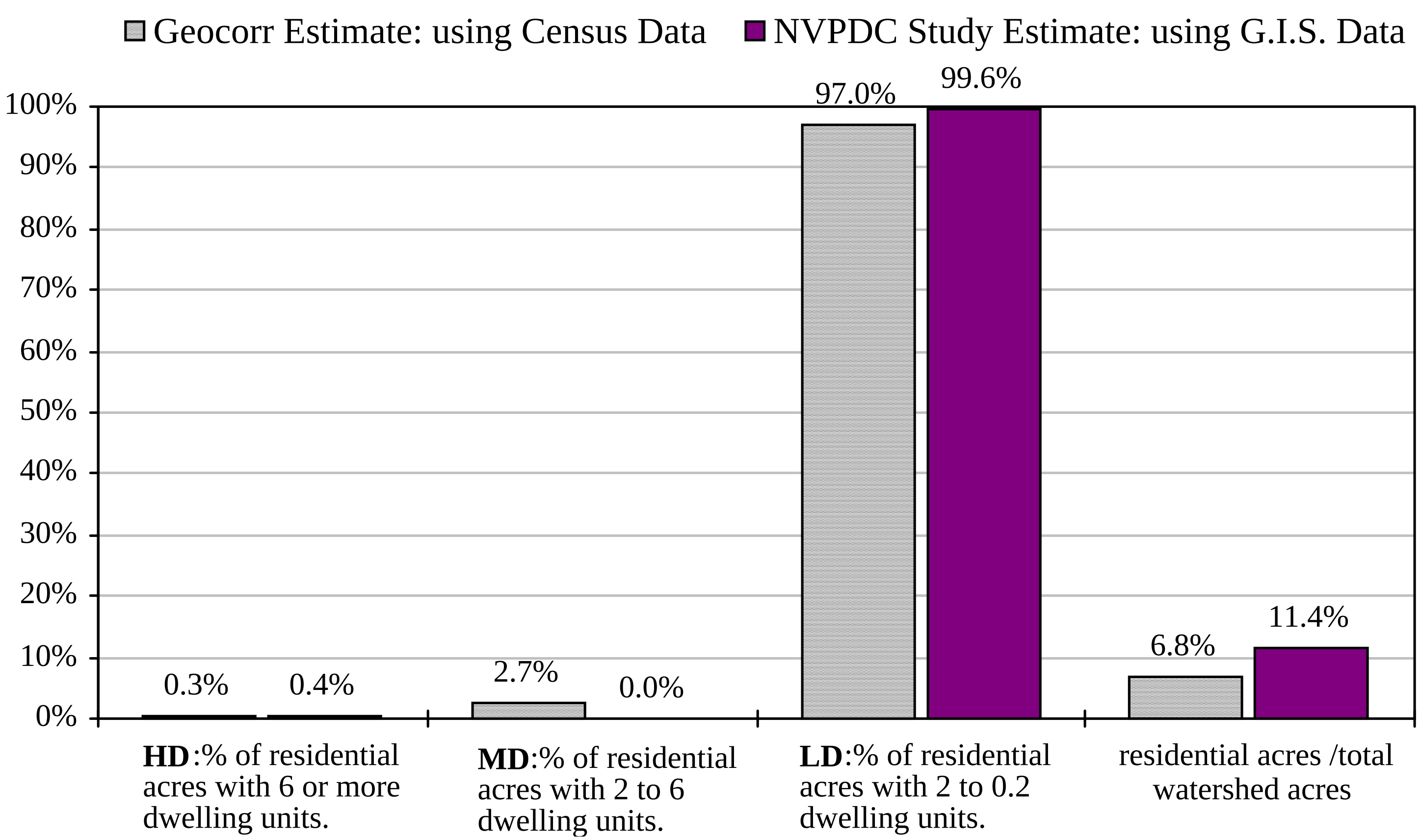

Figure 6.5. Comparison of Two Different Residential Land Use Estimates for the Portion of Fauquier County within the Occoquan Watershed.

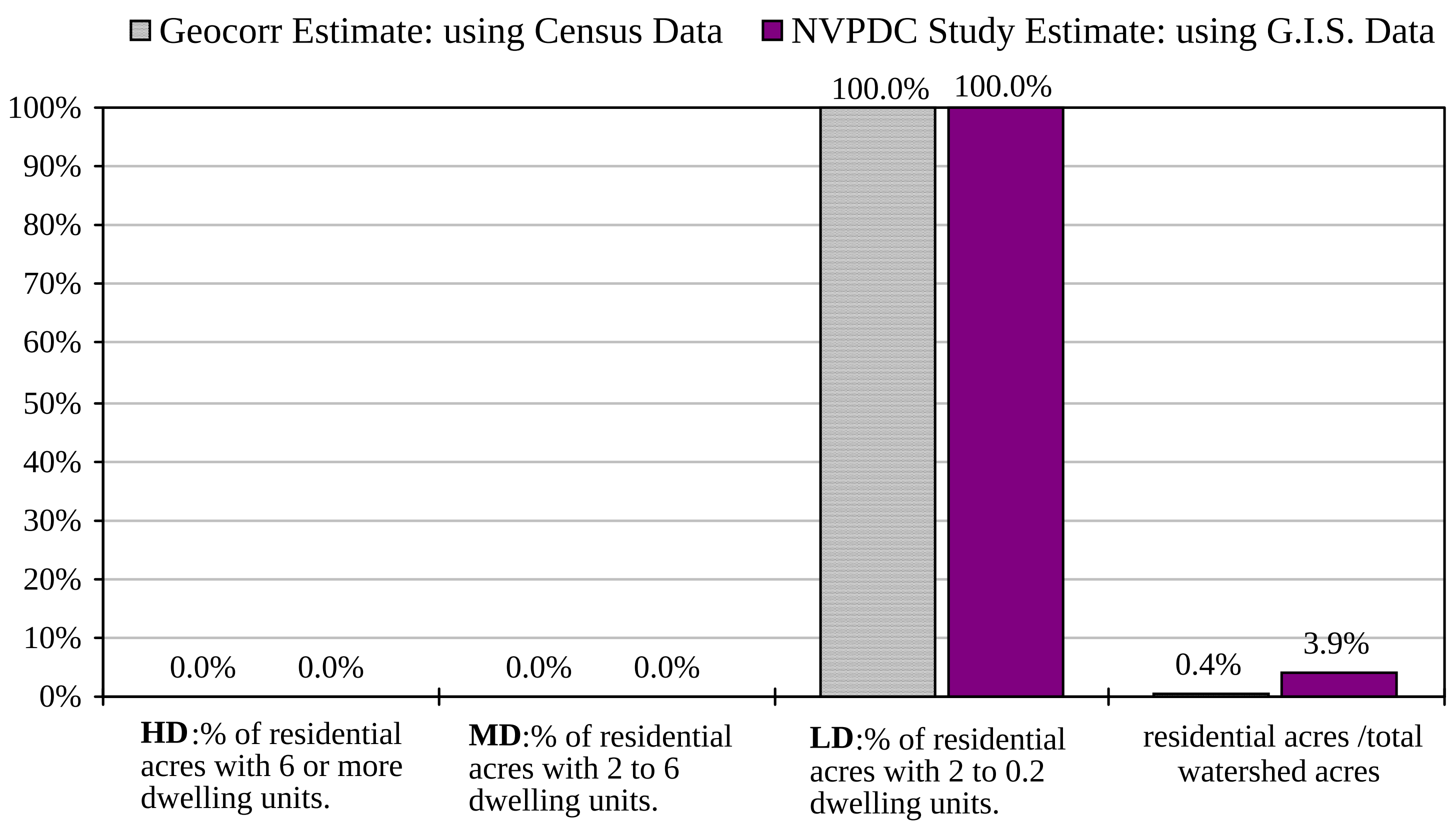

Figure 6.6. Comparison of Two Different Residential Land Use Estimates for the Portion of Loudoun County within the Occoquan Watershed.

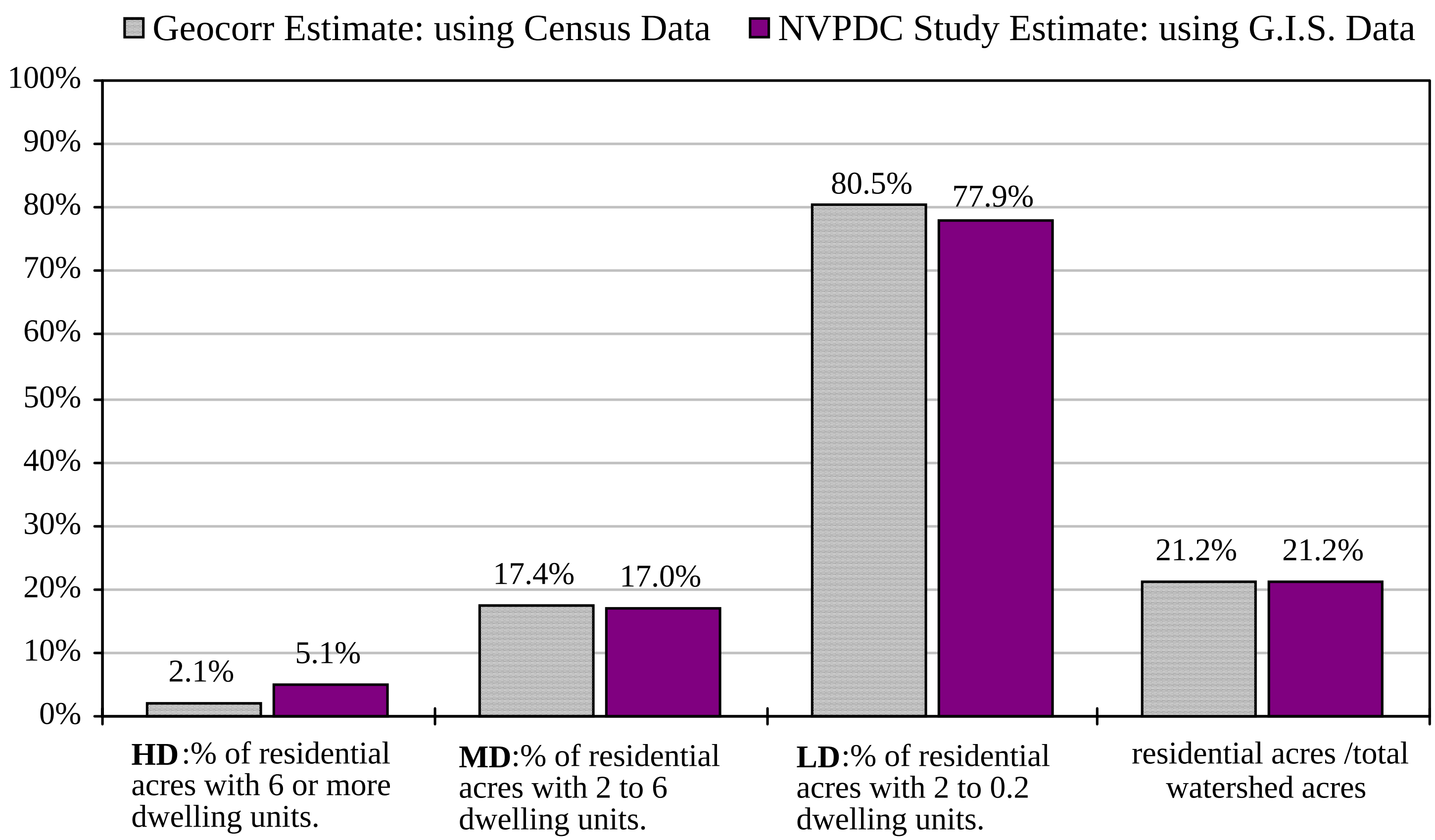

Figure 6.7. Comparison of Two Different Residential Land Use Estimates for the Portion of Prince William County within the Occoquan Watershed.

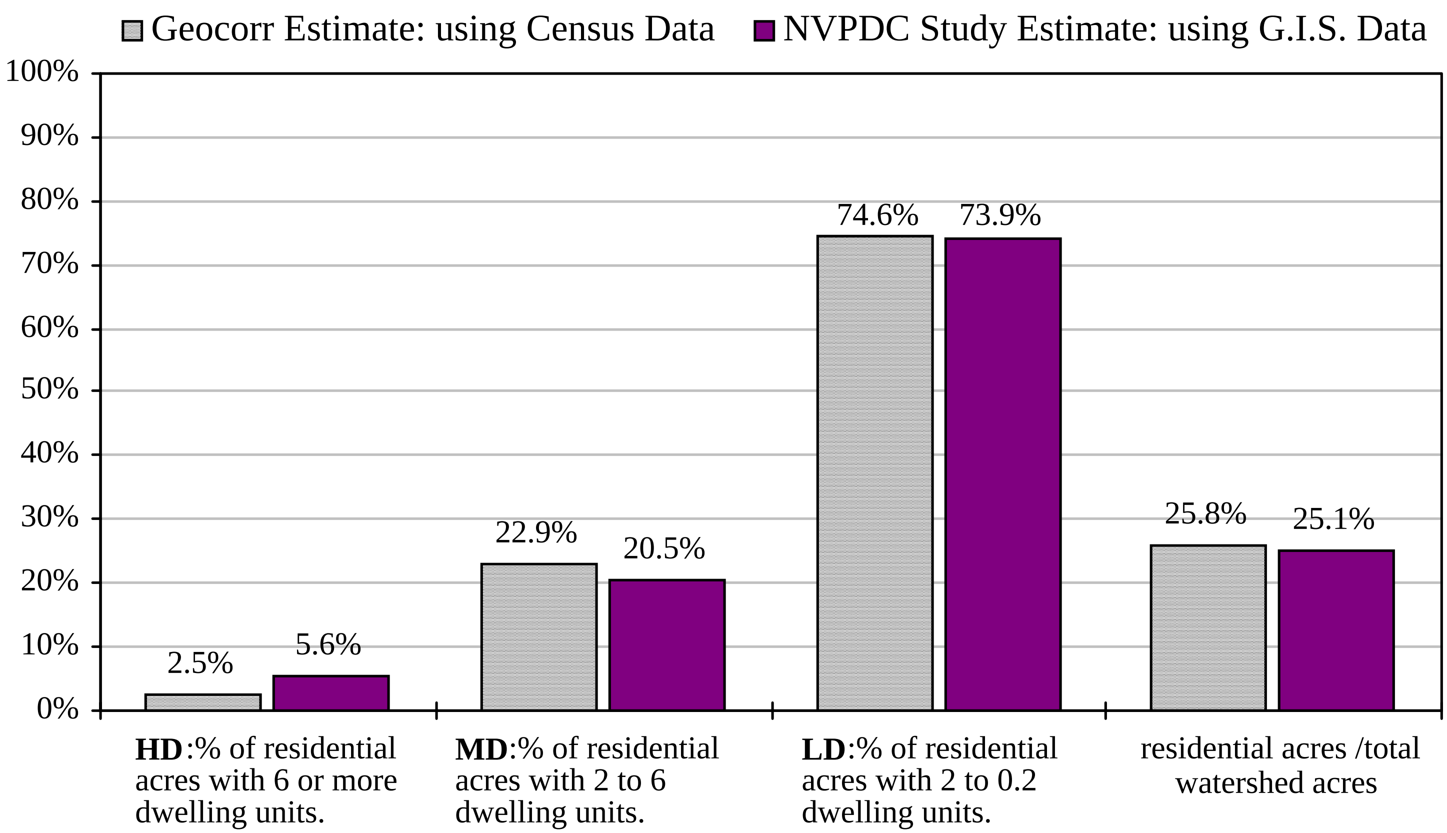

Figure 6.8. Comparison of Two Different Residential Land Use Estimates for the Entire Occoquan Basin.

The portions of Fauquier and Loudoun county that lie within the Occoquan Watershed are predominantly rural. For these two counties, the GeoCorr estimates resulted in a slightly smaller percentage of the total land being classified as residential, than did the estimation made in the NVPDC study (Figure 6.5),(Figure 6.6). Conversely, for the more urban Fairfax county, the GeoCorr approach suggested that more of the total land was residential than did the NVPDC study (Figure 6.4). For Prince William and the entire Occoquan Watershed as a whole, the GeoCorr approach generated a close approximation of the NVPDC study results (Figure 6.7), (Figure 6.8). Based upon this comparison between the two estimation approaches, it was assumed files created by GeoCorr, using Census block data could be reasonably used for making estimates of residential land use levels, for Virginia's entire Potomac Basin.

6.5.2.3. Determining Nonresidential Urban Acres

There was no direct way from census data to determine the levels of nonresidential urban acres. However, within the literature on the CBWQM, there are tables which separate the urban land within each hydrologic unit into the percentage which is residential, commercial, industrial, institutional, and used for transportation (USEPA,1991). These tables were used to estimate the total number of commercial, industrial, and institutional acres from the residential acres within each subregion. The percentages from the CBWQM were for 1985 land use conditions, so the use of these percentages for 1998 requires the assumption that these percentages have remained approximately the same during the interim.

The ratio of transportation to residential land from the CBWQM, was not used, however. The reason is that the transportation category used by the CBWQM encompasses: roads, railroads, airports, seaports, and facilities associated with the transportation of water, gas, oil, electricity, and communications (VDEQ, 1996). This category was then assigned an impervious value of 10%. For this particular study, this category was too aggregated, combining such disparate land uses as power line right of ways, which have an impervious surface value close to 0%, and highways, which have an impervious value close 100%. Instead the method used by the Center for Watershed Protection (CWP), in its report "Limits to Growth: Sustainable Development in the Occoquan Basin," was adopted for this study (Schueler, 1996). The CWP used a separate urban land use category for the network of collector, arterial, and main thoroughfare roads that link together businesses and neighborhoods.

In the CWS report, the land use data for the Occoquan watershed had been divided into 15 subwatersheds (Schueler, 1996). These subwatersheds include a broad mix of urban, suburban, and rural land uses. It was hoped that a generalized relationship between urban land levels and road surface area, could be derived by using this information. Such a relationship could then be used to estimate road surface area for the rest of the Potomac Basin. Regression analysis was used to compare the relationship between urban land levels and the proportion of urban land that was devoted to roadways, in each subwatershed. The resulting regression equation was:

$$\ln y = -3.3350763 + \ln x * -0.8085613$$

This equation had an R2 value of 0.9212, which suggests a strong correlation between the amount of roads and the amount of urban land within a given area. What the equation suggests is that as the percentage of urban land in an area declines the portion of urban land devoted to roads increases significantly (Figure 6.9). This equation was used to compute the amount of roadway surface in each of the subregions.

Estimates of existing septic systems were derived from 1990 census data (National Census,1991). This was accomplished by estimating the percentage of homes on septic systems for each census tract within a county and then determining the percentage for each subregion. This percentage was then applied to 1998 housing estimates for each subregion to determine the overall number of septic systems.

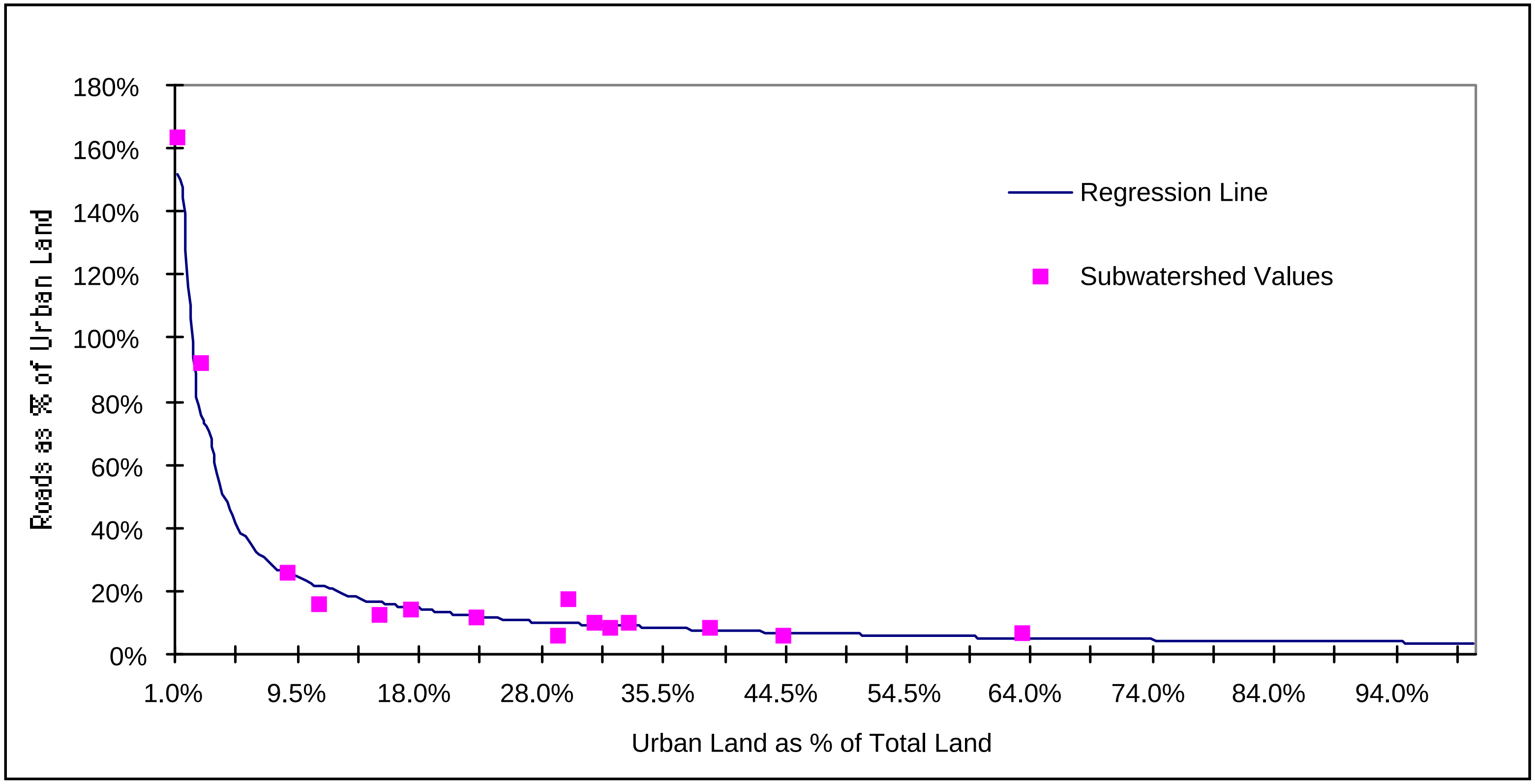

Figure 6.9. Relationship Between Connector Road and Urban Land in the 15 Occoquan Subwatersheds

6.5.3. Modelling Urban Land Use

Some aspects modelling of urban land use have already been touched upon in the preceding section. This section is intended to explain how the urban submodules framework is designed to represent urban land use. The section begins with an explanation of how the urban land use categories are partitioned, then proceeds to a description of how future population growth affects the various land use categories.

6.5.3.1. Urban Land Use Categories

The urban land use categories consist of the 6 residential types, a commercial/industrial/institutional category (CMIN), and the road category. The acres in each of these categories are partitioned into current acres that have already been retrofitted, those that are unretrofitted, and new acreage. Acres that are already retrofitted cannot be converted to other uses, and cannot be considered for additional BMPs. So within the context of the urban submodule, they essentially only take-up land and contribute to the overall loadings. A portion of the unretrofitted urban land can be considered for retrofitting, based upon the level of retrofitting that is feasible. Since the use of BMPs can be incorporated into the site planning process, all new acres can potentially be covered by BMPs. The same partitioning into retrofitted, unretrofitted and new is also done for onsite wastewater treatment systems. The one difference is that all unretrofitted septic systems can be retrofitted.

The way the urban land use category, Residential Type F, is modeled deserves brief mention. As explained previously, these were acres from, census blocks where the housing density was less than 0.2 DU/acre. It is assumed that the primary land use within these census blocks is not residential, but either forest or agriculture. It may be that the land is still urban in nature, being used for commercial or industrial purposes. Regardless of what the actual primary land use is for the census block, at such a low-density level, it is highly unlikely that it is residential. As a result, Residential Type F is allocated no land within the model. Any BMPs used on the land within these census blocks will presumably be for some land use other than residential. So there are no BMPs available for Type F either. This is not unreasonable when considering that many of these homes are either farmhouses, or on isolated lots just off of or alongside rural roads. Such disparate housing would to have individualized stormwater BMPs, which would be extremely impractical.

6.5.3.1. Future Urban Land Use

The model can be adjusted to allocate future population growth to the various residential categories in a number of ways. The first way is to allow the configuration of future settlement patterns to be left completely unrestricted. When this is done, the model settles new population in a way which allows the N goal to be met while maximizing total net revenues. The other ways to run the model, are to place restrictions on the way future land development occurs. The most straightforward way is to specify a minimum or maximum number of acres that can be converted to a specific urban land use category. Another way is to constrict the model to use specific ratios of urban land uses. These ratios could be based upon historical land use ratios, or they could represent a potential land use plan or policy option.

Once the method for settling new population has been chosen, the model then begins the urbanization process by introducing increases in population to each of the subregions. The model settles the new population by increasing the acreage of one of the six Residential Types. The additional acreage per person for each Residential Type was derived by first estimating the average number of people per house, then the average number of DUs per acre of each Residential Type. Two averages were derived from 1990 census data (National Census,1991). One for the Shenandoah regions the other for Northern Virginia. With the addition of new population comes increased demand for infrastructure. This required increase in infrastructure is represented within the model by connecting new residential acres to new CMIN and road acres, as well as additional demands upon either public sewer connections or on-site wastewater treatment. It needs mentioning that Residential Type F, incurs no additions to infrastructure.

The ratio of CMIN acres to one acre of each Residential Type is based upon the average number of people per acre for each Residential Type. This assumes that the acreage of needed CMIN is constant regardless of the residential type. However, evidence suggests that as population density increases less acres of CMIN are required per person (USEPA, 1976).

The less dense and the further away from an urban center new residential land is, the more arterial and connector roads that will need to be built to connect the development to the main road system. Also as population increases in rural areas rural roads are typically widened to accommodate the increase in traffic. There was no published research found which gave estimates of new road acres as a function of different residential patterns. In the urban submodule it is assumed there will be 0.04667 acres of new road for an additional acre of Residential Type A, 0.248 for Type B, 0.0785 for Type C, 0.0923 for Type D, and 0.037 for Type E.

Due to a lack of data on the topic, numerous assumptions had to be made concerning the allocation of wastewater treatment for new residential patterns. Since it is very costly and in cases physically difficult to connect development, characterized by Residential Type A, with centralized municipal wastewater treatment systems, the model will put 90% of new Residential Type A DUs on septic systems, and the remaining 10% will be connected to the public sewer system. For Residential Type B, the DUs are in a closer configuration yet the distance to the centralized sewer network is still far, so 90% will be on-site cluster systems while the remainder will be connected to the public sewer system. For Residential Type C, 90% are connected to public sewer and 10% on septic systems. For Residential Type D all new DUs will be connected to public sewer system. For Residential Type E, being close to centralized sewer networks, but with an increased distance between DUs, its assumed that the houses will be divided equally between public sewer and septic systems.

6.5.3. Modelling Nitrogen Loads

The discussion of the actual equations and variables for the urban submodule begins with the description of modelling N loads. For the urban submodule, the N loading rates are not based upon average estimates from published literature. Instead an empirical equation is used to compute N loads as a function of impervious surface (Schueler, 1987). As mentioned in chapter three, impervious surface estimates are a function of building and road density, which are themselves a function of population levels. So the urban loading rate for an area is an indirect function of the areas population density.

After residential land was classified into types A, B, C, D, E, and F, an impervious surface estimate had to be calculated for each category within each subregion. To determine imperviousness, four linear equations were devised which relate imperviousness levels to density values based upon published estimates (Schueler, 1987). These equations are listed in Table 6.7.

Table 6.7. Assumed Relationship Between Dwelling Unit Density and Impervious Surface Level.

Average Density (AD) in DU/AC	Imperviousness Equations
$0 < AD \leq 0.2$	$AD * 25 = \%$ Imperviousness
$0.2 < AD \leq 2$	$AD * 8.333 + 3.333 = \%$ Imperviousness
$2 < AD \leq 6$	$AD * 2.5 + 15 = \%$ Imperviousness
$6 < AD$	$AD * 2.143 + 17.143 = \%$ Imperviousness

Impervious surface estimates for nonresidential urban land were derived from several sources. For the commercial/industrial/institutional land use category the impervious surface values were a weighted average based upon estimates used in the CBWQM (CBP, 1991). These weighted averages were different for each subregion, ranging from 66% to 76% impervious surface. For roads the impervious estimate was 85% for all subregions (NVPDC, 1994a).

Once the impervious surfaces were estimated the empirical equation, referred to as the Simple Method, was used to derive the N load (Schueler, 1987) (Chandler, 1996).

$$\text{Annual N load lb./ac} = ((P * Pj * ((0.09 + 0.009(I)))/12) *(C)*2.72$$

where:

P= normal annual rainfall in inches = 40 for Potomac Basin.

Pj = factor that corrects P for storms that produce no runoff. It is 0.9 for Washington D.C. metropolitan area.

I = the percent of site imperviousness

C = N concentration of stormwater in mg/l

12 & 2.72 are unit conversion factors

The average level of N in stormwater, or "C value," is not the same for all urban land. According to the USEPA's Nationwide Urban Runoff Program (NURP) the national average concentration for urban areas is 3.31 mg/l (Horner et al., 1994). Thomas Schueler suggests that the value for older highly urbanized areas should be slightly higher than this, and slightly lower for newer suburban areas, or 2 mg/l (Schueler, 1987). So for this study, 3.31 mg/l was used for residential types B, C, and D, and for the commercial/industrial/institutional category. For residential types A, E, and F, a concentration of 2 mg/l was used. A study conducted by the Federal Highway Administration suggested that C values are typically about twice as high for urban roads as they were for rural roads (Schueler, 1987). So the C values were 3.31 for roads in the NOVA region and 1.6 mg/l for the Shenandoah regions.

It may appear odd that Type F does generate an N loading. Since the acres where these houses actually reside are already being accounted for by some other land use, this appears to be double counting the N load. Yet, this is necessary, because in rural subregions, a significant percentage of the DUs fall into category F. For modelling purposes, the load from a Type F house was considered to be the same as that coming from a Type A house, which is actually less than the loading for an acre of forest or a meadow.[6] By including the additional loading from DUs in category F, the assumption is being made that this represents the additional loadings that result from the impervious surface on these nonresidential acres.

Along with the N loads from urban stormwater, there were the additional loadings from on-site wastewater disposal. Septic tank effluent typically has a N level of 40 to 80 mg/l (Novotny & Olem, 1994), (USEPA, 1993). The estimated daily consumption of water per person ranges from approximately 175 to 375 liters (Novotny & Olem, 1994), (USEPA, 1993). This suggests a range of 7 to 30 grams of N per capita per day. It was decided to use the conservative 10.4 grams per day suggested by the USEPA (1993). Septic tank drainfield systems typically remove between 15 and 45% of the N entering the system (USEPA, 1993). So using an estimated 28% removal rate, there will still be an estimated 6.64 lbs. of N per person which is not removed by septic systems each year. Using a household occupancy of 2.7 people we have 17.93 lbs. of N per DU, annually leaving the drainfield. This N leaving the drainfield will either be in surface runoff, interflow, or baseflow. It is difficult to estimate the portion of this N that will eventually reach surface waters. It was assumed that an additional 25% of the annual N loading leaving drainfields will not reach waterways. So the final estimated N loading, from the use of septic systems, is 13.5 lbs./year.

Because many assumptions were necessary for deriving this figure. A deliberate attempt was made to keep the figure conservative. The estimate does not take into account additional loadings due to improper siting of septic systems, or due to failing septic systems. Only 32% of the land area in the United States is suitable for conventional septic systems (Peterson et al., 1992). Typically between 1 and 5% of all septic systems fail each year (EPA, 1993).

The resulting N load from the above mentioned sources is the edge of stream base load for all the urban acres located within the Shenandoah Regions. The reason is that no further adjustments need to be made to account for urban BMPs, since none have been implemented within these regions (VDEQ, 1996). However, in Northern Virginia efforts have been made to control the N loads from urban runoff. The assumption was made that since 1990, all new development acres in Northern Virginia, excluding the Occoquan Watershed, have been covered by an urban BMP. In the Occoquan region, as a result of concerns about the supply of clean drinking water, the use of BMPs began even earlier (Schueler, 1996). Based upon the projected increase in population, within the Occoquan region, between the years 1985 to 1990, BMP coverage was applied to 30% of the pre1990 urban land (NVPDC, 1994b). The load from these urban acres are reduced by 40% to compensate for this BMP coverage.

6.5.3. Modelling Urban Best Management Practices

The four BMPs considered in the urban submodule again are: on-site ponds, regional ponds, urban vegetated filter strips, and ultra-urban techniques. The performance, costs and applicability of these BMPs, were previously discussed in chapters three and four, respectively. The focus of this

[6] This is not likely to be the case in the real world since all evidence suggests that adding impervious surfaces to the land increases the resulting N load. The difference arises from the fact that the loads for forests and fields come from the CBWQM, and the load for urban land comes from the use of the Simple Method. When the Simple Method is applied to an acre of forest the resulting estimated N load is 0.45 lbs. per year (Schueler, 1987). While the CBWQM uses an approximate value of 3 lbs. per acre per year for forest

section will primarily be upon how these BMPs are represented within the urban submodule, and how their use is restricted.

The estimated efficiency at removing N from stormwater was based upon an average from several sources (Schueler et al., 1992), (USEPA, 1993), (NVPDC, 1994), (Schueler, 1997a). Since several of the studies cited by these sources are the same, the average efficiency reported from each source was weighted to ensure the that results of any one study did not have a disproportional influence on the parameter value used in this current study. The Table 6.8 provides the estimated efficiency of stormwater BMPs at removing N, used for this study. Then the Table 6.9 lists the model parameters for urban N loadings based upon baseline loadings and the BMP removal rates shown in Table 6.8. The Table 6.9 uses the same conventions as described previously for Table 6.5.

Table 6.8. Estimated Efficiency at Removing Nitrogen for Urban Stormwater BMPs.

Best Management Practice	**on-site ponds**	**regional ponds**	**urban vegetated filter strip**	**ultra-urban techniques**
Set Item Suffix	OSP	RGNL	UVFS	ULTR
N Removal Rate	35%	35%	25%	44%

Table 6.9. Model Parameters for Urban Nitrogen Loadings (lbs./ac/year).

	SOUTHERN SHENANDOAH			NORTHERN SHENANDOAH			NORTHEN VIRGINIA			
URBNACTV	**170**	**190**	**200**	**180**	**190**	**200**	**180**	**220**	**550**	**530**
Set Items	**1X**	**1Y**	**1Z**	**2X**	**2Y**	**2Z**	**3W**	**3X**	**3Y**	**3Z**
RESABL	2.08	1.88	1.99	2.07	1.84	1.87	2.15	1.95	1.81	1.95
RESAOSP	1.35	1.22	1.29	1.35	1.20	1.22	1.40	1.27	1.18	1.27
RESARGNL	1.35	1.22	1.29	1.35	1.20	1.22	1.40	1.27	1.18	1.27
RESAUVFS	1.56	1.41	1.49	1.55	1.38	1.40	1.61	1.46	1.36	1.47
RESBBL	7.51	7.30	6.84	6.96	7.65	7.36	8.24	7.04	6.65	7.78
RESBOSP	4.88	4.74	4.45	4.52	4.97	4.78	5.36	4.57	4.32	5.06
RESBRGNL	4.88	4.74	4.45	4.52	4.97	4.78	5.36	4.57	4.32	5.06
RESBUVFS	5.63	5.47	5.13	5.22	5.73	5.52	6.18	5.28	4.99	5.84
RESCBL	5.00	7.14	6.78	7.18	7.19	7.12	5.00	7.04	7.06	7.09
RESCOSP	3.25	4.64	4.41	4.66	4.67	4.62	3.25	4.58	4.59	4.61
RESCRGNL	3.25	4.64	4.41	4.66	4.67	4.62	3.25	4.58	4.59	4.61
RESCUVFS	3.75	5.36	5.09	5.38	5.39	5.34	3.75	5.28	5.30	5.31
RESDBL	9.00	10.77	11.06	10.80	10.01	9.86	9.00	11.80	10.37	13.63
RESDULTR	5.04	6.03	6.20	6.05	5.60	5.52	5.04	6.61	5.81	7.63
RESDOSP	5.85	7.00	7.19	7.02	6.50	6.41	5.85	7.67	6.74	8.86
RESDRGNL	5.85	7.00	7.19	7.02	6.50	6.41	5.85	7.67	6.74	8.86
RESEBL	3.00	2.10	2.07	2.10	2.23	2.48	3.00	2.22	2.34	2.54
RESEOSP	1.95	1.36	1.34	1.36	1.45	1.61	1.95	1.44	1.52	1.65
RESERGNL	1.95	1.36	1.34	1.36	1.45	1.61	1.95	1.44	1.52	1.65
RESEUVFS	2.25	1.57	1.55	1.57	1.67	1.86	2.25	1.67	1.76	1.91
CMINBL	17.83	18.58	20.20	20.30	18.58	20.20	20.30	18.00	19.10	18.55
CMINULTR	9.98	10.40	11.31	11.37	10.40	11.31	11.37	10.08	10.70	10.39
CMINOSP	11.59	12.07	13.13	13.19	12.07	13.13	13.19	11.70	12.41	12.06
CMINRGNL	11.59	12.07	13.13	13.19	12.07	13.13	13.19	11.70	12.41	12.06
CMINUVFS	13.37	13.93	15.15	15.22	13.93	15.15	15.22	13.50	14.32	13.91
HWBL	10.91	10.91	10.91	10.91	10.91	10.91	10.91	22.56	22.56	22.56
HWUVFS	8.18	8.18	8.18	8.18	8.18	8.18	8.18	16.92	16.92	16.92
SSBL	17.93	17.93	17.93	17.93	17.93	17.93	17.93	17.93	17.93	17.93
SSRF	11.76	11.76	11.76	11.76	11.76	11.76	11.76	11.76	11.76	11.76

Table 6.9. Continued

	SOUTHERN SHENANDOAH			NORTHERN SHENANDOAH			NORTHEN VIRGINIA			
RTRFUSES Set Items	**170 1X**	**190 1Y**	**200 1Z**	**180 2X**	**190 2Y**	**200 2Z**	**180 3W**	**220 3X**	**550 3Y**	**530 3Z**
RFRESA	1.25	1.13	1.20	1.24	1.10	1.12	1.29	1.17	1.08	1.17
RFRESB	4.50	4.38	4.11	4.18	4.59	4.42	4.94	4.22	3.99	4.67
RFRESC	3.00	4.29	4.07	4.31	4.31	4.27	3.00	4.23	4.24	4.25
RFRESD	5.40	6.46	6.64	6.48	6.00	5.92	5.40	7.08	6.22	8.18
RFRESE	1.80	1.26	1.24	1.26	1.34	1.49	1.80	1.33	1.41	1.53
RFCMIN	10.70	11.15	12.12	12.18	11.15	12.12	12.18	10.80	11.46	11.13
RFHW	8.18	8.18	8.18	8.18	8.18	8.18	8.18	8.18	8.18	8.18
RFSS	11.76	11.76	11.76	11.76	11.76	11.76	11.76	11.76	11.76	11.76

ITEM PREFIXES *	ITEM MIDDLE TERMS**	ITEM SUFFIXES ***
RESA = residential type A	BL = baseline	1X = Southern Shenandoah, Sub-Basin 170
RESB = residential type B	OSP = on-site detention ponds	1Y = Southern Shenandoah, Sub-Basin 190
RESC = residential type C	RGNL = regional detention ponds	1Z = Southern Shenandoah, Sub-Basin 200
RESD = residential type D	UVFS = urban vegetated filter strips	2X = Northern Shenandoah, Sub-Basin 180
RESE = residential type E	ULTR = ultra-urban techniques	2Y = Northern Shenandoah, Sub-Basin 190
CMIN = commercial/industrial/institutional	RF = retrofit	2Z = Northern Shenandoah, Sub-Basin 200
HW = highway		3W = Northern Virginia, Sub-Basin 180
SS = septic systems		3X = Northern Virginia, Sub-Basin 220
RF = retrofitted		3Y = Northern Virginia, Sub-Basin 550 (Occoquan)
		3Z = Northern Virginia, Sub-Basin 530 (Potomac)

* Item prefixes for the URBNACTV and RTRFUSES variables pertain to land uses.
** Item middle terms for the URBNACTV and RTRFUSES variables pertain to a BMP. When BMPs are used in combination,
then only the first letter of each BMP term is used.
*** Item suffixes for the URBNACTV and RTRFUSES variables pertain to the subregion used.

As stated previously, all new development can accommodate BMPs. Therefore the main concern is with representing the potential for retrofitting. For the submodule to accurately choose between the most appropriate BMP for retrofitting, and also estimate the BMP's proper size and configuration of each, it would be necessary to first identify all the potential sites, along with the unique set of circumstances that exist at each. This would require extremely detailed hydrologic and geospatial land use data for all the urban land within the Basin. Instead the model relies upon feasibility studies and published site screening criteria to derive an approximate potential level of retrofitting possible (MWCOG, 1991), (Schueler, 1987), (NVPDC, 1993), (NVPDC,1994). The percentage of each land use category that can feasibly be retrofitted is given in Table 6.10. It needs to be kept in mind, that these percentages are only rough approximations of the potential for retrofitting. They were not necessarily suggested by the sources mentioned, but rather they fall within what could be considered a reasonable estimate by them.

Table 6.10. Maximum Feasible Level of Urban Land Use Considerable for Retrofitting by an Urban Best Management Practice.

		Urban Best Management Practices			
		ULTR	**OSP**	**RGNL**	**UVFS**
Urban Land Use	RES**A**		30%	60%	80%
	RES**B**		30%	60%	60%
	RES**C**		30%	60%	40%
	RES**D**	25%	20%	60%	
	RES**E**		30%	60%	80%
	CMIN	50%	30%	60%	10%
	ROAD				80%

6.5.4. Summary of the Urban Submodule

The Figure 6.10 provides an illustration of how the urban submodule is structured. As with Figure 6.3, the arrows originate from both the POPLVL and NULLVL equations, which stand for new population level and new urban land level, respectively. Depending on how the model is run, either the POPLVL -> POPUGROW -> NEWPOP sequence would be used to allow the model to determine the residential patterns, or the NULLVL equation would be used to set the residential settlement patterns directly.

The NURBUSES variable represents the various new residential patterns. For each residential pattern there are specified amounts of nonresidential urban land and wastewater treatment options which automatically are generated. The new urban land is joined with existing urban land that is already divided between retrofitted and unretrofitted acres. The unretrofitted acres are available for retrofitting. All urban land variables are connected to the NITLOD equation; while only the currently unretrofitted acres, which the model retrofits, contribute to the MAXREV.

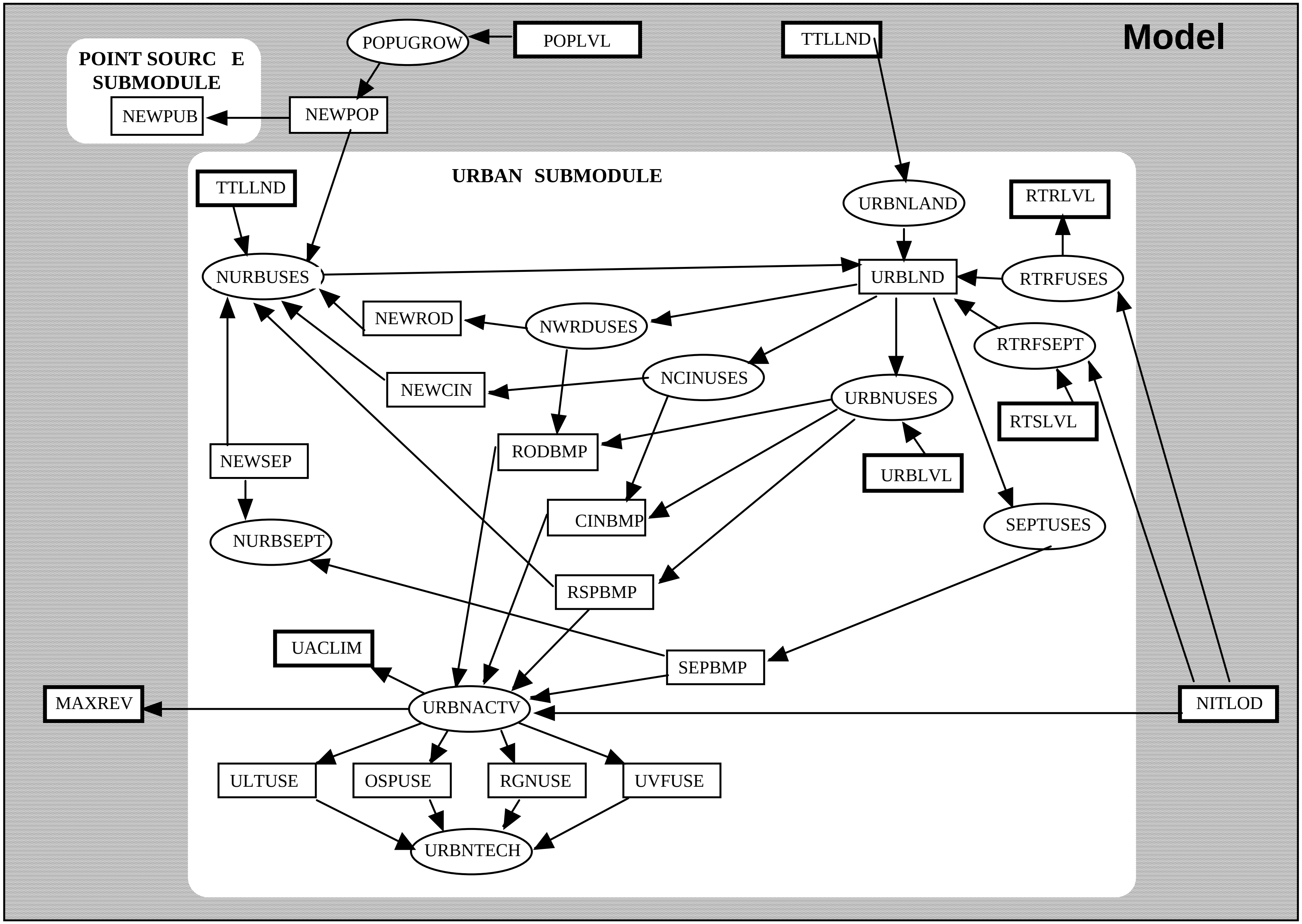

Figure 6.10. Diagram of Urban Submodule Equations and Variables. (The Diagram Key is on the Next Page)

VARIABLE PREFIX	EQUATION PREFIX	PREFIX MEANING
	CIN	Commercial, Industrial, and Institutional urban land uses.
	MAX	Maximize the level.
NCIN		New Commercial, Industrial, and Institutional urban land uses.
	NEW	New urban nonpoint sources.
NWRD		New connector roads.
NURB		New urban land use.
	NIT	Nitrogen measured in pounds.
	OSP	On-site detention ponds.
POPU	POP	Population.
	RGN	Regional detention ponds.
	ROD	Connector Roads.
	RSP	Residential Settlement Patterns.
RTRF	RTR	Retrofitted urban nonpoint source.
RTS		Retrofitted septic systems.
SEPT	SEP	Septic Systems.
	TTL	Total .
	UAC	Urban activity.
	ULT	Ultra-urban stormwater BMPs
URBN	URB	Urban.
	UVF	Urban vegeteated filter strips.

VARIABLE SUFFIX	EQUATION SUFFIX	SUFFIX MEANING
	BMP	Cluster.
	CIN	Connection.
	CUR	Current.
GROW		Increase.
	LIM	Limit.
LAND	LND	Land.
	LOD	Edge of stream loading.
	LVL	Level.
	POP	Population.
PSRC		Point source.
	PUB	Public works.
	REV	Revenue.
	ROD	Conector Roads.
SEPT	SEP	Septic system.
TECH		Nitrogen control technology.
USES	USE	Uses.

Figure 6.10. Continued. (Key to the Diagram on the Previous Page)

6.5. CONCLUSION

This chapter has covered a broad range of topics that were relevant to the development of each submodule. Also discussed were issues regarding the derivation of model parameters. Not all aspects of the modelling process could be included in the chapter. What has been included, is what was regarded as being the most important aspects, for an understanding of how the submodules are supposed to representative of actual activities and process.

Addressed in this chapter were steps necessary to represent not only current conditions, but future conditions as well. Many of these steps will be discussed further in the next chapter. The next chapters will focus on the selection of different parameters to represent different scenarios, and the results from running these scenarios.

The modelling process outlined in this and the previous chapter, have included the development of an optimization model, with four distinct submodules, and the sets of parameters required for representing current and future conditions. The process for developing these parameter sets involved using the initial data gathered as part of the literature review and transforming it through a series of linked spreadsheets into the final parameter sets. Together these linked spreadsheets with the optimization model will henceforth be referred to as the Potomac Basin Model.

CHAPTER VII

MODEL RESULTS

This chapter is intended to describe how the model, designed for this study, (Potomac Basin Model), was used to generate the information necessary for addressing the research objectives. The chapter begins with a description of the various model runs used to meet each of the research objectives stated in Chapter One. The results of these runs are then presented along with a discussion of their relevancy. A series of summary tables and figures are used to present information from the model results, as needed within the chapter. Additional figures and tables of model results can be found in Appendix E.

7.1 MODEL SCENARIOS

Model scenarios are a series of model runs that together are designed to generate results that could be used to meet the three study objectives outlined in Chapter One. All three objectives pertain to the effects of land use change and changes in population. Since such changes occur over a period of time, a key consideration when developing the scenarios was the time span and intervals they would cover. The first scenario is the Trend Scenario, which provides a prediction of how N loadings to the Potomac will likely change over time as a result of changes land use and population. The next scenario is the Expend Scenario, which predicts the annual cost of maintaining the N reduction goal over a period of time. The third and fourth scenarios are the Alternative 1 Scenario and Alternative 2 Scenario, which predict the potential cost savings from the use of two alternative settlement patterns over the same time period.

7.1.1. Time Span

Each model scenario is defined by the year it represents, the N load level, and the settlement pattern being simulated. There was a tradeoff to consider when deciding upon the time span to be covered by the model runs. One of the principle objectives of the study is to determine the effect of future population growth and land use changes on the State's ability to meet the N reduction goal. The greater the time span the larger the population increase, and therefore the more pronounced the potential effects. Yet, the further in the future that projections are made, the greater the possibility for inaccuracy. It was decided that the time span covered by the model runs would be the 15 years between 1998 and 2013.

It was also necessary to determine how many of the years to model within this time period. Modelling only the years of 1998 and 2013 would neglect important information on the relationship between land use change and future loading rates, as well as, the cost of meeting the goal. However, the population increase and land use changes from year to year are not likely to be great enough to require model runs for every year within the time span. So, the time period difference between model runs was set at five years.

7.1.2. Trend and Expend Scenarios

Trend refers to model runs where the model is not constrained to meet the N cap. All Trend runs are collectively referred to as the Trend Scenario. Existing N control techniques are still included, but no additional BMPs are used. These runs essentially represent the expected conditions if no additional N reduction efforts were to occur. The Expend Scenario consists of those runs where the model is constrained to meet the N cap. The level of the N load cap, used for the Expend runs, was based upon information from the CBWQM. According to the CBWQM in 1985 the combined load from these three regions was 29,290,510 pounds of N, and of this 19,760,590 pounds were controllable (VDEQ, 1995). Reducing the controllable load by 40% we have 11,856,354 pounds. Combining this with the uncontrollable portion we have a total cap load of 21,386,314 pounds of N annually.

The Trend runs, by themselves, provide useful information on how population growth and land use change can effect overall N loadings within the basin. Yet, the Trend runs also provide basecase N loadings and net revenues for comparison with loadings and net revenues from the Expend runs. By subtracting Expend run net revenues from Trend run net revenues, an estimate of the total additional cost for meeting the N goal during that year can be derived. It is extremely important to bear in mind that these cost estimates will be minimum costs or “best possible case” costs, and that actual costs would much more likely be higher rather than lower than these estimates.

It is of use to know if a change in total cost is due to the fact that N loads are increasing or because the available best management practices are becoming more expensive. Determining the trend in average cost over time can provide useful information for answering that question. This is because, if the average cost remains relatively constant while N loads are increasing then the total cost will go up, solely as a result of rising N loads. However, if N loads remain stable, while the average cost is increasing over time, then rising costs can be attributed to a more expensive mix of BMPs. However, if both N loads and average costs increase over the same period, it becomes difficult to determine the relative affect of increased N loadings and the changing availability of BMPs on the total cost. Average costs were determined in two steps. First, by subtracting the Cap level N load from the Trend N load, an estimate of the amount of N loadings that need to be reduced to meet the goal can be made. Then by dividing the total additional cost by the number of pounds of N which need to be reduced, an estimate of the average cost per pound of N reduced, can be made.

Initially for the Trend runs the N load equation was set to be completely unconstraining. However, this led to difficulties with multiple optimal solutions. Under the Trend runs, the model was constrained to have a certain fixed number of agricultural land uses and a fixed number of existing agricultural BMPs. When the model was run, it then combined the agricultural land uses with BMPs. These combinations had no effect on revenue maximization, since the existing BMPs are not assigned costs, yet they did have an impact on the resulting N load. Therefore the resulting N loads from these runs were subject to fluctuations of as much as a million pounds To address this problem the model was first run without a N load constraint but still including all existing BMPs. The net revenues from this run, for each of the four sectors: agriculture, forestry, urban, and point sources, were then combined to provide a base net revenue. The model run was then modified so that the revenue maximizing objective function became a minimum revenue constraint, where total net revenues had to be at least as high as the base revenue estimate, and the N load constraint became the new objective function. So the model run was essentially altered from maximizing revenues while not exceeding a maximum amount of N loadings, to minimizing N loadings while meeting a minimal level of net revenue. What this adjusted run provided was the lowest N loading the model could achieve while still maintaining the base net revenue. In this way the problem with multiple optimal solutions was overcome.

From the Trend and Expend runs we are able to derive estimates for both the total and average per pound cost of meeting the goal. Estimating the marginal cost of reducing an additional pound of N would also provide useful information. The marginal cost gives an indication of the cost of further reductions, and it also provides an indication of the sensitivity of the total cost to the cost effectiveness and feasibility estimates used for the parameters. In other words, if the marginal cost is much higher than the average cost, then the total cost estimate is likely to be more sensitive to the parameter estimates, than if the average and marginal costs were similar. To determine the marginal cost the N load constraint was restricted by a million additional pounds. Then the resulting difference in total cost was divided by a million to derive a marginal cost per pound.[7]

7.1.3. Alternative Settlement Patterns

Results from the Trend runs provide a prediction of the effects of future population growth and land use changes on N loads to the basin. The addition of the Expend runs allows for the assessment of the potential costs of meeting the goal under these changes. To assess potential cost reductions that may result from the use of different settlement patterns, it was necessary to devise additional scenarios. Two alternative scenarios were developed, which place restrictions on the way land is settled in the Northern Virginia (NOVA) region. The restrictions were only used in NOVA for two reasons. First, the vast majority of new urban development will occur in the Northern Virginia region, so this is the area where restricting settlement patterns will likely have the greatest impact. Secondly, issues surrounding the impact of urban growth are regularly on the agenda of Northern Virginia governments (NVPDC, 1994a). So this would be the region to more likely consider changing settlement patterns to improve water quality.

The first of two principle means, by which an alternative settlement pattern could reduce the cost of meeting the N reduction goal, is by reducing the average load per additional dwelling unit. The second method is by settling the land in such a way that the mix of BMPs, which are available for implementation are less costly, than those BMPs that would be available under the present trend in land settlement. The first alternative is intended to represent a policy of favoring higher density settlement patterns over lower density. Although higher density patterns have a higher per acre load, they require less

[7] Reducing the N load constraint by less than 1 million resulted in rounding errors in the model output.

acreage per DU. So the average load per DU is actually less for higher density patterns than it is for lower density ones. Also, since many localities, in NOVA, already regulate the housing densities of new developments, high-density requirements would not be unprecedented. Higher density patterns are more likely to be connected to a centralized sewer system as well. This is because the connection cost per house is lower since there is less space between houses (EPA, 1991).

To simulate higher density requirements, Alternative 1 restricts all new dwelling units to be either in residential patterns B, C, or D. For the estimates of future Trend settlement patterns the percentage of new DUs in each residential category was the same as it was for the 1990 Census, with adjustments being made for infill. For Alternative 1, the DUs, which were allocated to residential patterns A, E, or F for the Trend run, were reallocated to B, C, and D. The portion of new DUs that went to either B, C, or D was based upon the 1990 Census proportions of each of these residential patterns within each Basin locality.

It is important to note that under the Trend scenario a portion of new DUs were allocated to residential pattern F, which does not increase urban acreage, but does increase loadings. Under Alternative 1, the DUs that were in F under Trend, now went to either B, C, or D. This could cause a slight increase in total new urban acres for some localities, if a significant portion of new housing was predicted to go to pattern F, under Trend. However, this would not cause an increase in total N loadings, since new DUs, in pattern F, also increased loading rates, under the Trend Scenario.

The second alternative is to limit growth outside of existing urban areas. Using the definition of an urban area as defined in the previous chapter, this would restrict all new DUs to be either in residential patterns C, D, or E. The two advantages of this scenario are: that there would be less need for new road infrastructure to connect new developments to existing urban areas; and there would also be less need to rely upon on-site wastewater treatment systems. The DUs that would be in patterns A, B, and F under Trend, will be reallocated to patterns C, D, and E in the same way that they were for Alternative 1. The Table 7.1 provides a numerical breakdown of urban land for each of the three scenarios. For a complete description of the trend residential numbers used in the model consult Appendix D. This appendix consists of a set of tables that provide the number of acres, dwelling units, and annual N loadings for each residential pattern, in all 10 subregions, for the years 1998, 2003, 2008, and 2013.

Table 7.1. Acres in Each Urban Land Use, in the Northern Virginia Region, for the Three Scenarios, during the years 1998, 2003, 2008, & 2013. (Septic System numbers reflect the number of Dwelling Units using them.)

		EXPEND SCENARIO					ALTERNATIVE SCENARIO 1					ALTERNATIVE SCENARIO 2				
		3W	3X	3Y	3Z	NOVA	3W	3X	3Y	3Z	NOVA	3W	3X	3Y	3Z	NOVA
	Residential A	3,914	11,201	21,208	16,648	**52,970**	3,914	11,201	21,208	16,648	**52,970**	3,914	11,201	21,208	16,648	**52,970**
1	Residential B	207	822	338	798	**2,164**	207	822	338	798	**2,164**	207	822	338	798	**2,164**
9	Residential C	-	19,863	18,336	48,300	**86,498**	-	19,863	18,336	48,300	**86,498**	-	19,863	18,336	48,300	**86,498**
9	Residential D	-	2,662	2,280	12,677	**17,619**	-	2,662	2,280	12,677	**17,619**	-	2,662	2,280	12,677	**17,619**
8	Residential E	-	70,707	65,200	84,980	**220,887**	-	70,707	65,200	84,980	**220,887**	-	70,707	65,200	84,980	**220,887**
	Com/Indus	1,626	45,522	22,954	66,309	**136,411**	1,626	45,522	22,954	66,309	**136,411**	1,626	45,522	22,954	66,309	**136,411**
	Roads	1,715	26,558	11,588	10,275	**50,137**	1,715	26,558	11,588	10,275	**50,137**	1,715	26,558	11,588	10,275	**50,137**
	Septic Systems	6,464	26,962	90,327	13,452	**137,205**	6,464	26,962	90,327	13,452	**137,205**	6,464	26,962	90,327	13,452	**137,205**
	Residential A	4,324	12,687	23,730	18,705	**59,447**	3,914	11,201	21,208	16,648	**52,970**	3,914	11,201	21,208	16,648	**52,970**
2	Residential B	250	931	422	981	**2,585**	366	975	408	1,249	**2,998**	207	822	338	798	**2,164**
0	Residential C	-	21,751	20,242	51,907	**93,900**	-	22,749	24,941	50,587	**98,277**	-	21,947	23,000	51,014	**95,960**
0	Residential D	-	2,917	2,522	13,383	**18,822**	-	2,952	3,479	13,166	**19,597**	-	2,884	3,144	13,040	**19,067**
3	Residential E	-	77,223	71,748	92,366	**241,337**	-	70,707	65,200	84,980	**220,887**	-	76,664	75,428	89,731	**241,822**
	Com/Indus	1,639	45,935	23,391	67,014	**137,979**	1,635	45,795	23,739	66,630	**137,799**	1,626	45,875	23,783	66,713	**137,996**
	Roads	1,749	27,110	12,187	11,098	**52,144**	1,761	26,859	12,256	10,639	**51,515**	1,715	26,990	12,470	10,723	**51,898**
	Septic Systems	7,062	31,516	95,210	18,876	**152,664**	6,893	28,269	92,555	15,381	**143,098**	6,464	29,573	95,145	15,859	**147,040**
	Residential A	4,626	13,896	26,567	20,273	**65,362**	3,914	11,201	21,208	16,648	**52,970**	3,914	11,201	21,208	16,648	**52,970**
2	Residential B	282	1,020	520	1,124	**2,946**	482	1,124	476	2,033	**4,115**	482	822	338	798	**2,439**
0	Residential C	-	23,330	22,451	55,442	**101,223**	-	25,096	32,070	53,060	**110,226**	-	23,590	28,004	53,351	**104,946**
0	Residential D	-	3,140	2,799	14,073	**20,012**	-	3,192	4,733	13,647	**21,572**	-	3,065	4,043	13,389	**20,497**
8	Residential E	-	83,044	79,147	99,824	**262,015**	-	70,707	65,200	84,980	**220,887**	-	81,682	86,700	94,834	**263,216**
	Com/Indus	1,649	46,293	23,888	67,696	**139,526**	1,642	46,019	24,573	66,978	**139,212**	1,642	46,164	24,671	67,099	**139,576**
	Roads	1,773	27,586	12,868	11,881	**54,108**	1,795	27,111	12,971	11,112	**52,989**	1,795	27,345	13,425	11,154	**53,719**
	Septic Systems	7,501	35,368	100,747	23,902	**167,518**	7,208	29,395	94,939	18,263	**149,806**	7,208	31,737	100,413	18,266	**157,624**
	Residential A	4,996	15,255	29,054	22,133	**71,438**	3,913	11,200	21,208	16,647	**52,968**	3,914	11,201	21,208	16,648	**52,970**
2	Residential B	321	1,120	605	1,290	**3,336**	625	1,266	542	2,665	**5,098**	207	822	338	798	**2,164**
0	Residential C	-	25,082	24,391	58,919	**108,391**	-	27,755	38,620	55,380	**121,755**	-	25,498	32,621	55,880	**113,999**
1	Residential D	-	3,378	3,045	14,753	**21,176**	-	3,460	5,909	14,118	**23,487**	-	3,270	4,890	13,736	**21,896**
3	Residential E	-	89,180	85,745	107,013	**281,938**	-	70,707	65,199	84,980	**220,886**	-	87,215	96,875	99,550	**283,641**
	Com/Indus	1,661	46,678	24,328	68,373	**141,040**	1,650	46,270	25,346	67,305	**140,571**	1,626	46,489	25,490	67,487	**141,091**
	Roads	1,804	28,100	13,471	12,668	**56,042**	1,836	27,388	13,630	11,529	**54,383**	1,715	27,745	14,299	11,584	**55,343**
	Septic Systems	8,040	39,589	105,638	29,054	**182,321**	7,595	30,603	97,141	20,692	**156,031**	6,464	34,154	105,198	20,604	**166,420**

7.1.4. Model Runs

For the years 2003, 2008, 2013, there were Trend, Expend, and Alternatives 1 and 2 scenarios model runs. Since 1998 model runs represent the present and not future conditions, there was no reason to include runs for Alternatives 1 and 2. So in all, there were fourteen separate model runs necessary to simulate the four scenarios. What follows is a listing and brief description of the model runs used to generate the model results:

1998TRND The model run 1998TRND was the base case scenario. It represents the conditions that are estimated to currently exist, as described in the previous chapter.

1998XPND The run 1998XPND was the same as 1998TRND, except the nitrogen load constraint was changed to the cap level. In this way 1998XPND suggests the additional costs that would have incurred if the cap had been met for this year.

2003TRND To simulate Trend conditions in 2003, changes were made to both the agricultural and urban submodules. First, the amount of agricultural land use and livestock in each subregion was adjusted to reflect expected changes. Secondly the number of existing agricultural BMPs was increased to reflect increased adoption of BMPs due to current cost share efforts. Finally, urban land use acres were adjusted to reflect the impact of population growth between 1998 and 2003.

2003XPND The run 2003XPND was the same as 2003TRND, except the nitrogen load constraint was changed to the cap level.

2003ALT1 The nitrogen load constraint was set to the cap level for this run, and the parameters for new urban land were adjusted to prohibit low-density residential patterns.

2003ALT2 The nitrogen load constraint was set to the cap level for this run, and the parameters for new urban land were adjusted to only allow for contiguous residential patterns.

2008TRND To simulate Trend conditions in 2008, changes were again made to the agricultural and urban submodules. The level of agricultural land use and livestock in each subregion was adjusted to reflect expected changes, but the number of existing agricultural BMPs was not increased. This is based upon the assumption that for the implementation of additional BMPs after the year 2003, would require additional cost share money beyond what is currently spent. Urban land use acres were adjusted to reflect the expected impact of population growth between 1998 and 2008. More land went out of agricultural production that was predicted for subregion 3Z, in order to accommodate the increase in urban land.

2008XPND The run 2008XPND was the same as 2008TRND, except the nitrogen load constraint was changed to the cap level.

2008ALT1 For 2008ALT1 agricultural land use levels were the same as they were for 2008XPND. The nitrogen load constraint was set to the cap level for this run, and the parameters for new urban land were adjusted to prohibit low-density residential patterns.

2008ALT2 For 2008ALT2 agricultural land use levels were the same as they were for 2008XPND. The nitrogen load constraint was set to the cap level for this run, and the parameters for new urban land were adjusted to only allow for contiguous residential patterns.

2013TRND For 2013TRND agricultural land was only reduced enough to allow for the increase in urban land for all the subregions except 3Y and 3Z. In subregion 3Y both forest and agricultural land was reduced to accommodate new urban land. In 3Z, all remaining agricultural land was completely converted to urban, and the amount of forestland had to be reduced past its minimum level. The new urban land use parameters were changed to reflect the impact of expected population growth between 1998 and 2013.

2013XPND The run 2013XPND was the same as 2013TRND, except the nitrogen load constraint was changed to the cap level.

2013ALT1 For 2013ALT1 agricultural land use levels were allowed to adjust within a range of values. The upper bound of this range was 2008TRND levels and the lower bound was the 2013TRND levels. The nitrogen load constraint was set to the cap level for this run, and the parameters for new urban land were adjusted to prohibit low-density residential patterns.

2013ALT2 For 2013ALT2 agricultural land use levels were handled in the same manner as they were for 2013ALT1. The nitrogen load constraint was set to the cap level for this run, and the parameters for new urban land were adjusted to only allow for contiguous residential patterns.

7.2. PREDICTED TRENDS

The first objective of the study was to make predictions of the expected N load to the Potomac River, from the three regions being considered. This was done with the Trend Scenario runs for the years 1998, 2003, 2008, and 2013. In order to derive these predictions, estimates of land use acreage, population levels, and point source flows were made. The methodology for generating these predictions has been outlined in the two previous chapters.

The first prediction was for the current year 1998, and it had three purposes. First, this provided a prediction of how close the state is towards meeting their N reduction goal. Secondly, the results of this study could be compared to results used by the Chesapeake Bay Program and the state of Virginia. Thirdly, the results provide the baseline, by which to measure future trends in N loadings. The predictions for the years 2003, 2008, and 2013 provide the additional information necessary to predict this future trend.

7.2.1. Summary of Current(1998) Estimates

The model results for the year 1998 have been organized by land use levels and N loadings. The model generated land use levels for each subregion considered. These land use levels are summarized in Table 7.2. The model also generated N loadings for each of these subregions and these are summarized in Table 7.3.

It is evident from Table 7.3, that the total Basin load exceeds the N goal of 21,386,314 pounds of N annually, mentioned earlier in the chapter. The table also suggests that the greatest source of N to the Potomac is point sources followed by urban land use, agricultural land use, and then forestland. Since farm practices tend to produce the highest N load per acre, it was surprising to see that nonpoint urban sources contributed a greater amount of N to the Potomac River than did agricultural sources. However, This is likely for several reasons. First, farmland acreage has been declining while urban acreage has been increasing. Secondly, over the past 13 years, the majority of nonpoint pollution control efforts have been directed toward agricultural sources of N. Thirdly, the greatest concentration of agricultural land is in the Southern Shenandoah, while the greatest portion of urban land is in Northern Virginia. So many of the nutrients entering the Shenandoah river from this region are removed by biophysical processes before they ever reach the fall line of the Potomac. By contrast much of the urban land in Northern Virginia drains into the Potomac below the fall line.

Table 7.2. Total Estimated Land Use Levels (acres) in Virginia's Potomac Basin, for 1998.

	Farm Land	Forest Land	Urban Land	Region Land
Subregion 1X	26,425	44,134	1,153	71,712
Subregion 1Y	380,420	513,940	82,846	977,206
Subregion 1Z	95,980	140,640	10,318	246,938
Southern Shenandoah	502,825	698,714	94,316	1,295,855
Subregion 2X	71,390	123,130	33,621	228,141
Subregion 2Y	12,935	31,555	7,377	51,867
Subregion 2Z	206,510	339,880	29,269	575,659
Northern Shenandoah	290,835	494,565	70,267	855,667
Subregion 3W	48,149	24,095	7,462	79,706
Subregion 3X	192,030	42,944	177,330	412,304
Subregion 3Y	93,384	168,840	141,900	404,124
Subregion 3Z	22,470	42,091	239,990	304,551
Northern Virginia	356,033	277,970	566,682	1,200,686
Potomac Basin	Farm Total	Forest Total	Urban Total	Basin Total
	1,149,693	1,471,249	731,266	3,352,208

Table 7.3. Total Estimated Nitrogen Loadings (pounds) to the Potomac River, from Virginia, for 1998.

	Farm Load	Forest Load	Urban Load	Nonpoint Source Load	Point Source Load	Region Totals
Subregion 1X	127,175	130,710	18,447	276,331		
Subregion 1Y	2,960,792	1,364,800	861,760	5,187,352	702,690	
Subregion 1Z	977,808	334,640	197,186	1,509,634		
Southern Shenandoah	4,065,775	1,830,150	1,077,392	6,973,317	702,690	7,676,007
Subregion 2X	339,304	390,970	398,369	1,128,644	324,840	
Subregion 2Y	57,572	83,724	95,773	237,069		
Subregion 2Z	1,064,476	810,870	449,760	2,325,106	455,970	
Northern Shenandoah	1,461,353	1,285,564	943,902	3,690,819	780,810	4,471,629
Subregion 3W	262,186	77,547	132,349	472,082		
Subregion 3X	1,096,513	134,610	1,831,910	3,063,033	1,127,900	
Subregion 3Y	744,123	443,900	2,177,230	3,365,253	2,526,000	
Subregion 3Z	140,977	109,800	2,315,275	2,566,052	4,803,400	
Northern Virginia	2,243,798	765,857	6,456,764	9,466,419	8,457,300	17,923,719
Virginia Potomac Basin	**Farm Total** 7,770,926	**Forest Total** 3,881,572	**Urban Total** 8,478,058	**NPS Total** 20,130,555	**Point Total** 9,940,800	**Basin Total** 30,071,355

The Table 7.4 provides a comparison of the model N load results, referred to as Potomac Basin Model, with predictions for the years 1985, 1994, and 1996. The 1985 and 1994 predictions are from the VDCR, while the 1996 prediction is from the Chesapeake Bay Program.[8] All three of these predictions are based upon results from the CBWQM. A direct comparison between these predictions, and those of this study, is made difficult by the fact that land use was not always accounted for in the Potomac Basin Model as it was for in the CBWQM. The forested acres that exist on farms are counted as farmland in permanent vegetation by this study's model, while they are counted as forestland by the CBWQM. This results in approximately a million pounds of N that would be considered to be coming from forestland by the CBWQM, is counted as agricultural loadings in the 1998 results. Secondly, the loadings from residential pattern F are counted as urban loadings by this study's model, while these DUs are not considered by the CBWQM. This causes the urban 1998 urban load to be 708 thousand pounds more than it would be under the CBWQM.

Estimates of N loadings from agriculture, forestland, and point sources are all reasonably similar and appear to be moving in a downward trend. However, there is a considerable discrepancy between the loadings from urban land uses. Although each prediction indicates a general upward trend, loadings increase by 25% over the 9 years between 1985 and 1994, 56% over the next two years, and then by 69% from 1996 to 1998. This appears to suggest that urban loadings were increasing exponentially. However, the more likely case is that different methods for computing loading rates, BMP adoption and effectiveness, and urban land use levels, are the reason for the degree of difference between the predictions.

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[8] The 1996 numbers were initially for the entire Virginia Potomac Basin including the Northern Neck Region. 1994 load estimates from the VDCR, for the Northern Neck were used to adjust the 1996 CBP numbers to reflect only the regions considered in this study. Therefore, these numbers may differ slightly from the actual CBP predictions for the portion of the Basin considered in this study.

Table 7.4. Comparison of Predictions for the Annual Nitrogen Load to the Potomac Basin, used by the Virginia Department of Conservation and Recreation (VDCR), Chesapeake Bay Program (CBP), and this study.

Year (Source)	Farm Load	Forest Load	Urban Load	Nonpoint Source Load	Point Source Load	Basin Load
1985 (VDCR)	12,012,296	4,474,631	2,573,047	19,059,974	10,033,547	29,093,521
1994(VDCR)	11,709,940	4,311,424	3,217,235	19,238,599	10,446,780	29,685,379
1996 (CBP)	8,874,680	2,862,340	5,021,510	16,758,530	10,001,960	26,760,490
1998 (Potomac Basin Model)	7,770,926	3,881572	8,478,058	20,130,555	9,940,800	30,071,355

Table 7.5. Comparison of Predicted Land Use Levels within the Virginia Potomac Basin, used by the Virginia Department of Conservation and Recreation (VDCR), Chesapeake Bay Program (CBP), and this study.

Year (Source)	Farm Land	Forest Land	Urban Land	Total Land
1985 (VDCR)	1,231,396	1,748,026	361,485	3,340,907
1994(VDCR)	1,203,389	1,685,280	452,256	3,340,925
1996(CBP)	1,264,012	1,551,246	539,576	3,354,834
1998 (Potomac Basin Model)	1,149,693	1,471,249	731,266	3,352,208

As mentioned above, the Potomac Basin Model includes estimated loads from rural residential housing. It is unlikely that the impact from this dispersed form of housing was considered within the CBWQM. Yet, the model run 1998TRND estimates that the additional N loading from these acres amounts to 707,936 pounds of N per year. Assuming that this source of N hasn't been included in the CBWQM, this could be one source for the difference. By subtracting the rural housing N load from the urban load, then the 1998 numbers are 71% higher than the 1996 prediction.

According to CBP, 1.17 million pounds of the 1996 load estimate was a result of septic systems (CBP, 1998). Although the CBWQM calculates the additional loadings from septic systems, they only consider the nitrate-N loadings, and not potential ammonia-N loadings (CBP, 1998). However, measurements of between 10-78 mg/l of ammonia-N have been measured reaching groundwater from septic systems (Novotny & Olem, 1994). The total load from septic systems, estimated by the Potomac Basin Model, for 1998, was 2.84 million pounds of N. This a difference of 1.67 million pounds per year. As was alluded to in the previous chapter, there is considerable uncertainty in estimating the contribution of septic systems to the overall urban loading rate. Therefore, it is not unexpected that the loading estimates would vary considerably.

If both, the difference between septic system loads and the rural residential load, are subtracted from the total 1998 urban load, the new load is 6.1 million pounds of N per year. This is 21.4% more than the 1996 estimate. The most likely reason for the remainder of this difference is due to different estimates of urban land levels. The 1998 estimate of land used (Table 7.5) for this study is 731,266 acres, while the number estimated for the 1996 prediction is 553,260. This is a 32% difference that more than compensates for 21.4% difference in loadings, and actually suggests that the average per acre urban load is slightly less for this study.

7.2.2. Summary of Future Predictions

The model runs: 2003TRND, 2008TRND, and 2013TRND, are used to create a description of how future population growth and land use changes could potentially effect N loadings to the Potomac. In general the trend shows a continued gradual increase in the total loadings to the Potomac (Figure 7.1). The Figure 7.2 depicts the trend in N loads for each of the four major sources of N. When the trend line in Figure 7.1 is compared to the values from Table 7.4, the loading trend from 1998 to 2013 seems to be consistent with the load increase from 1985 to 1994 in the table. The one anomaly in this overall trend appears to be the estimate for 1996 from Table 7.4. This suggests that the overall trends in N loadings are very stable, and the anomaly that occurs can be attributed to differences in measuring land use and N loads.

One potential reason for the anomaly is that these numbers reflect the increased adoption of BMPs, particularly by point sources and the agriculture sector. The increased adoption rate is due in part to stepped up efforts by the state in order to meet the N reduction goal, by the year 2000. By contrast, the period before 1996 and the period after 1998, reflect the general effects of two long-term trends in the Basin. One being, a gradual decline in the amount of land used for agricultural production. The second being, the effects of population growth, which increases both urban acreage and flows to point sources.

The trend lines from 1998 to 2013 do not reflect any increase in BMP adoption, except for adoptions of additional farm BMPs between 1998 and 2003. This is because the trend lines are supposed to reflect loading rates as a result of sustaining the current annual level of spending, by the State and Federal Governments, and by private individuals within the Basin. By including additional farm BMPs, for the period between 1998 and 2003, the assumption is made that, at current cost share spending levels, additional farm BMPs will be adopted in this time period. This however, neglects to include the additional costs that may be spent by farmers on these new BMPs.

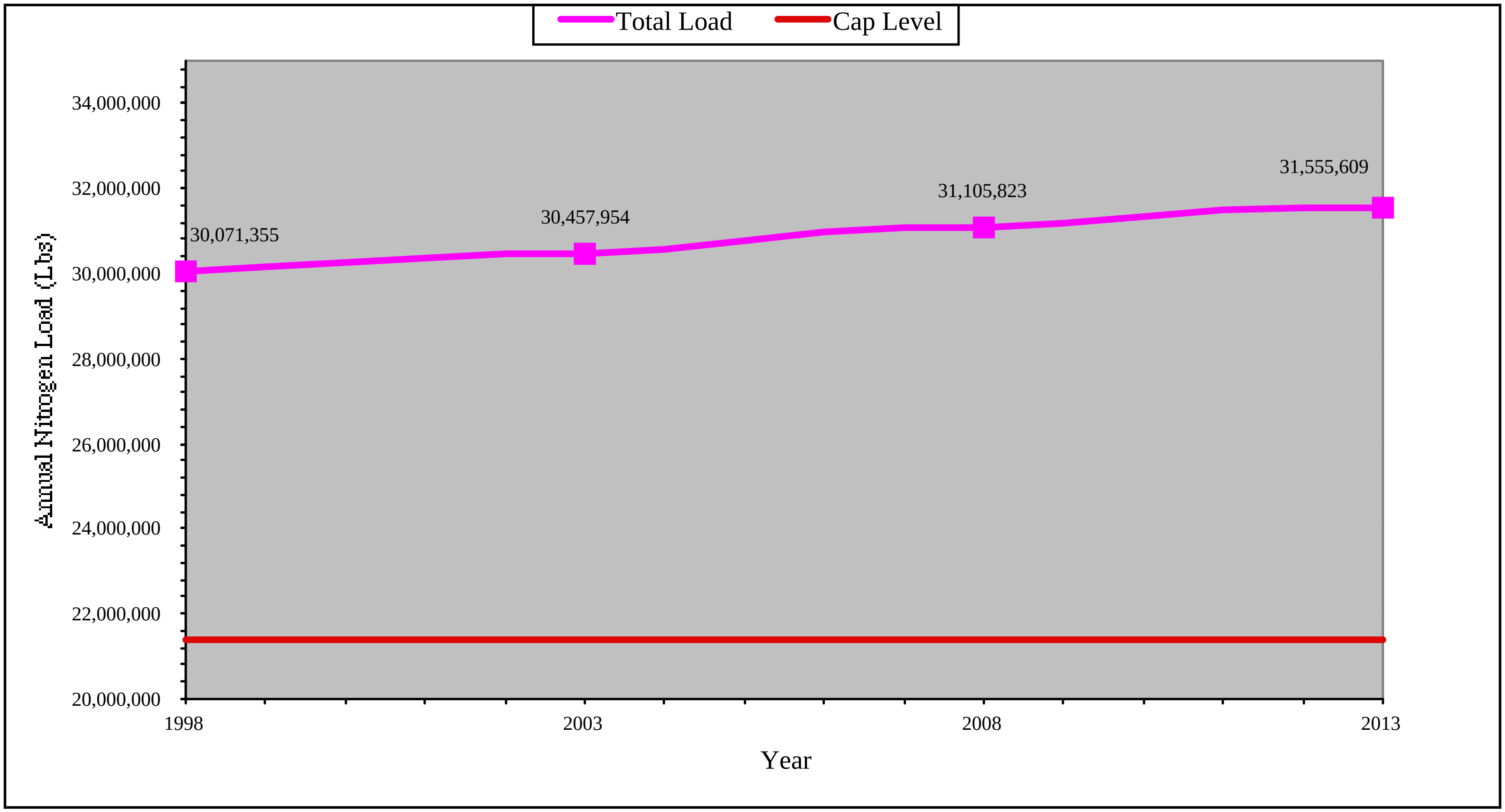

Figure 7.1. Predicted Trend of Total Nitrogen Load to the Potomac River, from Virginia.

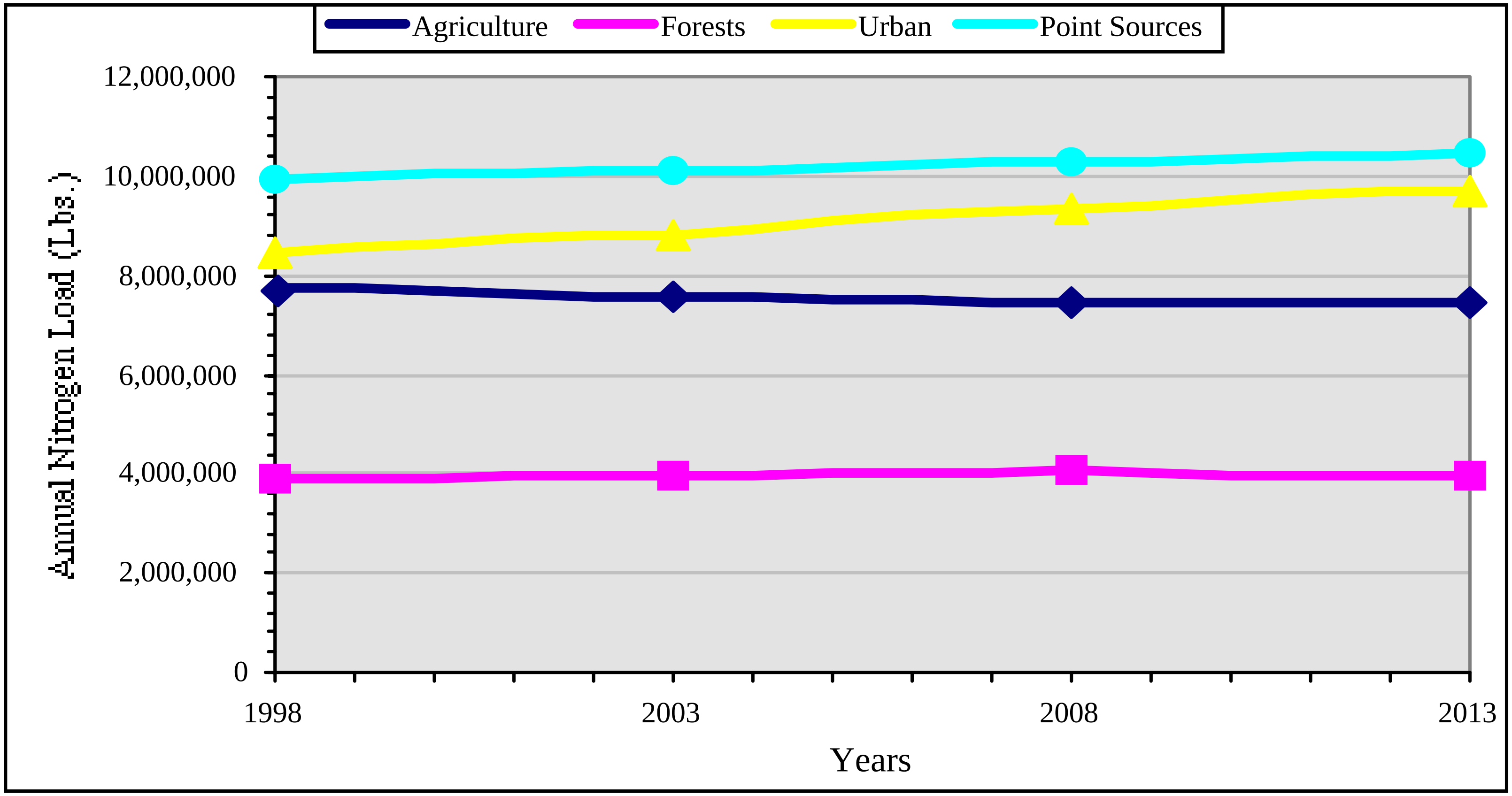

Figure 7.2. Predicted Trend in Nitrogen Loads, from Four Major Sources, to Potomac River, from Virginia.

Even with the inclusion of additional agricultural BMPs, the decline in farm loading rates between 1998 and 2003 is not as sharp as it was between 1994 and 1998. There are two likely reasons that the decline in loadings is not as great. The first being, that as more farm BMPs are adopted for the same acres, the predicted reduction in N becomes muted for each BMP. In other words, two BMPs which will both reduce loadings by 50%, applied together on the same acre, will reduce loadings by 75% not 100%, according to the model. For a more detailed explanation see the previous chapter. The other factor, which has a dampening effect on the decline in agricultural N loads, is that although farmland acres are in decline, the amount of livestock in the Basin will actually increase over this period.

In general what Figure 7.2 suggests is that N loadings from agriculture and forestry loadings will continue to decline slightly, even without the adoption of additional BMPs. This will be due in part to a decline in forest and farmland (Figure 7.3). Much of this decline will be caused by development pressures from urban growth. Yet the model predictions for decline in agricultural land exceed the number of acres required to accommodate urban growth. This suggests that the decline in the amount of land used for agricultural production cannot be contributed solely to urbanization, and it is likely that many farms will cease to operate as a result of other socioeconomic factors. Because of this total forest acres actually increase slightly from 1998 to 2008, as shown in Figure 7.3.

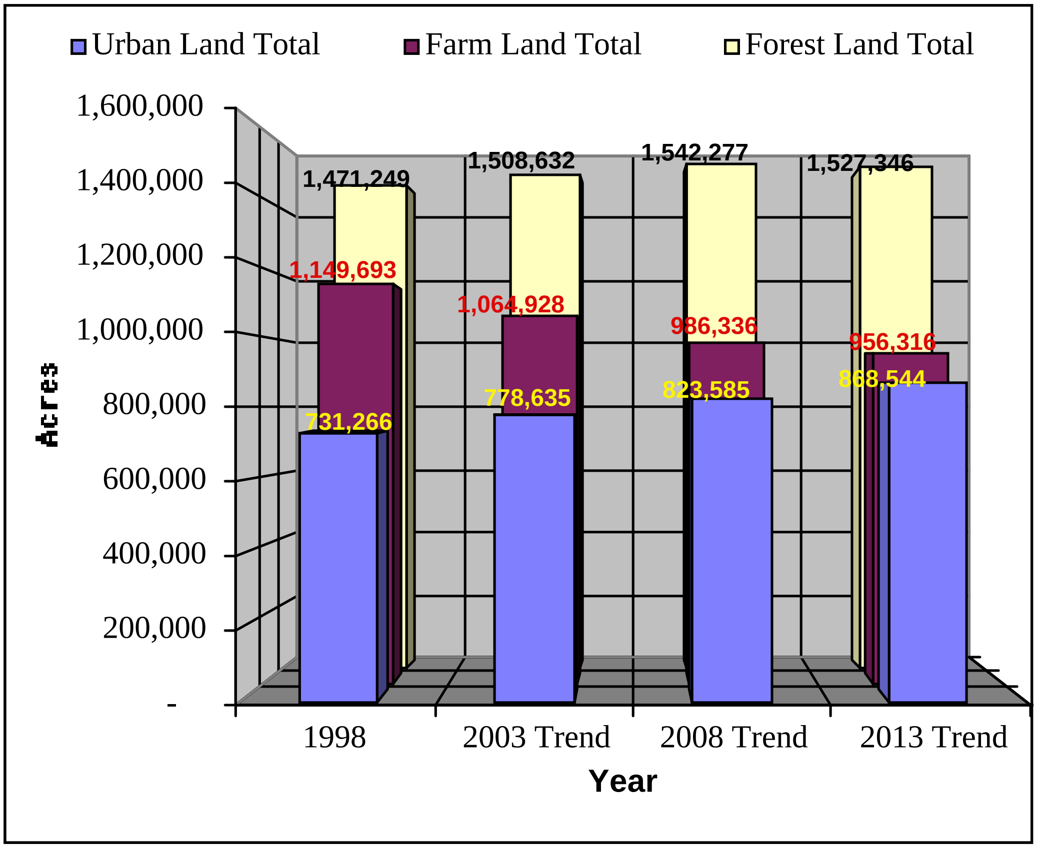

Figure 7.3 Estimated Changes in Land Use Acreage for Virginia's Potomac Basin

When the model results from 2013TRND are compared with those from 1998TRND, the overall N load increased by 1.48 million pounds (Figure 7.1). From Figure 7.2 it is evident that the greatest N load increase comes from urban sources. Over this 15 year time span an estimated 60,704 new septic systems will be installed within the Basin. The N loadings generated from these systems accounts for 66% of the increased urban load. If septic systems are factored out of urban loadings, the total NPS nitrogen loadings from 1998 to 2013 increase by only 167,614 pounds. When the additional load from septic systems and point sources are combined, it turns out that the additional wastewater needs from the population increase results in a N load increase of 1.32 million pounds. This suggests that the principle cause for the increased annual load over the fifteen-year period is a direct result of the wastewater needs of the new population within the Basin.

7.3. PREDICTING THE COST OF MEETING THE NITROGEN CAP

The second objective of the study was to make predictions of the expected total annual costs of meeting and maintaining the N cap. These costs are in addition to what is currently being spent, and it is assumed that all parties are already committed to maintain current spending levels, in perpetuity. The Expend Scenario runs were used to derive these cost figures. The run 1998XPND is used to ascertain cost estimates for meeting the cap this year. It also provides a base cost by which future costs can be compared. The runs 2003XPND, 2008XPND, and 2013XPND are used develop a predicted trend for maintaining the N goal over time.

The cost figures generated by the model are a function of the BMPs chosen by the model. As the N load grows, more BMPs are needed to meet the N cap, thus causing the cost of meeting the cap to rise. Increases in N loads can stem from two situations. The first situation, is that land uses are staying the same but sources of N are increasing. For instance, population growth causes increases in wastewater flow to point sources, and growth in livestock numbers causes increased loadings from animal waste facilities. The other situation that can cause an increase in N is when acreage changes from one land use, to another land use that generates a higher N loading. However, this second situation may or may not cause an increase in cost. For instance the change in land use, on an acre, could result in a slightly higher load, but also allow for the use of a different set of BMPs with a much greater cost efficiency. This could then cause the cost for reducing N loadings from that acre to decline.

Results from each run of the model provide information on which BMPs were needed to meet the cap. The number of acres that can be covered by BMPs during each model run, is a function of the land use parameters for that run. As land use parameters change, so does the potential level implementation for each BMP. Therefore, changes in land use, also has an indirect impact on the cost of meeting the goal.

7.3.1. Summary of Costs for Meeting the N Goal

The primary purpose for estimating the additional costs necessary to meet the goal in 1998, a baseline can be established for comparison with cost predictions from other years. Figure 7.4 provides a summary of total, average and marginal costs for the year 1998. The difference between the net revenues for 1998TRND and 1998XPND provides the total cost estimate. The large difference between the average and marginal cost suggests that the task of meeting the N reduction will become increasingly expensive, per pound of N reduced, as the state gets closer to meeting the goal.

Looking at the net revenues for both the 1998TRND it may appear unusual that point sources are generating revenues. Certainly industrial plants that are point sources could be turning a profit. However, as mentioned in the previous chapter, the only economic consideration for point sources was the cost of retrofitting. The reason revenues are positive for point sources, is because two of the retrofits are predicted to actually save on operating expenses; and the 236 thousand dollars is the estimated annual savings.

Net Revenues Under 1998TRND		**Total Annual Costs**		**% of Cost**
Agricultural Net Revenues	$194,520,000	Farm Cost	$4,690,000	18%
Forestry Net Revenues	$20,033,000	Timber Costs	$206,000	1%
Urban Net Revenues	$0	Urban Costs	$0	0%
Point Source Net Revenues	$235,780	Point Source Costs	$21,900,000	82%
Net Revenues Under 1998XPND			$26,796,000	
Agricultural Net Revenues	$189,830,000			
Forestry Net Revenues	$19,827,000	At the Cap, the Average Cost of		
Urban Net Revenues	$0	Reducing a Pound of Nitrogen is:		
Point Source Net Revenues	$-21,900,000		$3.09	
Cost of reducing Nitrogen load 1,000 lbs below Cap				
Agricultural Net Revenues	$-720,000	At the Cap, the Marginal Cost of		
Forestry Net Revenues	$-495,000	Reducing a Pound of Nitrogen is:		
Urban Net Revenues	$0		$10.49	
Point Source Net Revenues	$-9,270,000			
	$-10,485,000			

Figure 7.4. Cost Summary for Meeting the N reduction Goal in 1998.

Looking at the total annual costs, it is apparent that the vast majority of the additional money spent would need to go towards point source retrofits. This coincides with the evidence from Table 7.6, which shows where N reductions, would occur in order to meet the Cap at the lowest cost. The point source load reductions makeup 61% of the total reductions necessary. Two factors determine where the model chooses to reduce N loadings: the cost effectiveness of employing a BMP; and the potential amount of the BMP that can be implemented. To understand why so much of the reductions occur at point sources, it is necessary to look at mix of BMPs chosen from the other sectors. Results revealed that 86% of potential forest BMPs were being utilized, and from Figure 7.4, it is apparent that no BMPs were chosen from the urban sector. This leaves the agricultural BMPs to consider.

In general, a high percentage of the agricultural BMPs, which could potentially be used, were chosen by the model (Table 7.7). The Table 7.7 provides estimates on the number of farm acres, and animal units, upon which BMPs were used under 1998XPND. The table also shows how close this number is to the potential limit of adoption. From the table it is apparent that some BMPs which have a relatively high cost efficiency, were not being used to their fullest extent. Again this is do in part to the way the model is configured to implement more than one BMP on a given acre. As mentioned previously, costs for all the BMPs on one acre will be added together , while the removal efficiencies are multiplied. So as more BMPs are used on the same acre the cost effectiveness, or pounds reduced per dollar, is declining. For example, on cropland, where five potential BMPs can be used, there are 35 possible combinations for each acre. Each combination has a different cost effectiveness. Ironically using all five at once will reduce the most amount of N, but will also have the lowest cost effectiveness.

Table 7.6. Comparison of Nitrogen Loadings from 1998TRND and 1998XPND Model Runs (pounds/year)

Regions	1998TRND Farm Load	1998TRND Forest Load	1998TRND Urban Load	1998TRND NPS Load	1998TRND PS Load	Region Totals
Southern Shenandoah	4,065,775	1,830,150	1,077,392	6,973,317	702,690	7,676,007
Northern Shenandoah	1,461,353	1,285,564	943,902	3,690,819	780,810	4,471,629
Northern Virginia	2,243,798	765,857	6,456,764	9,466,419	8,457,300	17,923,719
Basin Totals	7,770,926	3,881,572	8,478,058	20,130,555	9,940,800	30,071,355
Regions	**1998XPND Farm Load**	**1998XPND Forest Load**	**1998XPND Urban Load**	**1998XPND NPS Load**	**1998XPND PS Load**	**Region Totals**
Southern Shenandoah	2,212,636	1,825,250	1,077,392	5,115,278	402,160	5,517,438
Northern Shenandoah	997,400	1,275,283	943,902	3,216,585	216,888	3,433,474
Northern Virginia	1,405,213	756,653	6,456,764	8,618,631	3,816,740	12,435,371
Basin Totals	4,615,249	3,857,187	8,478,058	16,950,494	4,435,788	21,386,282
Regions	**Reductions Farm Load**	**Reductions Forest Load**	**Reductions Urban Load**	**Reductions NPS Load**	**Reductions PS Load**	**Region Totals**
Southern Shenandoah	1,853,139	4,900	0	1,858,039	300,530	2,158,569
Northern Shenandoah	463,953	10,281	0	474,234	563,922	1,038,155
Northern Virginia	838,585	9,204	0	847,789	4,640,560	5,488,349
Basin Totals	3,155,677	24,385	0	3,180,062	5,505,012	8,685,073

Table 7.7 Agricultural Best Management Practices Implemented Under 1998 XPND Model Run.

Year 1998		SOSH		NOSH		NOVA	
Best Management Practices		1998 BMPs under Cap	% of potential adoption	1998 BMPs under Cap	% of potential adoption	1998 BMPs under Cap	% of potential adoption
Conservation Tillage	ac	65,019	100.00%	19,705	100.00%	16,062	38.97%
Nutrient Management	ac	162,137	88.16%	83,999	88.28%	68,020	55.99%
Vegetative Filters	ac	4,512	6.94%	-	0.00%	135	0.33%
Cover Crops	ac	54,340	83.58%	355	1.80%	10,286	24.96%
Contour & Strip Crops	ac	65,019	100.00%	19,705	100.00%	31,394	76.17%
Dairy Waste Facilities	au	34,730	99.35%	4,132	97.95%	3,170	73.28%
Confinement Lot Man.	au	35,307	100.00%	4,261	100.00%	4,369	100.00%
Poultry Waste Facil.	au	4,962,224	100.00%	487,320	100.00%	-	100.00%
Grazing Land Protec.	ac	222,436	100.00%	107,506	100.00%	144,576	100.00%
Stream Bank Protec.	ac	22,672	10.19%	723	0.67%	1,493	1.03%
Permanent Veg. Cover	ac	94,646	72.75%	87,223	81.20%	88,761	77.85%

7.3.2. Parametizing Cost Curves for Nitrogen Reductions

From the results discussed above, it is apparent that most of the reductions in N will need to come from point sources, in order to meet the goal. Likewise, the majority of the costs for meeting the goal, will come from point source retrofits. However, it would be interesting to see how the cost of reducing N to the Potomac changes as more N is reduced. By systematically adjusting the total level of allowable N loadings by one million pounds, a total cost curve can be sketched. One benefit of such a curve, is that it can provide an indication of the sensitivity of total costs to parameter errors. Clearly, total costs will be sensitive to errors in cost parameters. However, the total predicted cost is also sensitive to loading rates, BMP effectiveness, and feasible level of BMP implementation. This is because the total cost is a direct function of the choice of BMPs, and the model's choice of BMP is a function not of BMP cost per se, but of BMP cost effectiveness ratios, and feasible implementation. (For a more thorough discussion of this aspect of the model's structure see Chapter 5.)

From Figure 7.5 it is evident that the total cost of reducing N loads to the Potomac rises exponentially as the level of N is reduced. The graph shows that the N cap level intersects the cost curve at approximately $26.8 million. This intersects the total cost curve at a point where the slope of the curve is transitioning from a horizontal incline to a vertical incline. If the state's goal was to reduce N by only 25%, the N cap would be approximately at 24.4 million pounds At that level, the cost would be a manageable $12.1 million per year. If the goal were to reduce controllable N by 55%, this would be equivalent to moving the current N cap three million pounds to the right on the graph. The annual cost then escalates to $76.5 million a year, which would financially be very difficult for the state to support perpetually. This evidence suggests that the total estimated cost is indeed sensitive to potential parameter errors.

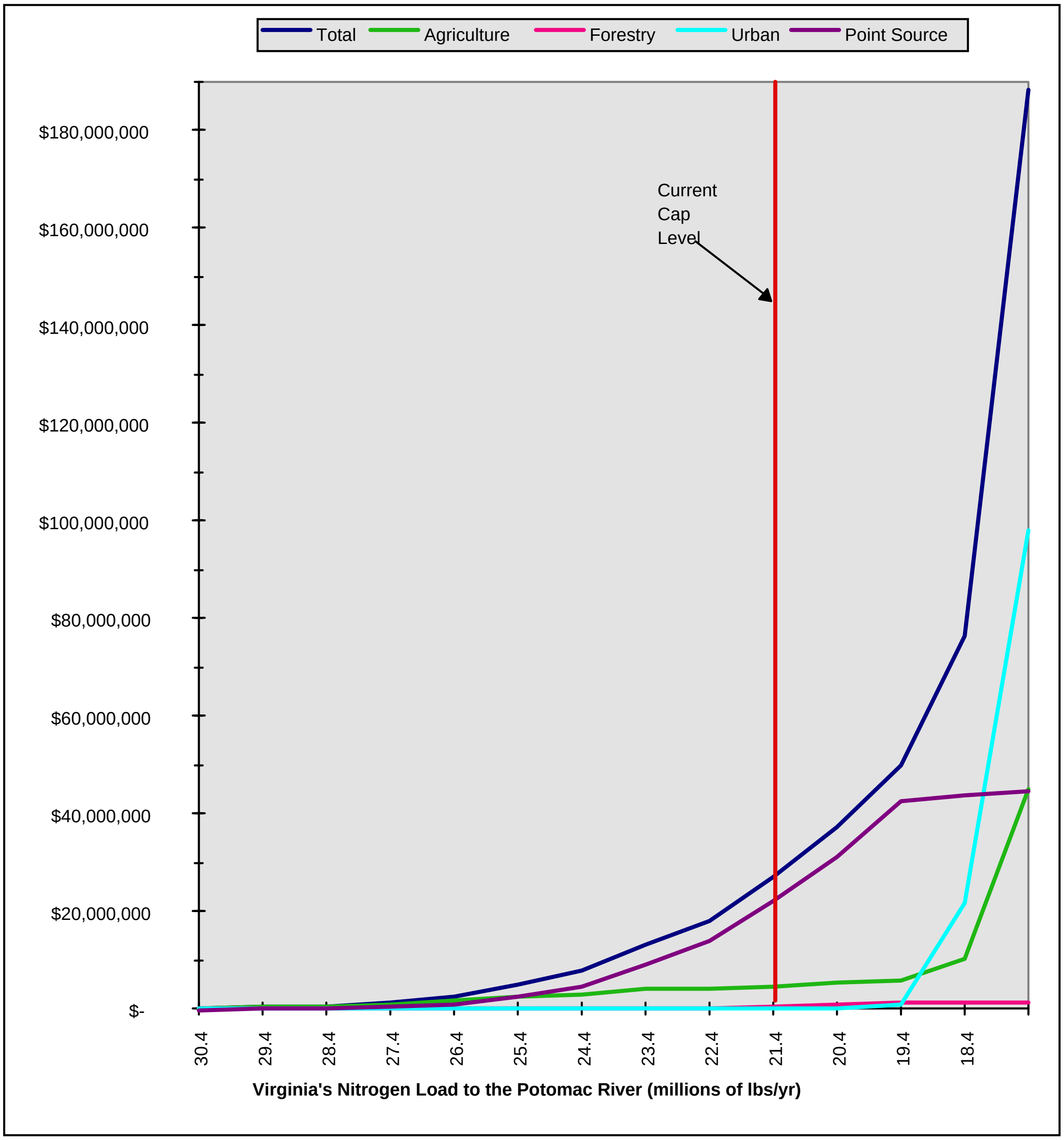

Figure 7.5. The Total Cost of Allowing Different Levels of Nitrogen from Virginia's Potomac Basin, for the year 1998.

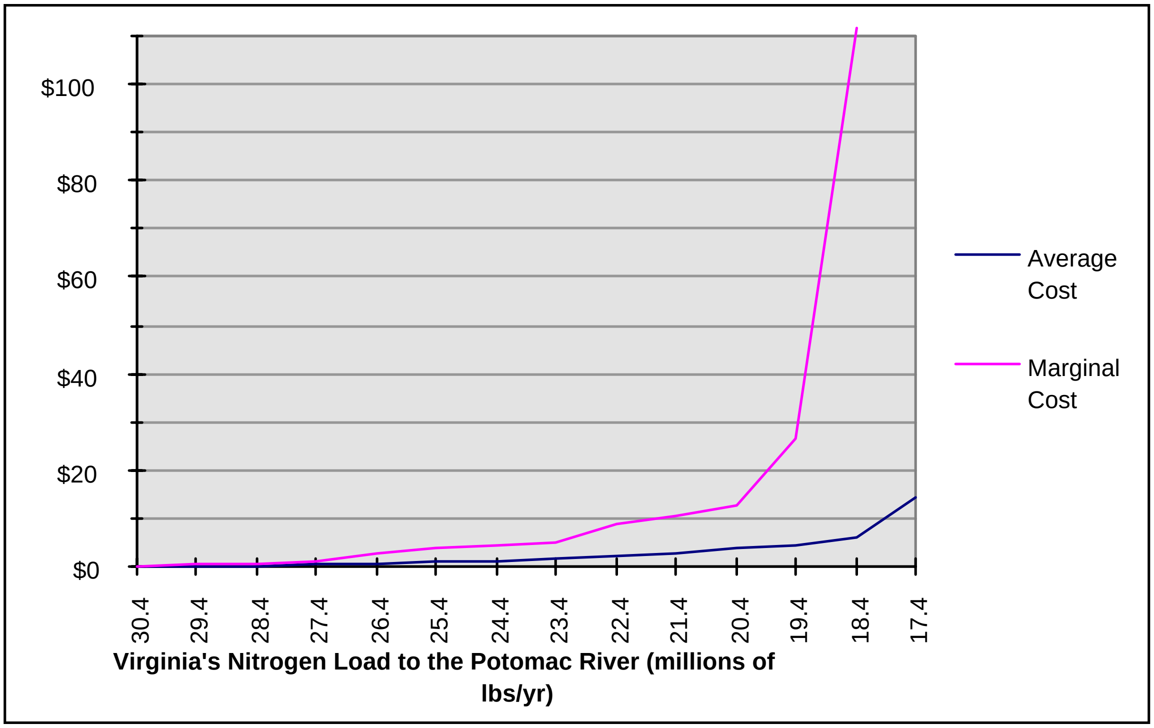

Figure 7.6. The Average and Marginal Cost of Allowing Different Levels of Nitrogen from Virginia's Potomac Basin, for the year 1998.

The trajectory of the total cost curve, is notably influenced by the use of point source retrofits (Figure 7.5). This is true until the load is reduced to 20.4 million pounds After that point, the model begins to rely less on point source retrofits, and begins relying more on expensive Urban BMPs and the remaining agricultural BMPs. The heavy emphasis on point source retrofits suggests that the results are particularly sensitive to the parameters of the point source submodule.

Like the total cost curve, the marginal cost curve rises at moderate rate until the cap is reduced to 20.4 million pounds of N (Figure 7.6). Between 20.4 and 19.4 million pounds of N, the marginal cost doubles, and from 19.4 to 18.4 pounds it increases by 318%. As expected the average cost curve is trending upward as well, but at a much more gradual rate.

7.3.3. Predictions of Future Costs for Maintaining Cap

The total cost curve in Figure 7.5 gives a depiction of how the total cost changes as total loads are varied, but all other parameters are held constant. Another useful way to construct cost curves is to keep the nitrogen constraint fixed at the cap level, and to vary the land use parameters instead. This is a means for representing changes in costs as they are likely to occur over time. By using time as the independent variable to construct total, average, and marginal cost curves, the potential affects of future population growth and land use changes on the cost of meeting the N goal can be examined. The model runs: 2003XPND, 2008XPND, and 2013XPND, are used to create a sketches of these cost curves.

The Figure 7.7 shows the projected trend in total costs. Over the fifteen-year period, the total cost is predicted to rise from $26.4 million to $38 million. The rate of increase is relatively constant, suggesting that increase in total costs will continue after 2013, at a stable rate. Since population numbers and urban acres are both steadily rising over this same period, this suggests that there is a direct correlation between urban growth and an increasing cost for meeting the cap. From the results of the Trend Scenario, it is estimated that population and urban growth will cause the 2013 annual N load to be 884 thousand pounds more than in 1998. Over this same time period urban acres grow, while farm acreage declines, thus changing the mix of available BMPs. However, it is difficult to discern relative importance of both of these effects.

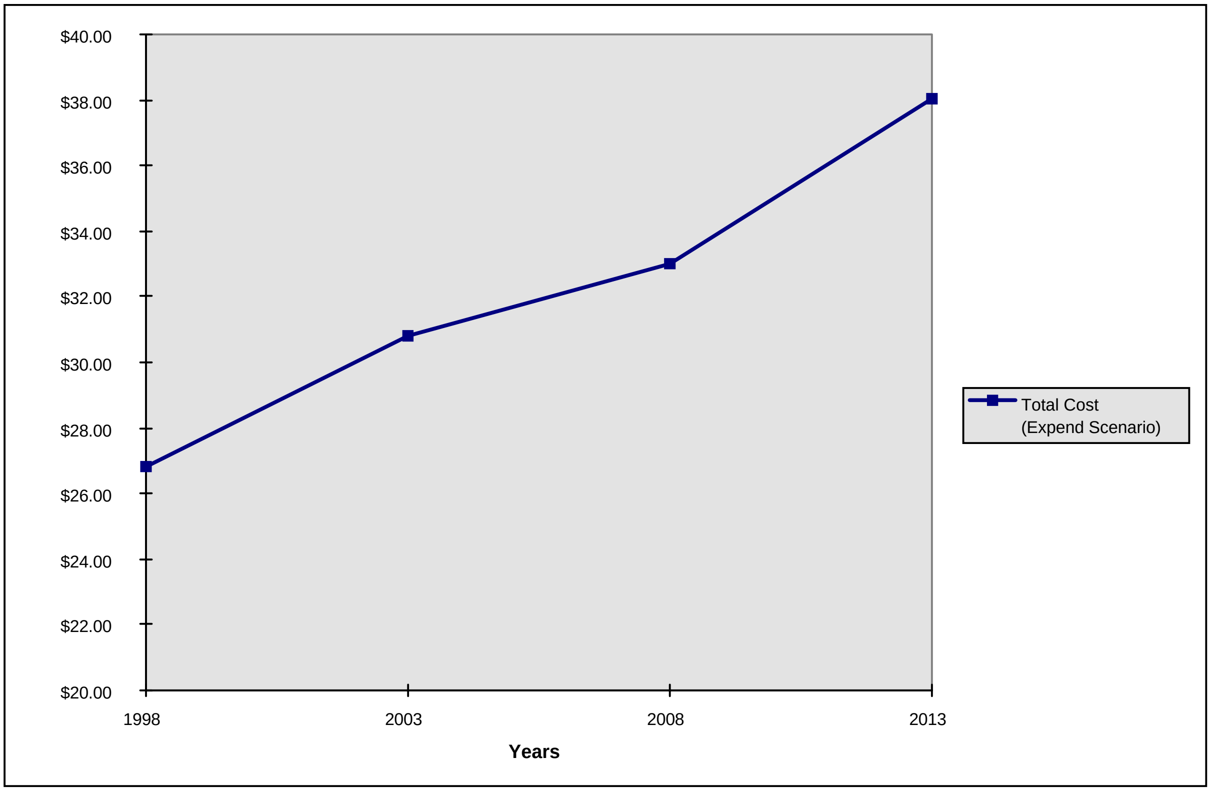

Figure 7.7. Trend in Total Annual Costs for Maintaining the N Reduction Goal For Virginia's Potomac Basin.

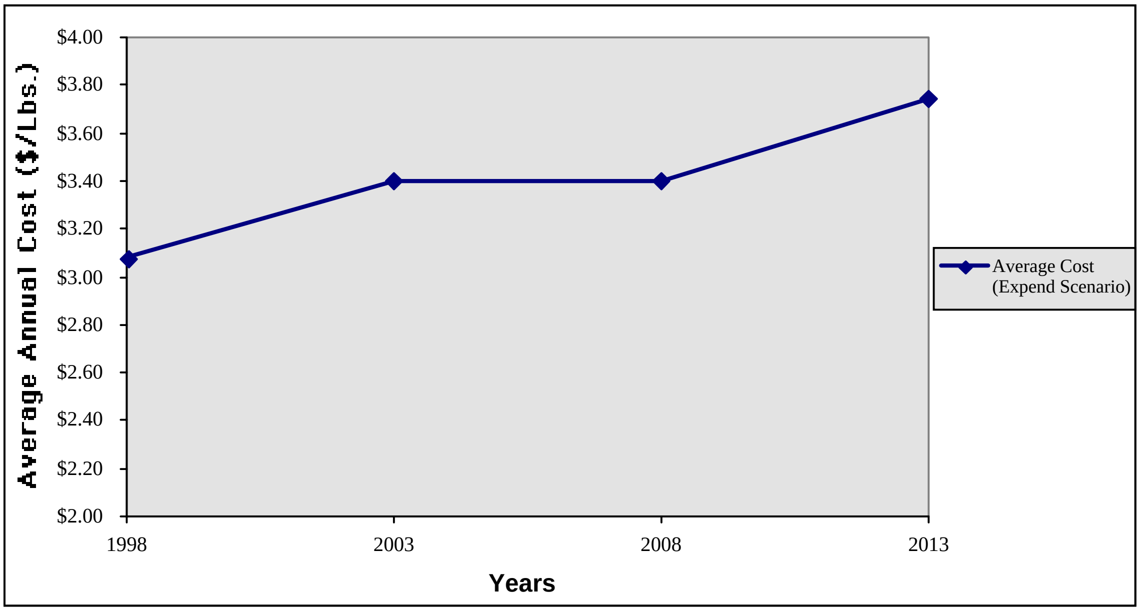

Figure 7.8. Trend in Average Annual Costs for Maintaining the N Reduction Goal For Virginia's Potomac Basin.

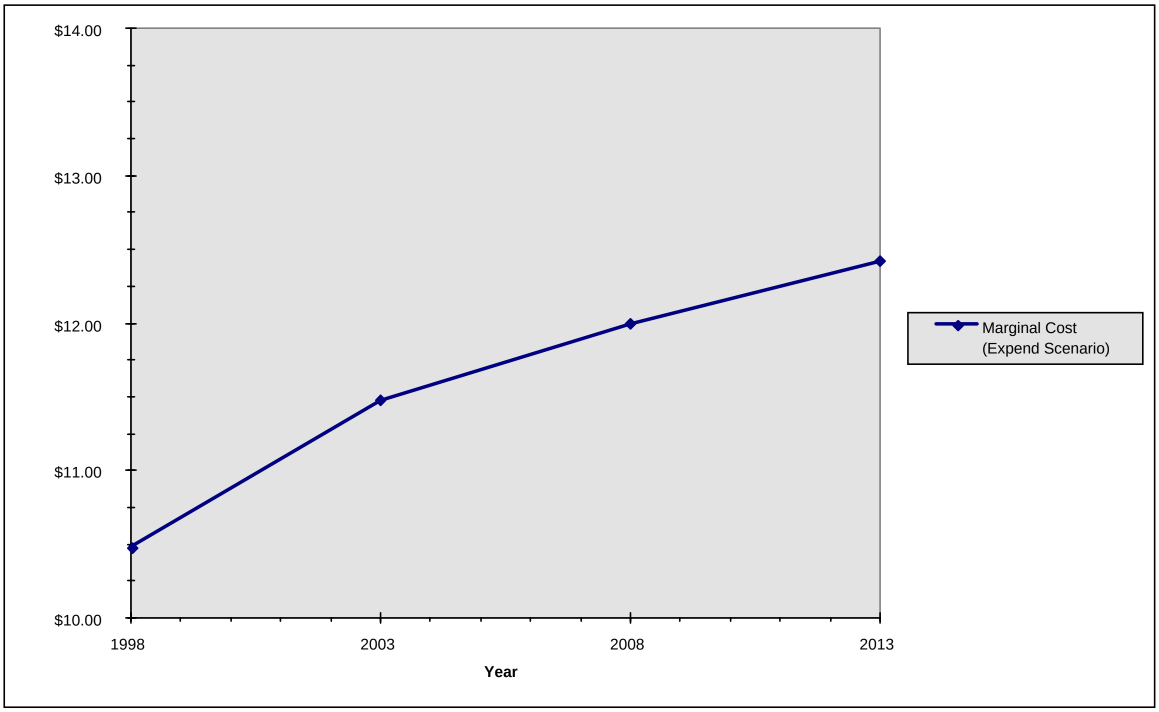

Figure 7.9. Trend in Marginal Costs for Removing an Additional Pound of N, Past the Reduction Goal For Virginia's Potomac Basin.

Predictably, average costs (Figure 7.8) also show a steady increase over the same time period. What the marginal cost curve shows is the marginal cost is increasing but at a decreasing rate (Figure 7.9). This suggests that the total cost of meeting the goal will continue to increase after 2013, but the increase may level off to a constant rate rather than an increasing rate. So these three basic cost curves appear to indicate that the total annual cost will continue to increase after 2013. What is unclear is the likely rate of increase.

To better understand how the cost of meeting the cap is changing over this time period, a total cost curve, with total nitrogen load as the independent variable, was estimated for the year 2013. Figure 7.10 compares the total cost curve for 2013 with the curve developed for 1998. The shape of the curve for 2013 differs little in appearance from the 1998 curve. The main difference is that the 2013 curve is to the left of the 1998 curve. This suggests that changes in population and land use are causing the total cost curve to shift leftward over time, while still maintaining its basic shape. If the total cost curve is indeed shifting leftward over time, then the total cost trend line in Figure 7.7, should over time, continue to follow the same upward trend as that of the total cost curve from Figure 7.5. From this it can be inferred that the trend for the marginal costs (Figures 7.9) will follow a similar path to the marginal costs curve, in Figure 7.6, and eventually begin to increase at an increasing rate.

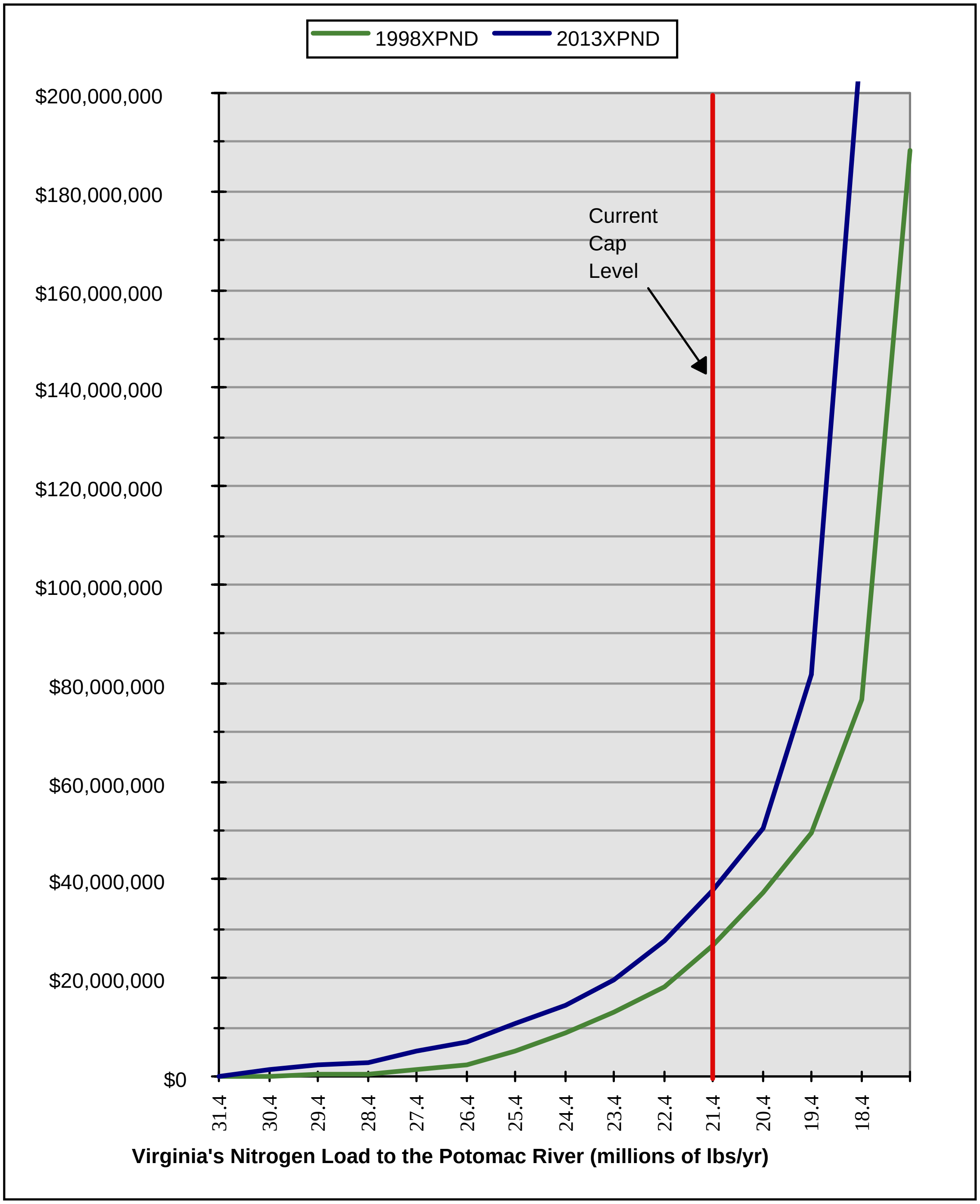

Figure 7.10. The Total Cost of Allowing Different Levels of Nitrogen from Virginia's Potomac Basin, for the years 1998 and 2013.

7.4. THE COST SAVINGS FROM ALTERNATIVE SETTLEMENT PATTERNS

The third and final objective of the study was to assess the potential cost savings from the use of Alternative Settlement Patterns in the Northern Virginia Region, over the next 15 years. As mentioned at the beginning of the chapter, two alternative scenarios were devised. Alternative 1 represents a denser settlement pattern than what is currently predicted. Alternative 2 represents a settlement pattern that is more contiguous to urban centers. The runs 2003ALT1, 2008ALT1, 2013ALT1, and 2003ALT2, 2008ALT2, 2013ALT2 were used to develop predictions of land use and N loading rates over the 15-year period. The runs 2003XPA1, 2008XPA1, 2013XPA1, and 2003XPA2, 2008XPA2, 2013XPA2 were then used estimate the costs for maintaining the N cap. These costs were then compared to the cost from the Expend scenario to assess the potential cost savings. Then the N load constraints, for runs 2013XPA1 and 2013XPA2, were parametized to develop total cost curves, which could also be compared to the 1998XPND and 2013XPND cost curves.

7.4.1. Comparison of Cost Trends Between Alternative 1, Alternative 2, and Expend Scenarios

The Figures 7.11, 7.12, and 7.13 show a comparison of the annual costs, of maintaining the N reduction goal, under the Alternative 1, Alternative 2, and Expend Scenarios. The results from the Alternative 1 Scenario show that future total costs appear to have a trajectory similar to that of the costs from the Expend Scenario (Figure 7.11). Yet the Alternative 1 costs do not keep pace with the Expend Scenario costs. From Figure 7.11, it is evident that over time there would be increasing cost savings, if the policy represented by Alternative 1 was followed. Yet even after 15 years, the difference between the two costs is only $5.12 million. This is approximately a 13.5% saving in total costs in the year 2013. The results from Alternative 2 are very similar to those of Alternative 1, saving $4.95 million over the Expend Scenario in 2013, for a 13% saving in total costs.

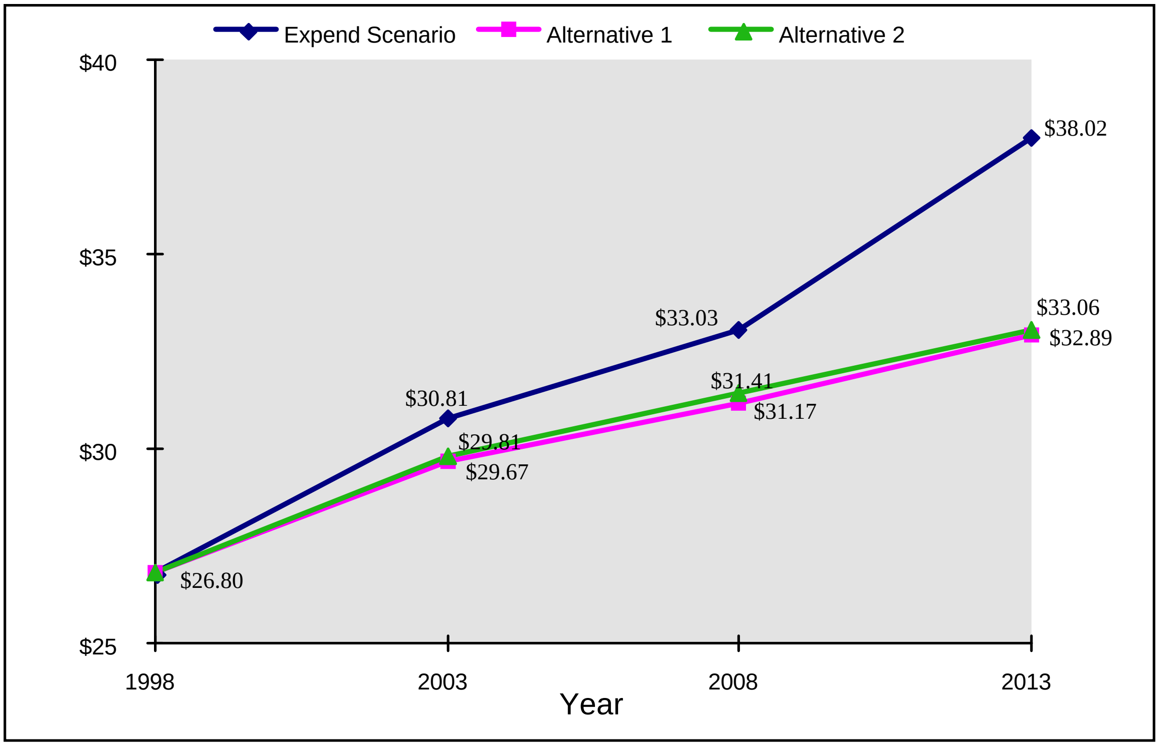

Figure 7.11. Trend in Total Annual Costs for Maintaining the N Reduction Goal For Virginia's Potomac Basin, Under the Three Settlement Scenarios.

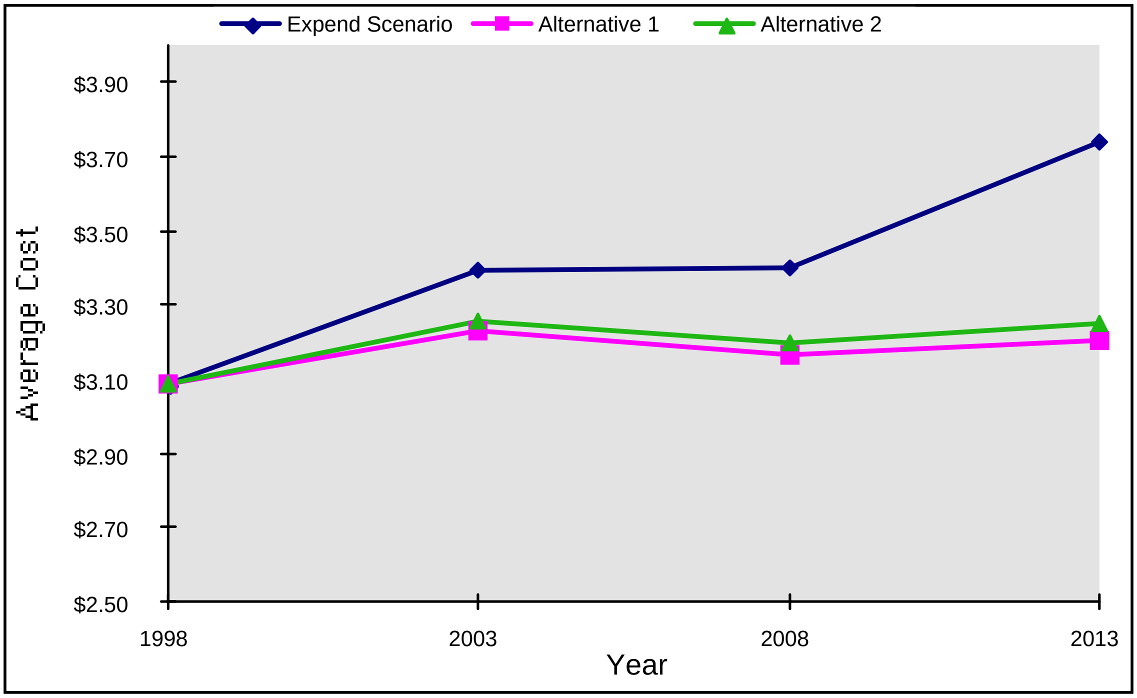

Figure 7.12. Trend in Average Annual Costs for Maintaining the N Reduction Goal For Virginia's Potomac Basin, Under the Three Settlement Scenarios.

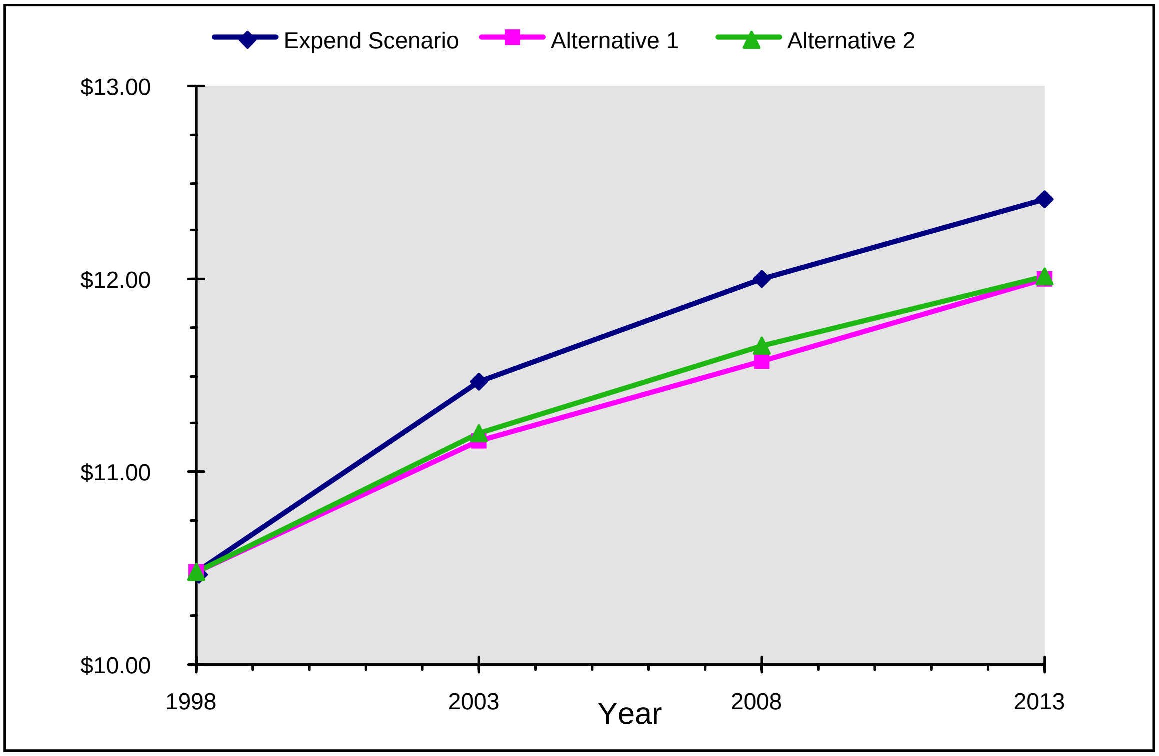

Figure 7.13. Trend in Marginal Costs for Removing an Additional Pound of N, Past the Reduction Goal For Virginia's Potomac Basin, Under the Three Settlement Patterns.

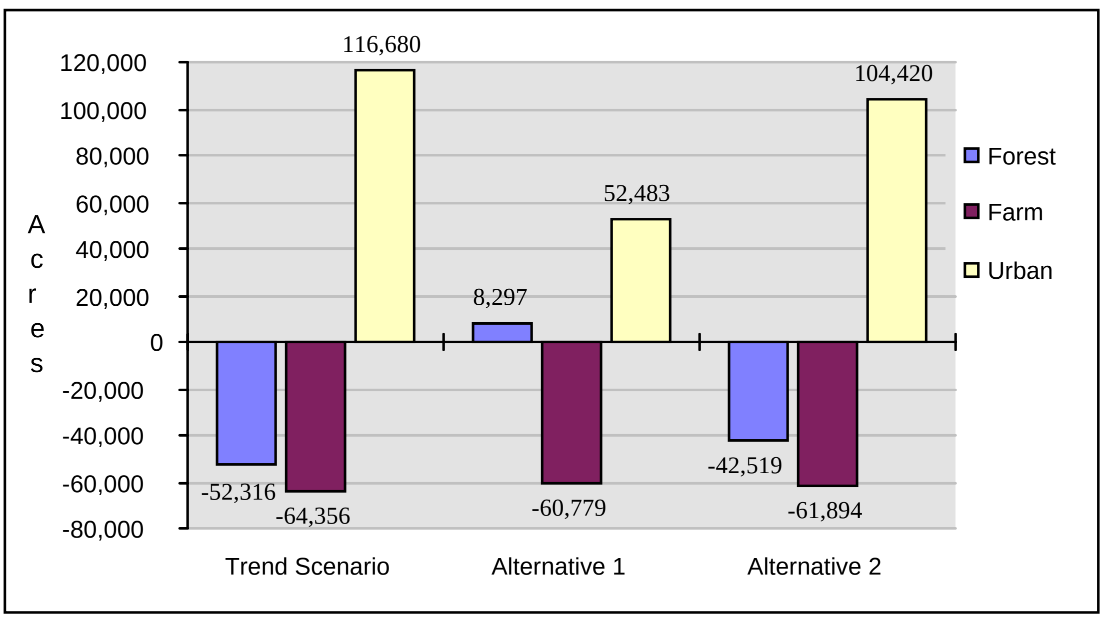

Figure 7.14. Changes in Land Use Levels in the Northern Virginia Region, Under the Three Scenarios.

It is important to understand why the alternative settlement patterns have a lower total cost than does the Expend Scenario. The first explanation might be that there is significantly less land taken up by urban land uses under the two alternatives. This allows more land to be left in either agriculture or forestry. The Figure 7.14 shows that Alternative 1 does allow for more land to be forested than does the Trend Scenario. Yet the Figure 7.14 also shows that Alternative 2 does not allow for substantially more forest than under Trend, and neither alternative allows for the preservation of significantly more farmland than does Trend. Since Alternative 2 does nearly as well as Alternative 1, this suggests that the limiting of urban acres is not the primary reason that the Alternatives do better than the Expend Scenario.

Looking at the average costs for the three scenarios, Figure 7.12 shows that there is a greater divergence between average costs than there was between total costs. By the year 2013, average cost for Alternative 1 is 14.3% less than the average cost for the Expend Scenario, and the average cost for Alternative 2 is 13% less. Since the difference between total cost is likely to increase after 2013, it can be expected that the difference between average costs is likely to continue to widen after 2013.

To meet the Cap in 2013, 10,169,343 pounds of N would need to be reduced under the Expend Scenario; 10,266,951 pounds of N under Alternative 1; and 10,169,163 pounds under Alternative 2. These figures show that N loadings were actually slightly higher for Alternative 1 than they were for the other two scenarios in 2013. This rules out the possibility that the Alternatives do better than the Trend Scenario, because they result in lower N loads. However, it is of interest that although there are less total pounds to reduce under the Expend Scenario the cost is approximately 13% higher than for the two Alternatives. This provides a strong indication that the available mix of BMPs is less costly under the two alternatives, than they are under Expend Scenario.

In fact average costs actually decrease for Alternative 1 and 2, between 2003 and 2008; even though the N loads are rising under these scenarios during this time period. This suggests that the available selection of BMPs is becoming less expensive, during this period. This is true in part to the way the point source submodule is designed.[9] Increases in wastewater flow cause total loadings to increase, but do not cause the cost of retrofitting a wastewater treatment plant to rise. Therefore the average cost per pound of N removed by a retrofit actually decreases as the wastewater flow increases. This has the effect of dampening any cost increase that results from the change in mix of available land use BMPs. Since Alternative 1 has the highest proportion of new DUs connected to sewer systems, while Expend has the lowest proportion, this dampening effect is most pronounced for Alternative 1's average cost, and the least for the Expend average cost.

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[9] The reason for setting up the point source submodule in this way was because plant capacity and future wastewater flows are assumed to have been taken into consideration, when retrofits were designed for a specific plant. So the model does not consider the impact of additional flows on retrofitting costs. There is a caveat to this argument. Increased flows do affect the cost of operating and maintaining a plant. Since retrofitting a plant can affect maintenance and operation costs, it may be the case for some plants that the increased wastewater flow would result in a greater increase in maintenance cost than what would occur without the retrofit. Such a discrepancy in costs would be difficult to estimate and would need to be done on a plant by plant basis.

From this it can be deduced that a principle reason that the Alternatives have a lower total cost for maintaining the Cap, than does the Trend Scenario, is because they have a higher proportion of DUs connected to sewer systems. However, Table 7.1, shows that over the 15 year period, the total number of new septic systems under Trend, Alternative 1, and Alternative 2, were 45,116, 18,826, and 29,215 respectively. Since all three scenarios are subject to the same population increase, each has the same number of dwelling units. This suggests that Alternative 1 has significantly higher proportion of new DUs connected to sewer lines than does Alternative 2, yet this does not result in a significant difference in total costs (Figure 7.11).

The reason why Alternative 2 does nearly as well as Alternative 1, even though it allows for 55% more septic systems than does Alternative 1, has to do with total loadings. As mentioned above, in 2013, Alternative 2 and the Trend Scenario have relatively similar N loading rates, while Alternative 1's is approximately 100 thousand pounds higher. This difference in total loads can be attributed to the fact that on average connecting to point sources results in a higher annual N load than does using a septic system. So connecting DUs to sewer lines will cause total loads to be higher than if they were on septic systems. However, having more DUs, connected to sewer lines results in a lower cost mix of BMPs. Ultimately the cost savings derived from the lower cost mix of BMPs, outweighs the benefits of lower N loading rates from the use of septic systems.

7.4.2. Parametizing Costs Curves For the Three Scenarios

Using the same method employed in section 7.3, the N load constraints, for Alternatives 1 and 2, were parametized in order to develop total cost curves, for 2013. These total cost curves were then added to the graph pictured in Figure 7.8, in order to create Figure 7.15. This figure provides a comparison of the total cost curves for the three scenarios in 2013, as well as the total cost curve for the base year 1998. The total cost curves for Alternatives 1 and 2 are nearly identical, which is in keeping with their similar trends in Figures 7.11, 7.12, and 7.13. The total cost curves, for the two alternatives, fall predictably between the 1998XPND and 2013XPND curves. So it appears that both alternatives tend to dampen, but not eliminate the effects of increased urbanization on total costs.

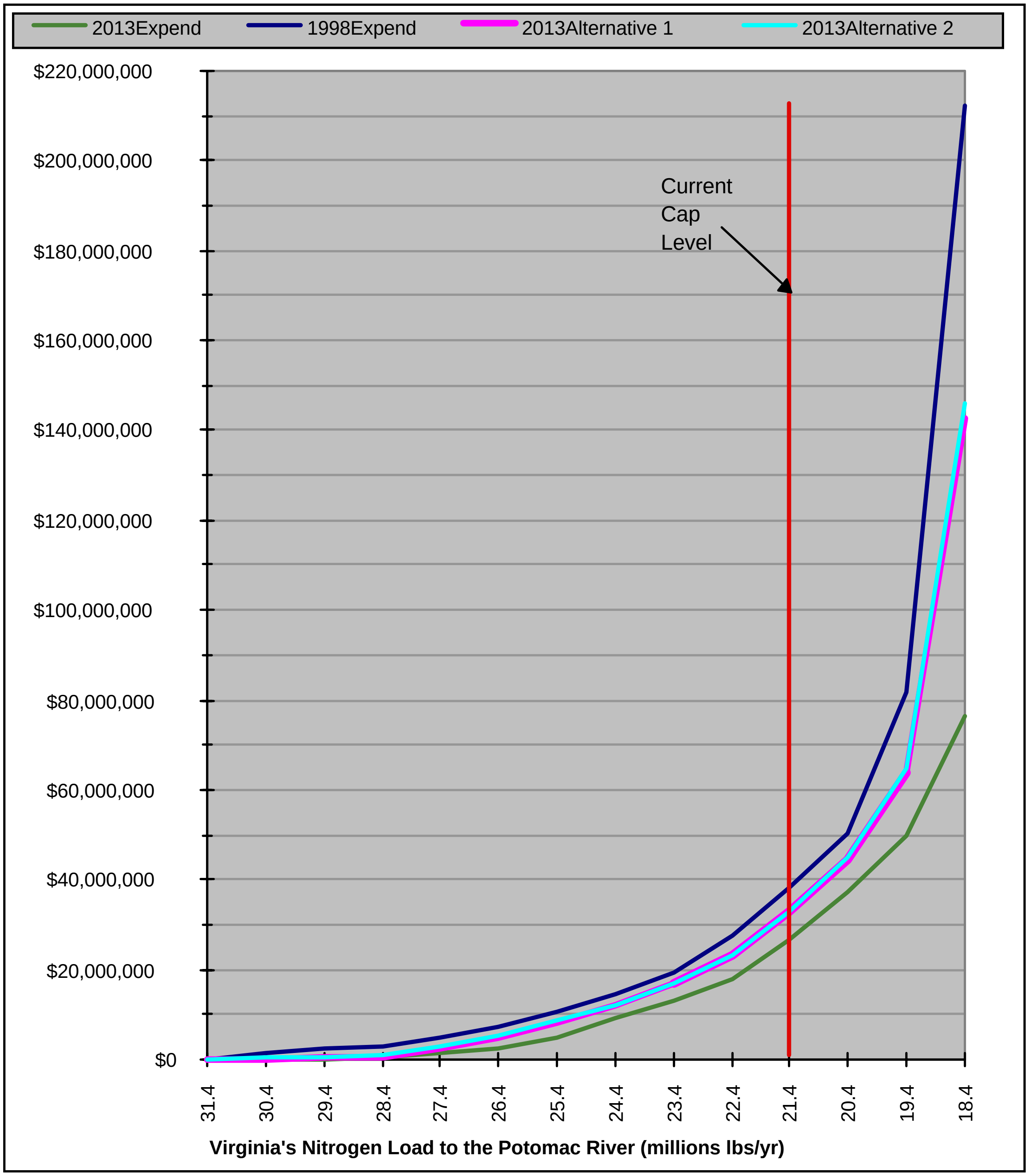

Figure 7.15. The Total Cost of Allowing Different Levels of Nitrogen from Virginia's Potomac Basin, for the years 1998 and 2013.

There is a noticeable difference between the shape of total cost curves for the two alternatives and the total cost curve for 2013 Expend. After the allowable N level of 20.4 million pounds, the trajectory of the two alternative curves is less steep than that of the 2013 Expend curve. This lends support to the proposition that the cost savings from the use of either alternative would continue to increase after the year 2013.

7.5. CONCLUSION

The primary purpose of this chapter was to address the three primary objectives of the study. This was done through the development of different model scenarios, which were then run to produce the information necessary to address the questions posed in the objectives. The results were then analyzed to determine what the answers to the questions were.

The first objective was to predict the current and future annual N loadings to the Potomac River from Virginia, and to determine if the 40% N reduction goal will be met. According to the results from the Potomac Basin Model, the total 1998 load to the Potomac from Virginia is estimated to be 30.1 million pounds This is approximately 8.7 million pounds above the N cap level of 21.4 million pounds of N per year. The estimated annual N loadings are predicted to continue to rise into the near future, reaching 31.55 million pounds annually, by the year 2013. The trend is driven primarily by population growth within the Basin , and so is likely to continue as long as population continues to increase.

The second research objective was to determine the cost of meeting the N reduction goal, and to also determine the cost of maintaining this goal into the future. Model results predict that if the goal were met in 1998 the total annual cost would be $26.8 million dollars. This cost will continue to increase over time, reaching $38 million, by the year. 2013. Past 2013, the total cost will likely continue to increase at an increasing rate.

The third objective of the study was to assess the potential cost savings over time, from the adoption of alternative settlement patterns. What the results show is that there is very little difference between the cost of meeting the goal under either alternative settlement pattern. However, both of the alternative settlement patterns can save money over the current trend in land settlement, represented by the Expend Scenario. By the year 2013, Alternative 1 saves $5.12 million, while Alternative 2 saves $4.95 million. The cost of maintaining the cap under either alternative would continue to increase after 2013, but at a lower rate than will the present land settlement trend. This suggests that the savings from the adoption of either alternative would continue to grow after 2013.

How well these results address the primary research objectives, and the implications of the findings will be the focus of the next chapter. The next chapter will also discuss the relevancy of the study findings to the two issues of urban growth in the Potomac Basin, and Virginia’s ongoing efforts to meet the N reduction goal.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

There are six intentions to this chapter. The first is to provide a brief explanation of why the study was undertaken, and what the basic objectives are. The second is intended to provide a basic summary of the findings. The third is to draw implications from the findings. The fourth is to discuss the efficacy of the research method used, and important caveats that need consideration when evaluating the results. The fifth is to suggest areas for further possible research. The sixth is to conclude the paper by offering a perspective on the State's efforts to meet the N reduction goal.

8.1 STUDY PURPOSE AND OBJECTIVES

For the past 13 years, the state of Virginia has been working toward reducing the amount of controllable N that enters the Potomac river, from the land within its jurisdiction, by 40%. This N reduction goal for the Potomac is part of a broader multi-state and Federal effort to improve the water quality of the Chesapeake Bay and its tributaries. In Virginia, state policymakers are interested in seeing that the goal is met at the lowest cost, and that the financial burden is apportioned fairly. The purpose of this study was to estimate the current progress toward meeting this N reduction goal, and also to predict what future efforts would be necessary to meet and maintain the goal while minimizing future expenditures. Such information could assist policymakers in developing long term water quality goals for the Potomac, and in devising a realistic strategy for meeting these goals. What follows is a restatement of the three principle objectives for this study.

I.) To predict the annual nitrogen loadings to the Potomac River, from the state of Virginia, for the years 1998, 2003, 2008, and 2013.

II.) To estimate the minimum costs, above what is currently spent, to meet and perpetually maintain the nitrogen cap, for the years 1998, 2003, 2008, and 2013.

III.) To assess the potential cost savings from changes in land use that result from the adoption of two alternative settlement patterns, for the years 2003, 2008, and 2013.

These alternative settlement patterns are:

1) restricting all post 1998 dwelling units within the NOVA region to medium and high-density settlement patterns.

2) restricting all post 1998 dwelling units within the NOVA region to settlement patterns that are either within urban areas or are within five miles of an urban center.

To undertake this study, an extensive literature review had to be done. This review focused upon the sources of N to the Potomac, the BMPs used for reducing these loadings, and the economic costs associated with these BMPs. This review provided the information necessary to both develop a framework for a mathematical model, and also to determine the values for the model parameters. Sets of parameters were developed to represent expected land uses for the years 1998, 2003, 2008, and 2013. These sets were entered into the model and then used to generate the information necessary to meet the study objectives.

8.2. STUDY SUMMARY

The study produced three important findings. First, the results suggest that the current level of N entering the Potomac from Virginia, is actually slightly higher than it was in 1985, and that this gradual increase will continue over the next fifteen years. As a result Virginia is unlikely to meet its N reduction goal by the year 2000. Secondly, the minimum cost for maintaining the N cap will also continue to rise over the next fifteen years, at an increasing rate. Finally, by adopting a policy of controlling settlement patterns, policy makers can slow the rate of increase for the cost of maintaining the cap.

8.2.1. Current Trend in Nitrogen Loadings From Virginia's Potomac Basin

Before N loadings could be predicted, the 1998 levels of farm, forest, and urban land uses had to be estimated. This study's land use estimates differed from those used by the VDCR and CBP for previous years, with this study's estimates having a greater portion of land in the urban category and less in farm or forest. This is due in part to the steady growth of urban land within the Basin, but also to differences in the method for computing land use acres.

Estimates of current N loadings to the Potomac River, from Virginia, were generated with the Potomac Basin Model. The results indicate that the N reduction cap will not be met during 1998. The results also suggest that the greatest load of N to the Potomac River comes from point sources, followed by urban land use, agricultural land use, and then forestland. When compared to load predictions by the CBWQM for earlier years, the Potomac Basin Model appears to predict significantly more N loadings from urban sources, than do the CBWQM estimates.

Future load estimates for the years 2003, 2008, and 2013, predict a continued increase in N loadings. With exception of urban loadings, the basic trends in N loadings appear to be a continuation of the trend suggested by the CBWQM from 1985 to 1996. By the year 2013, the total N load to the Potomac is expected to have risen to 31.3 million per year.

8.2.2. Estimated Minimum Annual Cost of Maintaining the Nitrogen Reduction Cap

If the N cap were to be met this year, the Potomac Basin Model predicts that it would require approximately $26.8 million dollars to be spent on additional N reduction measures. This money is in addition to what is already expected to be spent in 1998. It is also, not a one-time expenditure, but rather an annual amount that would need to be used for repayment of loans, routine operation, and any necessary maintenance or repairs, for the additional BMPs. This figure also takes into account some of the lost potential revenues to farmers, and timber companies. Approximately 80% of this money would need to be spent on Point Source retrofits, while the other 20% would go towards additional agricultural BMPs. The average cost per pound of N reduced would be $3.09. At the cap level, the marginal cost would be $10.49.

Over the next fifteen years this annual cost is predicted to rise at an increasing rate. By the year 2013, the expected minimum annual cost is approximately $38 million. The average cost would be $3.83 in 2013, an increase of 24% over 1998. While, the marginal cost for reducing an additional pound of N is expected to have risen by 18.4% to $12.42 per pound.

8.2.3. Potential Cost Savings of Alternative Settlement Patterns

Model parameters for new residential acres were adjusted to represent two possible alternatives to the existing urban development trend, represented by the Expend Scenario. These changes were only made to residential parameters for the Northern Virginia region. The first alternative represented a policy of increased housing density for new residential developments. The other alternative represented a policy of containing new residential development to be within or adjacent to existing urban areas.

The results suggest that initially after five years the cost savings from the adoption of Alternative 1 are only $1.14 million. While the adoption of Alternative 2 results in total cost savings of just $1 million. However, after 15 years the annual savings from the use of Alternative 1 rises to $5.12 million per year, this is approximately a 13.5% reduction in costs from the Expend Scenario. In 2013 Alternative 2 generates $4.95 million, a 13% savings in cost from the Expend Scenario.

The average costs for the two Alternatives follow a similar trend to total costs for the fifteen-year period. In 2013, the average cost of Alternative 1 is $3.20 per pound and the average cost for Alternative 2 is $3.33, which respectively 16.3% and 13% less than the Expend average cost of $3.83 per pound. The Alternatives' marginal costs appear to follow a very similar pattern, differing by only $0.02 by the year 2013.

8.3. IMPLICATIONS

There are several conclusions that can be inferred from the results presented in the previous chapter. Some of these conclusions have implications for both land use policy within Virginia's Potomac Basin and water quality goals for the Chesapeake Bay.

8.3.1. Implication of Results

The results from the first model run 1998TRND, indicate that the goal of reducing the N load from Virginia's Potomac Basin has not yet been met. Furthermore they suggest that no real progress has been made toward meeting the N reduction goal. In fact the evidence suggests that N loads are actually continuing to rise. The continued increase is principally due higher volumes of wastewater being generated by the growing population throughout the region. The major implication is that thus far, N reduction efforts have only been able to curb, but not reverse the trend of increasing N loadings.

Another important implication which comes from the results of the first run are that the methods used, by the state, to generate the total N load from urban sources may be underestimating the actual value. There are several reasons why their predicted load could be under estimating the actual load. The first reason is that they are likely under counting the acres impacted by urban development. The second is that they are not calculating the increase in N loadings that result from rural housing. The third reason is that they could be underestimating the load generated by on-site septic systems.

Evidence from the additional Trend Scenario runs suggests that over the next fifteen years the N loading rates to the Potomac will continue to rise. Based upon the model results, this will completely be the consequence of increases in the amount of wastewater generated by the new DUs in the Basin. It is also apparent from model results that the conversion of nonurban land to urban land results in increased N loadings. Yet, when wastewater treatment is not considered, it is unclear from model results, whether or not the conversion of farmland into urban land, results in a net increase or decrease in annual N loadings. This is because some farmland is converted into forestland, during the fifteen-year period. Since the net decrease in nonwastewater NPS loadings is only 79 thousand pounds annually, by 2013, it is unlikely that declines in N loadings as a result of converting land from agriculture to urban uses would result in significant load decreases.

From the first run of the Expend Scenario, 1998XPND, it is evident that to meet the N reduction goal, the main focus will need to be on retrofitting point sources, and then on the further adoption of agricultural BMPs. Results from meeting the cap in 1998, suggest that approximately 63.4% of the load reduction would need to come from point sources, and 36.3% will need to come from the adoption of agricultural BMPs. The other 0.3% would come from forestry BMPs. However, of the total cost retrofitting point sources would comprise 82%, while the cost of farm BMPs would only be 18%. This suggests that retrofitting point sources is not the lowest cost method of reducing N, but rather that after a certain threshold of farm BMP implementation is passed, the adoption of additional farm BMPs will not be as cost effective as retrofitting point sources. This is supported by the trajectory of the point source and farm total cost curves in Figure 7.5.

From Figure 7.5, it is also apparent that the total cost for meeting the cap is most sensitive to the predicted cost effectiveness of point source retrofits. If the estimated cost effectiveness for forestry, agricultural, or urban BMPs, is moderately higher or lower than what the model predicts, this would not change the shape of the cost curve in Figure 7.5, and it would have only a negligible on the total cost. However if the cost effectiveness of point source retrofits is under or over estimated, this would alter the shape of the cost curve, causing the total cost for meeting the goal to be either much more expensive or inexpensive.

The combined results from the rest of the runs in the Expend Scenario, suggest that the annual total cost of maintaining the cap will increase by 42% over the 15-year period. This increase in cost will result primarily from the fact that loads are increasing, and not from the changing mix of BMPs. This is because in 2013, 81% of the total cost of meeting the cap is still devoted to point sources and changes in land use over the fifteen years will have no baring on the availability of point source retrofit options.

Over time it appears that the increasing loading rate is causing the total cost curve to shift leftward (Figure 7.10). If this is the case, then from Figure 7.10 it looks as if the total cost will continue to rise at a steady rate for the next 25 to 30 years, then the total cost of maintaining the cap will begin to increase at a much more rapid rate. It is very unlikely that the state will be able to annually spend 80 or 100 million dollars on maintaining the N cap. So when costs begin to escalate at such a rapid rate, it is very likely that policy makers will need to reconsider continuing to maintain the 40% reduction goal. The point at which the cost begins to rapidly escalate on both of the curves in Figure 7.10 is at approximately 19.4 million pounds of N for 1998, and 20.4 million pounds for 2013.

Neither Alternative 1 nor Alternative 2 prevents the total load from increasing over time. In fact the load actually rises faster under Alternative 1, than it does under the Trend Scenario. Under Alternative 2 it rises at approximately the same rate as with the Trend Scenario. The primary reason for this is that the two alternatives have a higher percentage of the new DUs being connected to sewer lines than to septic systems. Within the context of the model, on average it generates less N loadings, for a new DU to be on a septic system than to be connected to wastewater treatment plant. However, having a greater number of connections to sewer lines, results in an available selection of BMPs that ultimately generates a lower cost solution. The implication from this is that settlement patterns which allow for a higher number of connections to wastewater treatment plants, will help curb the increasing cost of maintaining the N reduction Cap.

However, it does not appear that the use of alternative settlement patterns can prevent the cost of maintaining the cap from rising in response to increasing population growth. What they can do is slow the rate of increase, and slow the leftward shift of the total cost curve. Referring back to Figure 7.5, eventually the time will come, under any scenario, when the retrofitting of point sources can no longer be relied upon to maintain the cap, and the use of much less cost effective urban and agricultural BMPs will need to be considered. As mentioned, at such higher levels of spending it is very unlikely that the state could perpetually maintain the N cap, and may have to reconsider the 40% N reduction goal.

It is the forestalling of the eventual rapid acceleration of costs, and not the modest cost savings that they provide over the current settlement pattern in the near future, that is the main benefit of the alternative settlement patterns. What they do is in essence buy the state more time. Eventually the rate of population growth within the Basin is likely to level off. When this occurs the annual cost of maintaining the cap should as well. If this happens before the point where the cost curve rises rapidly, then it is possible that the cap could be perpetually maintained.

There is also the possibility that technological advances in the future could bring down the average cost of reducing a pound of N. This would be particularly beneficial towards keeping future costs in check, if innovations were to happen in the area of urban stormwater runoff or on-site wastewater treatment. This is because it is the eventual reliance on these methods of controlling N that cause the total cost to increase at a rapidly increasing rate. Having more time, allows for additional efforts to be focused upon improvement of these technologies.

8.3.2. Policy Implications

The results of the study provide implications for both land use policy and regional water quality efforts. For land use policy, the results suggest that there are benefits from the use of alternative development patterns, but the primary emphasis should be on managing the impact of future wastewater treatment needs. In regards to water quality efforts in the Potomac Basin the results suggest there should be a reevaluation of the tributary strategy, and perhaps a reevaluation of the overall N reduction goal for the Bay.

8.3.2.1. Land Use Policy

Study findings suggest that ADPs can play a role in maintaining the N reduction cap; but they cannot be expected to prevent the rise in cost for maintaining the cap. However, ADPs are still desirable components of land use policy within the Potomac Basin. As discussed in Chapters 3 and 4, there are many additional benefits to ADPs besides helping the state maintain the N reduction cap.

On the issue of future wastewater treatment needs, the study findings suggest three things for the policy makers. The first is that future developments should be located in such a way that makes connections to the regional sewer systems possible. This can be done locating the development close to existing sewer mains. Higher density developments also lower the overall cost of connecting a neighborhood by reducing the distance between each house. As small communities grow, particularly in the Shenandoah area, there will be a need to expand the capacity at many small wastewater treatment plants. By including the capacity for BNR in the design of these plant expansions, these localities can avoid much of the cost of retrofitting the plant for BNR in the future. The final suggestion is that whenever centralized wastewater treatment is not an option for a new development, the developer should be encouraged to install on-site treatment systems that include some form of tertiary treatment. This is strongly recommended for areas where conventional septic systems are not well suited.

8.3.2.2. Reevaluating the Nutrient Reduction Goal

An important conclusion, based on study findings, is that eventually the annual cost of maintaining the cap will begin to rise exponentially. There are two reasons for this rise in cost. First, the N loadings will continue to increase as a result of population increase. Secondly, all the lower cost potential agriculture, forestry, and point source BMPs will eventually be put into place . This force the state to begin relying on the more expensive urban BMPs to maintain the N cap. The changes in land use policy suggested above, may forestall the rapid rise in cost, but they are unlikely to prevent it from eventually occurring.

Given the likelihood of this eventual rapid rise in costs, the state of Virginia along with the other signatories of the 1987 Chesapeake Bay Agreement find it beneficial to reevaluate the overall goal. This could be done by revising the tributary strategy approach, or by revising the actual 40% N reduction goal. Whichever approach they choose, perhaps the best place for them to begin the reevaluation is by focusing more on the problem they wish to remedy rather than just on two of the pollutants that contribute to the problem.

The principle problem that the 40% nutrient reduction goal seeks to address is the declining ecological integrity of the Chesapeake Bay. This decline is due in large part to the problem of eutrophication caused by nutrient enrichment. However other factors such as increases in sediment, heavy metals, and pesticides, along with the loss of spawning habitat in the Bays tributaries all contribute to the decline as well. Many of the BMPs mentioned in this study can also serve to reduce the impact from these factors as well.

Through the use of CBWQM and other resources it may be determined that by modifying the 40% goal, the overall long-term ecological integrity of the Bay could be better off. For example, it may be the case that by readjusting the targeted decrease in N to only 30%, while at the same time setting targeted reductions for other pollutants such as sediment and heavy metals, the long run recovery of key indicator species may be improved at a lower annual cost.

Given the enormous commitment made by the signatories to the Chesapeake Bay Agreement, the thought of relaxing the N reduction goal at this point may appear to be breach of the Agreement. Therefore if the participants in the Agreement wish to continue with the 40% N reduction goal for the Bay, it may be in every party's best interest to reevaluate the tributary strategies instead. The tributary strategies could be adjusted based upon long term N loading trends to the Bay so that some tributaries reduced N by less than 40% while others reduced N by more.

The Potomac Watershed is expected to experience a much higher rate of growth over the next 20 years than is the Susquehanna Watershed (Year 2020 Panel, 1988). If Susquehanna's the long term trend in N loadings appears to be relatively flat in comparison to the Potomac's, then it may be more cost effective to adjust the N reduction targets for these two rivers. For example, suppose it was determined that by lowering the N reduction target for the Potomac to 30%, while raising the target for the Susquehanna to 45%, the 40% reduction to the Bay could still be achieved. Then the states of Maryland and Virginia could be given the option of meeting the 40% reduction goal for the Potomac; or reducing N to the Potomac by only 30%, while providing funding for the implementation of enough BMPs within the Susquehanna Basin to reduce that rivers total load to the Bay by an additional 5%. This type of readjustment to the tributary strategies could potentially save both the states of Maryland and Virginia millions of dollars in water quality expenditures annually.

8.4. CAVEATS CONCERNING METHODOLOGY AND ASSUMPTIONS

The previous three chapters were intended to describe the modelling process used for this study, and the subsequent results. Within these chapters numerous mentions were made regarding necessary assumptions, and certain caveats the reader should bear in mind. In summary there are several key assumptions which deserve rementioning, as well additional issues which need addressing.

8.4.1. Modelling Sources of Nitrogen

As with any attempt to model real world phenomena, there is a necessary process of deciding which factors to represent within the modelling framework, and which to leave out. Ideally only those factors which are known to be irrelevant to the objective of the modelling effort would be excluded. However, lack of substantiated evidence, and difficulty in obtaining reliable estimates often play into the decision making of what will be contained in the model. There were several sources of N, which may potentially be significant factors in the amount of N annually reaching the Potomac, that were not represented within the model. What follows is a list of potential sources of N that were not included within the calculated annual N load.

- Direct deposition of atmospheric N to the Potomac and its tributaries.
- Elevated N levels as a result of increased sediment loadings from construction projects.
- Gradually diminished ability of urban green spaces and waterways to remediate N from urban stormwater.
- Nitrogen runoff and leachate from land application of sewage sludge and waste disposal sites.
- Increased N as a result of runoff from clear-cut land that has not yet regenerated a protective cover.
- The affects of increased application of manure on farmland as a result of growth in the livestock industry.

8.4.2. Measuring Progress Towards the Goal

Although the determination of an expected annual loading rate should be based upon the best available scientific evidence; the decision of whether or not the goal has been reached will ultimately be a political one. Ideally, the goal would be used to gauge the progress being made, toward reducing the inflow of N to the Potomac, which results from human activities. This would be done by monitoring the changes in N loadings over the fifteen year time period. Monitoring results could then be used to determine how effective current efforts have been, and how they need to be adjusted to ensure that the goal is met. However, such an undertaking would be extremely difficult, under the best of circumstance, and within the timetable set to meet the goal, it is not possible. The reason it is not possible, results from the fact that the annual N load for a given year, is the consequence of both geophysical processes and human activities.

Numerous natural factors such as, air currents, temperature, humidity, and the frequency, pattern and volume of rainfall all will play a factor in the resulting N load. Likewise, every year that passes, more people move into the Basin, a portion of the existing land uses change, and additional BMPs are adopted. If trying to gauge the impact of all these factors was not enough to make assessment through monitoring impossible, the additional N from groundwater sources does make it unattainable. According to the USGS, as much as 50% of the N load to the Chesapeake Bay and its tributaries comes from groundwater sources (USGS, 1998). The time frame for measuring the travel of nutrients through baseflow stretches from days to centuries, with the average being 10 to 20 years (USGS, 1998). Being able to detect changes in current N loadings that are resulting from current human activities if possible would require many years of detailed monitoring efforts.

Therefore, determining the progress toward the goal becomes an accounting problem, in which sources are assigned estimated annual N loads, and BMPs are attributed with reduction efficiencies. This is not an expedient practice taken in lieu of a more appropriate procedure, but rather a necessary method for assessing sources of the problem and accrediting steps taken to alleviate the problem. The accuracy of this type of accounting relies upon the body of research from which it draws its numbers. So as the complexity of watershed systems comes to be better understood, the precision of the accounting will improve.

Under present circumstances the determination of what the annual loads are, and how much reduction to attribute to various efforts cannot be based directly upon monitoring results, but instead must be derived from the best available scientific evidence. However, this leaves room for a great deal of subjectivity in the overall process. A consensus of opinion amongst the signers of the Bay agreement will be necessary to determine if and when the goal is met.

8.4.3. Key Assumptions

There is an important point concerning the way costs are represented that deserves remention. To begin, the model used to represent the results is an optimization model. Therefore, the resulting total cost measurements are the lowest that the model could generate given the model equations and parameters. This implicitly assumes that the implementation of this least cost combination of BMPs, occurs without any additional costs. In reality there are likely to be significant transaction costs associated coordinating, monitoring, and enforcing such a specific combination of BMPs.

Another major assumption, that is directly related to both costs and loading rates, is that all BMPs will be properly cited and installed. It is assumed that they will also be adequately maintained, as long as needed into the future. However, there is much research left to be undertaken concerning the most effective way to control N through the use of certain practices. In reality, many BMPs are implemented improperly, providing little is if any benefit.

8.5. FUTURE RESEARCH

The process of carrying out this study provided insight into several areas of future potential research. What follows are two sections: the first discusses potential research that could be of value to studies like this one; the second suggests possible ways that the Potomac Basin Model, developed for this study, could be used for additional research purposes.

8.5.1. Future Research Needs

Certainly studies such as this one could benefit from additional research into issues such as: the transport of nutrients to waterways, the long term effectiveness of BMPs, and all the costs regarding installation and long term operation of BMPs. However, there are some specific areas where future research could be potentially of great use for studies such as this.

Better information on the effectiveness of different combinations of BMPs, would be very useful. This is particularly true for agricultural BMPs, where numerous BMPs could be potentially used in combination. For urban BMPs it would be very useful to have information on the benefits of preceding on-site ponds systems with vegetated filters, or the use of on-site ponds within small watersheds that are covered by regional ponds.

The Chesapeake Bay Program has relied upon the use of several cost equations developed to estimate the cost of retrofitting various plant capacities (Camacho, 1992). However, subsequent work done by Dr. Clifford Randall at Virginia Tech, calls into question the accuracy of these cost curves (Randall, 1998). As mentioned, for several point sources in this study, published CBP costs were modified to more closely reflect the cost figures that Dr. Randall produced for other plants. Ideally, information from Dr. Randall's research on retrofit costs would be used to develop more new cost equations for point sources. It is likely that these cost curves would be contingent upon several important factors such as inflow N concentrations, current flow and projected inflow volumes, treatment system used at plant, current level of tertiary treatment technology used, and desired outflow N concentration. Such information could be of great benefit not only to studies conducted within the Chesapeake Watershed Area, but also to many point source retrofit studies done outside of the Chesapeake Basin.

Another area where additional research would be useful is in the area of urban growth. To begin, methods for determining residential characteristics from census data alone, and in combination with geospatial data, need to be refined. Research into how differing patterns of residential development, affect patterns of new commercial, industrial, and institutional development, is needed. Likewise, further research should be undertaken into the relationship between residential patterns and the resulting number of road miles and the percentage of DUs on septic systems.

There is evidence to suggest that the level of impervious surface could be calculated as a function of road miles within a region (May et al., 1997), (Zand, 1998). The development of an impervious surface equation, dependent upon road and housing density within a given area would be extremely useful for deriving impervious estimates for large areas where detailed GIS data may be lacking.

Finally, one of the primary objectives of this study was to assess the cost savings from the use of alternative settlement patterns, in regards to maintaining a cap on N loadings. However there is numerous other economic and environmental benefits have been suggested from the use of alternative development patterns. Additional work needs to be done which examines the economic tradeoffs between the use of SPECIFIC development patterns. Likewise, more evidence concerning the potential environmental benefits of such patterns.

8.5.2. Future Uses of the Model

Initially, the Potomac Basin Model was designed, as part of this study, to predict the potential minimum cost of meeting the 40% N reduction goal for Virginia's Potomac Basin. However the basic structure of the optimization model, along with the series of linked spreadsheets used to develop the parameters, could be used in a variety of different ways for future studies. There are also numerous ways in which the Potomac Basin Model could be modified to both broaden the ways in which it could be used and improve the quality of the results.

8.5.2.1. Additional Uses as Presently Designed

To begin, the state is interested in meeting the N reduction goal at the lowest cost, yet it is also interested in seeing that the costs are borne by the affected parties in a fair and equitable manner. One of the uses of the model, the way it is currently set up, would be to add additional constraints so that the model met the goal in a more equitable manner. In other words, the model could be restricted so that certain sources of N were not required to reduce more than a certain amount, while others were required to meet a minimum level of reduction. In this way, policy makers could examine the tradeoff in dollars between different reduction scenarios. For instance, it may turn out that one scenario that is viewed as much more equitable than the lowest cost solution, is only slightly more expensive.

There is nothing within the structure of the model that prevents it from being used to assess other potential pollutants, such as phosphorus, sediment, or heavy metals. The main task would be to gather all the necessary initial data through a literature review, such as the one undertaken for this project. The model could even be configured to assess the cost of meeting loading caps for several pollutants at once. It could also include such goals as maintaining a prespecified amount of forest or farmland within given areas.

As it is currently set up, the model maximizes revenues while constrained to not exceed a set level of N loadings. However, as mentioned in the previous chapter the model can be easily adjusted to minimize N loadings, while not falling below a set level of net revenues. So in much the same way the model was used to predict minimum costs of meeting a water quality goal, it could be used to maximize environmental benefits, while not exceeding a specified amount of spending. For many localities, operating under a tight budget, using the model in this way could help them target scarce funds, in order to get the most nutrient reduction while still operating within budget constraints. The model could be used to minimize the loadings of several pollutants at once while staying within a budget. However, the pollutants would have to be assigned a value under an acceptable weighting system for this to occur.

Since the model is designed to cover four economic sectors, over a number of predefined land areas, it can be used to compare the benefits of reducing loads in one area as opposed to another, or between two different sectors. The model could be configured to meet a prespecified goal, such as reducing N by 40%, separately in each geographic unit or in each sector. In this way it could be used to assess the possible benefits of pollutant reduction trading, across geographic areas or economic sectors.

8.5.2.2. Potential Modifications to the Model

Several things could be done to improve the model. There are three that readily stand out. The first is by adding a spatial dimension through the use of GIS. The second is by modifying the agricultural submodule so it works as a mass balance for nutrients entering and leaving a farm. The third is through having the capability to compute edge of stream loadings, rather than relying upon published values.

Data from a GIS system such as VirGIS could be used to add a spatial dimension to the model. The hydrologic units in combination with either county or census tract boundaries would form the new land units. This would greatly improve the modelling of streamside BMPs such as riparian buffers, and stream fencing on pastureland. Also data layers of roads, land use, public works lines could all be incorporated. The data from the GIS system could be represented in spreadsheet format and then linked to the existing spreadsheets to incorporate this additional information into the existing model.

Since there are many ways that N enters and leaves farms, mass balance equations should be developed for N on all the farmland, within each land unit. This would better allow for the modelling of such things as nutrient management, exporting and spreading of manure, feed production, changes in feed rations and stocking rates, rotational grazing, and crop rotations. This could be done in conjunction with the GIS component. It would still treat all the farmland within each land unit as one farm but these units would be much smaller.

The model needs to incorporate some method of directly estimating edge of stream N loadings rather than relying upon published numbers. This could be done through a number of methods.

- The simplest and most direct approach would be to use the Universal Soil Loss Equation or some modification of it to derive initial edge of field loading rates. Then using VirGIS with a delivery equation, such as MUSLE to compute edge of stream loadings. The Soil Conservation Runoff Curve Model could also be included, to more accurately predict runoff levels.
- The EPIC model could be used to predict nutrient loads and also to predict crop yields as well. The EPIC model provides the user with the option of using the above equations, as well as several other methods for determining runoff volume, N loadings, and delivery rates. Another benefit of EPIC is that the prediction of crop yields would provide a better estimate of the economic impact of different crop rotations and differing management methods.
- Still another potential option would be to link the model to the EPA's BASINS model. Rather than being a single model, BASINS is a comprehensive software package, which includes a variety of data sets, analytical tools, and hydrologic simulation models. The geographic information system ArcView is used to integrate these various components into one system that can be operated in a Windows environment. The available data sets include:
    - Physiographic Data such as are land use/land cover, surface waters, roads, watershed and political boundaries.
    - Monitoring Data on drinking water, weather, stream flow, water quality indicators, and NPS pollutants like sediment and bacteria.
    - Point Source Data from a variety of EPA monitoring programs.

  Linking the optimization model to BASINS could be accomplished through the use of the ArcView interface. Initial data from the optimization model could be used as a data set for the BASINS model, which would in turn provide the loading levels that could be used by the model for optimization.

There are hydrologic simulation models, other than those mentioned above, which could potentially do a better job of simulating the fate of nonpoint source pollutants within a watershed. These models rely more upon physically based equations rather than empirical equations. However, there are two drawbacks to using these models for land areas as large as the Potomac Basin. First, the physically based models tend to be more data intensive, and for the entire basin the data requirements would be enormous. Secondly, these models were designed to simulate the hydrology of much smaller watersheds, and there is no guarantee that they can be directly applied to much larger areas with any greater accuracy than models more empirical in nature.

8.6. FINAL COMMENTS

The results of this study provide evidence that the state of Virginia has made little progress, to date, toward reducing its annual N loadings to the Potomac, by 40%. This study predicts that if this goal were met, the current annual cost would be $26.8 million. This annual cost is expected to increase at a steady rate, in response to continued population growth in the Basin; and at some point in the future, the cost will begin to rise exponentially. Adopting policies, which require the use of alternative settlement patterns, can slow this rate of growth. However, these measures by themselves cannot prevent the eventual dramatic increase in costs. Other measures such as restricting population growth, or the development of new inexpensive technologies might be necessary for this goal to be maintained indefinitely into the future.

To address the problematic situation discussed in the first chapter, this research project had by necessity to be very broad in its scope. The undertaking of a comprehensive project such as this one requires the use of numerous assumptions, and the making of countless difficult decisions concerning the most appropriate way to represent the problem. This inevitably leaves the final results and conclusions subject to a high degree of scrutiny. Yet that is exactly as it should be. Ideally this study will spur additional research on issues that were raised in these pages. Further research may call into question assumptions or methods used within this study. However, even if arguments concerning the validity of certain numbers or procedures does occur, it is highly unlikely that any of them will alter the basic conclusion of this study. Which is that if the current trend in population growth continues unabated, eventually the annual cost, of meeting Virginia's N goal for the Potomac, will rise dramatically. Exactly when this will occur in the future is the main issue left open for debate.

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VITA

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APPENDIX A

Glossary of Terms

Animal Unit (AU): unit of measurement for any animal calculated as: the number of slaughter and feeder cattle multiplied by 1; the number of dairy cows by multiplied 1.4; the number of hogs by 0.4; the number of sheep by 0.1; the number of horses by 2; the number of layers and broilers by 0.01; and turkeys by 0.18. **

Best Management Practices (BMP): are methods, measures, or practices used to meet its nonpoint (diffuse) source control needs.*

Biological Nutrient Removal (BNR): A modified form of activated sludge wastewater treatment that enhances P and N removal by microbial cells instead of chemical systems. ***

Buffer Area: a designated area, around a stream or waterbody, of sufficient width to minimize the entrance of chemicals or nutrients to the waterbody.**

Conservation Tillage: any tillage of planting system that leaves at least 30% of the soil surface covered with crop residue after planting.***

Conventional Tillage: complete inversion of the soil incorporating all residues with a moldboard plow or any practice with less than 30% residue remaining on field after plowing.***

Cover Crop: is a close-growing crop grown primarily for the purpose of protecting and improving soil between periods of regular crop production.**

Effluent Standard: determines how much pollutant can be discharged from municipal and industrial wastewater sources and by some types of diffuse pollution.*

Hydrologically Active Areas: are the areas that produce surface runoff within a watershed, based upon net rain estimation.*

Impervious Surface: a hard surface area that prevents or retards the entry of water into the soil mantle as under natural conditions prior to development.**

Landing (log deck): a place where logs are gathered for further processing or transport.**

Load: is the quantity (i.e. mass) of a material that enters a waterbody over a given period of time.**

Nutrients: elements or compounds, essential as raw materials for organism growth and development.**

Pasture: grazing lands planted primarily with introduced or domestic forage species that receive periodic renovation and or cultural treatments such as tillage, fertilizers, mowing, and weed control. Not in rotation with crops.**

Performance Standards: determine how much pollution can result from land use activities, are used to control pollution from subdivisions, construction sites, and mining.*

Point Source: means any discernable, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft from which pollutants are or may be discharged. This term does not include agricultural stormwater and return flows from irrigated agriculture.*

Pollution: is a change in the physical, chemical, radiological, or biological quality of the resource (air, land or water) caused by man or due to man's activities that is injurious to existing, intended, or potential uses of the resource.*

Skid Trail: a temporary nonstructural pathway over forest soil used to drag felled trees or logs to the landing.**

Standard: a definite rule, principle or measure established by an authority.*

Waste Assimilative Capacity: is the quantity of potential pollutants that can be discharged into the environment (receiving water body, air, or land) that does not result in the violation of a standard established by an authority.*

Water Quality: reflects the composition of water as affected by natural causes and man's cultural activities, expressed in terms of measurable quantities and related to intended water use. *

Waterbody: is any recognizable area of surface water, which is either permanent or occurs with regularity, and that may potentially provide a use for man. A water body can be a pond, wetland, stream, or ocean, but not a puddle.

Watershed: a drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake.**

Waterway: is a body of water with a flow and which is part of a larger network of waterbodies. Streams, creeks, rivers, and bays are typical of waterways.

* Novotny, Vladimir, Harvey Olem, *Water Quality: Prevention, Identification, and Management of Diffuse Pollution*, Van Nostrand Reinhold, 1994.

** United States Environmental Protection Agency, *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* . Office of Water, USEPA. Washington D.C. January 1993.

*** Virginia Department of Environmental Quality, Virginia Department of Conservation and Recreation, Virginia Chesapeake Bay Local Assistance Department, Virginia Department of Game and Inland Fisheries, Virginia Marine Resources Commission, *Draft for Public Review and Comment, Virginia's Potomac Basin Tributary Nutrient Reduction Strategy*, Richmond, VA. August 1995.