Baywide Nutrient Reduction Strategy 1990 Progress Report

Chesapeake Bay Program

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Introduction

The 1987 Chesapeake Bay Agreement established a framework for coordinated action by the Federal Government and the Chesapeake Bay States to reverse the trend of declining water quality conditions within the Chesapeake Bay and to restore the productivity of the ecosystem. One section of the Agreement specifically called for the following commitments related to nutrient enrichment of the Bay:

- By July 1988, to develop, adopt, and begin implementation of a basinwide strategy to equitably achieve by the year 2000 at least a 40 percent reduction of nitrogen and phosphorus entering the mainstem of the Chesapeake Bay. The Strategy should be based on agreed upon 1985 point source loads and on nonpoint source loads in an average rainfall year.
- By December 1991, to reevaluate the 40 percent reduction target based on the results of modeling, research, monitoring, and other information available at that time.

In response to this Agreement, the Chesapeake Bay jurisdictions, working through a Water Quality Task Group, developed the *Baywide Nutrient Reduction Strategy* (Chesapeake Bay Program, 1988a) for reducing nutrients entering the Bay to attain the year 2000 goal. The Nutrient Reduction Strategy called for more stringent point source controls and increased emphasis on reducing nonpoint source nutrient loadings from agricultural and urban sources. To achieve these goals, the jurisdictions within the Chesapeake Bay Program are implementing a variety of actions and programs.

The Nutrient Reduction Strategy specifically (1) defined how the 1985 base loads were developed, (2) discussed the actions and programs being implemented by the jurisdictions in point and nonpoint source categories to achieve the necessary load reductions, and (3) described the information that is needed to prepare for the 1991 Reevaluation and to more accurately measure progress towards meeting the year 2000 target. The Nutrient Reduction Strategy was presented as a three-phased approach, with Phase I marking the period between the benchmark loading year 1985 and the development of the Strategy in 1988, Phase II occurring between the adoption of the Nutrient Reduction Strategy and the reevaluation date of December 1991, and Phase III as the period following the December mid-course reevaluation. Currently, the Chesapeake Bay Program is in Phase II of the Nutrient Reduction Strategy and is actively developing and assimilating information necessary for the upcoming reevaluation.

In the process of developing the Nutrient Reduction Strategy, several key areas were identified where the jurisdictions needed to develop a common means of organizing and using existing information and where additional information was needed to fully understand and address the problems of nutrient enrichment in the Chesapeake Bay. Therefore, the Nutrient Reduction Strategy identified a number of specific annual goals for the Bay Program participants to accomplish during Phase II of the Nutrient Reduction Strategy. Table 1 identifies the Phase II milestones of the Nutrient Reduction Strategy proposed for 1990. In order to keep track of information obtained through Phase II research and water quality monitoring and modeling, the Nutrient Reduction Strategy required that annual progress reports be produced to:

- Provide information on point and nonpoint source management programs and document progress towards the year 2000 target
- Report on new information
- Incorporate any necessary adjustments to the approaches outlined in the Nutrient Reduction Strategy.

Since most of the proposed Phase II milestones identified in the Nutrient Reduction Strategy related to nonpoint sources of nutrients, the Nonpoint Source

Table 1. Steps Toward Refining the Nutrient Reduction Strategy Baywide Milestones for 1990

- Complete development of the basinwide Watershed Model (Chapters 3 and 4)
- Quantify and characterize nonagricultural (urban, forest, shoreline erosion) nonpoint source loadings into the Bay basin (Chapter 5)
- Develop consistent load reduction accounting methodologies for BMPs (to include the effective "working life" of various BMPs) (Chapter 6)
- Identify performance capability and refine cost information for wastewater treatment processes such as biological nutrient removal (Chapter 7)
- Complete refinement of habitat requirements for living resources that will be used with the 3-D model (Chapter 8)
- Evaluate approaches that may be used for nitrogen reduction (e.g., available technology, regulatory actions, incentive programs) (Chapter 9)
- Evaluate the effectiveness of the voluntary programs for the implementation of BMPs (Chapter 9)
- Implement necessary new and expanded monitoring programs for nonpoint sources (will be documented in the 1991 progress report)
- Implement necessary new and expanded monitoring programs for point sources (will be documented in the 1991 progress report)

Source: Chesapeake Bay Program (1988a).

Subcommittee of the Chesapeake Bay Program was tasked with the lead in preparing the annual progress reports. However, most of the Chesapeake Bay Program Subcommittees (e.g., Living Resources, Modeling, and Monitoring) are involved in the implementation of the Nutrient Reduction Strategy and, therefore, contribute to the progress reports.

The first progress report was completed in 1989; this is the second progress report. It summarizes the activities that occurred during 1990 to achieve the Nutrient Reduction Strategy Phase II milestones. For instance, the report describes enhancements made to the basinwide Watershed Model, presents new nutrient loadings estimates from the Watershed Model, and provides additional information on loadings from nonagricultural nonpoint sources. The progress report also summarizes the major findings of Chesapeake Bay Program studies examining the effectiveness of best management practices (BMPs) in reducing nutrient loads to surface and ground water, assessing the performance and cost effectiveness of certain wastewater treatment processes, and identifying refinements to living resources habitat requirements for major Chesapeake Bay indicator species. The progress report also outlines the findings of the Nonpoint Source Evaluation Panel, which addressed two 1990 Phase II milestones by evaluating the effectiveness of voluntary programs for the implementation of BMPs and assessing approaches that may be used for nitrogen removal. In addition, this report summarizes the progress being made in reducing nonpoint and point sources of nutrients within the Chesapeake Bay basin based on information provided by the Chesapeake Bay jurisdictions and summarized in the Chesapeake Bay Program's nonpoint and point source tracking systems.

Issues not fully resolved in this progress report will be subject to continuing refinement and will be documented in the 1991 progress report. For example, the Monitoring Subcommittee is currently reevaluating and revising, as needed, the monitoring strategy for the entire Chesapeake Bay basin. The findings and recommendations of this monitoring reevaluation are still too preliminary for inclusion in this progress report.

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Progress in Implementing Nonpoint and Point Source Control

Nutrients that enter the Chesapeake Bay originate from nonpoint sources (e.g., cropland, animal wastes, urban and suburban runoff) and point sources (e.g., municipal and industrial wastewater discharge). The commitment to a 40-percent reduction in nitrogen and phosphorus loadings to the Bay by the year 2000 agreed to in the 1987 Chesapeake Bay Agreement applies to both "controllable" nonpoint and point sources. Water quality modeling conducted by the Chesapeake Bay Program generally indicates that agriculture (including cropland and animal waste) is the most significant "controllable" nonpoint source of nutrients and that municipal dischargers are the most significant point source to the Bay. Accordingly, State strategies to attain nutrient reduction goals have generally focused on programs designed to reduce nutrient loadings from these two sources.

One goal of the *Baywide Nutrient Reduction Strategy Progress Report* is to document progress toward the year 2000 goal, by:

- Recording estimates of soil and nutrients prevented from entering the Bay through agricultural best management practice (BMP) implementation (nonpoint source).
- Tracking the extent of implemented and planned sewage treatment plant (STP) technology upgrades and using annual flow and nutrient concentration information from the major STP and industrial point source dischargers to estimate overall nutrient reductions (point source).

Each jurisdiction receiving implementation grants from the Chesapeake Bay Program is required to keep annual records of accomplishments (e.g., number of BMPs implemented with grant funds and resulting soil saved) in reducing nonpoint and point source nutrient pollution. The Environmental Protection Agency's Chesapeake Bay Liaison Office (CBLO) assembles this information and maintains an overall nonpoint and point source tracking system. Each jurisdiction also maintains its own tracking system containing more detailed information than that compiled by the CBLO; the CBLO tracking system contains only the information necessary to provide annual estimates of nutrient reductions.

This chapter summarizes information provided by the States to the CBLO tracking systems to measure progress in nonpoint and point source program implementation. Information on nonpoint source progress is presented first as estimates of soil erosion and nutrient reductions attributed to cost-shared BMP installations. The status of nutrient management planning in the Bay basin is also described. Point source progress is presented as a description of research endeavors on advanced STP technologies, planned or implemented STP upgrades, and legislative actions. Nutrient reduction estimates from the point source tracking system are also provided.

Nonpoint Source Reduction

To date, many nonpoint source nutrient control programs have devoted much attention to agricultural approaches (i.e., cropland and animal waste). The Chesapeake Bay Program nonpoint source tracking system, started in 1985 through the implementation grants program, reflects this emphasis by following the implementation of cost-shared agricultural BMPs in the Chesapeake Bay basin. The States summarize the information on cost-shared BMPs and provide it to the CBLO for inclusion in the nonpoint source (BMP) tracking system. This tracking system is currently the primary method used to estimate basinwide nonpoint source nutrient reduction progress toward attaining the 40-percent goal. States are also promoting nutrient management planning as a means to reduce nutrient loadings from agricultural nonpoint sources. The CBLO assembles this information in a separate tracking system that summarizes the number of nutrient management plans implemented and the land acreage covered by the plans. Nutrient management planning information is not currently incorporated into the overall nonpoint source (BMP) tracking system, as the CBLO has not developed a means to quantify the nutrient management information in a manner compatible with the existing nonpoint source tracking system.

BMP Implementation

States receiving implementation grants under the Chesapeake Bay Program are required to provide input to the CBLO-maintained nonpoint source tracking system, including the number of BMPs installed annually, information on BMP location (by county and watershed), number of acres served by the BMP, tons of soil erosion saved by the BMP, and number of animal units served or manure stored. These data are used to estimate reductions in nutrient loadings attributed to BMP installation and animal waste storage. Although the tracking system includes several different types of information on agricultural BMPs, only the nutrient reduction estimates are used to chart progress. The tracking system also includes information on BMP installation and related estimates of soil erosion and nutrient reductions achieved through the U.S. Department of Agriculture (USDA) Agricultural Conservation Program.

In general, the CBLO measures progress by applying specific nutrient reduction factors (i.e., pounds of total phosphorus or total nitrogen per ton of soil or animal waste) to estimates provided by the States of the reduction in soil erosion (derived from the universal soil loss equation) and animal wastes associated with BMP installation. The Chesapeake Bay Program determined the nutrient reduction values using information from several State research efforts that estimated nutrient values attributed to soil erosion and animal waste. The specific procedures for tracking and estimating progress are described in the *Chesapeake Bay Nonpoint Source Programs* report (Chesapeake Bay Program, 1988b). For example, in 1989, the States estimated that 3,190,000 tons of soil were prevented from entering the Chesapeake Bay system as a result of cost-shared BMP implementation. Using the designated nutrient reduction factor of 5.4 pounds per ton of soil for nitrogen (Chesapeake Bay Program, 1988b), the CBLO estimated that 17,226,000 pounds of nitrogen were prevented from entering Bay waterways. Since the tracking system is largely based on reductions in soil erosion, it is more efficient in tracking phosphorus, which tends to chemically bind to sediment more than to nitrogen, which is more soluble.

Once estimates of annual nutrient reductions are determined, they are compared to a base year (i.e., 1985) to track nutrient reduction progress relative to the Chesapeake Bay Agreement goal. The 1985 base year was determined using cropland information contained in the 1982 USDA National Resource Inventory (NRI), corrected to 1985 levels, and estimates of manure stored and generated based on animal populations identified in the agricultural census (Bureau of Census, Agricultural Census, 1982).

Table 2 summarizes estimated reductions in soil erosion and animal waste and associated nutrient loads as determined from the CBLO tracking system using the procedures described above. Figures 1 and 2 depict the data contained in Table 2 by showing estimated nutrient reductions from 1985 to 1989 compared to goals derived from the Nutrient Reduction Strategy for the same time period. In general, the figures show that estimated reductions in nutrients are exceeding expectations. Several factors must be considered when examining this information, including the following:

- The nonpoint source (BMP) tracking system does not include a BMP until it is certified as complete with the cost-share paid, which causes a

Table 2. Cumulative Reduction in Total Phosphorus and Total Nitrogen Based on Reductions in Cropland Erosion and Animal Waste Managed

Reduction Parameter	1985 Base	1985	1986	1987	1988	1989
	Tons in 1,000s					
Soil Saved	31,921.7	613	1,227	1,655	2,294	3,190
Animal Waste Managed	22,838.7	206	411	1,108	1,609	2,265
	%					
TP Reduction		1.45	2.91	5.03	7.12	10.0
TN Reduction		1.43	2.86	5.03	7.12	10.0
TP Remaining	(of 100)	98.55	97.09	94.97	92.88	90.0
TN Remaining	(of 100)	98.57	97.14	94.97	92.88	90.0

Source: State Chesapeake Bay Programs and USDA ACP Program.

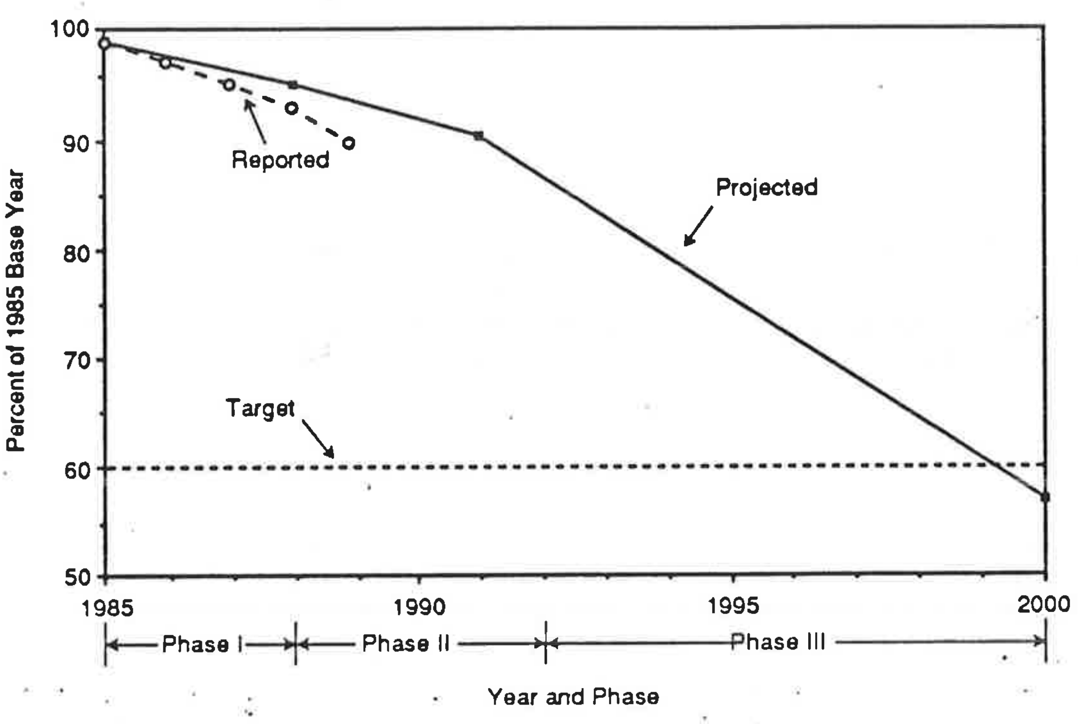

Figure 1. Nonpoint Source Phosphorus Reduction Progress as Reflected by BMP Implementation Compared to Projected Reductions From the *Baywide Nutrient Reduction Strategy* (Chesapeake Bay Program, 1988a)

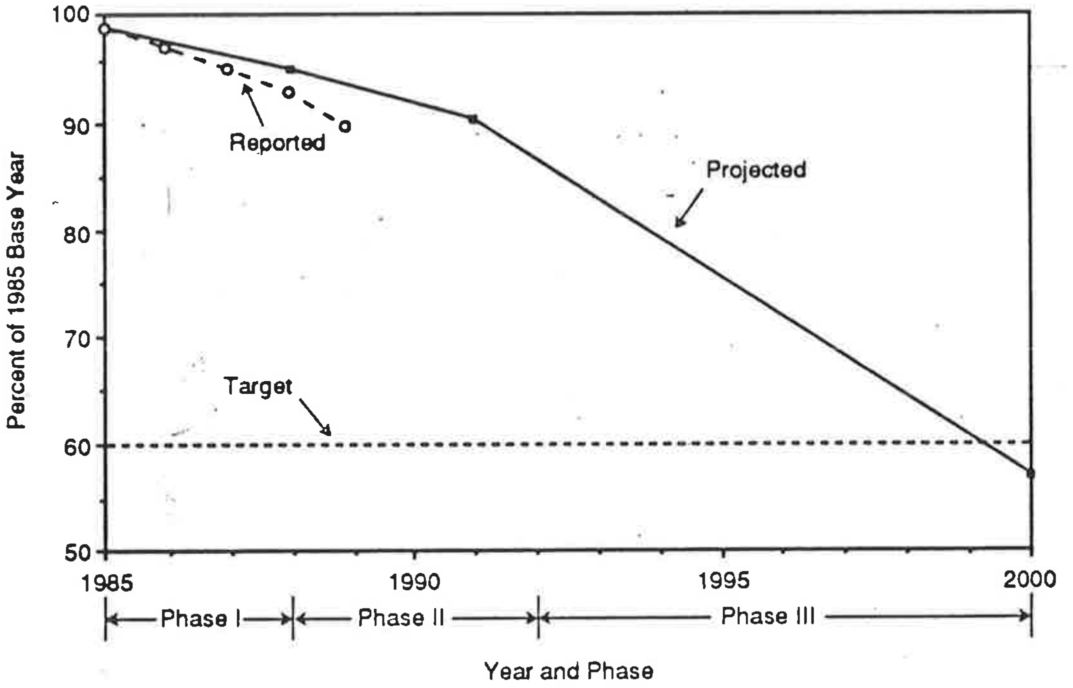

Figure 2. Nonpoint Source Nitrogen Reduction Progress as Reflected by BMP Implementation Compared to Projected Reductions From the *Baywide Nutrient Reduction Strategy* (Chesapeake Bay Program, 1988a)

considerable time lapse between the approval of BMPs for cost-share funding and the appearance of the installed BMP in the nonpoint source tracking system. BMPs are reported using these guidelines to help ensure that only properly constructed and functioning BMPs are counted. This delay also affects the USDA program. BMPs are removed from the nonpoint source tracking system when their contract life is expired.

- The nonpoint source tracking system currently does not track the number of BMPs that are voluntarily employed, although the Chesapeake Bay Program is working with the USDA to develop a method to include them. While the extent of voluntary BMP implementation is unknown, all Chesapeake Bay jurisdictions encourage and support it through a substantial outreach program.
- Only agricultural BMPs are included in the current tracking system. Although some States have begun tracking nonagricultural BMPs, these efforts have not yet been coordinated with CBLO's tracking system.

In addition, the data set is based on estimated reductions in soil erosion from BMP implementation; therefore, it does not consider the effectiveness of BMPs in controlling soluble nutrients. Chapter 6 of this report summarizes the findings of several studies conducted under the auspices of the Chesapeake Bay Program that examined BMP effectiveness in reducing nutrients from agricultural sources (Camacho, 1990; Dillaha, 1990). These studies showed that, although many traditional BMPs are very effective in reducing soil erosion, some are less successful in reducing loadings of soluble nutrients (e.g., nitrogen). These same studies showed that nutrient management planning, in conjunction with traditional soil erosion BMPs, greatly reduced nutrient loadings to surface and ground waters. Recognizing this, all of the Chesapeake Bay jurisdictions are actively pursuing nutrient management planning, coupled with traditional BMPs, to reduce overall nutrient loadings from agricultural sources.

Despite some of the apparent limitations with the CBLO-maintained nonpoint source tracking system, it does provide one means of demonstrating the effectiveness of nonpoint source program implementation and approximating progress in reducing nutrient loads to the Chesapeake Bay. The Chesapeake Bay jurisdictions and the USDA are currently refining the means to track nonpoint source progress through such measures as monitoring progress in nutrient management planning efforts, examining other BMPs, such as those applied to forestry, and assessing the extent of voluntary BMP implementation.

Nutrient Management

In addition to traditional BMPs, the *Baywide Nutrient Reduction Strategy* recognized nutrient management as one of the major tools to reduce nonpoint source nutrient loadings to the Bay (Chesapeake Bay Program, 1988a). Nutrient management is designed to reduce the application of nutrients to the land, with the ultimate goal of leaving very little or no nutrients in the soil at harvest time. Nutrient management considers all nutrient sources available to produce a crop, including natural nutrient sources, crop residues, and various fertilizers (animal wastes, sewage sludge, and commercial fertilizers), when developing a nutrient management plan. Such plans provide nutrient recommendations for an optimal crop yield based on factors including the production capability of the soil, the annual rainfall, and the past yield history for the field. The plan specifies the extent of nutrients to be applied, the form of the nutrients, and the application time and method. A nutrient management plan usually reduces the amount of nutrients applied to a field without greatly affecting the yield. As a result, a farmer's fertilizer usage is usually reduced. Data on chemical fertilizer use in the Chesapeake Bay basin assembled from Tennessee Valley Authority (TVA) information show recent declines in the use of chemical fertilizers (Figure 3). Although many factors affect the willingness of people to use fertilizers, some of the recent reductions in fertilizer use shown in this figure may be attributed, in part, to the increasing awareness and promotion of nutrient management in the Bay basin.

The CBLO also assembles information provided by the States to track the implementation of nutrient management plans. States provide information on the number of plans implemented, total acres covered by the plans, and estimates of nitrogen and phosphorus reductions. By July 1990, the States reported that there were nutrient management plans in place for animal waste and chemical fertilizer application for approximately 114,300 acres (1.4 percent of eligible cropland in the basin). The CBLO estimates that implementation of these plans reduced total nitrogen and total phosphorus use by 31.5 and 37.5 pounds per acre, respectively. States initially prioritized nutrient management efforts towards animal waste operations. Because initial nutrient

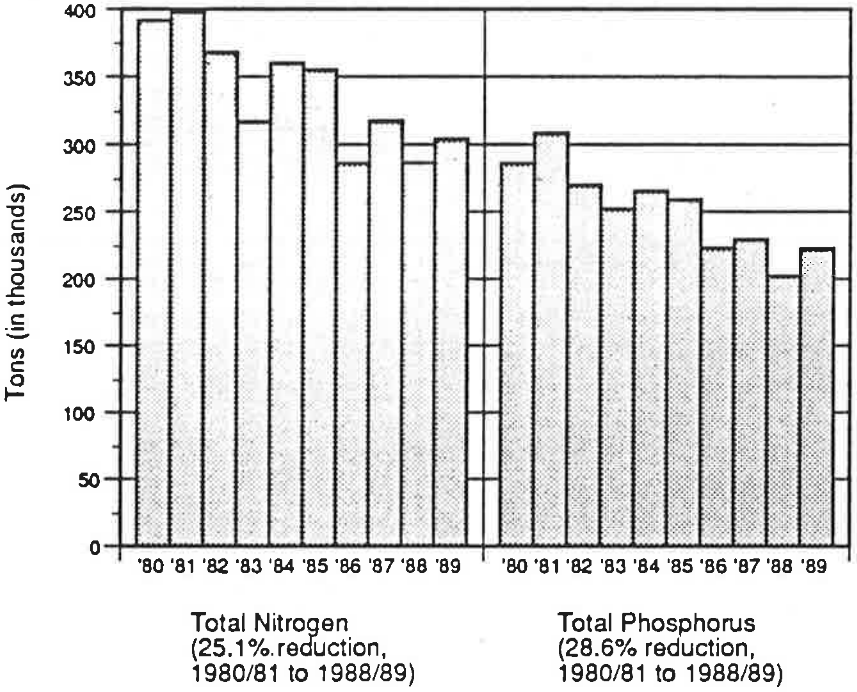

Figure 3. Summary of Chemical Nutrient Use in the Chesapeake Bay Basin States From 1980 to 1989 (compiled from TVA, 1988 and 1989 data)

management planning focused on animal wastes (which have a relatively high total nitrogen and total phosphorus loading factor), estimates of nutrient reductions attributed to nutrient management planning may decrease as more cropland is enrolled in nutrient management programs. Information on nutrient loadings reductions from nutrient management planning will be used in the Watershed Model, in conjunction with estimated nutrient reductions attributed to BMP implementation and animal waste storage, to convert these reduction estimates into water quality improvements in the main Bay.

Point Source Reduction

As reported earlier, municipal wastewater discharge contributes the majority of the point source nutrient load to the Bay. Therefore, one of the priorities of the Chesapeake Bay jurisdictions is sewage treatment plant upgrades to reduce nutrient loadings from these sources. The need for more advanced wastewater treatment is particularly important to help offset increasing municipal inputs as human populations and the resultant volume of wastewater increase in the Chesapeake Bay basin. The approaches planned by the jurisdictions for municipal point source nutrient control were outlined in the *Baywide Nutrient Reduction Strategy* (Chesapeake Bay Program, 1988a). The first priority for nutrient reduction in most cases was phosphorus removal, followed by planned phosphorus and nitrogen removal, where appropriate.

Research completed by the Chesapeake Bay Program participants and outside parties has identified biological nutrient removal (BNR) systems as the most cost-effective and environmentally sound approach to reducing phosphorus and nitrogen loadings from municipal sources, where feasible. Maryland and Virginia have conducted BNR demonstration projects, as summarized in Table 3. In addition, Table 4 highlights other recent research endeavors by the States focusing on BNR technology, including a BNR feasibility study at the District of Columbia's Blue Plains Facility. Chapter 7 of this report describes some of the major findings of these studies. Clearly, the States are incorporating BNR technology into upgrades for existing facilities and full BNR for new facilities as part of their nutrient reduction strategies. Table 5 illustrates six municipal wastewater treatment plants in Maryland, discharging a total of approximately 24 million gallons per day (mgd), that have nitrogen removal in place. As outlined in the Nutrient Reduction Strategy, Maryland and Virginia, and the DC Blue Plains Facility are planning for BNR at new and existing facilities (Table 6). In Pennsylvania, it appears that the most cost-effective means of meeting the nutrient reduction goal is through the agricultural nonpoint source control program. Depending on the success of that program, Pennsylvania will consider additional point source controls.

An effective approach for reducing nutrient loadings to the Bay is through phosphate detergent bans. Virginia, Maryland, and DC all implemented such bans during Phase I of the Nutrient Reduction Strategy (1988, 1985, and 1986, respectively). Pennsylvania recently passed similar legislation (effective March 1990) banning the use of phosphates in household laundry detergents

Table 3. STPs Where Nitrogen Removal Technologies Were Demonstrated

State	Plant	Current Flow (mgd-1989)	Design Flow (mgd)	Type Control	NPDES Permit Limit (mg/L-TN)	Status
MD	BOWIE	1.99	3.30	BNR demo	Not determined	Demo 1984-1987
MD	MD City	0.75	2.50	BNR demo	8	Demo 1984-1987
VA	HRSD*- Lamberts Pt. (renamed VIP plant)	34.00	40.00	BNR/VIP pilot & new construction	None	Planned 3/91
VA	HRSD- York river	7.00	15.00	BNR demo	None	Demo project from 7/86-10/89
VA	HRSD- Nansemond	10.00	30.00	BNR/VIP pilot & retrofit	None	Planned 10/93

*HRSD = Hampton Roads Sanitation District.

Table 4. Recent Research Activities Related to BNR Technology Conducted in the Chesapeake Bay Basin

- In October 1989, the Virginia State Water Control Board completed a planning level study to evaluate feasible technologies (including BNR) and the associated costs of implementing four nutrient removal scenarios (i.e., varying levels of phosphorus and nitrogen removed) at 26 municipal point sources.
- The Hampton Roads Sanitation District (HRSD) was awarded a process patent for a new BNR system called the Virginia Initiative Process (VIP) in fall 1989 by the Federal Government. The new technology enables cost-effective upgrades for phosphorus and nitrogen control and is being installed as part of the expansion of the 40 mgd VIP, formerly Lambert's Point STP in Norfolk, Virginia. HRSD is also evaluating the possible use of this technology at the Nansemond facility.
- In May 1989, the Maryland Department of the Environment completed a planning level study to assess the capability and cost-effectiveness of BNR technology to upgrade municipal point sources.
- The Maryland Department of the Environment contracted with Virginia Polytechnic Institute and State University to evaluate 10 plants as to the feasibility and cost effectiveness of biological nitrogen and phosphorus removal. As a result, six plants are being modified to obtain BNR capability through operational or minor structural modifications. The plants are Aberdeen, Frederick, Havre de Grace, Thurmont, Perryville, and Joppatown. The project is scheduled for completion in October 1992.
- The Blue Plains STP and its contractor are evaluating the feasibility of biological phosphorus control and other treatment alternatives for nitrogen control at this 317 mgd facility.

Table 5. STPs Where Nitrogen Removal is in Place

State	Plant	Current Flow (mgd-1989)	Design Flow (mgd)	Type Control	NPDES Permit Limit (mg/L-TN)	Status
MD	MD City	0.75	2.50	New construction	8	Completed 7/90
MD	Dorsey Run	0.76	1.60	Methanol addition	3	Completed 9/90
MD	Fort Meade	2.63	4.50	Methanol addition	2*	Completed 6/90
MD	Patuxent	3.41	6.00	BNR (0 ditch)	10	Completed 4/87
MD	W. Branch	14.09	30.00	Methanol addition	3	Completed 9/90
MD	Easton	2.01	2.35	Land application	NA**	Completed 1989

* Permit limit is 2 mg/L for ammonia; no permit limit is given for TN.

** Easton Plant does not have a TN permit limit.

in the Chesapeake Bay drainage basin. In Virginia, Maryland, and DC, the implementation of phosphate detergent bans has resulted in decreased influent phosphorus concentrations to municipal wastewater treatment plants ranging between 26 to 34 percent (Sellers et al., 1987; Virginia State Water Control Board, 1990a). Significant reductions in operation and maintenance costs also occurred at facilities currently using chemicals for phosphorus removal. Similar results are expected in Pennsylvania.

In addition to monitoring STP upgrades, research and demonstration projects on BNR technology, and legislative initiatives, the CBLO assembles information provided by the States on municipal and industrial dischargers to track point source progress by estimating reductions in point source nutrient loads based on plant flow multiplied by nutrient concentration in the effluent. Using this method of "tracking," Figures 4 and 5 compare estimated annual reductions in nitrogen and phosphorus from point sources between 1985 and 1989 to reduction goals defined in the *Baywide Nutrient Reduction Strategy* (Chesapeake Bay Program, 1988a). This information shows that reductions in phosphorus are exceeding expectations, largely due to phosphate detergent bans implemented by the Chesapeake Bay jurisdictions. Nitrogen levels increased slightly above projected levels during Phase I of the Nutrient Reduction Strategy (1985 to 1988), but began to decline according to projections during Phase II of the Strategy's implementation. This trend was expected, however, since implementation of nitrogen removal technologies for municipal wastewater treatment plants was not actively initiated until Phase II of the Nutrient Reduction Strategy. The only nitrogen removal action scheduled in Phase I was Virginia's demonstration project at the HRSD-York STP and the retrofit of Maryland's Dorsey Run STP.

Table 6. STPs Where Nitrogen Removal Is Planned to Meet Nutrient Reduction Goal

State	Plant	Current Flow (mgd-1989)	Design Flow (mgd)	Type Control	NPDES Permit Limit (mg/L-TN)	Status
MD	Bowie	1.99	3.30	Retrofit	TBD**	Planned 6/91
MD	L. Patuxent	14.20	15.00	BNR	TBD	Planned 5/92
MD	Parkway	5.90	7.50	BNR	3***	Planned 8/91
MD	Sod Run	8.27	10.00	BNR	TBD	Planned 1993
MD	Piscataway	19.15	30.00	BNR	TBD	Planned 1994
MD	Annapolis	8.00	10.00	BNR	TBD	Planned 1992
MD	Ches. Beach	0.42	0.55	BNR	10	Planned 1991
MD	Freedom Dist.	1.76	1.90	BNR	TBD	Planned 1992
MD	Back River	183.74	180.00	BNR	TBD	Planned 1997
MD	Aberdeen	2.02	2.80	BNR	TBD	Planned 1991
MD	Frederick	7.48	8.00	BNR	TBD	Planned 1991
MD	Havre de Grace	1.62	1.90	BNR	TBD	Planned 1994
MD	Joppatown	0.72	0.75	BNR	TBD	Planned 1992
MD	MCI	0.80	1.20	BNR	TBD	Planned 1992
MD	Perryville	0.57	1.65	BNR	TBD	Planned 1991
MD	Thurmont	0.60	1.00	BNR	TBD	Planned 1991
MD	Hurlock*	0.475	1.10	Land Appl.	TBD	Planned 1992
MD	Aberdeen PG*	1.11	2.80	BNR	TBD	Planned 1992
MD	Broadneck*	4.184	6.00	BNR	TBD	Planned 1992
MD	La Plata*	0.612	1.00	BNR	TBD	Planned 1993
MD	Broadwater*	0.953	2.00	BNR	TBD	Planned 1993
MD	Ballenger*	0.60	2.00	BNR	TBD	Planned 1994
MD	Seneca Creek*	3.91	5.00	BNR	TBD	Planned 1994
MD	Mattawoman*	6.03	10.00	BNR	TBD	Planned 1995
MD	Cambridge*	3.79	8.10	BNR	TBD	Planned 1995
MD	Cox Creek*	11.12	15.00	BNR	TBD	Planned 1995
MD	Westminster*	2.88	3.00	BNR	TBD	Planned 1996
MD	Crisfield*	0.794	1.00	BNR	TBD	Planned 1996
MD	Salisbury*	5.23	6.80	BNR	TBD	Planned 1996
MD	Pine Hill Run*	2.81	4.50	BNR	TBD	Planned 1997
MD	Cumberland*	11.05	15.00	BNR	TBD	Planned 1997
MD	Halfway*	1.37	1.60	BNR	TBD	Planned 1997
MD	Pocomoke City*	0.93	1.47	BNR	TBD	Planned 1998
MD	Kent Island*	0.83	1.00	BNR	TBD	Planned 1998
MD	Elkton*	1.17	2.70	BNR	TBD	Planned 1998
MD	Damascus*	0.634	0.90	BNR	TBD	Planned 1999
MD	Chestertown*	0.727	0.70	BNR	TBD	Planned 1999
MD	Hagerstown*	6.68	8.00	BNR	TBD	Planned 1999
MD	Patapsco*	55.55	60.00	BNR	TBD	Planned 2000
MD	Edgewood-APG*	1.19	3.00	BNR	TBD	Planned 2000
VA	Little Falls Run	0.00	8.00	BNR, Oxidation	TBD	Planned 4/91
VA	Proctor Creek	3.76	27.00	BNR	TBD	Planned
VA	Falling Creek	10.11	10.00	BNR	TBD	Planned
VA	Ft. Eustis	1.65	3.00	BNR	TBD	Planned
VA	Henrico	0.00	45.00	BNR	TBD	Planned

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Table 6. STPs Where Nitrogen Removal Is Planned to Meet Nutrient Reduction Goal (cont.)

State	Plant	Current Flow (mgd-1989)	Design Flow (mgd)	Type Control	NPDES Permit Limit (mg/L-TN)	Status
VA	HRSD-Army Base	12.99	18.00	BNR	TBD	Planned
VA	HRSD-Boat Harbor	15.85	25.00	BNR	TBD	Planned
VA	HRSD-Ches./Eliz	14.36	24.00	BNR	TBD	Planned
VA	HRSD-James River	10.34	20.00	BNR	TBD	Planned
VA	HRSD-Williamsburg	9.72	22.50	BNR	TBD	Planned
VA	Petersburg	8.48	15.00	BNR	TBD	Planned
VA	Richmond	66.10	70.00	BNR	TBD	Planned
VA	Alexandria	35.60	54.00	BNR	TBD	Planned
VA	Aqui	1.14	6.00	BNR	TBD	Planned
VA	Arlington	26.56	40.00	BNR	TBD	Planned
VA	Dale Svc. Corp. #1	2.00	4.00	BNR	TBD	Planned
VA	Dale Svc. Corp. #8	0.84	2.00	BNR	TBD	Planned
VA	L Hunting Cr.	3.82	6.60	BNR	TBD	Planned
VA	Lower Potomac	32.98	72.00	BNR	TBD	Planned
VA	Mooney	7.58	24.00	BNR	TBD	Planned
VA	USMC-Mainside	1.45	2.00	BNR	TBD	Planned
VA	Upper Occoquan	9.40	15.00	BNR	TBD	Planned
VA	FMC	0.00	6.00	BNR	TBD	Planned
VA	Fredericksburg	2.57	4.50	BNR	TBD	Planned
VA	Massaponax	1.55	6.00	BNR	TBD	Planned
VA	HRSD-York	7.36	15.00	BNR	TBD	Planned
DC	Blue Plains****	316.71	370.00	BNR/ Conventional	None	Planned

* Completion of planned upgrades is subject to funding availability and results of the 1991 Reevaluation.
** To be determined.
*** NPDES permit limit effective 10/1/91.
**** DC has proposed to perform a pilot study of a recommended BNR process at its Blue Plains facility. The DC government hopes the pilot study will begin in 1992.

The data presented in this chapter show that the Chesapeake Bay jurisdictions are taking positive actions towards implementing their nutrient reduction strategies and that some nutrient reductions are exceeding expectations defined in the *Baywide Nutrient Reduction Strategy* (Chesapeake Bay Program, 1988a). The nonpoint source (BMP) tracking system provides a limited means of monitoring nutrient reductions associated with increasing implementation of agricultural BMPs in the Bay basin. The CBLO and the jurisdictions are currently seeking to expand the scope of the nonpoint source tracking system by including BMPs applied to other types of land uses (e.g., urban, forestry) and trying to acquire additional information tracking the implementation of voluntary BMPs (i.e., those installed without cost-share assistance). Also, the States are reporting to the CBLO information on the extent of nutrient management planning in the basin, which should provide a better

3

Update on the Development of the Watershed Model

The Chesapeake Bay Program has relied heavily on water quality modeling to guide program strategies for nutrient reduction. This comprehensive modeling approach consists of two models, each with a specific role, that interact and ultimately predict the effects of nutrient loadings in the Chesapeake Bay watershed on water quality in the main Bay. The two models used by the Bay Program are the Watershed Model and the Time Variable Bay Model. The Watershed Model simulates runoff, ground-water flow, and river flow to estimate nutrient loadings from nonpoint and point sources to the tidal Chesapeake Bay. These loading estimates are used as input to the Time Variable Model, a continuous hydrodynamic and water quality model of the tidal estuary.

Water quality modeling efforts in the Chesapeake Bay began with the Watershed Model during the late 1970s. The first-generation Watershed Model was completed in 1983 and was used to support the subsequent development of a two-dimensional, steady-state water quality model of the Chesapeake Bay mainstem. The mainstem model, which was developed during 1985 through 1987, was used to test a number of potential nutrient control scenarios. This modeling effort became the basis for the nutrient load reduction goal of 40 percent by the year 2000 established in the 1987 Chesapeake Bay Agreement.

These initial modeling efforts were not static, however. The *Baywide Nutrient Reduction Strategy* required refinement of the models as part of the preparation for the 1991 Reevaluation (Chesapeake Bay Program, 1988a). Accordingly, both models are being improved and updated. The Nonpoint Source Subcommittee is most closely involved with the Watershed Model and has provided critical input into its development. This chapter concentrates on updates to the Watershed Model and briefly describes changes to the Time Variable Model.

Watershed Model

Model Development

A two-phased approach to upgrade the Watershed Model was initiated in October 1988. Phase I, completed in March 1990, was designed to improve the nonpoint loading representation, refine and reevaluate data input to the Model, and perform a preliminary recalibration to available water quality data for the 1984 through 1985 period (the same period used as the basis for the 40 percent nutrient load reduction goal). The goal of these activities was to provide data needed for the calibration of the Time Variable Model and to provide an initial analysis of basin nutrient loads delivered to the Bay. A Chesapeake Bay Program publication, *Watershed Model Application to Calculate Bay*

Nutrient Loadings: Preliminary Phase I Findings and Recommendations, documented changes to the Watershed Model completed during Phase I (Donigian et al., 1990). Briefly, these changes included:

- Incorporation of a snow melt simulation
- Allowance of variable hydrologic characteristics for each land use category
- Improvement of land slope estimates by deriving an average slope for each land use type in each model segment
- Inclusion of animal waste contributions
- Reevaluation of 1974-1978 land use inputs and inclusion of 1984-1985 land use data
- Update of meteorology and precipitation data to 1984-1985
- Update of diversions, point sources, and observed stream flow/water quality data to 1984-1985
- Accounting of water acreage within basins
- Inclusion of estimates of direct atmospheric deposition of nitrogen (for water surfaces only)
- Recalibration of model to 1984-1985 with model refinements and updated input.

Phase II of the Watershed Model update began in March 1989 and is scheduled to be completed in early 1991. This phase was designed to continue the refinements of Phase I, provide a better representation of the effects of agricultural best management practices, and enhance sediment transport equations with the goals of providing detailed scenario input data to the Time Variable Model for the 1991 Reevaluation of the Nutrient Reduction Strategy. Phase II revisions will also provide information for large-scale planning and tracking of nonpoint source controls.

Model Operation

The Watershed Model manipulates its many inputs to generate estimates of nutrient loadings to the Bay. To model conditions as accurately as possible, inputs were developed for individual segments of the Bay watershed, namely 10 river basins (as described in Chapter 4 of this report) and for above and below fall line sections of each basin. Each river basin is further subdivided into smaller segments; 63 segments compose the total Watershed Model (Hannawald, 1990, provides location maps and land use information for the river basins contained in the Model and for each model segment).

The Watershed Model consists of the following three submodels.

- *Hydrologic*—Uses time series of rainfall, evaporation, and other meteorological data. The submodel is capable of calculating soil moisture and converting rainfall input into runoff, subsurface recharge to stream channels, soil moisture, and evapotranspiration. The runoff and ground-water calculations of the Hydrologic Submodel ultimately drive the Watershed Model nutrient loading calculations.

- *Nonpoint Source*—Uses rainfall intensity records, as well as surface and subsurface output from the Hydrologic Submodel, to simulate soil erosion and surface and subsurface pollutant loads. This input is converted to nutrient and sediment loadings to river channels. Pollutant and sediment loads from the land are loaded into the River/Reservoir Submodel on an hourly time step for above fall line segments. Below the fall line, these loads are considered to be delivered directly to the tidal Bay.
- *River / Reservoir*—Routes stream flow and associated loads through the river, lake, and reservoir system of the Chesapeake drainage basin. Major physical, chemical, and biological processes of pollution decay and transformation are included. Input to this submodel includes point source loads, major water supply diversions, nonpoint source loads from the Nonpoint Source Submodel, atmospheric deposition loads, and flow from the Hydrologic Submodel.

The Watershed Model provides information on stream flow, nonpoint pollution loads, and sediment loads in the Bay's 64,000 square mile drainage area. Outputs from the Watershed Model, in turn, are used as inputs to the Time Variable Model of the mainstem Chesapeake Bay.

Time Variable Model

The Time Variable Model, now in the final stages of development and scheduled for completion in early 1991, can estimate the water quality response of the Chesapeake Bay to nutrient inputs estimated by the Watershed Model. The Time Variable Model simulates sediment nutrient flux, plankton growth, and other water quality processes. The Time Variable Model is capable of profiling an entire year and is able to evaluate in detail the needed phosphorus and nitrogen reductions in the mainstem of the Chesapeake Bay in order to achieve the desired restoration goals. In particular, the revised Time Variable Model will address the extent of nutrient reductions that are necessary to protect living resources in specific sensitive areas of the Bay and will estimate how long it will take before measurable improvement occurs in the Bay (given the existing reservoir of nutrients in sediments) once nutrient controls are in place.

The coupled Watershed and Time Variable Models will not provide absolute predictions of watershed nutrient loads and resulting Bay water quality. However, the models do provide an excellent tool for studying cause-effect relationships between activities in the Chesapeake Bay watershed and water quality in the main Bay. The data from these two models are one part of the 1991 Reevaluation and will provide program managers with some of the information needed to assess the adequacy of the 40-percent goal for achieving the desired Bay restoration goals.

4

Updated Nutrient Loadings as Predicted by the Watershed Model

The Chesapeake Bay Program began watershed modeling efforts in the late 1970s. The original Watershed Model, which was completed in 1983, is currently being refined and improved. These revisions to the original model began in the middle of the 1980s and are scheduled for completion in early 1991 so that output from the updated Watershed Model can be used in the 1991 Reevaluation of the Nutrient Reduction Strategy. Chapter 3 of this report describes progress made to date in updating and revising the Watershed Model. Phase I changes to the Watershed Model were completed in March 1990, resulting in the availability of new nutrient loadings estimates, by tributary and land use, for the Chesapeake Bay basin (Donigian et al., 1990).

One of the main goals of the Nutrient Reduction Strategy and the 1991 Reevaluation was to accomplish the following:

> By December 1991: Develop a tributary based basinwide strategy to achieve the required levels of nutrient reductions for the Chesapeake Bay.

To accomplish this goal, Phase I modifications to the Watershed Model were largely designed to improve the understanding of nutrient loadings on a tributary-by-tributary basis, as well as to expand and enhance the loadings estimates themselves. Results from the Watershed Model are one tool in developing a revised baywide nutrient reduction strategy based on assigning specific nutrient reduction targets to major tributaries in the Chesapeake Bay basin. This chapter summarizes preliminary results for 1990 from the recently revised Watershed Model. It presents the total phosphorus and total nitrogen loads from above and below fall line sources, subdivides total loads into their nonpoint and point source components, and further defines nonpoint source loads by land use type. Data are presented for each tributary included in the Watershed Model. As Phase II revisions to the model continue, it is possible that some of these initial loadings estimates may change slightly. Any changes to the preliminary loadings estimates are likely to be minor and will not affect the relative distribution of nutrient loadings between tributaries and land uses in the Bay Basin.

Preliminary Results from the Watershed Model

The watershed modelers surveyed many sources, including State data bases, the Agricultural Census, U.S. Department of Agriculture (USDA) Forest Service Timber Surveys, and USDA Soil Conservation Service information, to update and revise land use information for the Chesapeake Bay basin. An extensive literature review, and other research, was also undertaken to revise the nutrient loading factors for each land use type. These efforts are described in a number of Chesapeake Bay Program publications, including *Land Use for the Chesapeake Bay Watershed Model* (Hannawald, 1990), *Watershed Model Application to Calculate Bay Nutrient Loadings* (Donigian et al., 1990), *Estimation of Nonpoint Source Loading Factors in the Chesapeake Bay Watershed Model* (Blalock and Smolen, 1990), and *Nonpoint Source Pollution Loading Factors and Related Parameters from the Literature* (Blalock, 1990). The revised Watershed Model was calibrated to water quality monitoring station data throughout the basin. As a result of these updates, the Watershed Model predicts phosphorus and nitrogen loadings (reduced to total phosphorus and total nitrogen for presentation in this report) from the following land use categories:

- Agriculture
    - Cropland
    - Pasture
    - Animal Waste
- Urban
- Forest.

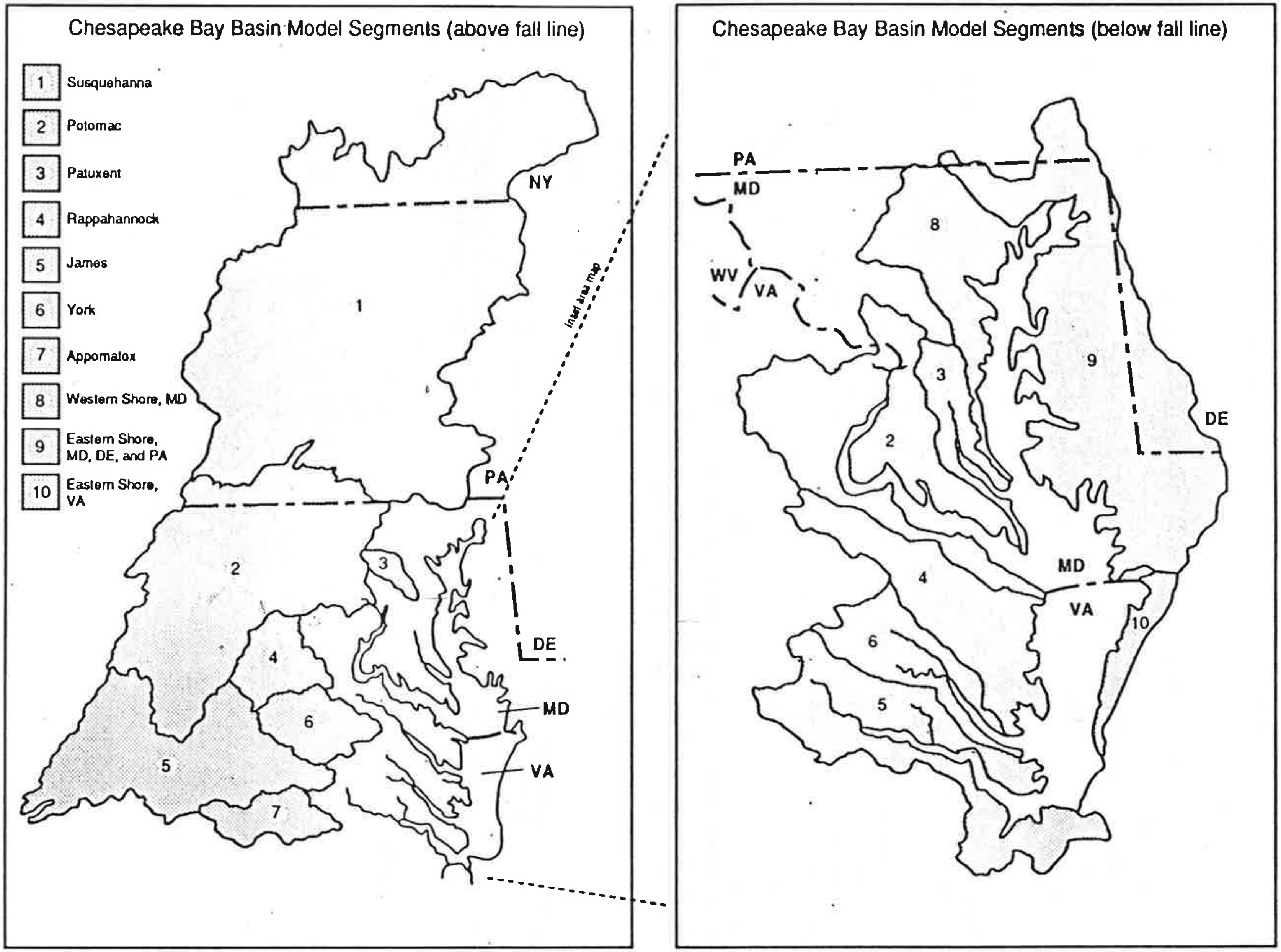
The Watershed Model also incorporates loadings estimates from point sources and atmospheric deposition to surface water for above fall line locations so that these estimates may be subject to the Watershed Model's simulation of transport through the watershed to the main Bay. Point source and atmospheric deposition loadings for below fall line locations are not subject to the transport simulation and are loaded directly into the Time Variable Model.

The Watershed Model can provide loadings estimates for 7 of the major tributaries in the Chesapeake Bay basin, including the Susquehanna, Potomac, James, Appomattox, York, Rappahannock, and Patuxent Rivers. Additionally, 3 aggregations of tributaries, the Eastern Shore of Virginia and Maryland, and the Western Shore of Maryland are modeled as sub-basin units (Figure 6). Some of these tributaries are further divided into above and below fall line sections for modeling purposes.

Detailed output tables providing a complete array of preliminary Watershed Model nutrient loading estimates for each tributary, above and below the fall line, are provided in Appendix A of this report. Summary tables and figures describing some of the major findings from the Watershed Model, based on the preliminary loadings, are provided in the remainder of this chapter.

Nonpoint and Point Source Loadings

Table 7 provides a cumulative summary of total phosphorus and total nitrogen loadings from nonpoint and point sources for all of the tributaries contained in the Watershed Model based on preliminary Model results. The summary data show that nonpoint sources (including animal wastes, cropland, pasture, urban, forest, and atmospheric deposition), contribute 82 percent of the nitrogen



*Maps are not the same scale

Figure 6. Location Map of Chesapeake Bay Tributaries Included in the Watershed Model* (Hannawald, 1990)

and 68 percent of the phosphorus to the Bay; point sources (primarily municipal wastewater treatment plants) contribute the difference (18 percent and 32 percent, respectively). Animal waste loads are included in the nonpoint source category since they are one of the components of agricultural land uses. Atmospheric deposition loads were only developed for nitrate-nitrogen.

Table 8 summarizes preliminary Watershed Model results for total phosphorus and total nitrogen loadings from nonpoint and point sources by tributary. Table 8 also describes the variation between above and below fall line loadings for each tributary. Figures 7 and 8 show the total phosphorus and total nitrogen loads (nonpoint and point source components) for each tributary.

Table 7. Nonpoint and Point Source Loadings of Total Phosphorus and Total Nitrogen From All Tributaries Contained in the Watershed Model (tons/year based on 1985 land uses)

Source	Total Phosphorus	Total Nitrogen
Nonpoint*	9,826.67	153,059.12
Point	4,641.91	33,943.04
Total	14,468.58	187,002.16

* The nonpoint source category includes animal waste as it is one of the components of the agricultural land use category. The animal waste contributions to the nonpoint source category were 2,249.76 tons/year of phosphorus and 13,861.88 tons/year of nitrogen, respectively.

Table 8. A Comparison of Phosphorus and Nitrogen Loadings for the Year 1985 From Nonpoint and Point Sources (tons/year based on 1985 land uses)

	Above Fall Line				Below Fall Line			
	Phosphorus		Nitrogen		Phosphorus		Nitrogen	
Watershed	Nonpoint	Point	Nonpoint	Point	Nonpoint	Point	Nonpoint	Point
Appomattox	338.82	0.0	2,551.41	0.0	—	—	—	—
Eastern Shore, MD	—	—	—	—	1,178.59	194.66	18,264.33	582.76
Eastern Shore, VA	—	—	—	—	60.84	0.95	369.54	30.86
James	1,259.60	250.19	8,729.71	853.36	433.17	1,484.90	7,446.22	9,093.48
Patuxent	61.60	36.96	839.52	452.98	97.96	71.64	1,527.18	200.52
Potomac	1,937.25	457.65	29,776.12	2,257.76	466.23	89.71	8,031.89	3,741.12
Rappahannock	266.43	19.70	2,644.52	47.51	283.38	62.29	3,025.26	224.83
Susquehanna	2,846.17	1,017.93	62,517.07	5,802.75	—	—	—	—
Western Shore, MD	—	—	—	—	292.89	867.56	4,488.20	10,473.81
York	180.46	3.00	1,498.93	12.01	123.28	84.77	1,349.22	169.29
Total	6,890.33	1,785.43	108,557.28	9,426.37	2,936.34	2,856.48	44,501.84	24,516.67

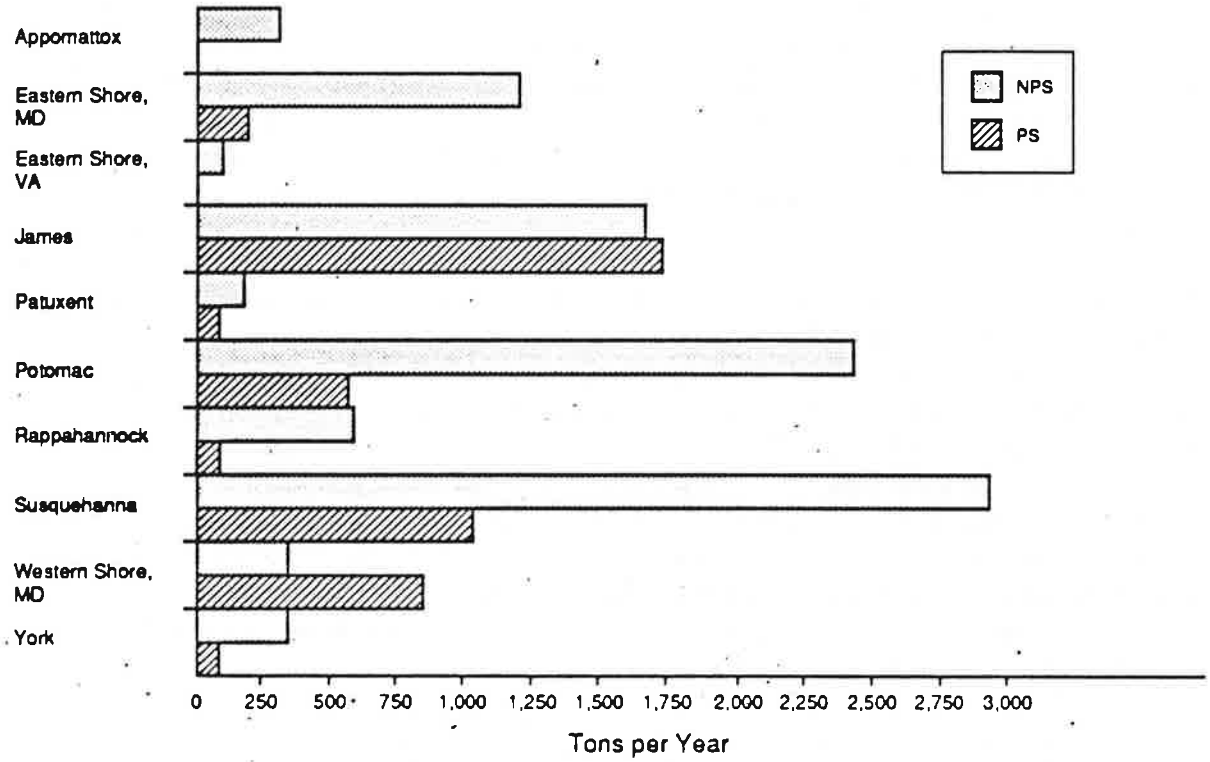


Figure 7. Total Nonpoint and Point Source Phosphorus Loads by Watershed, as Predicted by the Watershed Model

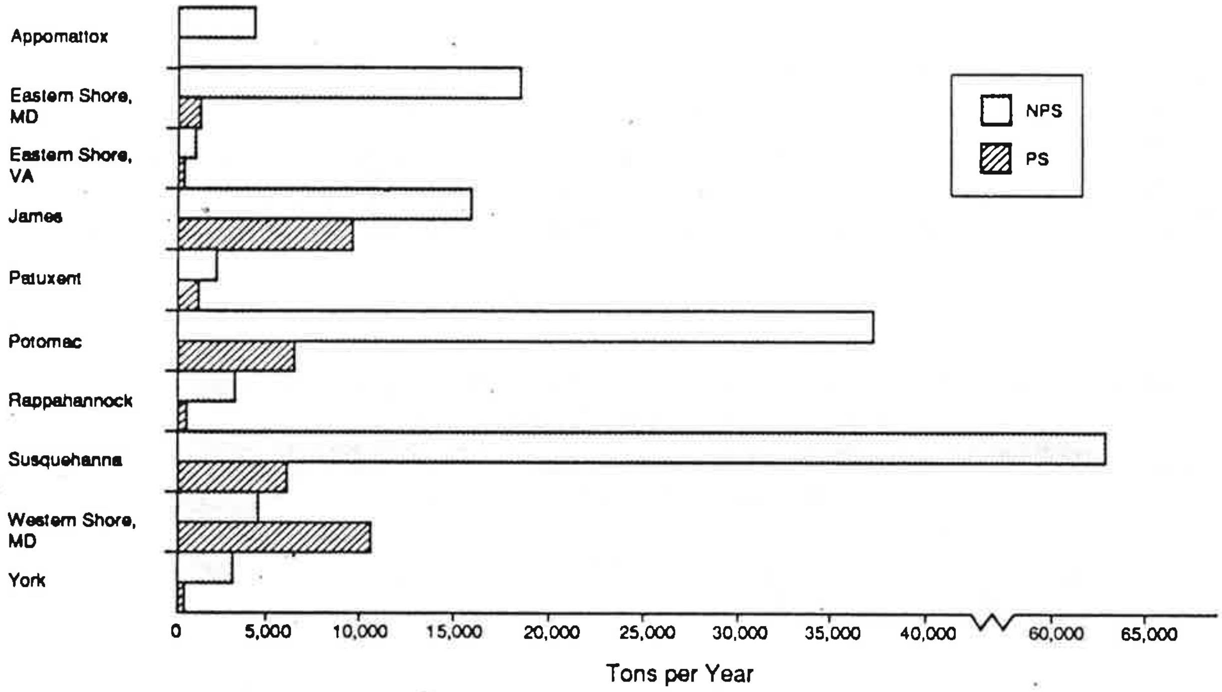


Figure 8. Total Nonpoint and Point Source Nitrogen Loads by Watershed, as Predicted by the Watershed Model

These preliminary Watershed Model results show that above fall line sources contribute almost twice as much nitrogen to the Bay than below fall line sources. The majority of this above fall line nitrogen is from nonpoint sources from the Susquehanna and Potomac rivers. Above fall line areas contribute about 1.5 times as much phosphorus to the Bay than below fall line locations. Most of this phosphorus originates from the Susquehanna, Potomac, and James rivers.

When examining these data, it is important to remember that these loadings estimates are cumulative (i.e., not given as a per acre loading factor) and reflect the land use and size of the individual watershed. The above fall line portion of the Chesapeake Bay basin is approximately 2.5 times greater in land area than below fall line segments.

Further examination of the distribution of total nitrogen and total phosphorus above and below the fall line yields some preliminary information on the types of pollution resulting from both areas. Table 9 identifies the distribution of total phosphorus and total nitrogen from nonpoint, animal waste, and point sources for above and below fall line locations.

The data in this table clearly show that nonpoint source and animal waste nutrient loadings are greater in above fall line areas, while point sources are significantly higher below the fall line. This distribution reflects land use development in the Chesapeake Bay basin; above fall line areas remain largely forested and agricultural in nature, while locations below the fall line are heavily urbanized and densely populated. The increased importance of point sources below the fall line is largely related to discharges from municipal wastewater treatment plants.

The Susquehanna River, by far, contributes the greatest nonpoint and point source phosphorus and nitrogen loads above the fall line. The Eastern Shore of Maryland contributes the greatest nonpoint source phosphorus and nitrogen loads below the fall line, and the Western Shore, Maryland and the James River are the two greatest contributors of point source nutrients below the fall line.

Table 9. Distribution of Total Phosphorus and Total Nitrogen Loadings Between Above and Below Fall Line Locations

Source	Total Phosphorus (%)		Total Nitrogen (%)	
	AFL	BFL	AFL	BFL
Nonpoint Source	69	31	72	28
Animal Waste	84	16	95	5
Point Source	38	62	28	72

In general, nonpoint sources of phosphorus and nitrogen are greater than point sources for each watershed, except for below fall line segments of the Western Shore, Maryland and the James River. In these two heavily urbanized basins, point sources of phosphorus and nitrogen are greater than nonpoint sources; point sources of phosphorus are 3.6 times higher than nonpoint sources in both basins, and point sources of nitrogen are 2.5 times and 1.4 times higher than nonpoint sources on the Western Shore, Maryland and James River areas, respectively.

Nonpoint Source Loads by Land Use Type

Many different land use types and activities contribute to the total nonpoint source nutrient loads. Tables 10 and 11 summarize preliminary nonpoint source nutrient loadings by nutrient source (including animal waste) for above and below fall line segments of each tributary. These data show that agricultural sources, especially cropland, are the greatest overall contributors of

Table 10. Nonpoint Source Nutrient Loads, by Land Use, for Above Fall Line Locations (tons/year)

	Total Phosphorus					
Watershed	**Conventional Crop**	**Conservation Crop**	**Pasture**	**Animal Waste**	**Urban**	**Forest**
Appomattox	106.30	56.76	22.89	55.61	28.45	68.81
Eastern Shore, MD	—	—	—	—	—	—
Eastern Shore, VA	—	—	—	—	—	—
James	320.13	266.84	195.12	229.36	72.77	175.38
Patuxent	12.99	13.07	1.70	6.37	25.36	2.12
Potomac	357.04	384.24	211.98	616.97	219.09	147.92
Rappahannock	66.02	33.06	26.26	122.91	11.91	6.28
Susquehanna	1,409.87	356.09	88.99	620.28	239.13	131.81
Western Shore, MD	—	—	—	—	—	—
York	70.57	37.61	4.29	25.14	10.24	32.61
Total	2,342.92	1,147.67	551.23	1,676.64	606.95	564.93

	Total Nitrogen						
Watershed	**Conventional Crop**	**Conservation Crop**	**Pasture**	**Animal Waste**	**Urban**	**Forest**	**Atmospheric Deposition**
Appomattox	639.54	532.42	217.06	278.07	190.87	678.90	14.54
Eastern Shore, MD	—	—	—	—	—	—	—
Eastern Shore, VA	—	—	—	—	—	—	—
James	1,835.05	2,240.58	891.62	1,168.83	467.63	1,790.18	45.28
Patuxent	139.36	245.54	29.39	43.88	296.66	47.23	37.46
Potomac	4,779.10	8,254.93	3,298.81	3,692.73	2,592.15	7,020.69	137.71
Rappahannock	604.31	602.12	357.19	718.66	116.58	236.89	8.83
Susquehanna	26,136.41	12,676.98	2,687.57	4,957.30	4,499.12	10,767.23	792.47
Western Shore, MD	—	—	—	—	—	—	—
York	469.61	447.38	39.91	136.84	71.56	317.86	15.78
Total	34,603.38	24,999.95	7,521.5	10,996.31	8,234.57	20,858.98	1,052.07

Table 11. Nonpoint Source Nutrient Loads, by Land Use, for Below Fall Line Locations (tons/year)

	Total Phosphorus					
Watershed	**Conventional Crop**	**Conservation Crop**	**Pasture**	**Animal Waste**	**Urban**	**Forest**
Appomattox	—	—	—	—	—	—
Eastern Shore, MD	370.57	349.22	15.62	276.29	131.03	35.82
Eastern Shore, VA	38.31	13.12	0.64	3.21	2.71	2.86
James	108.17	79.22	8.83	23.96	188.20	24.80
Patuxent	24.76	5.77	1.52	6.59	54.74	4.57
Potomac	120.82	68.26	23.36	58.89	167.02	27.87
Rappahannock	99.40	16.87	2.33	136.65	18.29	9.85
Susquehanna	—	—	—	—	—	—
Western Shore, MD	37.08	34.20	10.64	53.35	149.06	8.57
York	43.01	18.97	1.75	14.18	34.94	10.43
Total	842.12	585.63	64.69	573.12	745.99	124.77

	Total Nitrogen						
Watershed	**Conventional Crop**	**Conservation Crop**	**Pasture**	**Animal Waste**	**Urban**	**Forest**	**Atmospheric Deposition**
Appomattox	—	—	—	—	—	—	—
Eastern Shore, MD	4,568.79	8,640.75	310.83	1,381.43	1,426.41	1,611.68	324.43
Eastern Shore, VA	187.54	79.24	3.20	16.03	15.39	18.29	49.84
James	1,401.05	1,802.70	182.89	119.78	2,306.61	962.41	670.79
Patuxent	354.02	170.63	27.12	32.97	591.19	215.87	135.38
Potomac	1,475.73	1,584.95	349.86	294.46	1,765.57	1,064.93	1,496.39
Rappahannock	968.86	320.82	37.19	683.26	226.48	354.32	434.33
Susquehanna	—	—	—	—	—	—	—
Western Shore, MD	656.10	1,265.82	247.51	266.75	1,607.72	402.80	41.50
York	305.37	243.42	17.82	70.89	276.69	199.60	235.42
Total	9,917.46	14,108.33	1,176.42	2,865.57	8,216.06	4,829.90	3,388.08

nonpoint phosphorus and nitrogen to the Bay. Another agricultural source of nutrients, animal waste, also contributes substantial amounts of nutrients to the Bay. In most cases, the Watershed Model shows animal waste contributions to be less than those from cropland and more than those from pasture land.

Loadings from urban and forest sources are generally lower than loadings from total agriculture, including animal waste. However, urban sources can be locally important. For example, the urbanized below fall line areas of the Western Shore, Maryland, and the Patuxent River show greater phosphorus loadings from urban sources than from agricultural ones. Urban sources of nitrogen in these areas are also very high, exceeding agricultural sources in the Patuxent basin and being only slightly lower than agricultural sources on the Western Shore. Below fall line segments of the Potomac and James Rivers also have very high phosphorus and nitrogen loadings from urban sources. Forest loads, in general, are low relative to the other sources. However, above fall line nitrogen loadings from forests exceed animal waste and urban loadings because of the areal extent of the forests.

Preliminary results from the Watershed Model show substantial variation in nutrient loadings to the Chesapeake Bay between the individual river basins. This variability is largely a reflection of land use patterns across the Bay watershed. For example, the greater overall importance of urban sources below the fall line reflects the presence of large population centers in those areas. Conversely, the agricultural and forested nature of above fall line locations results in a diminished urban contribution.

Table 12 provides a distribution of land uses for the entire Chesapeake Bay basin. This information, when compared to nutrient loadings estimates for the Chesapeake Bay basin indicates the relative contribution of nutrients (i.e., nutrient loading factors) for individual land uses regardless of areal extent. For example, even though forests comprise 60 percent of the Chesapeake Bay basin, their nutrient contributions are low compared to total agriculture (cropland, pasture, and animal wastes), which comprises a much smaller land area (29.04 percent). This type of information becomes important when programs seek to target nonpoint source priorities. As refinements to the Watershed Model are completed, it will be possible to determine more specific nutrient loading factors for the various land uses reflected by the Model.

The revised Watershed Model and the resultant nutrient loadings estimates summarized in this chapter are one of many sources of information that will be considered as part of the 1991 Reevaluation of the Nutrient Reduction Strategy. The revised loadings from the Watershed Model will also be used in conjunction with the Time Variable Model of the Chesapeake Bay mainstem as one means to evaluate the suitability of the initial 40-percent reduction target in achieving Chesapeake Bay Agreement water quality goals.

Table 12. Distribution of Land Use in the Chesapeake Bay Basin

Land Use	Total Acreage	Percent of Total Basin
Cropland	8,237,391	20.00
Pasture	3,739,158	9.00
Forest	24,457,144	60.00
Urban	4,160,082	10.00
Water	526,115	1.00
Animal Waste	14,473	0.04

Source: Nutrient Reduction Strategy Task Force (1989).

5

Quantification and Characterization of Nonagricultural Nonpoint Source Nutrient Loadings

Nonagricultural nonpoint sources represent significant nutrient loadings to the Chesapeake Bay system, although they contribute less to the total loadings than agricultural sources. Varied in nature and difficult to define, the Chesapeake Bay Program has been quantifying and characterizing these nonagricultural sources so that they can be fully integrated into the overall nutrient control strategy for the Bay basin. In addition, information on nonagricultural nutrient loadings is used in the Chesapeake Bay Watershed Model, along with data on point source loads, and agricultural nonpoint source loads, to help predict total nutrient loads entering the Chesapeake Bay. This chapter discusses the progress made by the Chesapeake Bay Program in quantifying these nonagricultural sources, focusing on urban and forest runoff, shoreline erosion, and septic tanks.

Loadings from urban and forest sources are estimated by the Watershed Model. Shoreline erosion and septic tank loadings are not yet specifically estimated by the Watershed Model; however, these loadings are implicitly included in the modeling process. Shoreline erosion loads are implicitly included as part of the sediment flux load for the Time Variable Model and in the calibration process for the Time Variable Model. Septic tank loads are reflected in the loadings from land uses contained in the Watershed Model and in the loads measured at the fall line for Watershed Model calibration. As part of ongoing efforts to understand the nutrient problem in the Bay and to identify the extent of specific nutrient sources, the Chesapeake Bay Program jurisdictions recently completed extensive research efforts to estimate potential nutrient loadings from shoreline erosion and are beginning to gather available information on potential septic tank contributions.

Urban and Forest Runoff

Urban and forest nutrient loadings are estimated by the Watershed Model. Since the initial development of the Model in the late 1970s, the Chesapeake Bay Program has undertaken efforts to improve and refine the Watershed Model, in part by updating nutrient loading factors for various land uses and revising land use acreage estimates for the entire Chesapeake Bay watershed to the year 1985. These efforts and the resulting output from the Watershed Model are described in Chapters 3 and 4 of this report. Detailed descriptions of the methods used to update and revise these land acreage estimates are given in two Chesapeake Bay Program documents, *Land Use for the Chesapeake Bay Watershed Model* (Hannawald, 1990) and *Watershed Model Application to Calculate Bay Nutrient Loadings* (Donigian et al., 1990). This section presents the total phosphorus and total nitrogen loadings from urban and forest land uses as predicted by the Watershed Model.

Urban Runoff

Urban land acreage in the Chesapeake Bay basin in 1985 was estimated as 4,160,082 acres (or 10 percent of the total land use). However, urban land uses in the Bay watershed are expected to increase dramatically in the future. The Year 2020 Panel predicted that the Chesapeake Bay area would experience about a 20-percent increase in growth (approximately 2.6 million new residents) by the year 2020. Therefore, it is likely that the extent of urbanized land in the basin and the attendant nutrient loadings will also grow.

Based on the current distribution of land uses in the Chesapeake Bay basin and revised nutrient loading factors, as well as other Watershed Model modifications, urban land uses are predicted to contribute 1,352.94 tons per year of phosphorus (0.65 pounds per acre) and 16,450.63 tons per year of nitrogen (7.91 pounds per acre) to the Chesapeake Bay. This represents 14 percent and 11 percent of the annual total phosphorus and total nitrogen nonpoint source loadings to the Bay, respectively.

Forest Runoff

Forests are the single largest land use in the Chesapeake Bay watershed, covering approximately 24,475,144 acres, or 60 percent of the total land acreage in 1985. The Watershed Model estimated that forests contribute 689.70 tons per year of phosphorus (0.06 pounds per acre) and 25,688.88 tons per year of nitrogen (2.1 pounds per acre) to the Chesapeake Bay system. This represents 7 percent of the total nonpoint source phosphorus and 17 percent of the nonpoint source nitrogen contributed annually to the Bay system.

Shoreline Erosion

Many locations in the Chesapeake Bay are experiencing significant rates of shoreline erosion. While the implications of this problem to landowners are obvious, shoreline erosion also degrades Chesapeake Bay water quality and affects living resources by increasing sedimentation and associated nutrient loadings to the Bay. Although all aspects of sedimentation are important in the overall Bay scheme, the *Baywide Nutrient Reduction Strategy* focuses on nutrients (Chesapeake Bay Program, 1988a). During 1990, the Chesapeake Bay Program completed preliminary efforts to quantify these nutrient loadings from shoreline erosion. To calculate nutrient loadings, however, sediment contributions must be determined first.

Sediment Contributions From Shoreline Erosion

The U.S. Army Corps of Engineers (COE), in conjunction with the Maryland Geological Survey (MGS) and the Virginia Institute of Marine Sciences (VIMS), conducted the *Chesapeake Bay Shoreline Erosion Study* (COE, 1990) to define the nature of shoreline erosion in the Chesapeake Bay region and to identify the range and effectiveness of shoreline control measures appropriate for erosion control in the Bay. The study area encompassed the Chesapeake Bay and its tributaries to the head of the tide, including portions of Delaware, Maryland, Virginia, and Washington, DC. Maryland and Virginia account for all shoreline miles directly on the Bay.

The COE study assembled the available shoreline erosion data for Maryland and Virginia contained in the two studies mentioned above. The Maryland shoreline analysis used maps prepared by the MGS in the early 1970s showing historical shoreline positions from the early 1800s and recent shoreline positions from U.S. Geological Society 7.5 minute quad sheets (1965-1975). The comparison of recent and historical shoreline positions was used to determine average erosion/accretion rates over the period of record. In addition to the shoreline change maps, the accompanying Maryland report provided the percentages of shoreline length falling into one of the following categories of historical erosion rates (16 percent were designated as accreting shoreline):

- Slight (1-2 feet per year)—61 percent
- Low (2-4 feet per year)—14 percent
- Moderate (4-8 feet per year)—5 percent
- High (more that 8 feet per year)—4 percent.

Since the historical shoreline surveys did not include the entire Bay and tributary rivers, the data developed by MGS provided only an estimate of the erosion/accretion rates for 1,705 miles of Chesapeake Bay and tributary shoreline (about one-third of the total Maryland Bay shoreline).

Data from a comprehensive study of historical shoreline erosion in the Virginia portion of the Chesapeake Bay, conducted by the VIMS in the 1970s, were used for the Virginia shoreline analysis. The study evaluated about 80 percent of the Virginia Bay shoreline. The VIMS study compared two topographic map series, a historical shoreline from 1850 to 1880 and a base shoreline from 1941 to 1968. Findings were published in the *Shoreline Erosion in Tidewater Virginia* report (VIMS, 1980). Tables contained in this report provided a detailed description of shoreline type, shoreline length, and fastland (i.e., land above mean sea level) height, for a total of 1,725 reaches along the Bay and its major tributaries in Virginia. The erosion/accretion rate along with the erosion volume loss/gain were computed for each reach based on the difference between the two mapped shorelines.

Using the MGS and VIMS maps and report data, the COE determined that the Chesapeake Bay shorelines are eroding at an estimated average rate of 1.3 feet per year in Maryland and 0.7 feet per year in Virginia. These rates did not include areas where structural erosion control methods were implemented. Substantial variability in rates was noted (ranging from 0.3 to 1.8 ft/yr for Maryland and 0.2 to 2.1 ft/yr for Virginia). The study offered no conclusions as to whether the average rates were increasing or decreasing over time.

The COE used the shoreline erosion data to determine the total sediment volume contributed to the Bay from shoreline erosion. The COE study considered shoreline erosion as consisting of two components: a fastland erosion loss (above mean sea level) and a loss due to changes in the nearshore profile below mean sea level. The COE assumed that the shoreline maintains approximately the same profile when it erodes; therefore, erosion volume was estimated as the vertical distance between the top of the fastland to the depth of the seaward limit of sediment transport (average limit of active erosion in the Bay is to a depth of 8 feet), multiplied by the horizontal recession of the profile and the length of the measured shoreline.

Using this approach, the COE calculated a sediment volume contribution to the Bay system resulting from shoreline erosion below the head of the tide. The COE estimated fastland erosion loss at about 4.7 million cubic yards per year (45 percent of this amount originating in Maryland and 55 percent originating in Virginia). Changes in the nearshore profile below mean sea level were considered to contribute another 6.3 million cubic yards per year of sediment. Figure 9 shows the distribution of these sources of sediment throughout the Chesapeake Bay system. The COE estimated that both sources (fastland and profile below mean sea level) provided a sediment contribution from shoreline erosion of 11.0 million cubic yards per year.

It is important to note that the COE's estimate of sediment contribution only represents those portions of the Chesapeake Bay system where comparisons between historical and more recent shorelines were possible. Historical shoreline data were only available for about 80 percent of the Virginia Bay shoreline and 37 percent of the Maryland Bay shoreline. Since a substantial portion of the Maryland shoreline was not included in the COE's estimate, the Chesapeake Bay Liaison Office (CBLO) approximated the sediment contribution from fastland erosion for the remaining portion of the Maryland Bay shoreline (i.e., locations where historical shoreline data were not available). The CBLO estimated that the sediment contribution to the Bay from fastland loss along this additional Maryland shoreline was 2.2 million cubic yards per year.

Whereas the COE examined shoreline erosion from fastland above mean sea level and the nearshore profile below mean sea level, the CBLO was only interested in fastland shoreline erosion, since it represented an influx of new sediment to the Chesapeake Bay system. Using the fastland erosion estimate from the COE's report and the extrapolated estimates for the Maryland shoreline not included in the COE report, the CBLO estimated total fastland shoreline erosion for the Chesapeake Bay as 6.9 million cubic yards per year (represents the combination of the COE estimate of sediments from fastland erosion in Maryland and Virginia — 4.7 million cubic yards per year — and the CBLO estimate of sediments from additional fastland erosion in Maryland — 2.2 million cubic yards per year).

If the COE estimate of changes in the nearshore profile below mean sea level (an additional 6.3 million cubic yards per year of sediment) is also categorized as shoreline erosion, then the total contribution of sediments from shoreline

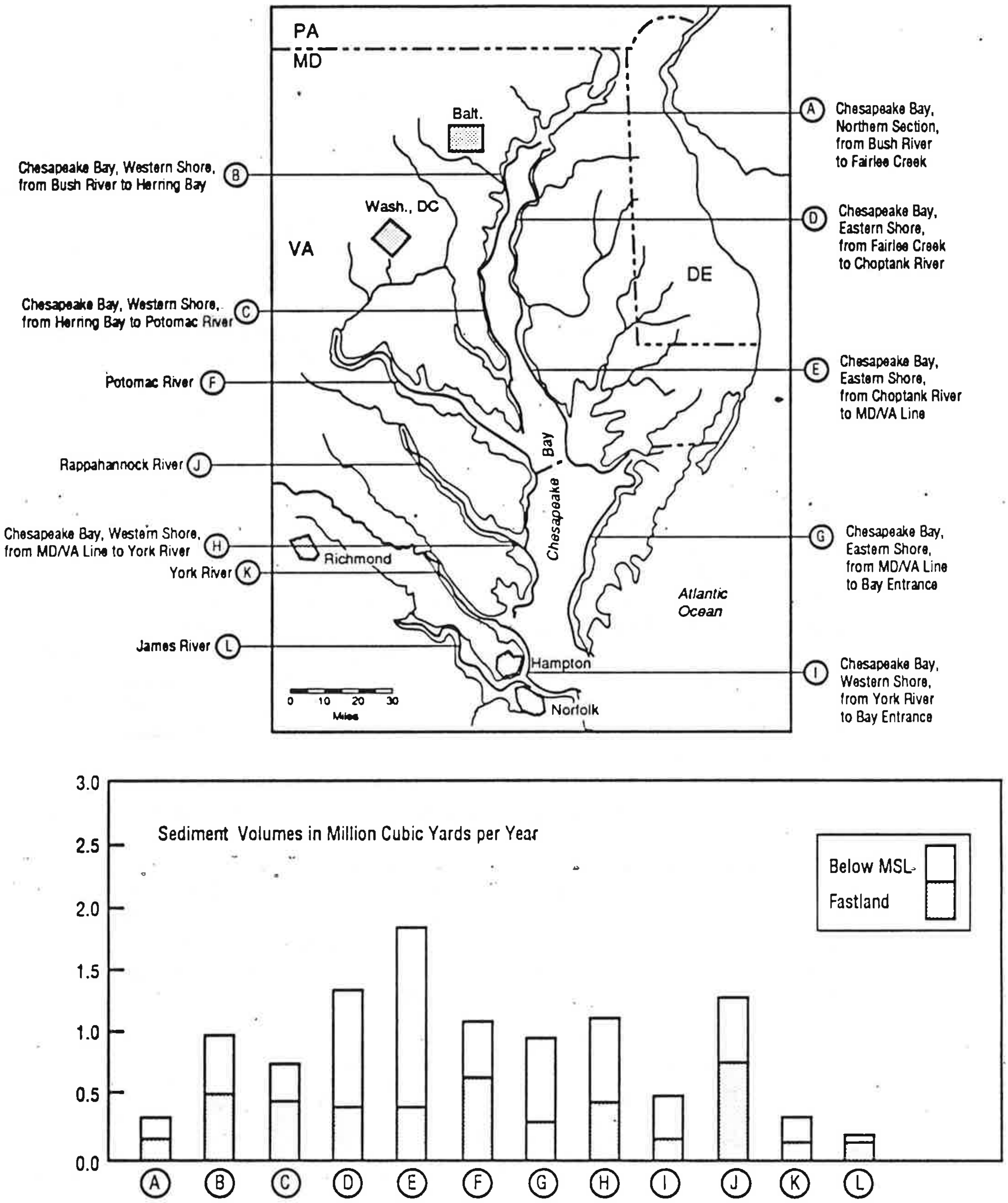


Figure 9. Distribution of Sediment Volumes from Shoreline Erosion Throughout the Chesapeake Bay (Army Corps of Engineers, 1990)

erosion below the head of the tide is 13.2 million cubic yards per year. The sediment loads of the inflowing rivers and creeks are estimated to contribute an additional 4.3 million cubic yards of eroded upland material to the Bay system, of which 3.6 million cubic yards per year originate from the three tributaries having the greatest freshwater inflow to the Bay (i.e., the Potomac, Susquehanna, and James rivers, which contribute 1.5, 1.1, and 1.0 million cubic yards of upland material per year).

Overall, the total contribution of sediments to the Chesapeake Bay from all sources (fastland, below mean sea level profile, and riverine sediment load) is estimated to be 17.5 million cubic yards per year. Shoreline erosion from the fastland above mean sea level contributes 39 percent of the total sediment contribution. Shoreline erosion of the fastland and nearshore profile below mean sea level combined contribute 75 percent of the total, with riverine sources comprising the remaining sediment load from these sources.

Nutrient Loads Associated With Shoreline Erosion

The CBLO combined the information on fastland sediment contributions from the COE study and the additional Maryland fastland erosion estimates with information on nutrient values presented in the *Sediment and Nutrient Contributions of Selected Eroding Banks of the Chesapeake Bay Estuarine System* report (Ibison et al., 1990), to determine nutrient loads for nitrogen and phosphorus to the Bay from fastland shoreline erosion. Nutrient loading factors varied according to bank height for the areas sampled. Bank heights of 6 feet were estimated to contribute 0.1 pounds of nitrogen and 0.14 pounds of phosphorus per foot of erosion per linear foot of bank per year. Bank heights of 8 feet contributed 0.145 pounds of nitrogen and 0.18 pounds of phosphorus per foot of erosion per linear foot of bank per year.

To determine the nutrient loads attributed to shoreline erosion in the Bay, average bank heights were calculated for the Virginia and Maryland segments of the Bay using the average erosion rates, erosion volumes, and shoreline lengths reported in the COE study and calculated by the CBLO for the additional Maryland shoreline that did not have historical information. As mentioned previously, the average erosion rate for Maryland is 1.3 feet per year and for Virginia is 0.7 feet per year (COE, 1990). Average bank heights for each State were determined using the following equation:

$$\boxed{\frac{\text{Total erosion volume (yd}^3\text{/yr) x 27 cubic ft/cubic yd}}{\text{Total shoreline length (ft) x Average erosion rate (ft/yr).}}}$$

Using this procedure, the CBLO calculated the average bank heights for Maryland and Virginia as 6 and 8 feet, respectively.

The CBLO then calculated the annual nutrient loads resulting from shoreline erosion using the following equation:

Shoreline length x Average erosion rate x Nutrient loading factor for the appropriate bank height

The CBLO combined the values for Maryland and Virginia derived from these calculations to provide preliminary estimates of the total potential annual nutrient loads to the Chesapeake Bay from shoreline erosion as 3.3 million pounds of nitrogen and 4.5 million pounds of phosphorus.

The *Baywide Nutrient Reduction Strategy* estimated average annual "controllable" nonpoint source loads to the Bay to be 100.1 million pounds of nitrogen and 9.8 million pounds of phosphorus (Chesapeake Bay Program, 1988a). A comparison of these estimates with the preliminary nutrient load estimates from shoreline erosion reveals that the shoreline nutrients (approximately 3.3 million pounds of nitrogen and 4.5 million pounds of phosphorus) would not have a large impact on the "controllable" nitrogen reaching the Bay, but do represent a large percentage of the "controllable" phosphorus loads.

Several efforts are being conducted by the COE, Maryland and Virginia, and private landowners to address the problem of shoreline erosion within the Chesapeake Bay basin. As well, efforts are being taken to refine the preliminary estimates of nutrient loadings associated with shoreline erosion presented in this chapter. The results of the preliminary studies and calculations show that shoreline erosion represents a potentially significant source of nutrients to the Bay, providing further impetus to continue with these projects as part of the overall control strategy for the Bay.

Septic Tanks

Populations in the Chesapeake Bay Basin States are increasing dramatically, with much of this growth occurring in rural and semi-rural areas without access to centralized public utilities, including water and sewer. The Year 2020 Panel, convened by the Chesapeake Executive Council in 1988, recognized the extent and type of growth that is occurring and identified many associated impacts, such as an increased proliferation of onsite wastewater treatment systems (e.g., septic tanks). While many of these systems are operated properly and are effective waste management methods, septic systems that are overloaded, improperly sited or designed, or not well-maintained, may fail or leak, thus contributing significant amounts of nutrients to surface and ground water. Even properly operating septic systems are not designed to remove 100 percent of the nutrients in the wastes and may therefore be a source of nutrient pollution (especially nitrogen) to the environment. The 1988 *National Water Quality Inventory* identified septic systems as one of the major threats to ground-water quality (EPA, 1990).

The increasing recognition that leaking or failing septic systems may lead to increased nutrient concentrations in water, especially ground water, has led the Chesapeake Bay Program, through the efforts of the 1990 Chesapeake Bay Nonpoint Source Program Evaluation Panel (see Chapter 9 of this report for more details), to identify septic systems as one of several nutrient sources inadequately addressed by current programs and worthy of additional research and control measures. A preliminary survey of Chesapeake Bay States conducted in support of the Panel's decision-making showed that there are already close to one million septic tanks in Chesapeake Bay Basin counties (Table 13). In an effort to indicate the potential for nutrient loadings from septic systems, the available literature describing nitrogen releases from these systems was examined. Nitrogen was selected as the parameter for the study due to its soluble nature and ability to leach into ground water, although phosphorus is also a potential contaminant of concern from septic systems.

Table 13. Septic Tanks and Associated Nitrate-Nitrogen Releases to the Chesapeake Bay Basin

State	Number of Septic Tanks in Bay Basin Counties*	Potential Releases of Total Nitrogen (tons/year)
Maryland	288,614**	2,752
Pennsylvania	365,160**	3,548
Virginia	281,814***	2,752

* Counties partially contained within the Basin were not included in this calculation because the distribution of septic tanks within the counties was not available.
** Source: Census of Population (1980).
*** Source: Wastewater Needs Assessment (1988).

According to the Environmental Protection Agency's *Design Manual: Onsite Wastewater Treatment and Disposal Systems*, an average of 4 kilograms of nitrogen per person per year are contributed to a septic system. Approximately 10 percent of this amount is expected to be removed in the septic tank and another 5 to 35 percent is expected to be removed within soil absorption trenches, depending on various site and design factors (EPA, 1980). Therefore, between 55 and 85 percent of the nitrogen that enters a septic system is potentially available for discharge into the water table beneath the absorption trenches.

Using the data on septic tank numbers presented in Table 13 and recognizing that even properly operating tanks release some nitrogen, some very preliminary estimates of total nitrogen releases to the environment were made as part of the Nonpoint Source Panel's background material (see Table 13). (It is important to realize that this is a very preliminary estimate designed only to provide an indication of potential loadings; the Chesapeake Bay Program plans to study these nutrient sources more in the future.) Total nitrogen releases from hypothetical septic systems were estimated using the following assumptions, derived from two reports—*Design Manual: Onsite Wastewater Treatment and Disposal Systems* (EPA, 1980) and Nitrate-Nitrogen Losses to Groundwater from Rural and Suburban Land Uses (Gold et al., 1989):

- Septic tank was functioning properly
- Septic tank served 3 people
- Septic tank had an average flow of 45 gallons per person per day
- Septic tank effluent contained about 45 mg/L of nitrogen (chosen from a range of 35 to 100).

These estimates did not consider natural denitrification processes. In addition, they did not take into account leaking or failing systems which pose a greater threat to water quality.

The information on septic tank nutrient loadings assembled for the Nonpoint Source Panel and by the Chesapeake Bay Program, to date, is very preliminary. So far, very few quantitative studies have examined the relationship of septic tank seepage with surface and ground-water nutrient enrichment. A variety of efforts have been undertaken to address some of these potential problems posed by septic tanks, such as expanding municipal or county health department permitting requirements, improving design standards, and enforcing maintenance requirements. However, additional research is needed to better understand the link between septic tank seepage and nutrient enrichment of surface and ground water. Preliminary efforts in quantitative research have been undertaken by Maryland's Department of Environment, although no results are available to date. In Pennsylvania, a Select Committee on Nonpoint Source Nutrient Management evaluated quantitative data on on-lot septic systems and related nutrient loads as part of their deliberations. The results of this evaluation are presented in the December 20, 1990 final report of the Committee. As one of their recommendations, the Committee called for the Department of Environmental Resources to do further assessments of the impact of on-lot systems on surface and ground water. The Chesapeake Bay Program also plans to continue efforts to identify the magnitude of nutrient loadings from septic tanks in the Bay Basin.

Table 14 compares nonpoint phosphorus and nitrogen loadings from urban and forest land uses, and shoreline erosion. The data on septic systems are too preliminary to be included at this time. Although forests comprise the largest land acreage in the Chesapeake Bay watershed, they are a relatively low contributor of nutrients on a per acre basis. Urban sources, on the other hand, contribute relatively low amounts of nitrogen and phosphorus overall, as urban areas currently constitute only about 10 percent of the watershed; however, the per acre loadings are relatively high. As the Chesapeake Bay watershed continues to increase in population, the overall importance of nutrient loadings from urban sources will certainly increase. Nutrient loadings per acre for shoreline erosion could not be calculated. Overall nitrogen loadings are significantly lower than nitrogen loadings from forest and urban areas, however. Conversely, overall phosphorus loadings from shoreline erosion exceed urban and forest estimates. These types of comparisons will be very important in the 1991 Reevaluation stage of the Nutrient Reduction Strategy as program officials seek the most effective and efficient ways to revise current control strategies.

Table 14. Comparison of Phosphorus and Nitrogen Loadings From Urban and Forest Land Uses and Shoreline Erosion

Nutrient	Urban[1]	Forest[1]	Shoreline[2, 3]
Phosphorus			
Total (tons/year)	1,298.20	685.13	2,250.00
(pounds/acre)	0.62	0.06	—
Nitrogen			
Total (tons/year)	15,859.44	25,473.01	1,650.00
(pounds/acre)	7.60	2.10	—

[1] Based on 1985 land acreage estimates.

[2] Based on a comparison of historical and recent shoreline positions.

[3] Shoreline erosion estimates are preliminary and may be subject to future refinement. Also, shoreline erosion estimates are not yet subject to Watershed Model simulation.

6

BMP Nutrient Reduction Efficiencies and Cost Effectiveness

To date, best management practices (BMPs) have been a major focus of programs carried out during the early stages of the Nutrient Reduction Strategy. Traditionally, BMPs have been designed to reduce sediment loadings and, consequently, the transport of sediment-bound pollutants from diffuse and varied sources, such as agricultural lands or urban/suburban construction sites. As the Chesapeake Bay Program enters the 1991 Reevaluation stage of the Nutrient Reduction Strategy, quantitative measurements are needed to assess the ability of BMPs to reduce nutrient loadings. This chapter reports on the results of several research efforts designed to develop a consistent accounting methodology for assessing the effectiveness of BMPs, focusing specifically on a literature review of the nutrient reduction efficiencies of agricultural BMPs and a pilot analysis of BMP longevity. Initial efforts to quantify the cost-effectiveness of certain BMPs in terms of dollars per pound of nitrogen or phosphorus removed also are documented. This research will ultimately provide watershed modelers with edge-of-field efficiency estimates for various BMPs and will provide insight about BMP effectiveness to resource managers, thus facilitating the decision-making process.

Overview of Parameters Affecting Performance of BMPS

Most of the BMPs currently employed within the Chesapeake Bay basin focus on agriculture, and, to a lesser extent, on urban development and forestry operations. Until recently, the major objective of agricultural BMPs has been to reduce soil loss. Since nutrients and other pollutants are often adsorbed onto soil particles, decreased soil loss is frequently accompanied by a reduction in nutrient and other pollutant loadings. Thus, nutrient reduction strategies in the Bay have historically focused on controlling the amount of soil lost through erosion. The level of BMP installation needed to sufficiently reduce soil erosion, however, is highly dependent on site-specific characteristics, such as topography, soil characteristics, land use, and weather patterns. Consequently, the effectiveness of BMPs is also highly site-specific.

Recent studies have introduced several additional factors that must be considered when assessing the effectiveness of BMPs. First, reducing soil erosion is no longer a sufficient criterion for meeting nutrient load reduction objectives. Some BMPs that reduce flow velocities trap only coarser sediments, while fine sediments, to which sediment-bound chemicals are preferentially adsorbed, often escape. Furthermore, most erosion control BMPs do little to control nutrients that dissolve in surface or subsurface water (Camacho, 1990; Dillaha, 1990).

A second factor affecting the performance of BMPs is the longevity of the practice itself. The concept of longevity or life span of a BMP is based on three factors: the design life of the BMP, site-specific environmental conditions, and the degree of maintenance undertaken. A recent pilot study by the Chesapeake Bay Program indicates that some BMPs are effective in the short-term, but deteriorate rapidly, resulting in little long-term water quality improvement (Rosenthal and Urban, 1990).

A Qualitative Assessment of Agricultural BMP Effectiveness

Agricultural BMPs address pollution that originates from cropland, pasture land, or animal livestock facilities. Cropland pollution is the result of soil erosion and nutrient leaching and the subsequent transport of fertilizers by surface runoff and ground water. Nutrient pollution also results from the runoff and leaching from animal production facilities and the intensive use of pasture land.

BMPs for cropland typically include various forms of conservation tillage, such as no-till farming and more efficient application of fertilizers. BMPs for animal wastes are commonly structural, involving the careful siting and construction of manure storage or treatment facilities in relationship to surface and shallow ground waters. Since animal wastes are often used as fertilizer, improved land application practices in regards to the season and local weather conditions are also an important part of controlling nutrients from manure.

BMP effectiveness varies widely from site to site. The level of sediment and nutrient loading reduction achieved is related, in part, to the degree to which the BMPs selected match the unique characteristics and needs of a given site. Recognizing this variability, some broad generalizations can still be made about effectiveness. Table 15 summarizes several studies conducted under the auspices of the Chesapeake Bay Program that analyzed the characteristic effectiveness associated with certain BMPs for reducing sediment and nutrient loads from agricultural lands (Dillaha, 1990; Randall and Krome, 1987; Rosenthal and Urban, 1990).

As shown in Table 15, the BMPs referenced are good to excellent in reducing sediment loss, with only vegetative filter strips receiving a mixed review. The effectiveness of each BMP for nutrient reduction is more variable. Although four BMPs received good ratings, nutrient reduction over the long-term is dependent upon diligent maintenance. Conservation tillage and vegetative filter strips received mixed ratings. Only nutrient management, which requires very little maintenance, received an excellent rating for reducing nutrient loadings. The relative levels of maintenance indicated in Table 15 are associated with the amount of labor, fuel, repair, and machinery required to maintain the design standards of a particular BMP.

Table 15. Effectiveness of Nutrient Reduction by a Sample Set of Agricultural BMPs

Practice	Effectiveness In Reducing Loadings		Level of Maintenance	Potential Disadvantages
	Sediment	Nutrients		
Conservation Tillage	Excellent	Mixed	Moderate	Increased loss of soluble phosphorus; potential to increase ground-water contamination
Vegetative Filter Strip	Mixed	Mixed	High	Potential to increase ground-water contamination
Contouring	Good	Good	High	Potential to increase ground-water contamination
Terracing	Excellent	Good	High	Potential to increase ground-water contamination
Strip Cropping	Good	Good	Moderate	Potential to increase ground-water contamination
Nutrient Management (modified rates, times, and method of application, source of fertilizer)	N/A	Excellent	Low	N/A
Animal Waste Management (animal waste control structures, transport of excess manure)	Good	Good	Moderate	Potential to severely increase ground-water contamination if operated without proper maintenance

Source: Dillaha (1990); Randall and Krome (1987).

It is important to note that of the BMPs listed in Table 15, all except nutrient management have the potential to increase ground-water contamination due to either a potential lack of maintenance or the creation of preferential flow by increasing soil permeability and providing a direct conduit to ground water. In general terms, recent studies suggest that nutrient management must be combined with sediment control practices to effectively reduce nutrient loads to the Bay.

Quantitative Nutrient Load Reduction Efficiencies

Data available to quantitatively assess BMP effectiveness for reducing nutrient loadings to the Chesapeake Bay are very limited. Although some field studies conducted over the last 5 years addressed BMP effectiveness, the scope of these studies was very narrow, and the results cannot be generalized to characterize effectiveness for the whole basin. The Interstate Commission on the Potomac River basin (ICPRB) recently conducted a review of the available literature on the nutrient reduction effectiveness of certain agricultural BMPs (Camacho, 1990). The purpose of the review was to provide Chesapeake Bay watershed modelers with some background information on the efficiencies of the BMPs simulated by the Watershed Model. The remainder of this chapter describes the major findings of the studies compiled by ICPRB, focusing on the nutrient reduction and cost efficiencies of various BMPs. Detailed descriptions and extensive data tables of reduction efficiencies are provided in Camacho (1990).

ICPRB summarized approximately 10 reviews of BMP effectiveness that were published between 1985 and 1990. From these studies, ICPRB calculated BMP efficiencies for surface water, ground water, and combined surface and ground water wherever possible. ICPRB defined reduction efficiency as follows:

$$\boxed{\text{Efficiency (\%)} = [1 - (\text{post-BMP}/\text{pre-BMP})] \times 100}$$

where pre-BMP refers to the nutrient load before installation of a BMP (i.e., the baseline condition is conventional tillage) and post-BMP refers to nutrient loads after BMP installation (Camacho, 1990). Using this equation, a negative efficiency will occur when the post-BMP nutrient load is greater than the pre-BMP nutrient load, meaning that an increase, rather than a decrease, of nutrients is occurring as a result of the BMP (Camacho, 1990).

ICPRB's study represents the most comprehensive collection of data regarding BMP nutrient load reduction efficiencies. Several factors, however, must be considered when examining ICPRB's results, including the following:

- There are an insufficient number of studies to characterize BMP nutrient reduction efficiencies for all regions in the Chesapeake Bay basin.
- Each study has unique hydrologic, soil, slope, crops, and fertilization characteristics that must be considered when making direct comparisons between the studies.
- There are an insufficient number of ground-water studies to characterize BMP nutrient reduction efficiencies with confidence.
- Many studies focused on short-term efficiencies from single rainfall events.
- Many studies were carried out in small field plots using artificial rainfall.
- Sampling techniques may be different for each study.
- Studies analyzing BMP nutrient reduction efficiencies from a combination of BMPs are usually the result of mathematical modeling, which may miscalculate BMP nutrient reduction efficiencies.
- Only a subset of BMPs was studied, and data were not available for many BMPs.

In general, however, the results of the studies summarized in the ICPRB report support the prevailing attitude that nutrient management must play a greater role in agricultural land management and that the most effective measures combine nutrient management with traditional soil erosion BMPs. Furthermore, the study provides some baseline data for the Chesapeake Bay watershed modelers, with which to compare the results of their own simulations.

ICPRB grouped its analysis of the available data by BMP groups developed by the Nutrient Reduction Task Force for simulation by the Watershed Model:

- Conservation tillage
- Conventional tillage with nutrient management
- Conservation tillage with nutrient management
- Conventional tillage with nutrient management and farm plan
- Conservation tillage with nutrient management and farm plan
- Animal waste management.

Table 16 describes the types of BMPs contained in each category.

Although some reduction efficiencies were available for groundwater, the data set relating to surface water was much more complete and better characterized in the available literature. Therefore, the research results described in this progress report are limited to surface water.

Figure 10 summarizes the range and median reduction efficiencies of nutrients in surface water by BMP category. Reduction efficiencies were calculated from each BMP nutrient load relative to the nutrient load in conventional tillage. Animal waste management was not included because no surface water data were available. Conceptual estimates of annual reduction efficiencies, however, suggest that total nitrogen is reduced by 5 to 40 percent, and total phosphorous is reduced by 8 to 40 percent when animal waste management practices are followed (Casman, 1990).

An initial examination of the median reduction efficiencies for surface water clearly reveals that conservation tillage, when accompanied by nutrient management and a farm plan, yields the most significant reduction in total nitrogen and total phosphorus. Overall, these data show that the combination of a farm plan, which includes structural BMPs, and nutrient management is the most effective means of reducing nutrients from agricultural lands, since both sediment-bound pollutants and soluble nutrients are addressed. Agricultural conservation practices that focus on either nutrient management or traditional BMPs but not both are less effective since they do not address all of the possible pathways of nutrients leaving agricultural lands.

The medians presented in Figure 10 suggest that none of the BMPs increase nutrient loadings to surface water.. However, the ranges of data presented for each

Table 16. Selected BMP Categories From the Chesapeake Bay Watershed Model

Conservation Tillage
- No-Till Cropland
- Minimum-Till Cropland

Conventional Tillage With Nutrient Management
- Fertilizer Management
- Nutrient Management Plans
- Soil and Manure Analysis
- Small Grain Cover Crop
- Legume Cover Crop

Conservation Tillage With Nutrient Management*
- Fertilizer Management
- Nutrient Management Plans
- No-Till Cropland
- Minimum-Till Cropland
- Soil and Manure Analysis
- Small Grain Cover Crop for Nutrient Management
- Legume Cover Crop

Conventional Tillage With Nutrient Management and a Farm Plan**

Conservation Tillage With Nutrient Management and a Farm Plan**
- Stripcropping
- Buffer Stripcropping
- Contour Farming
- Terrace Systems
- Sod Waterways
- Diversions
- Sediment Retention, Erosion, or Water Control Structures
- Water Control Structure
- Grass Filter Strips
- Protective Cover for Specialty Crops
- Field Wind Breaks

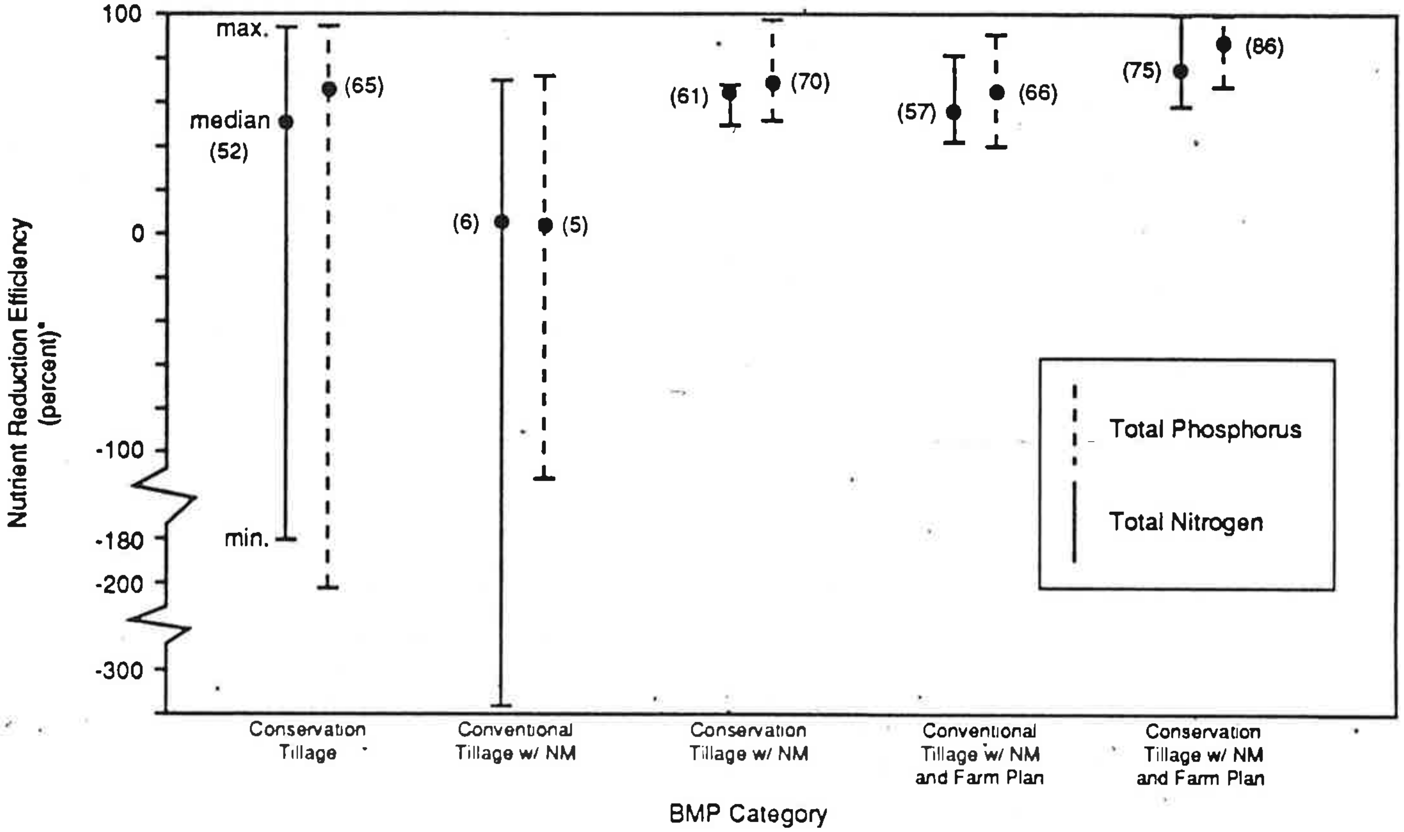
* Nutrient management entails practices that modify the rates, timing, and method of fertilizer application.

** A farm plan encompasses long-term operating goals and overall management of the farm, including soil conservation BMPs.

Source: Camacho (1990).

BMP show that significant negative reductions (i.e., nutrient contributions) to surface water were measured for conservation tillage and conventional tillage with nutrient management. In summary, conservation tillage alone is insufficient to significantly reduce nutrient loadings to surface water in the basin. Current research strongly supports the necessity of nutrient management, as part of long-term, comprehensive farm management, to substantially decrease nutrient loadings to surface water from agricultural land use.

A review by Casman (1990) compiled data from many studies to examine the relationship of nitrogen fertilizers to nitrogen loads in ground water. The



* Percentages were calculated relative to a baseline condition of conventional tillage.

Figure 10. The Range and Median Reduction Efficiencies of Nutrients in Surface Water By BMP (adapted from Camacho, 1990)

results showed that 20 percent to 40 percent of the total nitrogen fertilizer applied each year is lost to ground water. This contrasts to the 1 to 10 percent of total nitrogen lost to surface waters. These results support the widely held opinion that ground water constitutes the largest part of nitrogen loss.

The limited data on reduction efficiencies presented by ICPRB (Camacho, 1990) for ground water also suggest that ground water is an important vehicle for nutrient loss. As well, the data demonstrate the importance of nutrient management in reducing nutrient loads to ground water from agricultural sources. For example, the efficiencies seem to indicate that conservation tillage with nutrient management can reduce nutrient losses to ground water, while conservation tillage by itself can increase the nutrient loss to ground water. More studies are required before nutrient reduction efficiencies to ground water for BMPs can be reported with confidence.

Cost Effectiveness of BMPS for Nutrient Load Reduction

In addition to understanding the overall efficiency of BMPs in reducing nutrient loadings, resource managers need information on BMP cost effectiveness in order to make sound management decisions. To date, this information has been difficult to quantify, primarily because of hidden costs associated with the installation and execution of BMPs; the subjective nature of assigning a specific dollar value to management-oriented BMPs, such as the development of a nutrient management or farm plan; and a limited ability to correlate nutrient load reductions to specific BMPs. Recently, however, ICPRB has undertaken a study to quantify the cost effectiveness of BMPs (ICPRB, 1990). Although the study is still in its preliminary stages, ICPRB has developed cost estimates for some of the BMPs used by the Chesapeake Bay jurisdictions for nonpoint source nutrient reduction. Table 17 presents those cost estimates by BMP type.

The values reported in Table 17 are based upon cost-share estimates obtained from State BMP tracking efforts for 1988 and 1989. The original costs were

Table 17. Preliminary Cost Estimates for Example BMP Types*

BMP Type	Total Acres Treated	Total Cost (1990 dollars)	Annual Cost ($/acre/year)***	Lifespan
Conservation Tillage	20,627	372,704	18.1	1
Stripcropping	4,754	213,941	11.9	5
Terraces	812	175,925	35.3	10
Grassed Water Ways	4,311	2,488,144	94.0	10
Diversions	615	153,516	40.6	10
Sediment Retention and Water Control Structures	21,190	3,952,752	30.5	10
Grassed Filter Strips	4,351	44,206	2.7	5
Permanent Vegetative Cover on Critical Areas	18,041	627,368	9.2	5
Reforestation of Erodible Crop and Pasture Land	4,658	677,069	23.6	10
Cover Crops	1,845	20,022	10.9	1
Animal Waste Management	838,677**	10,693,396	2.0**	10

* Estimates were determined from information provided by Maryland, Pennsylvania, and Virginia, with the following exceptions: (1) values for conservation tillage and cover crops are limited to data from Pennsylvania and Virginia, (2) values for reforestation are limited to data from Maryland and Virginia, and (3) values for grassed filter strips are limited to data from Virginia.

** Units for animal waste are given as tons/year and $/ton/year.

*** Equivalent annual cost, interest rate = 10%. Costs do not include planning and technical assistance costs.

Source: Interstate Commission on the Potomac River Basin, 1990.

updated to 1990 dollars using the consumer price index. In most cases, data were available for Maryland, Pennsylvania, and Virginia. There were some discrepancies in BMP definitions or data collection techniques between States, however. Therefore, the dollar values for conservation tillage and cover crops are limited to data from Pennsylvania and Virginia, values for reforestation are limited to data from Maryland and Virginia, and values for grassed filter strips are limited to data from Virginia.

ICPRB plans to use these cost estimates in conjunction with nutrient load reduction estimates from the Watershed Model to determine a cost-effectiveness ratio that will compare dollars per acre per year expended for a particular BMP type to the pounds of nitrogen or phosphorus removed per acre per year for that same BMP. As more information becomes available, it will be possible to compare the cost-effectiveness of various BMPs and enhance the *Baywide Nutrient Reduction Strategy* (Chesapeake Bay Program, 1988a) by targeting the most cost-effective means for nutrient reduction.

Significance of BMP Longevity on Nutrient Load Reduction

As summarized previously, many recent studies have addressed the performance of BMPs under a variety of site-specific conditions. Very few technical studies, however, have considered the performance of these practices after they have been in use for several years. Recently, a pilot study was undertaken to redress this lack of information on the longevity of BMPs (Rosenthal and Urban, 1990). The study drew its conclusions from an 11-state survey; onsite evaluation in 3 States of 120 BMPs installed prior to 1985, and anecdotal and empirical information from discussions, observations, and available literature.

The study evaluated the longevity of actual versus potential effectiveness of five agricultural BMPs, including terraces and diversions, animal waste storage, vegetative filter strips, grassed waterways, and conservation tillage. In most cases, the actual life span of a BMP was less than its potential life span. Many factors affect the longevity of BMPs, as summarized in Table 18. Researchers concluded that the disparity between potential and actual life spans could be improved, in part, by placing greater emphasis on operation and maintenance activities. Strategies for improving operation and maintenance might include cost-share assistance for specific activities or materials, technical assistance, and educational outreach.

Furthermore, researchers strongly suggested that longevity estimates should play a key role in cost-benefit estimates prior to promoting a given BMP system. To apply longevity estimates more universally, however, additional research is necessary to better quantify costs of operation and maintenance activities and their relative effectiveness on increasing the longevity of BMPs.

Under the auspices of the Chesapeake Bay Program and State funds, several studies were conducted attempting to quantify agricultural BMP nutrient reduction efficiencies and to assess the cost-effectiveness and longevity of BMPs. The data presented in these studies reflect the need to combine nutrient management and comprehensive farm planning with more traditional soil conservation practices (Camacho, 1990). Furthermore, the effectiveness of BMPs in general is dependent upon diligent maintenance. It is anticipated that program managers will be able to use the BMP load reduction efficiencies from the Watershed Model, in conjunction with BMP cost information, to enhance their decision making and to develop programs based on maximum nutrient reductions at the least cost.

Table 18. Factors Affecting the Longevity of BMPs

BMP Type	Qualitative Assessment of Longevity	Factors Affecting* Longevity
Animal Waste Management	• Concrete and earthen systems last a long time • Minimum maintenance required • Soil Conservation Service (SCS) estimate of life span, 20 years • Existing systems many years away from design life expectancy	• Strength of operator's environmental ethic • Education level of operator • Economic prosperity of farm
Conservation Tillage	• The practice must be undertaken annually • Requires regular maintenance to prevent weed proliferation	• Education level of operator • Soil type and cropping system
Grassed Waterways	• SCS estimate of life span, 15 years • If designed as a sediment trap, life span reduced to as little as 5 years • Life span severely shortened if parallel cropping system used	• Slope of land and width of grassed berm
Terraces and Diversions	• SCS estimate of life span, 20 years • Requires tillage with the contour of the terrace and not across it • Regular repair and maintenance activities required	• Rented versus owned land • Economic prosperity of farm • Education level of operator • Slope of land
Vegetative Strips	• SCS estimate of life span, 5 years • Maintenance activities include reseeding, precaution when using herbicides and equipment	• Placement of field borders to prevent sediment runoff

Source: Rosenthal and Urban (1990).

7

Performance Capabilities and Cost Information for Wastewater Treatment Processes

Early estimates of nutrient loads to the Chesapeake Bay pointed to municipal point sources as the largest single contributor of phosphorus and one of the major contributors of nitrogen to the Bay. Therefore, an early focus of the *Baywide Nutrient Reduction Strategy* was nutrient reduction through municipal point source controls (Chesapeake Bay Program, 1988a). Preliminary approaches for municipal point source reduction concentrated on phosphorus removal (e.g., phosphate detergent bans, wastewater treatment plant upgrades) as a priority. Dual biological nutrient removal (BNR) demonstration projects and nitrogen removal feasibility/targeting studies were also advocated, with the focus of point source control shifting to these technologies as the Nutrient Reduction Strategy progressed. Chapter 2 of this report summarizes some of the activities undertaken by the Chesapeake Bay jurisdictions to reduce point source nutrients.

As part of the 1991 Reevaluation of the Nutrient Reduction Strategy, the Chesapeake Bay Program participants are completing efforts to evaluate the performance capabilities and cost effectiveness of certain wastewater treatment technologies. These efforts have focused on BNR technologies to reduce phosphorus and nitrogen point sources. This chapter summarizes the major findings from several such studies. Appendix B of this report presents summary tables prepared by the Interstate Commission on the Potomac River Basin that compile cost data contained in the individual studies so that preliminary cost effectiveness comparisons for retrofitting wastewater treatment plants with BNR may be made.

Overview of Available Point Source Technologies

The Virginia State Water Control Board (VSWCB) completed research in fall 1990 that described and evaluated the advantages and disadvantages of the most commonly used point source phosphorus and nitrogen removal technologies (VSWCB, 1990b). Table 19 summarizes the results of this research. The report identified BNR technologies as becoming increasingly popular when both phosphorus and nitrogen removal is required.

The VSWCB report also examined the average annual performance of wastewater treatment plants compared to permitted effluent limitations. By evaluating prototype BNR facilities and existing, well-operated facilities, the VSWCB concluded that the average annual performance of these plants is much better than the monthly average limits required by the National Pollutant Discharge Elimination System (NPDES) permit program. For example, long-term data from nine well-operating sewage treatment plants in Virginia

Table 19. Description, Advantages, and Disadvantages of Commonly Used Point Source Phosphorus and Nitrogen Removal Technologies

Nutrient Removal Technologies	Description	Advantages	Disadvantages
Phosphorus Removal			
• Chemical Addition (pre- and simultaneous precipitation)	Chemicals to aid in flocculation and settling are added directly to the existing primary or secondary settling units. Effluent levels of 1.0 to 2.0 mg/L normally achieved.	• Least costly of the chemical processes • Quick implementation time (12-18 months) • Low construction costs	• Sensitive to operation problems • Existing units might need expansion • Increased operation and maintenance costs • Increased sludge volume • May restrict sludge processing and disposal options
• Chemical Addition (post precipitation)	Chemicals to aid in flocculation and settling are added following the secondary treatment units into tertiary clarifiers or effluent filters. Effluent levels below 0.5 mg/L, and possibly below 0.1 mg/L (using lime) can be achieved.	• Readily meets effluent limits • Flexibility in operation • Flexibility in sludge processing and disposal	• Longer implementation time (3-5 years) • Higher cost due to larger scale construction • Substantial increase in operating and maintenance costs for chemical purchase and chemical sludge handling
• Biological Phosphorus Removal	Conventional biological treatment is modified so that phosphorus removal is increased from 15-20% to 70-85%. It requires special design and operation so that wastewater is exposed to anaerobic conditions as well as aerobic conditions during treatment. This process can achieve effluent levels of 2.0 mg/L or less, especially if standby chemical addition is available to ensure permit compliance.	• Little, or no, chemical addition needed • Less sludge produced • Potential for low construction and operating costs	• Relatively new technology • Can be more difficult to operate than conventional secondary treatment • Certain processes are patented, requiring the payment of license fees
Nitrogen Removal			
• Separate Stage Biological Nitrification/ Denitrification	Two biological treatment stages follow secondary treatment—one to nitrify or convert ammonia-nitrogen to oxidized forms, the second to denitrify or remove the oxidized nitrogen from the wastewater as nitrogen gas. Effluent levels of 3.0 mg/L can be achieved.	• High percentage of nitrogen removal • Relatively stable operation • Each process can be optimized separately	• High capital and operating and maintenance costs • Chemical (methanol) addition needed • Nitrification is temperature sensitive • Additional number of processes to operate • Three sludges produced
• Breakpoint Chlorination	Large quantities of chlorine are added to the wastewater to oxidize the ammonia-nitrogen gas. Used primarily with other nitrogen removal processes. Effluent levels for ammonia-nitrogen of 1.0 mg/L	• High efficiency • Disinfection achieved • Relatively low capital cost	• High operating and maintenance costs • Potential for chlorine toxicity • Little full-scale experience

—Table continued on next page—

Table 19. Description, Advantages, and Disadvantages of Commonly Used Point Source Phosphorus and Nitrogen Removal Technologies (cont.)

Nutrient Removal Technologies	**Description**	**Advantages**	**Disadvantages**
• Breakpoint Chlorination (cont.)	can be achieved. The level of total nitrogen discharged depends on whether nitrification occurred prior to chlorine addition and the amount of organic-nitrogen that is unaffected by the process. Some nitrate-nitrogen is formed from ammonia in the breakpoint reaction.	• Little space required	• Safety concerns due to large amounts of chlorine
• Ion Exchange	Highly treated effluent is passed through a bed of exchange material where nitorgen is removed from the wastewater. Depending upon the composition of the wastewater effluent levels of 2.0 mg/L can be achieved.	• High efficiency • Insensitive to temperature fluctuations • Recovered nitrogen can be used as a fertilizer	• Complex operation • High capital and operating and maintenance costs • Exchange materials treat only certain forms of nitrogen
• Ammonia Stripping	The pH of the wastewater is elevated and passed through towers to allow the ammonia-nitrogen to be released into the atmosphere. Effluent levels of 1.0 mg/L of ammonia-nitrogen can be achieved in combination with breakpoint chlorination.	• Effective in removing nitrogen from liquid stream	• Poor operation in cold weather • Only removes the ammonia-nitrogen form • Released ammonia may be returned to watershed by rainfall • Difficult process to operate
• Biological Nitrogen Removal	Conventional biological treatment is modified into a single-sludge nitrification/denitrification system so that nitrogen removal is increased from 10-20% to 60-85%. Can achieve effluent nitrogen levels between 3.0 and 12.0 mg/L based upon the sizing of units and complexity of operation.	• No chemicals • Potential low operating and maintenance costs • Proven effectiveness	• Temperature sensitive • Can be difficult to operate if system is operated for biological removal of both phosphorus and nitrogen
Biological Nutrient Removal	Desired in cases where both phosphorus and nitrogen are required. Wastewater is normally moved through a series of anaerobic, anoxic, and aerobic zones. A number of different BNR systems are available (Bardenpho, A2/0, UCT, VIP, A/O), some of which are patented. Each of these systems vary according to design, effectiveness, cost, and removal efficiency.	• Not described	• Not described

Source: VSWCB (1990b).

using chemical addition for phosphorus removal showed that all of the plants performed better on an annual basis than specified in their effluent requirements; more than half of the plants examined had annual reductions of effluents at least 45 percent below the required monthly limit.

Cost of Nutrient Removal

Virginia and Maryland each sponsored studies assessing the cost of upgrading wastewater treatment plants to achieve desired nutrient effluent goals (Beavin Company et-al., 1989; CH2M Hill, 1989). In both cases, the studies used engineering evaluations to estimate the cost of implementing various nutrient removal techniques at existing wastewater treatment plants.

The Maryland study evaluated 24 municipal wastewater treatment plants to determine the best practical methods for adding BNR technologies to the existing treatment processes and to provide cost estimates for constructing such modifications. Target goals for nutrient removal were to reduce total nitrogen to a level of 8 mg/L on a seasonal basis without the use of chemicals and to reduce total phosphorus to the lower of a level of 2 mg/L or the level specified in the plant's NPDES permit. The study evaluated a range of potential BNR technologies and developed conceptual reduction schemes unique to each wastewater treatment plant studied, realizing that there are many ways to achieve the same goals and that site-specific conditions should determine the most appropriate and effective techniques. In some cases, other technologies were evaluated when the desired nutrient effluent levels were not expected to be achieved with BNR. Table B-1 (Appendix B) describes proposed nutrient removal processes and associated costs escalated to 1990 dollars for each facility examined in the Maryland study. Using these engineering assessments, the study estimated that the modification of the 24 wastewater treatment plants would require about $305 million in capital costs and increase the operation and maintenance costs by $17 million annually (1990 dollars).

The Virginia study evaluated the cost of implementing four nutrient removal scenarios at 26 publicly-owned municipal wastewater treatment plants. The four scenarios addressed the following variable levels of phosphorus and nitrogen removal (monthly average limits):

- *Alternative 1*: Phosphorus removal to permit limit
- *Alternative 2*: Alternative 1 plus seasonal TKN or NH_3-N removal to permit limit
- *Alternative 3*: Alternative 1 plus seasonal nitrogen removal to 10 mg/L total nitrogen
- *Alternative 4*: Alternative 1 plus year-round nitrogen removal to 10 mg/L total nitrogen.

By examining this range of reduction alternatives, the report provided rough estimates of the cost of a phased point source reduction program.

The Virginia study considered an array of technologies needed to meet nutrient reduction goals for each wastewater treatment plant. Capital and operation and maintenance (O&M) costs of compliance with the four alternative nutrient removal scenarios were developed for each wastewater treatment plant. Table B-2 (Appendix B) summarizes the estimated increases in capital and O&M costs, escalated to 1990 dollars, necessary to upgrade all existing 26 municipal wastewater treatment plants evaluated in the study. Alternative 3 most closely approximates the approach used in the Maryland study. Table B-3 (Appendix B) describes proposed Alternative 3 nutrient removal processes and associated costs escalated to 1990 dollars for each facility examined in the Virginia study.

The U.S. Environmental Protection Agency (EPA) also commissioned a study to compile information on BNR to demonstrate the potential cost savings, treatment effectiveness, and reliability of BNR systems (Hazen and Sawyer Engineers and J.M. Smith and Associates, 1988). The study consisted of a comprehensive literature review, assessment of ongoing research efforts, and site visits to operating pilot- and full-scale BNR plants. The goal of the research was to provide a basis for estimating incremental costs for retrofitting and operating existing plants in the Chesapeake Bay drainage basin with BNR systems to achieve the following two selected levels of long-term average nutrient removal:

- *Low-Level Nutrient Discharge*: TN = 3.0 mg/L
  TP = 0.5 mg/L
- *High-Level Nutrient Discharge*: TN = 8.0 mg/L
  TP = 2.0 mg/L.

The high-level nutrient discharge scenario (TN = 8.0 mg/L; TP = 2.0 mg/L) most closely approximated the scenario examined in the Maryland study and Alternative 3 of the Virginia study.

The EPA study examined three specific BNR processes: Bardenpho, A2/0, and UCT. The study found that all three processes were able to attain the high-level nutrient discharge level without filtration given. Only the Bardenpho process with continuous chemical dosing to precipitate phosphorus and effluent filtration to remove fine solids was judged capable of meeting low level nutrient discharge concentrations (Hazen and Sawyer Engineers and J.M. Smith and Associates, 1988).

Cost estimates and cost curves for upgrading wastewater treatment plants in the Chesapeake Bay basin, using the above BNR technologies to achieve the high and low discharge levels, were developed for existing plants. The cost estimates were presented for plants in five size categories (0.5, 1.0, 5.0, 10.0, and 30.0 million gallons per day [mgd] design flows) and for eight additional plants in the Chesapeake Bay basin with design flows greater than 30.0 mgd. The CBLO used the cost estimates and cost curves presented in the EPA report (Hazen and Sawyer Engineers and J.M. Smith and Associates, 1988) in combination with data on existing wastewater treatment plants (greater than 0.5 mgd) in the Chesapeake Bay Watershed to develop an overall estimate of the cost to upgrade existing wastewater treatment plants to the high level nutrient discharge limit of 8.0 mg/L (seasonal) for total nitrogen and 2.0 mg/L for total phosphorus. Using this approach, the CBLO estimated that it would cost approximately $408 million to upgrade 72 plants having a combined design flow of 902 mgd.

Table 20 compares the cost estimates from the Maryland, Virginia, and EPA studies for upgrading wastewater treatment plants to a similar effluent goal. All three studies used slightly different approaches to achieve the desired effluent goal:

- *Maryland*—Primarily anoxic/aerobic nitrogen removal, chemical phosphorus removal, denitrification filters and methanol addition, various BNR technologies, such as A2/0 and Bardenpho; other technologies, based on site-specific conditions, were also used.
- *Virginia*—Primarily nitrification/denitrification with two anoxic zones, multipoint metal (or metal) salt addition, effluent filtration, pH adjustment.
- *EPA*—BNR technologies (Bardenpho, A2/0, UCT).

Table 20 summarizes cost estimates as dollars per mgd for each study. This provides a preliminary comparison of cost efficiencies between studies. Unit costs for wastewater treatment plant upgrades vary between the three studies, with Virginia projecting a unit cost of 0.90 dollars/mgd, and Maryland and EPA projecting costs of 0.68 and 0.53 dollars/mgd, respectively. It is important to realize that these cost comparisons are preliminary and that additional

Table 20. Comparison of Cost Estimates From Maryland, Virginia, and EPA Wastewater Treatment Plant Upgrade Studies

Study Parameter	Maryland	Virginia	EPA
Effluent Goal	TN=8.0 mg/L (seasonal) TP=the lower of 2.0 mg/L or NPDES permit	TN=10 mg/L (seasonal) TP=permit (2.0 mg/L or less)	T=8.0 mg/L (seasonal) TP = 2.0 mg/L
Approach	Long-term average	Monthly effluent limit	Long-term average
No. of Plants	24	26	72
Design mgd	450	691	902
Capital	$305 million	$621 million	$480 million
Dollars mgd	0.68	0.90	0.53
Confidence	Not given	+50, -30%	±25%

Source: Bevin Co. et al. (1989); CH2M Hill (1989); Hazen and Sawyer Engineers and J.M. Smith Associates (1988).

research is needed to provide more reliable cost estimates for specific wastewater treatment technologies. Also, cost estimates are very site-specific, depending on the needs and existing characteristics of each wastewater treatment plant.

The District of Columbia also commissioned a study, completed in 1989, to update an earlier report on the feasibility of implementing nitrogen removal at its Blue Plains wastewater treatment facility (Greeley and Hansen, 1984 and 1989). This recent update, *Report on Feasibility of Deep Bed Filter Denitrification at Blue Plains* (Greeley and Hansen, 1989), evaluated the feasibility of retrofitting the Blue Plains wastewater treatment plant using deep bed filter denitrification with the goal of achieving a total nitrogen annual effluent level of 7.52 mg/L (based on a 40-percent reduction of the 1985 nitrogen loads with the plant operating at the year 2000 average flow of 370 mgd). The two alternatives summarized in Table 21 were the most cost effective of the technologies examined. This is attributed to the seasonal nitrogen removal approach rather than the annual approach (i.e., TN = 5.75 mg/L in five summer months and TN = 8.78 mg/L in 7 winter months), and the use of biological phosphorus removal for alternative 5C. The final selection of alternatives for the Blue Plains facility may be subjected to the appropriateness of the seasonal removal concept for the Chesapeake Bay Program goals, the performance of biological

Table 21. Cost Efficiency Estimates from the Blue Plains Wastewater Treatment Plant Upgrade Study[1]

Alternative	Technology	Capital Costs ($)	Annual Operation and Maintenance Costs ($)	Equivalent Total Costs[3] (ETC) ($)	Equivalent Annual Costs[3] (EAC) ($)	EAC Flow[4] ($/mgd/yr.)
2C[5]	Two-stage biological-chemical system, anoxic reactor, reaaeration preceding anoxic reactor and 8 additional deep bed filters, with seasonal effluent quality (no new filters).	169,866,733	7,087,588	230,207,113	27,040,041	73,081
5C[5]	Same as 2C with addition of BPR (no new filters).	174,777,517	4,117,112	209,828,809	24,646,413	66,612

1. Original costs (Source: Greeley and Hansen, 1989) have been escalated to 1990 dollars using appropriate ENR construction cost indexes for capital costs, and EPA operation, maintenance and repair (OMR) indexes for O&M costs. Effluent Levels: TN = 7.52 mg/L (annual average), TP= 0.18 mg/L (current NPDES limit).[2]
2. Plant is already removing phosphorus to the permit level. Phosphorus removal costs are not included.
3. Equivalent Total Costs = present worth of annual O&M costs plus capital costs; Equivalent Annual Costs = amortized capital costs plus annual O&M costs; Interest rate = 10%, project life = 20 years.
4. Flow = design flow (370 mgd).
5. Design operating temperature = 23°C (5 months in the summer), 15°C (7 months in winter).

Source: ICPRB, 1990.

phosphorus removal and biological nitrogen removal in the anoxic reactors, and pilot studies to evaluate nutrient removal performance once the selection of alternatives has been narrowed (Greeley and Hansen, 1989).

More recently, a study was completed to evaluate the feasibility of BNR at the Blue Plains Wastewater Treatment Plant (McNamee, Porter and Seeley Engineers/Architects, 1990). Table 22 summarizes the major findings of this research, consisting of a literature review and onsite pilot testing. Detailed descriptions of the technologies and anticipated costs for all of the alternatives evaluated for the Blue Plains facility are described in the report by McNamee, Porter, and Seeley Engineers/Architects (1990). The study recommended that a demonstration program be undertaken at the Blue Plains facility to explore in greater detail biological phosphorus removal using the A/O process and the proposed nitrogen removal approach.

Table 22. Major Findings of the Study Evaluating the Feasibility of BNR at the Blue Plains Wastewater Treatment Plant

- Biological phosphorus removal (BPR) using the A/O process was found feasible at the secondary reactors at 75% of the maximum monthly flow. Retrofit cost was estimated to be $1.6 million, which should be paid for in approximately 1.5 years from cost savings from chemicals and sludge handling. BPR would eliminate the addition of iron salt at the secondary reactors, resulting in annual savings in chemicals and sludge handling of between $0.94 and $1.18 million (depending on dosages of 4 and 5 mg/L, respectively). This process was recommended for full scale demonstration to generate actual performance on efficiency and reliability for 12 months.

- Among five alternatives tested for nitrogen removal, the best alternative was addition of methanol at the fourth pass in the existing nitrification reactors. This pilot test resulted in effluent nitrogen concentrations below the proposed limit of 7.5 mg/L. The cost of retrofitting the existing plant is estimated at 12.9 million. Annual cost for methanol is estimated to vary between $1 to $2 million, depending on the required dosage. This alternative was recommended for full-scale demonstration.

Source: McNamee, Porter and Seeley Engineers/Architects (1990).

8

Refinement of Habitat Requirements for Living Resources

The Chesapeake Bay Program initiated work on two technical syntheses focusing on dissolved oxygen (DO) and submerged aquatic vegetation (SAV) in 1990 as part of ongoing efforts to refine habitat requirements for living resources (Chesapeake Bay Program, 1990a and Chesapeake Bay Program, 1990b). These syntheses were designed to:

- Establish living resources-based water quality restoration goals to be used in evaluating output from model simulations
- Provide a firm ecological basis for the reevaluation of the 40-percent baywide nutrient reduction goal
- Provide guidelines that can be used in the implementation of water quality and habitat protection programs
- Link living resources habitat requirements, water quality goals, and nutrient reduction commitments more directly than they have been in the past.

Dissolved oxygen and SAV were selected for detailed study because both provide key indications of the Bay's well-being and are critical components of a healthy and productive Bay ecosystem. Dissolved oxygen is one of the most important water quality habitat requirements for aquatic animals in the Bay and the associated commercial and recreational fisheries. Oxygen depletion in portions of the Bay in recent years has been implicated in the declines in commercial catches, especially of oysters. Submerged aquatic vegetation is a critical member of the Bay's ecosystem, providing both a food source and shelter for many of the Bay's species. Because restoration of SAV can directly improve the health and abundance of important finfish and shellfish in the Bay, the specific water quality habitat requirements for SAV have been identified.

Background on DO and SAV

Dissolved Oxygen

Dissolved oxygen is one of the major factors affecting the survival, distribution, and productivity of living resources in the Chesapeake Bay. Dissolved oxygen concentrations in the Bay vary throughout the year and by geographic location due to a number of natural conditions. The sensitivity of various species to fluctuating and low DO varies and depends on temperature, salinity, life stage, and duration of exposure, in addition to the absolute concentration of DO.

Unfortunately, in the Chesapeake Bay, DO concentrations frequently fall below levels required for healthy living resources. In summer (May through September), more than a quarter of the Bay suffers from low DO, primarily in the upper mainstem of the Bay. In addition, much of the deep water of the upper mainstem Bay becomes anoxic. These low levels and complete depletion of DO are lethal to many of the Bay's species so that many deep areas of the upper mainstem Bay often are devoid of animal life during the summer months. Many Chesapeake Bay tributaries also experience both serious episodic and persistent oxygen depletion in summer due to the decay of large amounts of organic matter and the movement of deep water low in oxygen into shallow areas. The decline in DO in the Bay is largely related to increased nutrient inputs into the Bay.

Submerged Aquatic Vegetation

As mentioned previously, SAV is a critical member of the Bay's food chain and is an ideal indicator of the Bay's health due to its sensitivity to water quality and its role as both shelter and food source for a variety of Bay species. SAV maintains the integrity of the surrounding shallow water habitat, helps to oxygenate Bay water through photosynthesis, and is able to take up nutrients in the spring and summer to help retard eutrophication of the Bay. SAV root systems also provide substrate support, reduce sediment resuspension, and dampen wave energy, thus slowing shoreline erosion. The health and productivity of SAV are affected by the amount of light it receives; a decline in light availability can result in a decline in SAV. Water quality parameters, such as total suspended solids, affect light availability. Therefore, these parameters are used as a link between SAV habitat requirements and water quality.

Declines in SAV are primarily attributed to increased nutrient and/or suspended sediment input into the Bay. One of the most important habitat requirements for successful SAV is the adequate availability of light. A number of factors, stemming from increasing development and population pressures in the Chesapeake Bay drainage area, are affecting the availability of light to these aquatic plants in some of the following ways:

- Excess nutrient inputs to the Bay encourage epiphytic algae (algae that lives on the surface of other plants) to grow on the SAV, reducing the availability of light by fouling the leaf surfaces of the SAV and reducing photosynthesis.
- Excess nutrient inputs also cause planktonic algal blooms, which cloud the water, reducing light availability.
- Suspended sediments from land runoff also cloud the water, further reducing light availability to the SAV.

The result of this increased light attenuation is a reduction in the depth at which SAV can grow, thus restricting growth to shallow water where increased wave energy, erosion, and grazing by waterfowl further stress the plants.

Although there has been some recent resurgence of SAV in the Potomac River and other locations, SAV still remains near its lowest levels in recorded history. For example, SAV levels in the mid-1960s ranged from 100,000 to 300,000 acres, while in 1987, baywide levels were only 49,714 acres. The diversity of the SAV population has also greatly decreased in the past 3 decades.

Steps Toward Defining Desired DO and SAV Habitat Requirements

DO and SAV habitat requirements were developed through syntheses of scientific literature and field research findings that defined water quality conditions that were protective for the greatest array of living resources in the Chesapeake Bay. Both DO and SAV studies will be used to aid managers in establishing water quality goals and to establish targets for the nutrient reduction scenarios to be used in the Chesapeake Bay Watershed and Time Variable Models.

Dissolved Oxygen

The dissolved oxygen restoration goals document was primarily designed to:

- Determine DO requirements for the survival, growth, and reproduction of the Bay's living resources
- Provide a basis for the evaluation of water quality model results
- Ensure applicability of DO habitat requirements as baywide restoration goals, given natural DO processes.

The natural fluctuations of DO and the varied ability of species to tolerate changeable DO levels were considered, and habitat goals were developed to reflect conditions acceptable for the reproduction, growth, and survival of several sensitive species. The selected target species for DO were chosen to represent, either directly or through food chain associations, the Bay's commercially, recreationally, and ecologically important species of fish, shellfish, and benthos. Fourteen species of fish, mollusks, and crustaceans (Table 23), and 32 benthic species were identified. Two major reports (Chesapeake Bay Living Resources Task Force, 1987, which summarized the results of over 30 individual reports, and Holland et al., 1989) were used to summarize all of the available information on DO tolerances for the target species at lethal, sublethal, long-term, and short-term levels. These data were combined and evaluated to develop the habitat restoration goals for DO.

The studies found that certain patterns of response to varying DO levels were noted throughout the investigations. For example, DO concentrations between 0 and 0.5 mg/L were lethal to all target species tested at those concentrations and to all benthic species examined, although variations in time till mortality at near anoxic conditions were noted. Another pattern observed from the re-

Table 23. Target Species for the Dissolved Oxygen Habitat Requirements Study

Finfish
Morone saxatilis (striped bass)
Alosa aestivalis (blueback herring)
Alosa pseudoharengus (alewife)
Alosa sapidissima (American shad)
Alosa mediocris (hickory shad)
Perca flavescens (yellow perch)
Morone americana (white perch)
Brevoortia tyrannus (menhaden)
Leiostomus xanthurus (spot)
Anchoa mitchilli (bay anchovy)
Shellfish
Molluscan
Crassostrea virginica (American oyster)
Mya arenaria (softshell clam)
Mercenaria mercenaria (hard clam)
Crustacean
Callinectes sapidus (blue crab)

Source: Chesapeake Bay Living Resources Task Force (1987).

search was the long-term tolerance of several target species to DO above 5.0 mg/L. The studies, therefore, concluded that a monthly mean DO concentration of 5.0 mg/L would be satisfactory for all species, as long as shorter term DO requirements were not violated and that the monthly mean presumably would represent substantial periods with DO above 5.0 mg/L. Based on this research, five categories of critical values for DO were selected as the basis for protecting the Bay's living resources as represented by the target species. Four of the values are "exceedance" concentrations that DO should not fall below for more than a specified length of time. The fifth value is a desired monthly average. Table 24 summarizes the recommended draft DO habitat requirements, as determined from the studies.

Submerged Aquatic Vegetation

The purpose of the SAV study was to:

- Determine the quantitative levels of relevant water quality parameters necessary to support continued survival, propagation, and restoration of SAV

Table 24. Recommended Dissolved Oxygen Habitat Requirements

Category	DO Value (mg/L)	Specific Requirements
Spawning Reaches		
Instantaneous DO	5.0	DO should not fall below 5.0 mg/L at any time within anadromous fish spawning reaches and nursery areas during late winter through late spring (February 1-June 15).
All Tidal Waters of the Chesapeake Bay for All Seasons Except the Spawning Areas and Times Defined Above		
Category I—Instantaneous DO	0.5	DO should not be below 0.5 mg/L at any location, at any season, or for any duration.
Category II—1-hour DO	1.0	DO should not fall below 1.0 mg/L for more than one hour at any location or at any time. Excursions below 1.0 mg/L should not occur more frequently than every 12 hours.
Category III—12-hour DO	3.0	DO should not fall below 3.0 mg/L for more than 12 hours at any location or time. Twelve-hour excursions below 3.0 mg/L should not occur more frequently than every 48 hours.
Category IV—Monthly Average DO	5.0	Monthly mean DO should not be below 5.0 mg/L at any location or season.

Source: Chesapeake Bay Program (1990b).

- Establish SAV regional distribution and species diversity goals for the Chesapeake Bay.

Data from laboratory, field, and mesocosm studies, transplanting efforts, and nearshore SAV habitat monitoring programs from four study regions (Figure 11), as well as historical and current literature, were compiled and synthesized to establish quantitative levels of water quality necessary to support continued survival and propagation of SAV. The overall approach of the study was to relate the growth and survival of SAV in regions of the Chesapeake Bay having certain salinity regimes to available water quality data from nearshore areas for specific water quality parameters. The study established empirical relationships between water quality characteristics and the presence of SAV beds using data collected from various regions of the Chesapeake Bay. These relationships were based on the following basic assumptions about the

Table 25. Draft Habitat Restoration Goals for the Chesapeake Bay SAV by Salinity Regime

Salinity Regime	TSS (mg/L)	Secchi Depth (m)	Light Atten. Coef. (m^{-1})	CHL (µg/l)	DIN (mg/L)	DIP (mg/L)	Critical Life Period(s)
Tidal Fresh (0.0-0.5 ppt)	<10	>0.8-1.0	<2	<15	<1.5	<0.01	April-early June; late August-September
Oligohaline (0.5-5.0 ppt)	<15	>0.8	<2	<15	<1.5	<0.01	April-early June; late August-September
Mesohaline (5.0-18.0 ppt)	<15	>0.8-1.0	<1.5-2	<10-15	<0.14	<0.01	May-October
Polyhaline (18.0-35.0 ppt)	<15	>0.8	<2	<15	<0.28	<0.03	Spring (9°-23° C) Fall (25°-13° C)

Source: Chesapeake Bay Program (1990a).

9

The Effectiveness of Nonpoint Source Nutrient Control Programs

As part of the preparation for the 1991 Reevaluation of the *Baywide Nutrient Reduction Strategy* (Chesapeake Bay Program, 1988a), the Administrator of the U.S. Environmental Protection Agency acted on behalf of the Chesapeake Bay Executive Council to convene a Nonpoint Source Program Evaluation Panel in March 1990. Consisting of 15 members representing a range of interests, the Panel was charged with independently assessing the ability of current nonpoint source control programs to achieve the 40 percent nutrient reduction goal. The Panel addressed two of the 1990 milestones for refining the Nutrient Reduction Strategy: the evaluation of approaches that may be used for nitrogen reduction and the evaluation of the effectiveness of voluntary programs for the implementation of best management practices (BMPs). As well, the Panel's purview included the full range of options for achieving nutrient load reductions available to the Chesapeake Bay jurisdictions.

Over the course of 8 months, the Panel reviewed an array of nonpoint source programs related primarily to agricultural, urban, and forestry nonpoint source pollution and evaluated issues associated with program design, implementation, financing, and research efforts. The Panel evaluated nonregulatory and regulatory approaches to controlling nutrient loadings from nonpoint sources but focused on the effectiveness of programs that encourage the voluntary adoption of control measures.

Although the Panel was generally impressed with the progress being made in the Chesapeake Bay basin in identifying and reducing nonpoint sources of nutrients, the Panel was not convinced that, based on the information it reviewed, current programs are adequate to meet the 40 percent reduction goal by the year 2000. The Panel identified several key areas in current nonpoint source programs that could be refined or enhanced. In addition, the Panel made recommendations to change and improve the focus and prioritization of current programs. The Panel also proposed a new approach to nutrient control. This chapter briefly summarizes the key recommendations of the Panel. A more detailed description of these and other recommendations is available in the Panel's *Report and Recommendations of the Nonpoint Source Evaluation Panel* (Nonpoint Source Evaluation Panel, 1990).

Summary of Panel Findings and Recommendations

The Panel believed that the nutrient reduction goal would not be met under current efforts for a number of reasons. First, the limited information available to the Panel on the rates of voluntary adoption of nonpoint source control measures suggested that implementation was occurring at too slow of a pace to ensure meeting the 40 percent reduction goal. For example, conservation programs developed under the 1985 Food Security Act (Farm Bill), such as the Conservation Reserve Program, showed below average participation rates in the Chesapeake Bay area when compared to the rest of the country.

Additionally, the Panel thought that current estimates of nutrient load reductions in the Chesapeake Bay basin are probably optimistic. The most commonly used estimation technique in the basin for predicting nutrient reductions associated with soil conservation measures (i.e., best management practices) is the universal soil loss equation. This estimation technique assumes certain relationships between soil loss and nutrient loadings that result in load reduction values that are much higher than estimates made using other techniques. Estimates of the nutrient reduction effectiveness of some structural BMPs based on the universal soil loss equation may be inflated because the technique may not fully account for the movement of soluble nutrients through ground water. Also, estimated reductions are made assuming that structural BMPs function at design capabilities.

Historically, most nonpoint source nutrient control programs have focused on agricultural practices, as the majority of nonpoint source nutrients were believed to come from fertilizers and animal wastes. The Panel found that because of continuing rapid urbanization in the Chesapeake Bay basin, the problem of nonpoint source pollution is intensifying and changing in character as many land types (e.g., forests or wetlands) that currently provide positive water quality benefits are being converted to more environmentally damaging uses. The Panel concluded that additional actions should be taken to address the nonpoint contributions from urban and suburban land uses, such as enhancing efforts to encourage counties, communities, and private landowners to protect environmentally beneficial land uses and land cover types. As well, the Panel recognized that other nonagricultural sources such as the atmospheric deposition of nutrients are potentially significant contributors of nutrients to the Bay system and that such sources should be given increased program emphasis. Linked to this issue is the Panel's finding that current nonpoint source control efforts are lacking an overall, systematic planning framework to capture all aspects of the nutrient management problem, including the wide range of nutrient sources and the variety of mechanisms—regulatory and nonregulatory—for controlling loadings. The Panel also thought that jurisdictions, individually and collectively, should work to improve the coordination of nonpoint source control strategies and program components. As one means of achieving this goal, the Panel recommended that the States should use compatible reporting formats so that it would be possible to compare the effectiveness of nutrient control approaches between jurisdictions to better improve program targeting and future program design.

Based upon the analyses and discussion conducted by the Panel, a number of specific recommendations were made in 9 subject areas (Table 26). In addition to specific recommendations for these areas, the Panel recognized that a fundamental change in the approach to overall management of nutrients should occur if the Bay is to achieve its ultimate reduction goals. Programs and practices that were originally intended to control soil erosion and soil loss provided

Table 26. Key Recommendations of the Nonpoint Source Evaluation Panel

Targeting Programs

- Continue to refine identification of specific geographic areas and activities that are the most important nutrient contributors.
- Adopt a tiered targeting structure to establish priorities based on explicit cost effectiveness considerations.

Program Design: Voluntary Versus Regulatory

- Augment voluntary programs with increased use of regulatory authority.
- Explore and use the wide spectrum of programs and policies that fall between voluntary and regulatory.

Nutrient Management

- Adopt the term Best Management System.
- Require and implement nutrient management plans.

Animal Wastes

- Become more aggressive in ensuring the effective management of animal wastes, including improved targeting, and the establishment of mandatory animal unit thresholds above which Best Management Systems are required.

Land Use, Growth, and Urbanization

- Increase efforts to devise land use management systems that accommodate growth in patterns that minimize environmental damage.
- Provide localities with the authority to implement plans that guide growth while protecting environmentally sensitive areas.
- Continue to increase emphasis on controlling urban sources of nutrients.
- Intensify efforts to protect land uses and land cover types that provide positive water quality benefits.

Education and Outreach

- Enhance education, especially to targeted audiences. Establish specific goals and measures of success.
- Use private sector expertise and establish public/private partnerships to further common education objectives. Provide additional training to applicable person(s) to enhance promotion of good nutrient management practices.

Inadequately Addressed Nutrient Sources

- Step up efforts to address nutrient loading associated with atmospheric deposition, ground water, septic systems, and shoreline and stream bank erosion. Include such sources in the Nutrient Reduction Strategy.

Information and Research Needs

- Coordinate information and research activities to strengthen and guide policy and program decisions. Develop a more consistent information management framework.
- Fund research and monitoring programs necessary to refine and perfect nutrient management efforts.

Program Administration

- Identify annual nutrient reduction action plans. Evaluate progress regularly.
- Use compatible reporting formats and data management systems.
- Establish a centralized accounting system for funding and labor resources allocated to nonpoint source programs.

Source: Nonpoint Source Evaluation Panel (1990).

a foundation for current strategies for controlling nonpoint sources of nutrients. Such mechanisms are frequently insufficient as a nutrient control strategy, without nutrient management planning that considers the full range of sources, pathways, and the ultimate removal of nutrients from the Chesapeake Bay basin ecosystem. The Panel proposed that a mass balance approach to identifying and quantifying total nutrient loadings to the Bay ecosystem is an essential component of an innovative nutrient management strategy. Such a mass balance approach would seek to fully understand the extent and type of nutrient loadings from all sources and balance nutrients removed from the system with those that are introduced and stored. A mass balance accounting system is regarded by the Panel as a necessary supplement to existing methods of identifying and measuring total nutrient loadings and controlling them in the context of removal processes in the Bay system.

The Panel's major recommendations are highlighted below in italics. A more detailed description of the Panel's findings and recommendations is provided in the Panel's report (Nonpoint Source Evaluation Panel, 1990).

Targeting Programs

Currently, each Chesapeake Bay State has its own means of identifying localities and activities within its nonpoint source program control as priorities for program funding. Generally, targeting efforts are focused on agricultural nonpoint source programs based on a ranking of watersheds according to their potential to contribute nutrients.

Because improved program targeting provides one of the most immediate opportunities for further reducing nonpoint source nutrient loadings to the Bay, the Panel ■ *recommended that the Chesapeake Bay States continue to refine their identification of specific geographic areas and activities that are the most important contributors of nutrients to the Bay system, and that they develop and improve targeting strategies accordingly.*■ The Panel further ■ *recommended that tiered targeting be used, with levels of program support directly related to established priorities, based on explicit cost-effectiveness considerations.*■ One of the main points stressed by the Panel was the importance of more effective targeting to improve program efficiency, with the goal of assuring more pollution reduction per unit of effort expended.

Program Design: Voluntary Versus Regulatory Approaches

State nonpoint source control programs currently comprise regulatory and nonregulatory options. Agricultural programs tend to rely most heavily on nonregulatory approaches, such as technical assistance to farmers and cost-share programs for BMP implementation. Urban programs are often more regulatory in nature. In addition, Virginia and Maryland are beginning to implement a more regulatory approach to land use management (i.e., Virginia's Chesapeake Bay Preservation Act and Maryland's Chesapeake Bay Critical Areas Act). Several Federal programs are also available as components of nonpoint source control strategies (e.g., the Conservation Reserve

Program of the Food Security Act of 1985 and the National Pollutant Discharge Elimination System [NPDES] permitting program for concentrated animal operations).

Information available to the Panel suggested that participation in many of the nonregulatory and regulatory programs for nutrient control in the Chesapeake Bay basin is low and insufficient to ensure attainment of the 40-percent reduction goal. To this end, the Panel ■ *recommended that the States and the Federal government augment voluntary programs with increased use of regulatory authority for the reduction of nutrient loadings and that, the wide spectrum of programs and policies that fall between voluntary and regulatory be fully utilized. To minimize financial burdens, the Panel recommended that regulatory requirements be accompanied by technical and, where appropriate, financial assistance.* ■

Nutrient Management

As described more fully in Chapter 6 of this report, many BMPs for controlling soil loss are ineffective in reducing loadings from soluble nutrients. Since most BMPs are specifically designed to slow soil erosion and runoff, only those nutrients that bind to sediments are addressed effectively. However, research completed by the Chesapeake Bay Program showed that traditional BMPs, in conjunction with nutrient management plans were far more effective in controlling overall nutrients than BMPs alone. Accordingly, the Panel recommended a uniform and clearly stated approach to the management of nutrient-rich materials that moves beyond the traditional BMP approach. Specifically, the Panel ■ *recommended that the term Best Management System, which would go beyond traditional soil loss concepts, be adopted by Chesapeake Bay jurisdictions and Federal agencies.* ■ The Panel considered a Best Management System to be a combination of conservation practices or management measures, which, when applied, will achieve nonpoint source pollution control through reduced transport of sediment, nutrients, and chemicals into surface and ground water. In addition, the Panel believed that there should be greater emphasis on nutrient management plans, and ■ *recommended that they be required and implemented for lands that are targeted as sources of nutrient loadings to the Bay.* ■

Animal Wastes

Watershed modeling and other nutrient loading estimates examined by the Panel pointed to animal wastes as one of the largest contributors of overall nutrients to the Chesapeake Bay. Land development patterns in the Chesapeake Bay suggest that animal numbers and density in the Bay basin will increase, while cropland acreage will decrease, in the future. Because of this trend, the Panel ■ *recommended that the Bay States target animal operations according to the impact that they may have on the Chesapeake Bay. Larger or more intensive operations should be a priority. Moreover, the Panel recommended that the States set mandatory animal unit thresholds above which they will require* nutrient reduction target. The Panel made several recommendations in these areas. For example, ▪ *program managers should clearly identify their annual action plans for accomplishing nutrient load reduction goals. Specific measurable objectives should be identified and progress in meeting those objectives evaluated regularly.*▪

Because of problems in comparing similar information (e.g., water quality monitoring, nutrient reduction progress estimates, program design, and resource allocation) from State to State, the Panel suggested that EPA require and the Bay jurisdictions use ▪ *compatible reporting formats and data management systems for nonpoint source monitoring and modeling data and information, and establish a centralized accounting system for funding and labor resources allocated to nonpoint source control programs.*▪

Although the Chesapeake Bay has an advanced program for nonpoint source nutrient control, the Panel, after 8 months of investigation and discussion, was not convinced that the current approach to nonpoint source control was adequate to meet the year 2000 goal. The Panel identified a number of key areas that could be improved, ranging from program targeting to increased nutrient management planning. The findings and recommendations of the Panel will be used in the 1991 Reevaluation of the Nutrient Reduction Strategy. Many of the recommendations may result in refinements to proposed Phase III programs of the Nutrient Reduction Strategy.

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Appendix A

Output Tables From the Watershed Model

Clarifications for the Watershed Model Output Tables

- Nutrient load calculations for above fall line locations are based on the following assumption; loads are delivered to the fall line and contain a loss factor for transport of the loads through the riverine system to the fall line.
- Nutrient loads from below fall line segments do not contain the transport factor, but are loaded directly into the Time Variable Chesapeake Bay Mainstem Model.
- Loadings from all land use types/nutrient sources, <u>except</u> atmospheric deposition and point sources, are calculated for above and below fall line model segments. Loadings from atmospheric deposition and point sources are calculated by the Watershed Model only for <u>above</u> fall line segments so that they may be subject to the transport subroutine of the Watershed Model. These loadings are directly loaded into the Time Variable Model from below fall line locations; loadings from these two sources are not output from the Watershed Model below the fall line.
- Watershed Model output numbers are the average 1985 loads, based on the average of model runs from 1984 to 1987. Since atmospheric deposition and point source loads below the fall line are not based on the Watershed Model, they represent 1985 loads based on data from air monitoring stations and from State point source tracking efforts.
- Phosphorus loads are estimated to surface water only. Nitrogen loads are estimated to surface and subsurface (as interflow and ground-water flow to streams) water. Subsurface nitrogen loads are <u>not</u> calculated for urban impervious, animal waste, or atmospheric sources.
- Only nitrogen loadings are predicted for atmospheric deposition.

Above Fall Line Loadings

Appomattox River** (Tons/Year)

Sources	Total P AFL	Percent of Total	Total N AFL	Percent of Total
Agricultural Land Use				
Conventional Cropland	106.30	31.37	639.54	25.07
Conventional Surface			481.76	18.88
Conventional Subsurface			157.78	6.18
Conservation Cropland	56.76	16.75	532.42	20.87
Conservation Surface			313.30	12.28
Conservation Subsurface			219.13	8.59
Pasture	22.89	6.76	217.06	8.51
Pasture Surface			140.15	5.49
Pasture Subsurface			76.91	3.01
Subtotal Agricultural Land Use	185.95	54.88	1389.02	54.44
Agricultural Surface			935.21	36.65
Agricultural Subsurface			453.82	17.79
Urban Land Use				
Urban Pervious	17.38	5.13	110.05	4.31
Urban Pervious Surface			73.31	2.87
Urban Pervious Subsurface			36.74	1.44
Urban Impervious	11.07	3.27	80.82	3.17
Subtotal Urban Land Use	28.45	8.40	190.87	7.48
Urban Surface			154.13	6.04
Urban Subsurface			36.74	1.44
Forest Land Use				
Subtotal Forest Land Use	68.81	20.31	678.90	26.61
Forest Surface			391.44	15.34
Forest Subsurface			287.46	11.27
Total Nonpoint Source	283.21	83.59	2258.80	88.53
Total Nonpoint Surface			1480.78	58.04
Total Nonpoint Subsurface			778.02	30.49
Other Sources				
Animal Waste*	55.61	16.41	278.07	10.90
Point Source*	0.0	0.0	0.0	0.0
Atmospheric Deposition*			14.54	0.57
Total Basin	338.83		2551.41	
Total Basin Surface			1773.40	69.51
Total Basin Subsurface			778.02	30.49

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* Animal waste, point source and atmospheric deposition are included in total surface loads.

** Only has AFL loads, with BFL portion of the stream included in James River BFL loads.

James River (Tons/Year)

Sources	**Total P AFL**	**Percent of Total**	**Total N AFL**	**Percent of Total**
Agricultural Land Use				
Conventional Cropland	320.13	21.20	1835.05	19.15
Conventional Surface			1507.61	15.73
Conventional Subsurface			327.44	3.42
Conservation Cropland	266.84	17.67	2240.58	23.38
Conservation Surface			1463.65	15.27
Conservation Subsurface			776.93	8.11
Pasture	195.12	12.92	1182.16	12.34
Pasture Surface			891.62	9.30
Pasture Subsurface			290.54	3.03
Subtotal Agricultural Land Use	782.09	51.80	5257.79	54.87
Agricultural Surface			3862.88	40.31
Agricultural Subsurface			1394.91	14.56
Urban Land Use				
Urban Pervious	49.72	3.29	304.49	3.18
Urban Pervious Surface			169.62	1.77
Urban Pervious Subsurface			134.87	1.41
Urban Impervious	23.04	1.53	163.14	1.70
Subtotal Urban Land Use	72.77	4.82	467.63	4.88
Urban Surface			332.76	3.47
Urban Subsurface			134.87	1.41
Forest Land Use				
Subtotal Forest Land Use	175.38	11.62	1790.18	18.68
Forest Surface			840.00	8.77
Forest Subsurface			950.18	9.92
Total Nonpoint Source	1030.24	68.24	7515.60	78.43
Total Nonpoint Surface			5035.64	52.55
Total Nonpoint Subsurface			2479.96	25.88
Other Sources				
Animal Waste*	229.36	15.19	1168.83	12.20
Point Source*	250.19	16.57	853.36	8.90
Atmospheric Deposition*			45.28	0.47
Total Basin	1509.79		9583.07	
Total Basin Surface			7103.11	74.12
Total Basin Subsurface			2479.96	25.88

* Animal waste, point source and atmospheric deposition are included in total surface loads.

Patuxent River (Tons/Year)

Sources	Total P AFL	Percent of Total	Total N AFL	Percent of Total
Agricultural Land Use				
Conventional Cropland	12.99	13.18	139.36	10.78
Conventional Surface			111.43	8.62
Conventional Subsurface			27.94	2.16
Conservation Cropland	13.07	13.26	245.54	19.00
Conservation Surface			156.34	12.10
Conservation Subsurface			89.19	6.90
Pasture	1.70	1.72	29.39	2.27
Pasture Surface			11.80	0.91
Pasture Subsurface			17.59	1.36
Subtotal Agricultural Land Use	27.75	28.16	414.29	32.05
Agricultural Surface			279.57	21.63
Agricultural Subsurface			134.72	10.42
Urban Land Use				
Urban Pervious	11.09	11.25	148.44	11.48
Urban Pervious Surface			69.09	5.35
Urban Pervious Subsurface			79.35	6.14
Urban Impervious	14.26	14.47	148.22	11.47
Subtotal Urban Land Use	25.36	25.73	296.66	22.95
Urban Surface			217.31	16.81
Urban Subsurface			79.35	6.14
Forest Land Use				
Subtotal Forest Land Use	2.12	2.15	47.23	3.65
Forest Surface			15.88	1.23
Forest Subsurface			31.35	2.43
Total Nonpoint Source	55.23	56.03	758.18	58.66
Total Nonpoint Surface			512.76	39.67
Total Nonpoint Subsurface			245.43	18.99
Other Sources				
Animal Waste*	6.37	6.47	43.88	3.40
Point Source*	36.96	37.50	452.98	35.05
Atmospheric Deposition*			37.46	2.90
Total Basin	98.56		1292.51	
Total Basin Surface			1047.08	81.01
Total Basin Subsurface			245.43	18.99

* Animal waste, point source and atmospheric deposition are included in total surface loads.

Potomac River (Tons/Year)

Sources	Total P AFL	Percent of Total	Total N AFL	Percent of Total
Agricultural Land Use				
Conventional Cropland	357.04	14.95	4779.10	14.92
Conventional Surface			2484.97	7.76
Conventional Subsurface			2294.14	7.16
Conservation Cropland	384.24	16.08	8254.93	25.77
Conservation Surface			2641.08	8.24
Conservation Subsurface			5613.84	17.52
Pasture	211.98	8.87	3298.81	10.30
Pasture Surface			1483.75	4.63
Pasture Subsurface			1815.06	5.67
Subtotal Agricultural Land Use	953.26	39.90	16332.84	50.99
Agricultural Surface			6609.80	20.63
Agricultural Subsurface			9723.04	30.35
Urban Land Use				
Urban Pervious	84.34	3.53	1452.99	4.54
Urban Pervious Surface			462.62	1.44
Urban Pervious Subsurface			990.37	3.09
Urban Impervious	134.75	5.64	1139.16	3.56
Subtotal Urban Land Use	219.09	9.17	2592.15	8.09
Urban Surface			1601.78	5.00
Urban Subsurface			990.37	3.09
Forest Land Use				
Subtotal Forest Land Use	147.92	6.29	7020.69	21.92
Forest Surface			656.04	2.05
Forest Subsurface			6364.66	19.87
Total Nonpoint Source	1320.28	55.27	25945.68	80.99
Total Nonpoint Surface			8867.61	27.68
Total Nonpoint Subsurface			17078.07	53.31
Other Sources				
Animal Waste*	616.97	25.83	3692.73	11.53
Point Source*	457.65	28.91	2257.76	7.05
Atmospheric Deposition*			137.71	0.43
Total Basin	2388.90		32033.88	
Total Basin Surface			14955.81	46.69
Total Basin Subsurface			17078.07	53.31

* Animal waste, point source and atmospheric deposition are included in total surface loads.

Rappahannock River (Tons/Year)

Sources	Total P AFL	Percent of Total	Total N AFL	Percent of Total
Agricultural Land Use				
Conventional Cropland	66.02	23.07	604.31	22.45
Conventional Surface			447.29	16.62
Conventional Subsurface			157.02	5.83
Conservation Cropland	33.06	11.55	602.12	22.37
Conservation Surface			331.57	12.32
Conservation Subsurface			270.55	10.05
Pasture	26.26	9.18	357.14	13.27
Pasture Surface			220.13	8.18
Pasture Subsurface			137.01	5.09
Subtotal Agricultural Land Use	125.33	43.80	1563.57	58.08
Agricultural Surface			998.99	37.11
Agricultural Subsurface			564.58	20.97
Urban Land Use				
Urban Pervious	7.11	2.49	77.59	2.88
Urban Pervious Surface			49.23	1.83
Urban Pervious Subsurface			28.36	1.05
Urban Impervious	4.80	1.68	38.99	1.45
Subtotal Urban Land Use	11.91	4.16	116.58	4.33
Urban Surface			88.22	3.28
Urban Subsurface			28.36	1.05
Forest Land Use				
Subtotal Forest Land Use	6.28	2.19	236.89	8.80
Forest Surface			21.51	0.80
Forest Subsurface			215.37	8.00
Total Nonpoint Source	143.52	50.16	1917.03	71.21
Total Nonpoint Surface			1108.72	41.19
Total Nonpoint Subsurface			808.31	30.03
Other Sources				
Animal Waste*	122.91	42.96	718.66	26.70
Point Source*	19.70	6.88	47.51	1.76
Atmospheric Deposition*			8.83	0.33
Total Basin	286.12		2693.03	
Total Basin Surface			1883.72	69.97
Total Basin Subsurface			808.31	30.03

* Animal waste, point source and atmospheric deposition are included in total surface loads.

Susquehanna River (Tons/Year)

Sources	**Total P AFL**	**Percent of Total**	**Total N AFL**	**Percent of Total**
Agricultural Land Use				
Conventional Cropland	1409.87	36.49	26136.41	38.26
Conventional Surface			15749.99	23.05
Conventional Subsurface			10386.41	15.20
Conservation Cropland	356.09	9.22	12676.98	18.56
Conservation Surface			5554.48	8.13
Conservation Subsurface			7122.50	10.43
Pasture	88.99	2.30	2687.57	3.93
Pasture Surface			958.95	1.40
Pasture Subsurface			1728.62	2.53
Subtotal Agricultural Land Use	1854.96	48.00	41500.95	60.75
Agricultural Surface			22263.42	32.59
Agricultural Subsurface			19237.53	28.16
Urban Land Use				
Urban Pervious	86.48	2.24	2778.04	4.07
Urban Pervious Surface			779.29	1.14
Urban Pervious Subsurface			1998.75	2.93
Urban Impervious	152.65	3.95	1721.08	2.52
Subtotal Urban Land Use	239.13	6.19	4499.12	6.59
Urban Surface			2500.36	3.66
Urban Subsurface			1998.75	2.93
Forest Land Use				
Subtotal Forest Land Use	131.81	3.41	10767.23	15.76
Forest Surface			789.99	1.16
Forest Subsurface			9977.24	14.60
Total Nonpoint Source	2225.89	57.60	56767.30	83.09
Total Nonpoint Surface			25553.78	37.40
Total Nonpoint Subsurface			31213.52	45.69
Other Sources				
Animal Waste*	620.28	16.05	4957.30	7.26
Point Source*	1017.93	26.34	5802.75	8.49
Atmospheric Deposition*			792.47	1.16
Total Basin	3864.10		68319.82	
Total Basin Surface			37106.30	54.31
Total Basin Subsurface			31213.52	45.69

* Animal waste, point source and atmospheric deposition are included in total surface loads.

York River (Tons/Year)

Sources	Total P AFL	Percent of Total	Total N AFL	Percent of Total
Agricultural Land Use				
Conventional Cropland	70.57	38.47	469.61	31.08
Conventional Surface			435.12	28.80
Conventional Subsurface			34.50	2.28
Conservation Cropland	37.61	20.50	447.38	29.61
Conservation Surface			366.66	24.27
Conservation Subsurface			80.72	5.34
Pasture	4.29	2.34	39.91	2.64
Pasture Surface			29.90	1.98
Pasture Subsurface			10.01	0.66
Subtotal Agricultural Land Use	112.48	61.31	956.91	63.33
Agricultural Surface			831.67	55.04
Agricultural Subsurface			125.23	8.29
Urban Land Use				
Urban Pervious	5.39	2.94	38.64	2.56
Urban Pervious Surface			25.74	1.70
Urban Pervious Subsurface			12.90	0.85
Urban Impervious	4.85	2.64	32.91	2.18
Subtotal Urban Land Use	10.24	5.58	71.56	4.74
Urban Surface			58.66	3.88
Urban Subsurface			12.90	0.85
Forest Land Use				
Subtotal Forest Land Use	32.61	17.78	317.86	21.04
Forest Surface			187.17	12.39
Forest Subsurface			130.69	8.65
Total Nonpoint Source	155.32	84.67	1346.31	89.10
Total Nonpoint Surface			1077.51	71.31
Total Nonpoint Subsurface			268.81	17.79
Other Sources				
Animal Waste*	25.14	13.70	136.84	9.06
Point Source*	3.00	1.64	12.01	0.79
Atmospheric Deposition*			15.78	1.04
Total Basin	183.45		1510.96	
Total Basin Surface			1242.14	82.21
Total Basin Subsurface			268.81	17.79

* Animal waste, point source and atmospheric deposition are included in total surface loads.

Below Fall Line Loadings

Eastern Shore Maryland (Tons/Year)

Sources	Total P BFL	Percent of Total	Total N BFL	Percent of Total
Agricultural Land Use				
Conventional Cropland	370.57	31.44	4568.79	25.47
Conventional Surface			2019.87	11.26
Conventional Subsurface			2548.92	14.21
Conservation Cropland	349.22	29.63	8640.75	48.17
Conservation Surface			2799.26	15.60
Conservation Subsurface			5841.49	32.56
Pasture	15.62	1.33	310.83	1.73
Pasture Surface			91.16	0.51
Pasture Subsurface			219.67	1.22
Subtotal Agricultural Land Use	735.40	62.40	13520.37	75.36
Agricultural Surface			4910.29	27.37
Agricultural Subsurface			8610.09	47.99
Urban Land Use				
Urban Pervious	62.89	5.34	932.39	5.20
Urban Pervious Surface			259.86	1.45
Urban Pervious Subsurface			672.53	3.75
Urban Impervious	68.19	5.79	494.03	2.75
Subtotal Urban Land Use	131.03	11.12	1426.41	7.95
Urban Surface			753.88	4.20
Urban Subsurface			672.53	3.75
Forest Land Use				
Subtotal Forest Land Use	35.82	3.04	1611.68	8.98
Forest Surface			86.17	0.48
Forest Subsurface			1525.51	8.50
Total Nonpoint Source	902.31	76.56	16558.46	92.30
Total Nonpoint Surface			5750.34	32.05
Total Nonpoint Subsurface			10808.13	60.25
Animal Waste	276.29	23.44	1381.43	7.70
Total Nonpoint and Animal Waste	1178.59		17939.90	
Point Source*	194.66		582.76	
Atmospheric Deposition*			324.43	

* 1985 loads only. Not calculated by Watershed Model.

Eastern Shore Virginia (Tons/Year)

Sources	Total P BFL	Percent of Total	Total N BFL	Percent of Total
Agricultural Land Use				
Conventional Cropland	38.31	62.96	187.54	58.66
Conventional Surface			163.62	51.18
Conventional Subsurface			23.92	7.48
Conservation Cropland	13.12	21.56	79.24	24.79
Conservation Surface			60.90	19.05
Conservation Subsurface			18.34	5.74
Pasture	0.64	1.05	3.20	1.00
Pasture Surface			2.64	0.83
Pasture Subsurface			0.56	0.17
Subtotal Agricultural Land Use	52.07	85.58	269.98	84.45
Agricultural Surface			227.16	71.05
Agricultural Subsurface			42.82	13.40
Urban Land Use				
Urban Pervious	1.31	2.15	5.71	1.79
Urban Pervious Surface			4.07	1.27
Urban Pervious Subsurface			1.65	0.51
Urban Impervious	1.40	2.30	9.68	3.03
Subtotal Urban Land Use	2.71	4.45	15.39	4.81
Urban Surface			13.74	4.30
Urban Subsurface			1.65	0.51
Forest Land Use				
Subtotal Forest Land Use	2.86	4.69	18.29	5.72
Forest Surface			5.07	1.59
Forest Subsurface			13.23	4.14
Total Nonpoint Source	57.64	94.73	303.66	94.98
Total Nonpoint Surface			245.97	76.94
Total Nonpoint Subsurface			57.69	18.05
Animal Waste	3.21	5.27	16.03	5.02
Total Nonpoint and Animal Waste	60.84		319.70	
Point Source*	0.95		30.86	
Atmospheric Deposition*			49.84	

* 1985 loads only. Not calculated by Watershed Model.

James River (Tons/Year)

Sources	**Total P BFL**	**Percent of Total**	**Total N BFL**	**Percent of Total**
Agricultural Land Use				
Conventional Cropland	108.17	24.97	1401.05	20.68
Conventional Surface			482.52	7.12
Conventional Subsurface			918.52	13.56
Conservation Cropland	79.22	18.29	1802.70	26.61
Conservation Surface			361.33	5.33
Conservation Subsurface			1441.37	21.27
Pasture	8.83	2.04	182.89	2.70
Pasture Surface			35.13	0.52
Pasture Subsurface			147.75	2.18
Subtotal Agricultural Land Use	196.21	45.30	3386.63	49.98
Agricultural Surface			878.98	12.97
Agricultural Subsurface			2507.65	37.01
Urban Land Use				
Urban Pervious	93.38	21.56	1617.35	23.87
Urban Pervious Surface			279.41	4.12
Urban Pervious Subsurface			1337.94	19.75
Urban Impervious	94.82	21.89	639.25	10.17
Subtotal Urban Land Use	188.20	43.45	2306.61	34.04
Urban Surface			968.67	14.30
Urban Subsurface			1337.94	19.75
Forest Land Use				
Subtotal Forest Land Use	24.80	5.73	962.41	14.20
Forest Surface			55.46	0.82
Forest Subsurface			906.95	13.39
Total Nonpoint Source	409.21	94.47	6655.65	98.23
Total Nonpoint Surface			1903.11	28.09
Total Nonpoint Subsurface			4752.53	70.14
Animal Waste	23.96	5.53	119.78	1.77
Total Nonpoint and Animal Waste	433.17		6775.43	
Point Source*	1484.90		9093.48	
Atmospheric Deposition*			670.79	

* 1985 loads only. Not calculated by Watershed Model.

Patuxent River (Tons/Year)

Sources	Total P BFL	Percent of Total	Total N BFL	Percent of Total
Agricultural Land Use				
Conventional Cropland	24.76	25.27	354.02	25.44
Conventional Surface			126.03	9.06
Conventional Subsurface			227.99	16.38
Conservation Cropland	5.77	5.89	170.63	12.26
Conservation Surface			40.79	2.93
Conservation Subsurface			129.84	9.33
Pasture	1.52	1.55	27.12	1.95
Pasture Surface			9.32	0.67
Pasture Subsurface			17.80	1.28
Subtotal Agricultural Land Use	32.05	32.72	551.77	39.64
Agricultural Surface			176.15	12.66
Agricultural Subsurface			375.62	26.99
Urban Land Use				
Urban Pervious	28.25	28.84	394.01	28.31
Urban Pervious Surface			125.22	9.00
Urban Pervious Subsurface			268.79	19.31
Urban Impervious	26.49	27.05	197.18	14.17
Subtotal Urban Land Use	54.74	55.89	591.19	42.48
Urban Surface			322.40	23.16
Urban Subsurface			268.79	19.31
Forest Land Use				
Subtotal Forest Land Use	4.57	4.67	215.87	15.51
Forest Surface			9.97	0.72
Forest Subsurface			205.89	14.79
Total Nonpoint Source	91.36	93.27	1358.83	97.63
Total Nonpoint Surface			508.52	36.54
Total Nonpoint Subsurface			850.31	61.09
Animal Waste	6.59	6.73	32.97	2.37
Total Nonpoint and Animal Waste	97.96		1391.80	
Point Source*	71.64		200.52	
Atmospheric Deposition*			135.38	

* 1985 loads only. Not calculated by Watershed Model.

Potomac River (Tons/Year)

Sources	Total P BFL	Percent of Total	Total N BFL	Percent of Total
Agricultural Land Use				
Conventional Cropland	120.82	25.91	1475.73	22.58
Conventional Surface			661.05	10.11
Conventional Subsurface			814.68	12.47
Conservation Cropland	68.26	14.64	1584.95	24.25
Conservation Surface			567.34	8.68
Conservation Subsurface			1017.61	15.57
Pasture	23.36	5.01	349.86	5.35
Pasture Surface			151.96	2.33
Pasture Subsurface			197.90	3.03
Subtotal Agricultural Land Use	212.44	45.57	3410.54	52.18
Agricultural Surface			1380.35	21.12
Agricultural Subsurface			2030.19	31.06
Urban Land Use				
Urban Pervious	87.91	18.86	1126.44	17.24
Urban Pervious Surface			412.79	6.32
Urban Pervious Subsurface			713.66	10.92
Urban Impervious	79.11	16.97	639.12	9.78
Subtotal Urban Land Use	167.02	35.82	1765.57	27.02
Urban Surface			1051.91	16.10
Urban Subsurface			713.66	10.92
Forest Land Use				
Subtotal Forest Land Use	27.87	5.98	1064.93	16.29
Forest Surface			87.92	1.35
Forest Subsurface			977.01	14.95
Total Nonpoint Source	407.34	87.37	6241.03	95.49
Total Nonpoint Surface			2520.18	38.56
Total Nonpoint Subsurface			3720.85	56.93
Animal Waste	58.89	12.63	294.46	4.51
Total Nonpoint and Animal Waste	466.23		6535.50	
Point Source*	89.71		3741.12	
Atmospheric Deposition*			1496.39	

* 1985 loads only. Not calculated by Watershed Model.

Rappahanock River (Tons/Year)

Sources	Total P BFL	Percent of Total	Total N BFL	Percent of Total
Agricultural Land Use				
Conventional Cropland	99.40	35.07	968.86	37.39
Conventional Surface			530.84	20.49
Conventional Subsurface			438.01	16.91
Conservation Cropland	16.87	5.95	320.82	12.38
Conservation Surface			127.06	4.90
Conservation Subsurface			193.77	7.48
Pasture	2.33	0.82	37.19	1.44
Pasture Surface			14.05	0.54
Pasture Subsurface			23.14	0.89
Subtotal Agricultural Land Use	118.60	41.85	1326.87	51.21
Agricultural Surface			671.95	25.93
Agricultural Subsurface			654.92	25.28
Urban Land Use				
Urban Pervious	9.16	3.23	158.02	6.10
Urban Pervious Surface			31.02	1.20
Urban Pervious Subsurface			127.00	4.90
Urban Impervious	9.12	3.22	68.46	2.64
Subtotal Urban Land Use	18.29	6.45	226.48	8.74
Urban Surface			99.48	3.84
Urban Subsurface			127.00	4.90
Forest Land Use				
Subtotal Forest Land Use	9.85	3.47	354.32	13.68
Forest Surface			23.15	0.89
Forest Subsurface			331.17	12.78
Total Nonpoint Source	146.73	51.78	1907.67	73.63
Total Nonpoint Surface			794.58	30.67
Total Nonpoint Subsurface			1113.09	42.96
Animal Waste	136.65	48.22	683.26	26.37
Total Nonpoint and Animal Waste	283.38		2590.93	
Point Source*	62.29		224.83	
Atmospheric Deposition*			434.33	

* 1985 loads only. Not calculated by Watershed Model.

Western Shore Maryland (Tons/Year)

Sources	**Total P BFL**	**Percent of Total**	**Total N BFL**	**Percent of Total**
Agricultural Land Use				
Conventional Cropland	37.08	12.66	656.10	14.75
Conventional Surface			166.25	3.74
Conventional Subsurface			489.86	11.02
Conservation Cropland	34.20	11.68	1265.82	28.47
Conservation Surface			193.04	4.34
Conservation Subsurface			1072.77	24.13
Pasture	10.64	3.63	247.51	5.57
Pasture Surface			57.21	1.29
Pasture Subsurface			190.30	4.28
Subtotal Agricultural Land Use	81.91	27.97	2169.43	48.79
Agricultural Surface			416.50	9.37
Agricultural Subsurface			1752.93	39.42
Urban Land Use				
Urban Pervious	56.98	19.46	945.61	21.27
Urban Pervious Surface			211.99	4.77
Urban Pervious Subsurface			733.62	16.50
Urban Impervious	92.08	31.44	662.11	14.89
Subtotal Urban Land Use	149.06	50.89	1607.72	36.16
Urban Surface			874.10	19.66
Urban Subsurface			733.62	16.50
Forest Land Use				
Subtotal Forest Land Use	8.57	2.92	402.80	9.06
Forest Surface			19.04	0.43
Forest Subsurface			383.76	8.63
Total Nonpoint Source	239.54	81.79	4179.95	94.00
Total Nonpoint Surface			1309.64	29.45
Total Nonpoint Subsurface			2870.31	64.55
Animal Waste	53.35	18.21	266.75	6.00
Total Nonpoint and Animal Waste	292.89		4446.70	
Point Source*	867.56		10473.81	
Atmospheric Deposition*			41.50	

* 1985 loads only. Not calculated by Watershed Model.

York River (Tons/Year)

Sources	Total P BFL	Percent of Total	Total N BFL	Percent of Total
Agricultural Land Use				
Conventional Cropland	43.01	34.89	305.37	27.42
Conventional Surface			207.51	18.63
Conventional Subsurface			97.87	8.79
Conservation Cropland	18.97	15.38	243.42	21.86
Conservation Surface			128.46	11.53
Conservation Subsurface			114.97	10.32
Pasture	1.75	1.42	17.82	1.60
Pasture Surface			9.19	0.83
Pasture Subsurface			8.63	0.77
Subtotal Agricultural Land Use	63.73	51.69	566.62	50.87
Agricultural Surface			345.16	30.99
Agricultural Subsurface			221.46	19.88
Urban Land Use				
Urban Pervious	8.20	6.65	63.75	5.72
Urban Pervious Surface			27.64	2.48
Urban Pervious Subsurface			36.11	3.24
Urban Impervious	26.75	21.70	212.95	19.12
Subtotal Urban Land Use	34.94	28.35	276.69	24.84
Urban Surface			240.59	21.60
Urban Subsurface			36.11	3.24
Forest Land Use				
Subtotal Forest Land Use	10.43	8.46	199.60	17.92
Forest Surface			24.46	2.20
Forest Subsurface			175.14	15.72
Total Nonpoint Source	109.10	88.50	1042.91	93.64
Total Nonpoint Surface			610.21	54.79
Total Nonpoint Subsurface			432.71	38.85
Animal Waste	14.18	11.50	70.89	6.36
Total Nonpoint and Animal Waste	123.28		1113.80	
Point Source*	84.77		169.29	
Atmospheric Deposition*			235.42	

* 1985 loads only. Not calculated by Watershed Model.

Table B-1. Maryland Wastewater Treatment Plants Nutrient Removal Retrofit Costs[1]

Wastewater Treatment Plant	Design Flow (mgd)	Technology	Capital Costs ($)	Annual Operating and Maintenance Costs ($)	Equivalent Total Costs[2] (ETC)($)	Equivalent Annual Costs[2] (EAC)($)	EAC/Flow ($/mgd/yr)
Joppatowne[4]	0.8	Anoxic/Aerobic & CPR[3]	3,581,641	70,231	4,179,555	490,929	654,572
Crisfield [5]	1.0	A^2/O^{TM}	456,900	58,442	954,447	112,109	112,109
Pokomoke City	1.2	Microstraining	3,181,724	75,571	3,825,103	449,295	374,413
Princess Anne[5]	1.2	Current System	0	0	0	0	0
Freedom District	1.8	Anoxic/Aerobic & CPR [3]	1,639,039	104,187	2,526,044	296,708	164,838
La Plata[5]	1.9	A^2/O^{TM} & CPR[3]	368,835	24,183	574,717	67,506	35,529
Broadwater	2.0	A^2/O^{TM} & CPR [3]	2,425,404	111,845	3,377,605	396,732	198,366
Kent Narrows[5]	2.0	RBC Nitr.,Fluid Bed Denitr.	4,394,944	95,723	5,209,891	611,952	305,976
Bowie[5]	3.3	UCT/VT 2.2	393,701	13,099	505,220	59,343	17,983
Aberdeen WWTP[5]	4.0	Denitrification Filters & Meth.	2,121,840	135,020	3,271,344	384,251	96,063
Seneca Creek[5]	5.0	Anoxic/Aerobic	4,331,745	432,770	8,016,162	941,575	188,315
Broadneck[4,5]	6.0	Anoxic/Aerobic Zones	1,265,023	433,274	4,953,730	581,863	96,977
Salisbury[4]	6.8	Fluid Bed Denitr. & CPR [3]	9,786,573	466,525	13,758,366	1,616,053	237,655
Frederick	7.0	Anoxic/Aerobic & CPR[3]	7,151,886	183,386	8,713,152	1,023,444	146,206
Parkway[5]	7.5	Bardenpho (5-stage)	18,338,168	891,739	25,930,041	3,045,733	406,098
Cambridge	8.1	A^2/O^{TM} & CPR[3]	1,832,781	255,934	4,011,691	471,212	58,174
Sod Run[5]	10.0	Anoxic/Aerobic	11,283,672	540,484	15,885,119	1,865,860	186,586
Cox Creek[5]	15.0	A^2/O^{TM}	6,834,853	534,036	11,381,398	1,336,855	89,124
Cumberland[5]	15.0	Modified Activated Sludge	1,755,077	381,987	5,007,143	588,137	39,209
Mattawoman[5]	15.0	A^2/O^{TM}	8,990,883	379,871	12,224,935	1,435,936	95,729
Little Patuxent[5]	18.0	A^2/O^{TM}	2,600,497	0	2,600,497	305,453	16,970
Piscataway[5]	30.0	Denitr. Filters & CPR[3]	7,051,388	1,936,635	23,539,050	2,764,888	92,163
Patapsco[4,5]	87.5	Anoxic/Aerobic	62,650,228	1,038,749	71,493,688	8,397,622	95,973
Back River[5]	200.0	Multi-Process BNR Facility	153,025,280	8,997,995	229,630,283	26,972,287	134,861
TOTALS	450.1		315,462,081	17,161,685	461,569,182	54,215,743	

[1] Original costs (Source: Beavin Co., Camp Dresser & McKee, and Metcalf & Eddy, 1989) have been escalated to 1990 dollars using appropriate ENR construction cost indexes for capital costs, and EPA operation, maintenance and repair (OMR) indexes for O&M costs. Effluent levels: TN=8.0 mg/L (Seasonal), TP=smallest of 2.0 mg/L or NPDES limit.

[2] Equivalent Total Costs=present worth of annual O&M costs plus capital costs. Equivalent Annual Costs=amortized capital costs plus annual O&M costs. Interest rate = 10%, project life=20 years.

[3] Construct new or upgraded facilities for chemical phosphorus removal.

[4] Costs reflect design temperature of 12.5°C.

[5] Plant is already removing phosphorus below 2.0 mg/L.

Source: ICPRB (1990).

Table B-2. Virginia Wastewater Treatment Plants Nutrient Removal Retrofit Costs[1]

Alternatives	Capital Costs ($)	Annual Operation and Maintenance Costs ($)	Equivalent Total Costs[2] (ETC)($)	Equivalent Annual Costs[2] (EAC) ($)
1 Phosphorus removal to permit limit	17,250,933	34,860,429	314,037,416	36,886,717
2 Alternative 1 + seasonal TKN or NH_3-N removal to permit limit	262,527,519	55,259,579	732,983,464	86,095,963
3 Alternative 1 + seasonal nitrogen removal to10 mg/L total-nitrogen	639,196,366	64,693,871	1,189,971,755	139,773,636
4 Alternative 1 + year-round nitrogen removal to 10 mg/L total nitrogen	854,499,443	76,248,183	1,503,643,205	176,617,367

[1] Original Costs (Source: CH2M Hill, 1989) have been escalated to 1990 dollars using appropriate ENR construction indexes for capital costs, and EPA operation, maintenance and repair (OMR) indexes for O&M costs. Costs=cost opinions expected to be accurate within +50 percent to -30 percent. (CH2M Hill, 1989).

[2] Equivalent Total Costs=present worth of annual O&M costs plus capital costs. Equivalent Annual Costs=amortized costs plus annual O&M costs. Interest rate=10%. Project life=20 years.

Source: ICPRB (1990).

Table B-3. Virginia Wastewater Treatment Plants Nutrient Removal Retrofit Costs (Alternative 3 Scenario)[1]

Wastewater Treatment Plant	Design Flow (mgd)	Technology	Capital Costs ($)	Annual Operation and Maintenance Costs ($)	Equivalent Total Costs[2] (ETC)($)	Equivalent Annual Costs[2] (EAC)($)	EAC/Flow ($/mgd/yr)
Quantico[8]	2.0	Nitr./Denitr. Two Anoxic Zones[3]	1,590,322	246,865	3,692,027	433,664	216,832
Fort Eustis	3.0	Nitr. Trick. Filt. & Denitr. Filt.[5]	4,402,941	243,843	6,478,910	761,010	253,670
Fredericksburg	4.5	Nitr./Denitr. Two Anoxic Zones[5]	1,963,487	420,175	5,540,675	650,806	144,623
Aquia[8]	6.0	Nitr./Denitr. Two Anoxic Zones[3]	104,856	1,454,995	12,492,048	1,467,311	244,552
FMC	6.0	Nitr./Denitr. Two Anoxic Zones[6]	7,209,391	629,759	12,570,884	1,476,571	246,095
Massaponax	6.0	Nitr./Denitr. Two Anoxic Zones[6]	11,480,747	652,934	17,039,543	2,001,458	333,576
Little Falls Run[8]	8.0	Nitr./Denitr. Two Anoxic Zones[5]	310,457	388,939	3,621,715	425,405	53,176
Falling Creek	10.0	Nitr./Denitr. Two Anoxic Zones[6]	3,011,023	266,010	5,275,718	619,684	61,968
HRSD-York Riv.	15.0	Nitr./Denitr. Two Anoxic Zones[6]	7,884,790	968,317	16,128,620	1,894,462	126,297
Petersburg	15.0	Nitr./Denitr. Two Anoxic Zones[6]	6,027,187	574,340	10,916,868	1,282,291	85,486
HRSD-Army Base	18.0	Nitr. Trick. Filt. & Denitr. Filt.[5]	20,989,783	1,362,294	32,587,764	3,827,746	212,653
HRSD-James Riv.	20.0	Nitr./Denitr. Two Anoxic Zones[5]	8,753,453	575,348	13,651,712	1,603,525	80,176
HRSD-Williamsburg	22.5	Nitr./Denitr. Two Anoxic Zones[5]	20,058,412	2,283,254	39,497,039	4,639,307	206,191
H. L. Mooney[8]	24.0	Nitr./Denitr. Two Anoxic Zones[3]	7,498,260	2,548,256	29,193,003	3,428,999	142,875
HRSD-Ches./Eliz.	24.0	Nitr./Denitr. Two Anoxic Zones[5]	47,596,580	763,772	54,098,998	6,354,448	264,769
HRSD-Boat Harbor	25.0	Nitr. Trick. Filt. & Denitr. Filt.[5]	58,165,488	2,178,462	76,711,962	9,010,558	360,422
Proctors Creek	27.0	Nitr./Denitr. Two Anoxic Zones[6]	10,872,169	1,079,155	20,059,622	2,356,196	87,267
HRSD-Nansemond	30.0	Nitr./Denitr. Two Anoxic Zones[5]	28,200,202	1,626,289	42,045,720	4,938,675	164,622
Arlington[8]	40.0	Nitr./Denitr. Two Anoxic Zones[3]	35,870,139	5,459,254	82,347,845	9,672,547	241,814
HRSD-VIP	40.0	Nitr./Denitr. Two Anoxic Zones[6]	31,481,591	2,237,911	50,534,190	5,935,727	148,393
Henrico	45.0	Nitr. Trick. Filt. & Denitr. Filt.[7]	59,143,119	2,657,079	81,764,328	9,604,007	213,422
Hopewell[10]	50.0	Nitr. Trick. Filt. & Denitr. Filt.	73,522,838	6,841,701	131,770,091	15,477,665	309,553
Alexandria[8]	54.0	Nitr./Denitr. Two Anoxic Zones[3]	73,336,769	7,048,261	133,342,592	15,662,371	290,044
UOSA[8]	54.0	Nitr./Denitr. Two Anoxic Zones[4]	17,846,147	12,969,003	128,258,577	15,065,204	278,985
Richmond[9]	70.0	Nitr./Denitr. Two Anoxic Zones[6]	40,786,054	99,754	41,635,314	4,890,468	69,864
Lower Potomac[8]	72.0	Nitr./Denitr. Two Anoxic Zones[3]	61,090,159	9,117,901	138,715,990	16,293,528	226,299
	691.0		639,196,366	64,693,871	1,189,971,755	139,773,636	

[1] Original costs (Source: CH2M Hill, 1989) have been escalated to 1990 dollars using appropriate ENR construction indexes for capital costs, and EPA operation, maintenance and repair (OMR) indexes for O&M costs. Costs=cost opinions expected to be accurate within +50% to -30% (CH2M Hill). Alternative 3 Effluent Levels: TN=10 mg/L (Seasonal), TP=Permit Limit (2.0 mg/L or less).

[2] Equivalent Total Costs=present worth of annual O&M costs plus capital costs. Equivalent Annual Costs=amortized capital costs plus annual O&M costs. Interest rate=10%, project life=20 years.

[3] With multi-point metal salt addition, effluent filtration, and pH adjustment.

[4] With high-line treatment, two-stage recarbonation, and effluent filtration.

[5] With metal salt addition and pH adjustment.

[6] With biological phosphorus removal, metal salt supplement, and pH adjustment.

[7] With low-line treatment and pH adjustment.

[8] Plant is already removing phosphorus (TP=0.18 mg/L or less). Current phosphorus removal costs included in O&M costs.

[9] Plant can meet TP=2.0 mg/L without chemical addition.

[10] Plant is phosphorus-limited.

Source: ICPRB (1990)